# African Journal of Agricultural Research

Volume 10 Number 7 12 February 2015

ISSN 1991-637X

Academic Journals

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Template: C:\Users\Daniel\AppData\Roaming\Microsoft\Templates\Normal.dotm
Title:
Subject:
Author: sunny
Keywords:
Comments:
Creation Date: 1/27/2015 5:46:00 PM
Change Number: 44
Last Saved On: 2/13/2015 12:50:00 PM
Last Saved By: Daniel
Total Editing Time: 88 Minutes
Last Printed On: 2/13/2015 12:51:00 PM
As of Last Complete Printing
Number of Pages: 7
Number of Words: 2,181 (approx.)
Number of Characters: 12,433 (approx.)

academicJournals

Vol. 10(7), pp. 579-587, 12 February, 2015
DOI: 10.5897/AJAR2014.9396
Article Number: 10D202650319
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

# Effect of sowing dates, varieties and weather factors on the occurrence and severity of *Alternaria* leaf blight and yield of Indian mustard

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Received 2 December, 2014; Accepted 9 February, 2015

**Field experiments were undertaken to determine the effect of sowing dates and weather parameters on the disease progression or severity of *Alternaria* blight of rapeseed mustard and their impact on yield for the two consecutive years 2008-2009 and 2009-2010. Disease severity gradually increased with delay in sowing irrespective of three different varieties (Binoy, Seeta and Bhagirathi). The crop sowing from 20$^{th}$ October to 5$^{th}$ November recorded significantly less disease severity with the highest seed yield irrespective of varieties and enhanced in subsequent sowing dates. Bhagirathi showed significantly less disease severity with maximum yield followed by Binoy and Seeta on leaf and siliqua infection on all sowing dates. 90 days old plants showed highest disease severity. From 20$^{th}$ October to 5$^{th}$ November, sowing only minimum temperature (9.69 to 12.04°C) had significant negative correlation, while minimum relative humidity (44.9 to 60.2% RH), wind velocity (during morning) (0.55 km to 1.04 km/h.) and total rainfall (5.74 mm) had positive significant correlation with disease progression upto 59%. Whereas in 20$^{th}$ November sowing minimum temperature (9.69 to 15.74°C, minimum(39 to 88%) and maximum (96 to 99%) relative humidity, wind velocity (during morning)(0.4 to 1.29 km/h), bright sunshine hours (3.8 to 9.0 h) and total rainfall (69.6 mm) had positive significant correlation and vapour pressure (noon, morning)(9.7-29.2 mb and 9.2-14.2 mb respectively), wind velocity (evening) (0.4 to 1.3 km/h) had negative significant correlation on disease progression upto 62%. In 5$^{th}$ December sowing, vapour pressure (noon)(9.7 to 17.5 mb), bright sunshine hours (3.8 to 9.2 h), total rainfall (73.7 mm) and minimum temperature(9.7-18.2°C) had positive significant correlation on disease progression upto 73%. In the West Bengal condition the suitable sowing date of mustard will be last week of October with tolerant variety Bagirathi could be cultivated to avoid loss from Alterania blight and increase the seed yield.**

**Key words:** *Alternaria* blight, mustard, sowing date, variety, weather, yield.

## INTRODUCTION

Indian mustard (*Brassica juncea*) is widely cultivated in Indian sub-continent because of its relative tolerance to biotic and abiotic stresses and inherent high yield potential. Amongst the major constraints in releasing higher yields, the disease likes *Alternaria* blight incited by *Alternaria brassicae* (Berk & Sacc.) is one of the most widespread and destructive disease throughout India causing 35 to 40% yield losses (Kolte et al., 1987). The disease also adversely affects quality by reducing seed size, imparting seed colours and oil content (Kaushik et al., 1984). A number of fungicides have been recommended to control this disease but the spraying of fungicides in standing crop in practically difficult, uneconomical and non eco-friendly to the environment.

However, the need for repeated application of fungicides to attain desirable level of disease control discourage the extensive adoption of chemical control by most marginal and resource poor farmers. Because of the present day public perception on pesticide contamination of foods specially the edible oils, there is need for development of alternative economical and eco-friendly approaches for leaf blight disease management (Chattopadhyay et. al., 2005). As *Alternaria* leaf blight severity requires high humidity and moderate temperature for rapid development, screening for potential resistance should be carried out when optimal levels of these two factors prevail (Sinha et. el., 1992). In order to determine the most effective dates of sowing that permits high or low level of leaf blight for screening cultivars against *Alternaria* leaf blight for crop production. Three cultivars were sown on four different dates over two years which is aimed at utilizing sowing date to reduce the devastation cause by the disease and the study of weather parameters particularly help the disease severity.

## MATERIALS AND METHODS

The field experiment was conducted during rabi season in two consecutive years in 2008-2009 and 2009-2010 at Jaguli University Instructional Farm of Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal (22.93° N, 88.33° E, 9.75 m above sea level). The climate of the region was humid sub-tropical, with a mean annual rainfall of 1500 mm of which 800 mm was received between June and September. The soil was sandy loam in texture having pH between 6.5 and 6.6 with good water holding capacity and organic carbon content of 0.7%.

The 3 cultivars like Seeta (susceptible), Binoy (moderately susceptible) and Bhagirathi (moderately resistant) and four dates of sowing 20 October, 5 November, 20 November, and 5 December were employed in a split plot design with three replicates. Within a replicate, the four dates of sowing were considered as main plots and within such a main plot the three cultivars were treated as sub plots. Dates of sowing were randomized first followed by randomization of cultivars within a date of sowing. Thus each replicate had represented by four dates of sowing Colums sub plots represented by three cultivars, providing a total of 36 plots. The dimension of each plot measured 5 x 5 m. Within a plot, one cultivar was sown in rows 30 cm apart and there was 15 cm spacing between plants in a row. Treatment wise thinning was done after 20 days of sowing to maintain the required plant population. Recommended fertilizers of N : P : K at 80 : 40 : 40 was applied in the form of Urea, single super phosphate and muriate of potash uniformly as basal dose at sowing and cultural practices were followed uniformly throughout the experimental periods. Although different foliar pathogens and insect pest may occur on mustard, during both years only, *Alternaria* leaf blight appeared which favoured the natural development of epidemics. Following the first appearance of leaf blight, plants were scored at weakly intervals. From each replicate 5 plants per plot and five leaflets on each plant were selected randomly and rated for blight severity and number of leaves infection. The blight severity was monitored throughout the life of each cultivar till siliqua maturity. During harvest percent siliqua infection was counted from five plants of each replication and numbers of spots per siliqua were counted from randomly selected 10 siliqua of each replication.

Disease severity records were averaged over three replicates for each cultivar and disease progress curves were plotted. For each plot, the area under the disease progress curve (AUDPC) was calculated as per Campbell and Madden (1990).

$$AUDPC = \sum [(Y_{i+1} + y_i)/ 2 (X_{i+1} - X_i)]$$

$Y_i$ = severity at 1$^{st}$ observation, $X_i$ = Time (days) at first observation
N = Total number of observation

Percent *Alternaria* blight severity was recorded on leaves at 7 days interval following 0–5 scale of Sharma and Kolte (1994) where 0= no symptoms; 1=1-10% leaf area damaged; 2, 10.1-25%; 3, 25.1-50%. 4, 50.1-75%; 5, >75% leaf area damaged.

The severity Index (SI) was then calculated as:

$$\text{Percent Disease Index (PDI)} = \frac{\text{Sum of all numerical ratings}}{\text{Total number of leaf observed x maximum rating}} \times 100$$

The yield attributes like number of siliqua per plant and yield kg/hectare was assessed after harvest. All the characters percent of leaf infection, AUDPC, percent of siliqua infection, number of spots per siliqua and yield and yield attributes were computed as analysis of variance of a split plot design (Syndecor and Cochran, 1967) to partition the variance due to cultivars, dates of sowing and their interactions. The significance was tested at 5% level.

## RESULTS AND DISCUSSION

### Effect of sowing dates

Severity of *Alternaria* blight was significantly influenced by date of sowing in all the three cultivars for both the years 2008-2009 and 2009-2010. Susceptibility of the *Alternaria* leaf blight varied with the dates of sowing. Significant effect of sowing dates in both the years of experimentation on *Alternaria* leaf blight severity and area under disease progress curve was noticed (Table 1). It was evident that disease severity increased gradually in crops with delay in sowing between 20$^{th}$ November to 5$^{th}$ December and decreased with early sowing 20$^{th}$ October to 5$^{th}$ November. Three varieties, Bhagirathi, Seeta and Binoy also showed increased disease severity with delay in sowing. Bhagirathi showed minimum disease severity (14.99%; AUDPC 8.27) on 20$^{th}$ October sowing and maximum in Seeta (26.94%; AUDPC 19.56). With delay in sowing the disease severity also

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**Table 1.** Percent of leaf infection and AUDPC of mustard variety under different dates of sowing in the two consecutive years.

| Sowing dates | Variety | Percent leaf infection | | | | | | AUDPC | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2008-2009 | | 2009-2010 | | Pooled | | 2008-2009 | | 2009-2010 | | Pooled | |
| 1st sowing (20th Oct.) | Binoy | 19.87 (26.47) | | 23.04 (28.69) | | 21.45 (27.58) | | 23.53 | | 22.84 | | 23.18 | |
| | Seeta | 23.82 (29.21) | | 30.06 (33.25) | | 26.94 (31.23) | | 20.66 | | 18.46 | | 19.56 | |
| | Bhagirathi | 13.87 (21.86) | | 16.11 (23.66) | | 14.99 (22.76) | | 8.52 | | 8.02 | | 8.27 | |
| 2nd sowing (5th Nov.) | Binoy | 21.79 (27.83) | | 26.23 (30.81) | | 24.01 (29.32) | | 25.76 | | 24.50 | | 25.13 | |
| | Seeta | 30.02 (33.23) | | 33.65 (35.46) | | 31.83 (34.34) | | 22.42 | | 22.92 | | 22.67 | |
| | Bhagirathi | 15.97 (23.55) | | 20.58 (26.98) | | 18.27 (25.26) | | 10.50 | | 9.19 | | 9.84 | |
| 3rd sowing (20th Nov.) | Binoy | 24.90 (29.93) | | 27.49 (31.62) | | 26.19 (30.77) | | 28.22 | | 27.75 | | 27.98 | |
| | Seeta | 34.87 (36.19) | | 36.25 (37.02) | | 35.56 (36.60) | | 31.16 | | 28.04 | | 29.60 | |
| | Bhagirathi | 19.78 (26.41) | | 23.54 (29.03) | | 21.66 (27.72) | | 15.47 | | 13.61 | | 14.54 | |
| 4th sowing (5th Dec.) | Binoy | 36.55 (37.20) | | 40.70 (39.64) | | 38.62 (38.42) | | 35.74 | | 30.23 | | 32.98 | |
| | Seeta | 55.07 (47.91) | | 59.80 (50.65) | | 57.43 (49.28) | | 49.00 | | 37.18 | | 43.09 | |
| | Bhagirathi | 21.79 (27.83) | | 24.53 (29.69) | | 23.16 (28.76) | | 16.22 | | 13.07 | | 14.64 | |
| | | Sem(±) | CD | Sem(±) | CD | Sem(±) | CD | Sem(±) | CD | Sem(±) | CD | Sem(±) | CD |
| Sowing | | 0.07 | 0.21 | 0.03 | 0.10 | 0.06 | 0.18 | 0.03 | 0.07 | 0.05 | 0.15 | 0.04 | 0.11 |
| Variety | | 0.06 | 0.19 | 0.03 | 0.09 | 0.05 | 0.16 | 0.02 | 0.06 | 0.05 | 0.13 | 0.03 | 0.1 |
| Sowing x variety | | 0.13 | 0.37 | 0.06 | 0.17 | 0.11 | 0.32 | 0.04 | 0.13 | 0.09 | 0.26 | 0.06 | 0.19 |

increased in Bhagiratghi though minimum among the three varieties (23.16%, AUDPC-14.64) when in Seeta (57.43%, AUDPC-43.09) was maximum (Table 1).

Percent of siliqua infection and numbers spots per siliqua were significantly increased with delay in sowing and it was noted on all the three varieties. Two years pooled mean showed that percent of siliqua infection was minimum in Bhagirathi (10.36%) and maximum in Seeta (29.36%) when sown on 20th October and with delay in sowing there was a significant increase in percent of siliqua infection. Minimum was noted on 20th October sowing followed by 5th November and maximum in 5th December followed by 20th November sowing, though minimum percent of siliqua infection was recorded in Bhagirathi (17.28%) and maximum in Seeta (72.39%) followed by Binoy (72.04%) when sown in 5th December. Number of spots per siliqua showed different reaction on different dates of sowing and it was increased significantly with delay in sowing irrespective of three varieties. Two years pooled mean showed minimum number of spots per siliqua on Bhagirathi (6.59) at 20th October sowing followed by 20th November (7.09) and also 5th December sowing of the same Bhagirathi variety (7.35). Maximum number of spots per siliqua was noticed on Seeta (14.13) at 5th December sowing followed by 20th November (13.58) and also 5th November sowing (11.78) (Table 2).

The yield characters like number of siliqua per plant and grain yield (kgha$^{-1}$) were also reflected among the varieties due to different dates of sowing and their differences were statistically significant. Different years showed different results. The two years pooled mean showed maximum number of siliqua per plant on Bhagirathi at 5th November sowing (151.63) followed by Bhagirathi at 20th October sowing (134.45). Minimum number of siliqua per plant was harvested on Seeta at 20th November sowing (75.57) followed by 20th October sowing (98.60) (Table 3).

Similarly seed yield of mustard was statistically significant in respect to dates of sowing, varieties and interaction between dates of sowing and variety for the two consecutive years. The seed yield was lowest in case of 5th December sowing for all the three varieties in all the two years of experimentation. The two years pooled mean showed that the maximum seed yield (1835.67 kgha$^{-1}$) was recorded on 5th November sowing followed by 20th October sowing (1687.17 kgha$^{-1}$). It was also observed that in every date of sowing upto 5th November, Bhagirathi produced maximum seed yield followed by Binoy and least in Seeta. Similar observation was also observed in 5th December sowing where as on 20th November, maximum seed yield was harvested on Binoy (1367.5 kgha$^{-1}$) followed by Bhagirathi (1339 kgha$^{-1}$) and least on Seeta (1112.17 kgha$^{-1}$) and their differences were statistically significant (Table 3). So among the three cultivars tested Seeta sown on all dates showed significantly more disease severity of leaf, siliqua infection and number of spots per siliqua followed by Binoy and least in Bhagirathi. It was also noticed that disease severity increased with age of plant and highest

**Table 2.** Percent of siliqua infection and number of spots per siliqua of ALB infected mustard variety under different dates of sowing in the two consecutive years.

| Sowing dates | Variety | Percent of siliqua infection | | | | | | number of spots per siliqua | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2008-2009 | | 2009-2010 | | Pooled | | 2008-2009 | | 2009-2010 | | Pooled | |
| 1st sowing (20th Oct.) | Binoy | 18.74(25.65) | | 19.74 (26.38) | | 19.24 (26.01) | | 8.51 | | 9.02 | | 8.77 | |
| | Seeta | 28.21(32.08) | | 30.51(33.53) | | 29.36 (32.80) | | 8.95 | | 9.05 | | 9.00 | |
| | Bhagirathi | 12.82 (20.98) | | 7.91(16.33) | | 10.36 (18.65) | | 6.41 | | 6.76 | | 6.59 | |
| 2nd sowing (5th Nov.) | Binoy | 19.89 (26.49) | | 21.84 (27.86) | | 20.86 (27.17) | | 11.76 | | 11.81 | | 11.78 | |
| | Seeta | 28.97(32.57) | | 30.94 (33.80) | | 29.95 (33.18) | | 10.26 | | 10.66 | | 10.46 | |
| | Bhagirathi | 13.49 (21.54) | | 14.99 (22.78) | | 14.24 (22.16) | | 7.96 | | 8.28 | | 8.12 | |
| 3rd sowing (20th Nov.) | Binoy | 32.75 (34.91) | | 36.89 (37.40) | | 34.81 (36.15) | | 9.72 | | 9.84 | | 9.78 | |
| | Seeta | 69.66 (56.57) | | 66.03 (54.35) | | 67.84 (55.46) | | 13.46 | | 13.71 | | 13.58 | |
| | Bhagirathi | 15.11 (22.87) | | 14.44(22.33) | | 14.77 (22.60) | | 7.15 | | 7.04 | | 7.09 | |
| 4th sowing (5th Dec.) | Binoy | 73.04 (58.72) | | 71.05 (57.45) | | 72.04 (58.08) | | 11.30 | | 12.08 | | 11.69 | |
| | Seeta | 73.24 (58.85) | | 71.55 (57.77) | | 72.39 (58.31) | | 14.00 | | 14.26 | | 14.13 | |
| | Bhagirathi | 16.27(23.79) | | 18.30 (25.33) | | 17.28 (24.56) | | 6.44 | | 8.26 | | 7.35 | |
| | | Sem(±) | CD | Sem(±) | CD | Sem(±) | CD | Sem(±) | CD | Sem(±) | CD | Sem(±) | CD |
| Sowing | | 0.06 | 0.18 | 0.05 | 0.13 | 0.05 | 0.14 | 0.08 | 0.23 | 0.08 | 0.24 | 0.07 | 0.2 |
| Variety | | 0.05 | 0.15 | 0.04 | 0.12 | 0.04 | 0.12 | 0.07 | 0.20 | 0.07 | 0.21 | 0.06 | 0.17 |
| Sowing x variety | | 0.10 | 0.31 | 0.08 | 0.24 | 0.08 | 0.25 | 0.14 | 0.40 | 0.14 | 0.422 | 0.12 | 0.34 |

**Table 3.** Number of siliqua per plant and yield (kgha$^{-1}$) of ALB infected mustard variety under different dates of sowing in the two consecutive years.

| Sowing dates | Variety | Number of siliqua per plant | | | | | | yield (kg/ha) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2008-2009 | | 2009-2010 | | Pooled | | 2008-2009 | | 2009-2010 | | Pooled | |
| 1st sowing (20th Oct.) | Binoy | 134.73 | | 103.37 | | 119.05 | | 1662.33 | | 1439.67 | | 1551 | |
| | Seeta | 100.37 | | 96.83 | | 98.60 | | 1554.00 | | 1422.00 | | 1488 | |
| | Bhagirathi | 139.75 | | 129.15 | | 134.45 | | 1726.67 | | 1647.67 | | 1687.17 | |
| 2nd sowing (5th Nov.) | Binoy | 124.95 | | 109.78 | | 117.37 | | 1745.00 | | 1493.67 | | 1619.33 | |
| | Seeta | 114.13 | | 111.00 | | 112.56 | | 1574.33 | | 1460.00 | | 1517.17 | |
| | Bhagirathi | 155.03 | | 148.23 | | 151.63 | | 1910.67 | | 1760.67 | | 1835.67 | |
| 3rd sowing (20th Nov.) | Binoy | 117.13 | | 114.83 | | 115.98 | | 1420.00 | | 1315.00 | | 1367.5 | |
| | Seeta | 75.73 | | 75.42 | | 75.57 | | 1262.33 | | 962.00 | | 1112.17 | |
| | Bhagirathi | 128.77 | | 124.69 | | 126.73 | | 1291.33 | | 1386.67 | | 1339 | |
| 4th sowing (5th Dec.) | Binoy | 105.89 | | 103.82 | | 104.86 | | 964.33 | | 815.00 | | 889.67 | |
| | Seeta | 107.08 | | 111.87 | | 109.47 | | 765.33 | | 590.00 | | 677.67 | |
| | Bhagirathi | 134.85 | | 124.17 | | 129.51 | | 936.33 | | 899.33 | | 917.83 | |
| | | Sem(±) | CD | Sem(±) | CD | Sem(±) | CD | Sem(±) | CD | Sem(±) | CD | Sem(±) | CD |
| Sowing | | 4.44 | 13.02 | 0.23 | 0.68 | 2.18 | 6.4 | 6.71 | 19.69 | 5.25 | 15.38 | 4.37 | 12.8 |
| Variety | | 3.85 | 11.28 | 0.20 | 0.59 | 1.89 | 5.54 | 5.81 | 17.05 | 4.54 | 13.32 | 3.78 | 11.09 |
| Sowing x variety | | 7.69 | 22.56 | 0.40 | 1.18 | 3.78 | 11.08 | 11.63 | 34.1 | 9.08 | 26.64 | 7.56 | 22.18 |

disease severity was recorded on all plant parts at 90 DAS. These results also confirm the results of Ghosh and Chatterjee (1988) and Saran and Giri (1987) that delay in sowing of rapeseed mustard reduce the siliqua percentage 24 to 57%. These results also support the findings of Mian and Akanda (1989) who have recommended early sowing for minimum damage of crop from *Alternaria* leaf blight disease. So, the progress of disease was found to be highly significant among the date of sowing and cultivars (Rahman and Biswas, 1994, Singh and Singh, 1999). The interaction of these variables were also significant (P<0.05). Among the three cultivars tested Bhagirathi sown on all the dates showed significantly less disease followed by Binoy and Seeta. It was also noticed that disease severity increased with age of plant and highest disease severity was recorded at 90 DAS. The present findings are in agreement with the result of Sarkar and Sengupta (1978) that susceptibility of rapeseed-mustard to *Alternaria brassicae* increases with the age of plant. So, the Bhagirathi on 5th November sowing produced maximum seed yield and minimum disease severity on leaf and siliqua. The result also confirm the result of Dasgupta et al. (1991) that delay in sowing of Varuna variety by one month increased the incidence of leaf blight on leaves by 37% and on siluqua by 31% which reduced the yield up to 38%.

## Effect of weather factors

The disease assumed serious proportions in crop sown between 20th November and 5th December and minimum progression on 20th October and 5th November sowing. Correlation analysis of disease severity with ten weather factors at different growth stages are indicated that weather factors showed different correlation with disease severity at different sowing dates in two different years. In the year 2008-2009, different sowings dates showed different disease reaction and it was observed that at 20th October sowing the maximum temperature (24.9 to 28.5°C), minimum temperature (9.7 to 18.4°C), minimum relative humidity (39.5 to 66.3%), vapour pressure (morning) (9.6 to 16.8 millibar), vapour pressure (noon) (9.7 to 16.9 millibar) and total rainfall (10.0 milimeter) had significant negative correlation with disease severity (0.001 to 53.13%) (Table 3a). whereas in the year 2009-2010, maximum temperature (22.8 to 29.7°C), minimum temperature (11.6 to 17.3°C), maximum relative humidity (97.1 to 98.8%), vapour pressure (morning) (11.0 to 15.5 millibar), vapour pressure (noon) (16.7 to 23.8 millibar) and bright sunshine hours (3.8 to 9.3 h) had negative significant correlation with disease severity while minimum relative humidity (74.4 to 88.3%), wind velocity (evening) (0.30 to 1.15 km/h), wind velocity morning (0.4 to 1.15 km/h) had significant positive correlation with disease severity (0.001 to 52.5%) at 90 DAS (Table 3b). Whereas, two years pooled mean showed that maximum temperature, minimum temperature and vapour pressure (morning) had negative significant correlation with disease severity and other seven factors were statistically non significant in the development of disease upto 90 DAS (Table 3c).

5th November sowing in the year 2008-2009 showed that maximum temperature (20.9 to 26.5°C) and bright sunshine hours (5.7 to 9.1 h) had negative significant correlation whereas minimum temperature (9.5 to 17.1°C), minimum relative humidity (40.1 to 62.2%), vapour pressure (morning) (9.4 to 12.7 millibar) and total rainfall) (5.4 to 19.4 millimeter) had positive significant correlation with disease severity at 90 DAS (0.12 to 58.57% ). Other weather factors were not statistically significant with disease severity (Table 3a). In the year 2009-10, it was observed that minimum temperature (10.3 to 16.3°C) had significant negative correlation with disease severity while wing velocity (evening) (0.56-1.12 km/h) and wind velocity (morning) (0.52 to 1.04 km/h) had significant positive correlation with disease severity (Table 3b). The two years pooled mean showed that only wing velocity (evening and morning) had positive significant correlation with disease severity at 90 DAS and others factors were not statistically significant (Table 3c).

In 20th November sowing, in the years 2008-2009 it was observed that maximum temperature (23.1 to 26.4°C) had negative significant correlation with disease severity while minimum temperature (9.7 to 12.1°C), maximum relative humidity (96.2 to 97.6%), minimum relative humidity (39.5 to 64.4%), vapour pressure (morning) (9.2 to 12.7 millibar), vapour pressure (noon) (9.7 to 12.1 millibar) had positive significant correlation with disease severity at 90 DAS (61.98%) (Table 3a). In the year 2009-2010, it was observed that maximum temperature (23.2 to 26.4°C), wind velocity (evening (0.50 to 2.00 km/h), wind velocity (morning) (0.5 to 2.00 km/h) and bright sunshine hours (3.8 to 9.0 h) had positive significant correlation with disease severity, while maximum relative humidity (96.2 to 97.7%), minimum relative humidity (39.5 to 64.4%) had negative significant correlation with disease severity (Table 3b). The two years pooled mean showed that maximum relative humidity wind velocity (evening), and wind velocity (morning) had positive significant correlation with disease severity where as other factors were not statistically significant (Table 3c).

5th December sowing in the year 2008-2009, it was noticed that minimum temperature (10.1 to 17.1°C), maximum relative humidity (97.1 to 98.7%), vapour pressure (morning) (9.4 to 16.4 millibar), vapour pressure (noon) (9.9 to 15.8 millibar) were significant positive correlation with disease severity to reach 66.97%, while other factors were not statistically significant. In the year 2008-2009, maximum temperature (25.2 to 32.2°C), minimum temperature (10.3 to 17.9°C), minimum relative humidity (32.7 to 87.6%), vapour pressure (morning) (9.7-16.4 millibar) and bright sunshine hours (5.7 to 9.1 h) had positive significant correlation with disease severity while vapour pressure noon (10.3 to 21.8 millibar) had negative effect. The two years pooled mean showed that maximum temperature, minimum temperature, vapour

**Table 3a.** Correlation co-efficient(r) between weather factors and *Alternaria* blight severity at different dates of sowing in the year 2007-2008. Correlation co-efficient(r).

| Dates of sowing | Weather factor | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ | $X_{10}$ |
| 20th Oct | -0.724** | -0.875** | -0.105 | -0.745** | -0.833** | -0.814** | 0.448 | -0.238 | 0.445 | -0.474* |
| 05th Nov | -0.540* | 0.584* | -0.168 | 0.768** | 0.522* | 0.307 | -0.114 | 0.276 | -0.699** | 779** |
| 20th Nov | -0.582* | 0.559* | 0.547* | 0.604* | 0.599* | 0.609* | 0.164 | 0.137 | -0.382 | 0.502* |
| 05th Dec | 0.415 | 0.696** | 0.654* | 0.363 | 0.789** | 0.816** | -0.106 | 0.469 | 0.039 | 0.053 |

**Table 3b.** Correlation co-efficient(r) between weather factors and *Alternaria* blight severity at different dates of sowing in the year 2008-2009. Correlation co-efficient(r).

| Dates of sowing | Weather factor | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ | $X_{10}$ |
| 20th Oct | -0.752** | -0.839** | -0.770** | 0.639* | -0.863** | -0.651* | 0.761** | 0.768** | -0.792** | - |
| 05th Nov | -0.073 | -0.576* | 0.358 | -0.031 | -0.283 | -0.216 | 0.921** | 0.897** | 0.166 | - |
| 20th Nov | 0.637* | -0.170 | -0.764** | -0.764** | -0.089 | 0.461 | 0.831** | 0.829** | 0.899** | - |
| 05th Dec | 0.950** | 0.675* | -0.087 | 0.885** | 0.674* | -0.671* | -0.327 | -0.179 | 0.774** | - |

**Table 3c.** Correlation co-efficient(r) between weather factors and *Alternaria* blight severity at different dates of sowing (Pooled two years).

| Dates of sowing | Weather factor | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ | $X_{10}$ |
| 20th Oct | -0.720** | -0.819** | -0.264 | -0.075 | -0.769** | -0.344 | -0.231 | 0.189 | -0.154 | -0.329 |
| 05th Nov | -0.286 | 0.058 | 0.162 | 0.158 | 0.043 | -0.023 | 0.533* | 0.642* | -0.142 | 0.497* |
| 20th Nov | 0.177 | 0.124 | 0.528* | -0.017 | 0.204 | 0.195 | 0.527* | 0.512* | 0.300 | 0.321 |
| 05th Dec | 0.603* | 0.680** | 0.172 | -0.488* | 0.721** | -0.175 | -0.227 | 0.070 | 0.473* | 0.036 |

Significant at 5%; ** Significant at 1%; $X_1$ = Maximum temperature ($^0$C); $X_2$=Minimum temperature($^o$C); $X_3$= Maximum relative humidity(%); $X_4$= Minimum relative humidity (%); $X_5$= Vapour presure (morning); $X_6$=Vapour presure (noon), $X_7$= Wind velocity (evening); $X_8$= Wind velocity (morning); $X_9$= Bright sunshine hours; $X_{10}$= total rainfall.

pressure (morning) and bright sunshine hours had positive significant correlation with disease severity while minimum relative humidity had negative effect and others factors were not statistically significant with disease severity in that cropping season. The results therefore indicated that temperature played an important role in *Alternaria* leaf blight disease severity (Figure 1) with association with relative humidity (Figure 2), Vapour pressure (Figure 3), Wave length (Figure 4) and Bright sunshine hour (Figure 5) directly effect on spore germination, penetration within the host. Whereas vapour pressure and wind velocity helps in spore liberation and dispersal within the crop for increase the disease progress (Gadare et al., 2002). So, it was noticed that both temperature (maximum and minimum), both relative humidity (maximum and minimum),

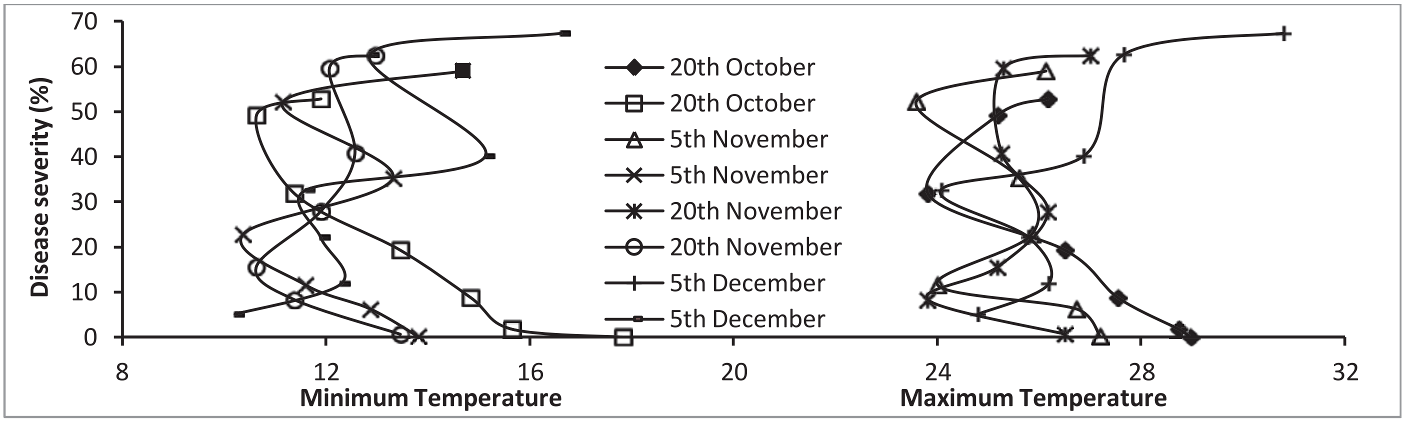


**Figure 1.** Effect of temperatures (°C) on disease severity.

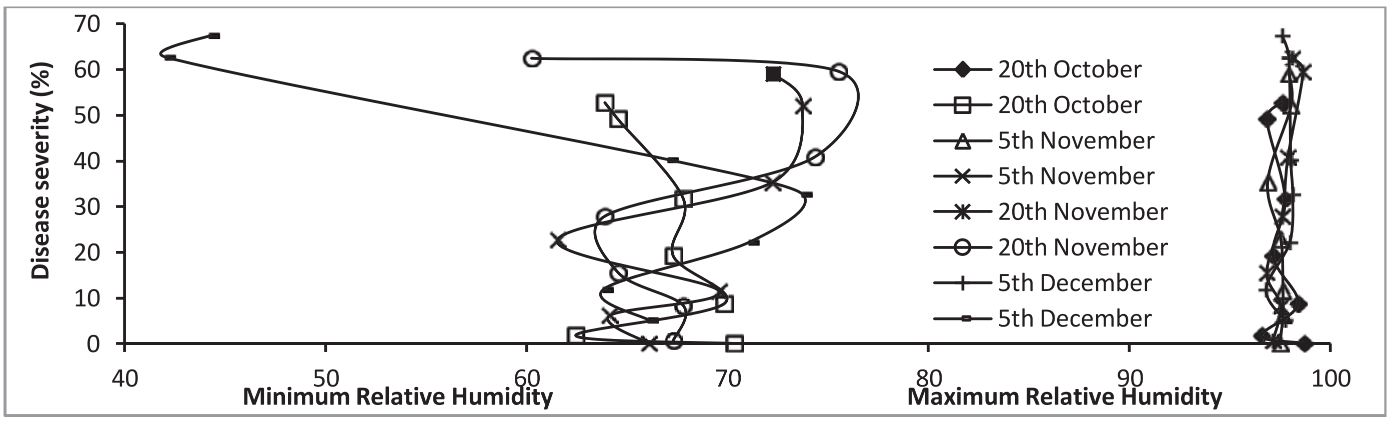


**Figure 2.** Effect of relative humidity (%) on disease severity.

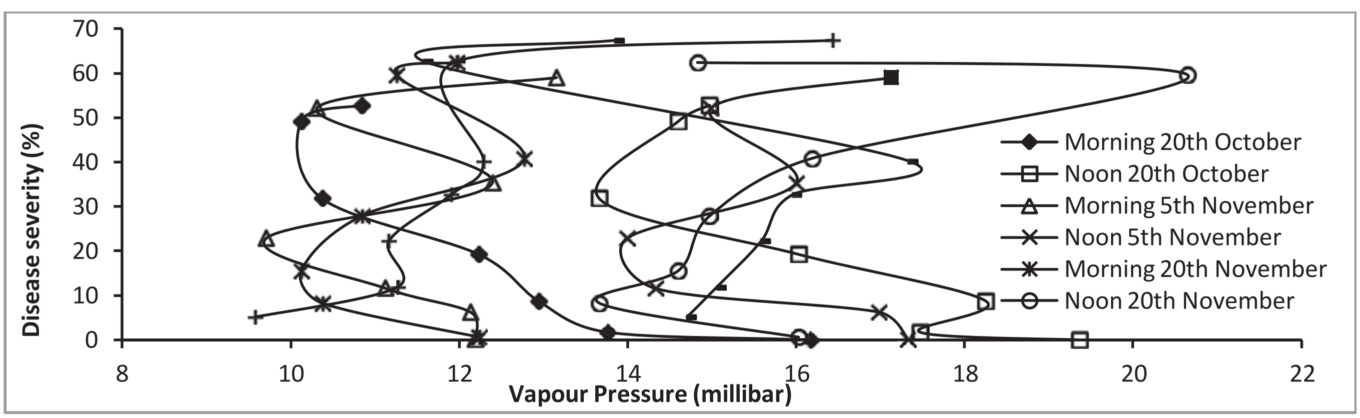


**Figure 3.** Effect of vapour pressure on disease severity.

vapour pressure (morning and noon) played a major role in *Alternaria* blight development irrespective of dates of sowing. Awasthi and Kolte (1994) reported that these two meteorological factors (temperatures and humidity) were extended profound effect on the disease progession of *Alternaria* blight of mustard. Increase in vapour pressure within the crop canopy cause spore liberation and also vulnerable to host for disease infection. Late sowing after 20$^{th}$ November increase in vapour pressure there was a increase in disease severity. Whereas, 20$^{th}$ October's

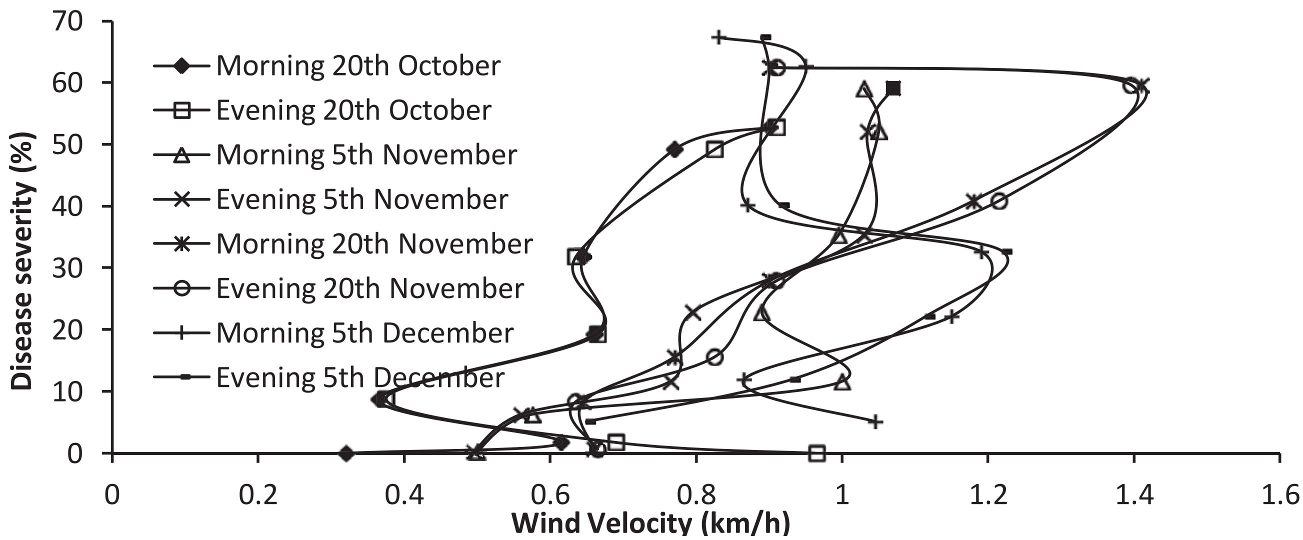


**Figure 4.** Effect of wind velocity on disease severity.

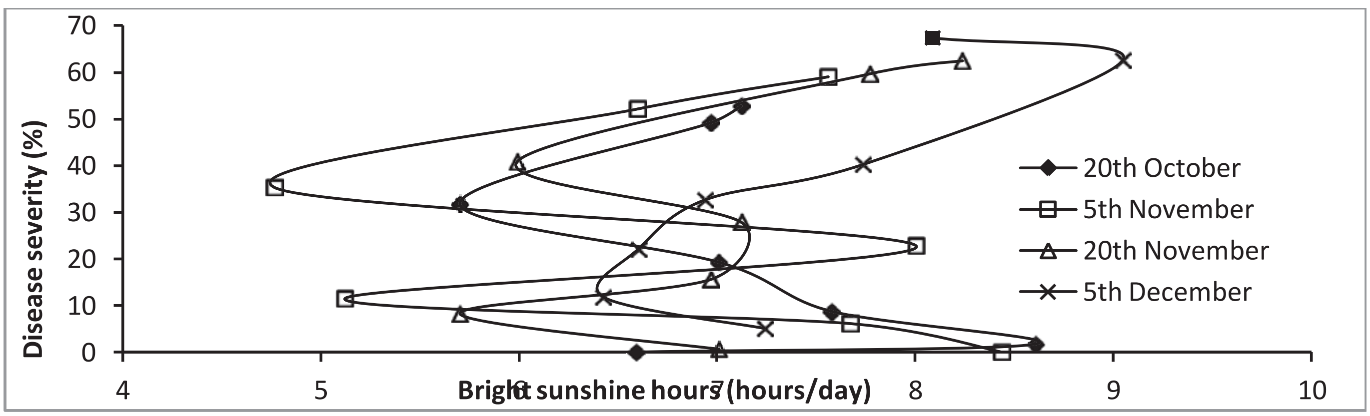


**Figure 5.** Effect of bright sunshine hours on disease severity.

sown crop showed the opposite result. It was also observed that different dates of sowing produced different disease severity within the same weather condition due to difference in crop age. In late sown crop with increase in bright sunshine hours there was an increase in disease severity where as early sowing (20th October) showed the opposite result. Gadare et al. (2002) reported that sunshine hours and crop age has significant correlation with disease severity. So, maximum temperature 26 to 29°C maximum relative humidity (>80%) and vapour pressure (> 8.0 millibar) favoured the progression of *Alternaria* blight of mustard when the crop age was above 40 DAS. From this study it may be concluded that by manipulating the sowing date of mustard between 20th October to 5th November with Baghirathi variety, the crop can be saved from heavy infection of *Alternaria* blight. Severity of disease at 90 DAS was favoured by high relative humidity and minimum temperature and vapour pressure in morning hours.

## Conflict of Interest

The authors have not declared any conflict of interest.

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academicJournals

Vol. 10(7), pp. 588-595, 12 February, 2015
DOI: 10.5897/AJAR2014.8484
Article Number: 2A369FA50324
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Combination of resistant cultivars, botanical insecticides, and biological control for *Plutella xylostella* management on cabbage

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Received 8 January, 2014; Accepted 22 January, 2015

**Novel strategies for *Plutella xylostella* management in cabbage need to be evaluated in order to increase its control and reduce adverse impacts on the environment. Thus, we evaluated the combined effects of the cabbage cultivars Ruby Ball, Matsukase Sakata, and Sessenta Dias, the aqueous extracts of *Azadirachta indica*, *Aspidosperma pyrifolium*, and *Melia azedarach*, and the parasitoid *Oomyzus sokolowskii* on *P. xylostella* control and selectivity to the parasitoid. This study attempted to give insights to further elaborate an IPM strategy for cabbage crop. The first assay recorded *P. xylostella* mortality, and the second assay recorded the number of parasitoids emerged from *P. xylostella* pupa and *O. sokolowskii* immature development in two successive generations. Cultivar Ruby Ball treated with *A. pyrifolium* extract increased *P. xylostella* mortality over 85%. Parasitism by *O. sokolowskii* combined with *A. pyrifolium* or *A. indica* extracts provided up to 95% mortality, regardless of the cabbage cultivar. Cultivar Matsukase Sakata treated with *M. azedarach* or *A. indica* extracts affected adversely *O. sokolowskii* development. The number of parasitoids emerged from *P. xylostella* pupa was increased from the first to the second generation on the resistant cvs. Ruby Ball and Matsukase Sakata. Further experiments are encouraged to confirm in greenhouse and field the high mortality rates of *P. xylostella* and selectivity to *O. sokolowskii*, in order to elaborate an efficient IPM program for cabbage against the diamondback moth.**

**Key words:** *Brassica oleraceae* var. *capitata*, diamondback moth, host plant resistance, integrated pest management, *Oomyzus sokolowskii*, plant extracts.

## INTRODUCTION

Cabbage, *Brassica oleracea* (L.) var. *capitata*, is an important social-economic crop in many countries. In Brazil, cabbage has been grown especially by small farmers (Filgueira, 2007). Plants of cabbage are

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extensively attacked by the diamondback moth *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), which is considered for years the key-pest of cabbage in Brazil and worldwide (Chen et al., 1986; Torres, 2004). Severe infestations of *P. xylostella* have resulted in more than US$ 6 million in crop losses (Shelton et al., 2000).

The chemical control is the major practice used for the diamondback moth management. This control practice has been widely employed because some insecticides control the pest at satisfactory levels in addition to the ease of application (Boiça Júnior et al., 2005). However, complete reliance on insecticide application is undesirable because of adverse economic and environmental reasons (Boiça Júnior et al., 2013). Moreover, the excessive use of insecticides may affect natural enemies in the field and promote the selection of resistant populations of the diamondback moth (Liu et al., 1981; Sarfraz and Keddie, 2005).

Among the natural enemies of *P. xylostella*, the larval-pupal parasitoid *Oomyzus sokolowskii* (Kurdjumov) (Hymenoptera: Eulophidae) has been employed in programs of biological control in different cabbage-producing regions in the world (Ooi, 1988; Mushtaque, 1990; Mahmood et al., 2004). In Brazil, the parasitoid was firstly reported in Rio Grande do Sul (Ferronatto and Becker, 1984), thereafter in Pernambuco (Loges, 1996), and some years later in Distrito Federal (Castelo Branco and Medeiros 2001). *O. sokolowkii* has a generalized occurrence in cabbage crops in Pernambuco State, Brazil. According to Ferreira et al. (2003), the number of generations of *O. sokolowskii* is always higher in average than the diamondback moth's. The parasitoid can produce approximately 24 generations yearly, against up to 20 generations for the herbivore. Parasitism rates up to 97% in the end of the phonological cycle of cabbage have been reported (Loges, 1996). Thus, this parasitoid is a promising agent to be used in programs of biological control against *P. xylostella* larvae in Brazil.

The cultivation of resistant cultivars is a promising alternative method to control *P. xylostella* (Hamilton et al., 2005; Sarfraz et al., 2006). This practice does not accumulate additional costs associated with insecticide applications, and reduces the intoxication risks to farmers and consumers. Also, the concentration of residues on food and environment can diminish considerably (Torres, 2004). Other plant species holding bioactive substances may also serve as source of extracts for pest control. Several studies have clearly demonstrated the insecticidal potential of plant species from diverse taxonomic families to the diamondback moth (Stein and Klingauf, 1990; Torres et al., 2001; Boiça Júnior et al., 2005; Torres et al., 2006; Thuler et al., 2008; Rondelli et al., 2011; Boiça Júnior et al., 2013).

Integrated pest management (IPM) is a decision support system in which control tactics are selected and used singly or harmoniously combined in strategies based on cost/benefit analyses (Kogan, 1998). Thereby, to elaborate an efficient IPM program for cabbage, multiple tactics such as resistant cultivars, botanical insecticides, and biological control must be evaluated together regarding their compatibility for pest control. According to Thuler et al. (2008), despite the broad knowledge on several methods to control agricultural pests, very few is known about the interaction among plant resistance, insecticides, herbivore, and its natural enemies. Thus, considering the importance of cabbage cultivars expressing moderate levels of resistance, the use of botanical insecticides, and *O. sokolowskii* as a biological control agent on *P. xylostella* control, we aimed to evaluate their combined effects on *P. xylostella* mortality and the selectivity on the parasitoid, attempting to elaborate an IPM strategy for cabbage crop.

## MATERIALS AND METHODS

The experiment was carried out in the Departament of Crop Protection of São Paulo State University, Campus of Jaboticabal, in Jaboticabal, SP, Brazil. The assays were performed in laboratory, under controlled conditions of 25 ± 1°C temperature, 70 ± 10% RH, and L14:D10 photoperiod.

Seeds of kale, *B. oleracea* var. *acephala* (cv. Georgia), and green cabbage, *B. oleracea* var. *capitata* (cvs. Ruby Ball, Matsukase Sakata, and Sessenta Dias) were sown in styrofoam trays with the potting mixture Plantmax®. Kale plants were further used for maintenance of the diamondback moth colony, and plants of the cabbage cultivars were used for the resistance assays. Larvae of *P. xylostella* were offered a different source of food (kale leaves) prior to the assays to prevent pre-conditioning. Following 30 days from sowing, plants were transplanted into 5 L pots with soil, sand, and manure (2:1:1 ratio), and placed in a greenhouse. Sprinkler irrigation and tillage practices were done as needed according to Filgueira (2007).

Larvae of *P. xylostella* were collected in cabbage plants grown in fields around Jaboticabal, SP, Brazil, and a colony was initiated and maintained under controlled conditions (25 ± 1ºC temperature, 70 ± 10% RH, and L14:D10 photoperiod). The *P. xylostella* larvae in the colony were fed leaves of the kale cv. Georgia. The parasitoid *O. sokolowskiii* was obtained by collecting parasitized pupae of *P. xylostella* in the same field-grown cabbage. Thereafter, the parasitoid was reared on *P. xylostella* larvae in laboratory. Both rearing procedures of *P. xylostella* and *O. sokolowskii* followed the methodology proposed by Torres (2004).

For the assays, leaf discs (8.0 cm diameter) prepared from the resistant cabbage cvs. Matsukase Sakata and Ruby Ball, and susceptible cv. Sessenta Dias (Torres, 2004) were immersed for 30 seconds in plastic containers with aqueous extracts from the following plant species: *Azadirachta indica* (A. Juss) (0.058 g 100 $mL^{-1}$), *Aspidosperma pyrifolium* (Mart.) (2.175 g 100 $mL^{-1}$), and *Melia azedarach* (L.) (2.905 g 100 $mL^{-1}$). These species of botanical insecticides and respective mean lethal concentrations ($LC_{50}$) were chosen because of their effectiveness on mortality of *P. xylostella* neonate larvae recorded by Torres et al. (2006). Thereafter, treated cabbage leaf discs were placed on paper towels and dried at room temperature for approximately 10 minutes. Also, untreated leaf discs of the cabbage cultivars were served as controls.

### Effects of cabbage cultivars, plant aqueous extracts, and parasitism by *O. sokolowskii* on *P. xylostella* mortality

Treated leaf discs and control leaf discs were placed individually in Petri dishes (9.0 cm diameter) lined with moistened filter paper.

Thereafter, 12 neonate larvae were collected from the aforementioned colony and placed in each Petri dish. Five replications were used in each treatment and control. The assay was set up in a completely randomized design in a 3 × 4 × 2 factorial arrangement, in which were evaluated three cabbage cultivars (Matsukase Sakata, Ruby Ball, and Sessenta Dias), four plant aqueous extracts (*A. indica*, *A. pyrifolium*, *M. azedarach*, and control) and the presence or absence of the parasitoid *O. sokolowskii*. Sixty replicates (five Petri dishes with 12 larvae each) were used in the assay.

Larval mortality was first recorded at the fourth day after the larvae were confined in Petri dishes. The leaf discs were switched daily with fresh untreated leaves by the larval fourth-instar. Upon this stage, *P. xylostella* larvae were removed from the Petri dishes and transferred into plastic cages (6.0 cm high × 5.0 cm diameter bottom × 7.5 cm diameter top). The cages were similar to those used for the parasitoid rearing, and followed the methodology described by Torres (2004). One 24 hour-old *O. sokolowskii* female was remained in the colony for mating and later introduced in the cage per each survived larva of *P. xylostella*. The larvae were subjected to *O. sokolowsii* parasitism during 24 h under controlled conditions (25 ± 1°C temperature, 70 ± 10% RH, and L12:D12 photoperiod). Thereafter, *P. xylostella* larvae were transferred into Petri dishes (9.0 cm diameter) containing leaf discs (8.0 cm diameter) of the cabbage cultivars they had previously fed upon. When *P. xylostella* larvae molted to pupae, they were transferred into ELISA test plates using a soft paintbrush. The ELISA plates were covered with plastic film with small punctures opened with a fine needle on top to allow air flow. The plates were daily observed to record *P. xylostella* or *O. sokolowskii* adult emergence.

For each treatment, the mortality rate of *P. xylostella* larvae and pupae was calculated as the sum of dead insects divided by the total number of larvae and pupae (dead and alive). Data were subjected to three-way ANOVA, and when significance was found means were separated by Tukey's HSD test ($p < 0.05$).

#### Effect of cabbage cultivars and plant aqueous extracts on *Oomyzus sokolowskii* selectivity

Neonate larvae of *P. xylostella* were placed onto treated or untreated leaf discs of cabbage as previously described, where they remained during four days. Next, the leaf discs were replaced daily with fresh untreated leaf discs. Four fourth-instar *P. xylostella* larvae were transferred in cages (6.0 cm high × 5.0 cm diameter bottom × 7.5 cm diameter top) containing a leaf piece (ca. 16.0 $cm^2$) of the respective cabbage cultivars they had previously fed upon. We used four fourth-instar larvae because Ferronato and Becker (1984) reported this was the maximum number of *P. xylostella* larvae parasitized by *O. sokolowskii* over 24 h. Next, one 24 hour-old *O. sokolowskii* female was remained in the colony for mating and thereafter was introduced in each cage, where she remained for 24 h. After this period, the *P. xylostella* larvae were transferred in Petri dishes with untreated leaves collected from the cultivars they were previously fed, and were observed daily until pupation. The pupae were individually transferred in each compartment of ELISA test plates using a soft paintbrush. The plates were covered with plastic film with small punctures opened with a fine needle to allow air flow. Observations were made daily to report *P. xylostella* or *O. sokolowskii* adult emergence. In each treatment, the number of parasitoids per pupa and immature development time (egg to adult) of *O. sokolowskii* were recorded.

We used initially 10 replications per treatment with four larvae in each replicate based on the results of the $LC_{50}$ for the plant extracts assessed (Torres et al., 2006), in order to set up later five cages per treatment for *O. sokolowskii* parasitism. Each treatment consisted of four *P. xylostella* larvae by one *O. sokolowskii* female. The assay was carried out during two successive generations of *P xylostella*. For this, upon *P. xylostella* adult emergence, the adults were collected using a flat bottom tube (8.0 cm high × 2.0 cm diameter) and put into plastic cages for mating (Torres, 2004). Neonate larvae of *P. xylostella* yielded from the second generation were used for the assay, and followed the same methodology as described before. The assay was set up in a completely randomized design in a 3 × 4 × 2 factorial arrangement (three cultivars x four plant aqueous extracts x two generations), with 20 replications (five cages with four *P. xylostella* larvae each). Data were subjected to three-way ANOVA, and means were compared by Tukey's HSD test ($p < 0.05$) whenever ANOVA was significant.

## RESULTS

### Effects of cabbage cultivars, plant aqueous extracts, and parasitism by *O. sokolowskii* on *P. xylostella* mortality

Based on the results with the three control methods combined, cv. Ruby Ball provided the highest mortality of *P. xylostella* (74.88%), differing significantly from cv. Matsukase Sakata (64.48%), and cv. Sessenta Dias (63.32%) (Table 1). Aqueous extracts from *A. pyrifolium* and *A. indica* caused similar mortality rates, and approximately 10% higher than the mortality rate caused by *M. azedarach* (Table 1). Parasitism by *O. sokolowskii* provided over 80% mortality, and was nearly 1.5-fold higher than in the absence of the parasitoid (Table 1).

Significant differences were found in the interaction of cultivars x aqueous extracts, and aqueous extracts × parasitism for *P. xylostella* mortality (Table 1), whereas the interaction of cultivars × parasitism, and cultivars × aqueous extracts × parasitism did not show significant differences. In the interaction of cabbage cultivars × aqueous extracts (Table 2), in general, the highest *P. xylostella* mortality was obtained for cv. Ruby Ball combined with *A. pyrifolium* aqueous extract (85.80%), which was ca. 20% higher than on untreated cv. Ruby Ball. Furthermore, untreated cv. Ruby Ball caused mortality 25% higher than untreated cv. Matsukase Sakata, and 45% higher than untreated cv. Sessenta Dias. In addition, even the susceptible cv. Sessenta Dias exhibited nearly 80% mortality when combined with *A. indica* or *A. pyrifolium* aqueous extracts. For the interaction of plant aqueous extracts × parasitism (Table 3), combination of *A. indica* and *A. pyrifolium* extracts with the parasitoid *O. sokolowskii* caused *P. xylostella* highest mortality, which were ca. 1.5- and 1.3-fold higher than in the absence of the parasitoid, respectively. On the other hand, combination of *M. azedarach* extract and the parasitoid was not as efficient as were with the other extracts.

### Effect of cabbage cultivars and plant aqueous extracts on *O. sokolowskii* selectivity

For the combined effects of cultivars, plant extracts, and generations, the number of parasitoids emerged per *P.*

**Table 1.** Mortality (%) of *Plutella xylostella* (larvae + pupae) caused by cabbage cultivars, plant aqueous extracts from *Azadirachta indica*, *Aspidosperma pyrifolium*, and *Melia azedarach*, and the parasitoid *Oomyzus sokolowskii*.

| Treatments | Mortality (%)[1] |
|---|---|
| **Cultivar (C)** | |
| Matsukase Sakata | 68.48[b] |
| Ruby Ball | 74.88[a] |
| Sessenta Dias | 63.32[c] |
| **Aqueous extracts (A)** | |
| *Azadiractha indica* | 79.12[a] |
| *Aspidosperma pyrifolium* | 81.57[a] |
| *Melia azedarach* | 69.74[b] |
| Control | 45.14[c] |
| **Parasitoid (P)** | |
| Absence | 56.97[b] |
| Presence | 80.81[a] |
| *F-ratio* (C) | 31.75*** |
| *F-ratio*(A) | 196.59*** |
| *F-ratio* (P) | 403.94*** |
| *F-ratio* (C x A) | 15.81*** |
| *F-ratio* (C x P) | 1.76[NS] |
| *F-ratio* (A x P) | 6.32** |
| *F-ratio* (C x A x P) | 0.55[NS] |

[1]Means with different letters in each column are significantly different by Tukey's HSD test. [NS] = non-significant. ** = significant at < 0.01. *** = significant at < 0.001.

**Table 2.** Mortality (%) of *P. xylostella* (larvae + pupae) upon feeding with cabbage cultivars previously treated with plant aqueous extracts from *A. indica*, *A. pyrifolium* and *M. azedarach.*

| Cultivars (C) | Aqueous extracts (A)[1] | | | | *F-ratio* (C) |
|---|---|---|---|---|---|
| | Control | *A. indica* | *A. pyrifolium* | *M. azedarach* | |
| Sessenta Dias | 28.50[cC] | 79.29[aA] | 79.25[bA] | 66.24[aB] | 136.56*** |
| Ruby Ball | 63.53[aC] | 77.70[aB] | 85.80[aA] | 72.48[aB] | 20.68*** |
| Matsukase Sakata | 43.40[bC] | 80.35[aA] | 79.67[bA] | 70.49[aB] | 70.97*** |
| *F-ratio* (A) | 73.18*** | 0.42[NS] | 3.19* | 2.40[NS] | - |

[1]Means with different lower-case letters in columns and upper-case letters in rows are significantly different by Tukey's HSD test. [NS] = non-significant. * = significant at < 0.05. *** = significant at < 0.001.

*xylostella* pupa was in average 9.7, and the duration of *O. sokolowskii* immature development was in average 16 days across the cultivars (Table 4). The cabbage cultivars did not differ for both parameters. Regarding the plant extracts, the number of parasitoids emerged per pupa and duration of the parasitoid immature development were not affected by *A. pyrifolium* extract (Table 4). Conversely, *M. azedarach* and *A. indica* extracts provided longer immature development and fewer parasitoids per pupa. The number of parasitoids emerged per *P. xylostella* pupa was significantly higher in the second generation than in the first generation, while no difference was found in the immature development time between generations (Table 4).

There were significant interactions in the number of parasitoids emerged per *P. xylostella* pupa in combinations of cabbage cultivars × aqueous extracts, and cultivars × generation (Table 4). In the former interaction, the number of parasitoids per pupa in general was significantly reduced in *P. xylostella* larvae fed

**Table 3.** Mortality (%) of *P. xylostella* (larvae + pupae) caused by combination of plant aqueous extracts from *A. indica*, *A. pyrifolium*, and *M. azedarach* and the parasitoid *O .sokolowskii*.

| Aqueous extracts (A) | Parasitoid (P)[1] | | *F-ratio* (A) |
|---|---|---|---|
| | Absence | Presence | |
| Control | 34.17[cB] | 56.11[cA] | 85.47*** |
| *A. indica* | 63.12[bB] | 95.11[aA] | 181.79*** |
| *A. pyrifolium* | 69.74[aB] | 93.41[aA] | 99.48*** |
| *M. azedarach* | 60.85[bB] | 78.63[bA] | 56.16*** |
| *F-ratio* (P) | 87.10*** | 115.81*** | - |

[1]Means with different lower-case letters in columns and upper-case letters in rows are significantly different by Tukey's HSD test. *** = significant at < 0.001.

**Table 4.** Number of parasitoids per pupa and immature development time (days) of *O. sokolowskii* on *P. xylostella* reared for two generations on cabbage cultivars treated with aqueous extracts from *A. indica*, *A. pyrifolium*,and *M. azedarach*.

| Treatments | Parasitoids per pupa[1] | Immature development (days)[1] |
|---|---|---|
| Cultivars (C) | | |
| Matsukase Sakata | 9.57[a] | 15.95[a] |
| Ruby Ball | 10.20[a] | 16.07[a] |
| Sessenta Dias | 9.26[a] | 16.05[a] |
| **Aqueous extracts (A)** | | |
| *A. indica* | 9.56[ab] | 16.22[a] |
| *A. pyrifolium* | 10.67[a] | 15.86[b] |
| *M. azedarach* | 8.30[b] | 16.26[a] |
| Control | 10.19[a] | 15.77[b] |
| **Generation (G)** | | |
| First | 9.18[a] | 15.97[a] |
| Second | 10.17[b] | 16.08[a] |
| *F-ratio* (C) | 1.58[NS] | 0.69[NS] |
| *F-ratio* (A) | 5.40** | 8.70** |
| *F-ratio* (G) | 5.04* | 1.72[NS] |
| *F-ratio* (C x A) | 2.77* | 1.15[NS] |
| *F-ratio* (C x G) | 3.20* | 0.09[NS] |
| *F-ratio* (A x G) | 1.48[NS] | 0.15[NS] |
| *F-ratio* (C x A x G) | 0.82[NS] | 1.38[NS] |

[1]Means with different lower-case letters in columns and upper-case letters in rows are significantly different by Tukey's HSD test. [NS] = non-significant. * = significant at < 0.05. ** = significant at < 0.01.

leaves of the resistant cv. Matsukase Sakata treated with *M. azedarach* or *A. indica* extracts (Table 5). However, *A. indica* extract did not differ from the control either. In the latter interaction, the resistant cvs. Ruby Ball and Matsukase Sakata treated with plant extracts had the number of parasitoids per pupa increased from the first to the second generation, whereas no difference was found for the susceptible cv. Sessenta Dias (Table 6). In the second generation, the number of parasitoids per *P. xylostella* pupa on cv. Ruby Ball was approximately 20% higher than on cv. Sessenta Dias.

## DISCUSSION

In the current study we demonstrated the combined effects of three control methods for *P. xylostella*. Also, we found increased mortality rates using only one or two methods separately. For the single effect of cabbage cultivars, it was evident that cv. Ruby Ball exhibits the

**Table 5.** Number of parasitoids of *O. sokolowskii* per pupa of *P. xylostella* from the interaction of cabbage cultivars x plant aqueous extracts.

| Cultivars (C) | Aqueous extracts (A)[1] | | | | *F-ratio* (C) |
|---|---|---|---|---|---|
| | Control | *A. indica* | *A. pyrifolium* | *M. azedarach* | |
| Sessenta Dias | $9.93^{aA}$ | $9.60^{aA}$ | $9.30^{aA}$ | $8.20^{abA}$ | $0.96^{NS}$ |
| Ruby Ball | $9.07^{aA}$ | $10.10^{aA}$ | $11.80^{aA}$ | $9.85^{aA}$ | $2.26^{NS}$ |
| Matsukase Sakata | $11.57^{aA}$ | $8.97^{aAB}$ | $10.92^{aA}$ | $6.95^{bB}$ | 7.72** |
| *F-ratio* (A) | $2.75^{NS}$ | $0.55^{NS}$ | $2.74^{NS}$ | 3.85* | - |

[1]Means with different lower-case letters in columns and upper-case letters in rows are significantly different by Tukey's HSD test. $^{NS}$ = non-significant. * = significant at < 0.05. ** = significant at < 0.01.

**Table 6.** Number of parasitoids of *O. sokolowskii* per pupa of *P. xylostella* from the interaction of cabbage cultivars x generation.

| Cultivars (C) | Generation[1] | | *F-ratio* (C) |
|---|---|---|---|
| | First | Second | |
| Sessenta Dias | $9.54^{aA}$ | $8.87^{bA}$ | $0.55^{NS}$ |
| Ruby Ball | $9.20^{aB}$ | $11.21^{aA}$ | 6.89** |
| Matsukase Sakata | $8.80^{aB}$ | $10.34^{abA}$ | 4.02* |
| *F-ratio* (G) | $0.46^{NS}$ | 4.33* | - |

[1]Means with different lower-case letters in columns and upper-case letters in rows are significantly different by Tukey's HSD test. $^{NS}$ = non-significant. * = significant at < 0.05. ** = significant at < 0.01.

highest level of constitutive resistance against the diamondback moth. Mortality of *P. xylostella* larvae fed cv. Ruby Ball leaves was almost 1.5-fold higher than larvae fed cv. Matsukase Sakata, and more than 2-fold higher on cv. Sessenta Dias (Table 2).

Resistant cultivars play an important role on diamondback moth management as an alternative tactic for synthetic insecticides. Several studies were conducted in the last years by evaluating various cabbage cultivars for *P. xylostella* management. For instance, Vendramim et al. (2010), while studying the biological development of *P. xylostella* fed on nine cabbage cultivars including cv. Ruby Ball used in our work, did not observe differences in larval mortality. However, cv. Toshin Takii caused the highest pupal mortality. Thuler et al. (2007) reported the cabbage cv. Chato de Quintal exhibited the highest *P. xylostella* larval and pupal mortality among six cultivars of cruciferous assessed. Sinigrin contents have been one of the mechanisms influencing the expression of resistance in cruciferous plants (Ulmer et al., 2002). Therefore, cultivars possessing higher concentrations of this glucosinolate should be pursued in genetic breeding programs of cabbage against *P. xylostella*.

Integrated pest management is a decision support system in which control tactics are selected and used singly or harmoniously combined in strategies based on cost/benefit analyses (Kogan, 1998). Thereby, to elaborate an efficient IPM program for cabbage, multiple tactics such as resistant cultivars and botanical insecticides must be evaluated together regarding their compatibility for pest control. We found efficient control rates of *P. xylostella* using aqueous extracts from *A. indica* and *A. pyrifolium* (Table 1). Further, aqueous extract application may enhance insect mortality upon susceptible cultivars, as was observed for cv. Sessenta Dias (Table 2). This cultivar had the mortality rate increased from 28.5 to nearly 80% when combined with *A. indica* or *A. pyrifolium* extracts. This is of great importance because susceptible but high yield cultivars can be used combined with botanical insecticides, thus being protected by larval *P. xylostella* injuries and maintaining their high yield.

Various investigations have been made in the last decade on combinations of resistant cruciferous cultivars and botanical insecticides for *P. xylostella* control as an alternative strategy to pesticide use. Thuler et al. (2008) found a positive interaction between cruciferous cultivars and botanical insecticides on *P. xylostella* mortality. Combinations of cabbage cv. Chato de Quintal with pyroligneous extract, and kale cv. Georgia with *A. indica* oil gave satisfactory results for *P. xylostella* larval mortality, and both mortality rates were higher than the rates provided by either of those cultivars treated with the insecticide deltamethrin. Boiça Júnior et al. (2005) reported 100% *P. xylostella* larval mortality for leaf discs of kale cv. Georgia treated with extracts of seed-containing fruits of *Enterolobium contortisilliquum* (Vell.) Morong, leaves of *Nicotiana tabacum* L., fruits of *Sapindus saponaria* L., and branches of *Trichilia pallida* Sw. Boiça Júnior et al. (2013) verified that *A. indica* aqueous extract applied at 5 or 10% concentrations on leaf discs of the cabbage cvs. Ruby Ball and Chato de Quintal repelled *P. xylostella* larvae. Moreover, the concentrations of *A. indica* aqueous extract attained up to 88.33% larval mortality at the fifth day after application. These studies have demonstrated that combination of resistant cultivars and botanical insecticides can be harmoniously used together for *P. xylostella* control.

The parasitoid *O. sokolowskii* has been used for biological control programs in many growing areas with cabbage in the world (Mahmood et al., 2004). We reported in laboratory conditions over 55% *P. xylostella* control using the parasitoid singly. In addition, the control rate reached up to 93 or 95% when *O. sokolowskii* was combined with *A. pyrifolium* or *A. indica* aqueous extracts, respectively. Thus, due to the importance of this parasitoid on *P. xylostella* control in natural conditions (Loges, 1996), control methods not affecting *O. sokolowkii* development must be preferred in order to augment its populations in the field.

The resistant cultivars Ruby Ball and Matsukase Sakata did not affect negatively *O. sokolowskii* development. The number of parasitoids per *P. xylostella* pupa and the parasitoid immature development in the resistant cultivars were similar to those on the susceptible cv. Sessenta Dias. Morphological or chemical traits in host plants conferring resistance to phytophagous insects may affect organisms in the third trophic level, such as the parasitoids and predators (Price et al., 1980). This did not happen in our study. On the contrary, we demonstrated that, in addition to being resistant against the diamondback moth, cvs. Ruby Ball and Matsukase do not impact negatively the parasitoid. Loges (1996) did not report differences on *O. sokolowskii* parasitism in field conditions across the cultivars Naniwa, Midore, Soshin, Kyozan, Matsukase, and Louco de Verão. Furthermore, the parasitism rate enhanced over the crop development, as well as the sex ratio and number of parasitoids emerged from *P. xylostella* pupae. However, the resistant cv. Matsukase Sakata treated with *M. azedarach* aqueous extract strongly reduced the number of parasitoids emerged from *P. xylostella* pupa in our study, and partially when treated with *A. indica* extract. The species *A. indica* and *M. azedarach* belong to Meliaceae family, of which plants possess azadirachtin as the major defensive compound. Azadirachtin acts by interfering on the endocrinal glands responsible for metamorphosis induction in insects, thus preventing ecdysis (Simões et al., 2007). Thuler et al. (2008) evaluated the tritrophic interaction of cruciferous, *P. xylostella*, and the egg parasitoids *Trichogramma pretiosum* Riley and *Trichogramma exiguum* Pinto & Platner (Hymenoptera: Trichogrammatidae) combined with chemical or botanical insecticides. The interactions between *A. indica* extract x cv. Chato de Quintal, and *A. indica* extract x Híbrido Roxo affected the parasitism, with reduced egg parasitism and parasitoid emergence. Thus, it is possible that azadirachtin or other secondary compounds from *A. indica* and *M. azedarach* affect the parasitoid development. It is important to mention that in our work the females of *O. sokolowskii* were forced to parasitize *P. xylostella* larvae fed on cabbage leaves treated with the plant extracts, and thereby were not given a choice for healthy larvae. In natural field conditions this choice might attenuate the negative effects of *M. azedarach* and *A. indica* extracts on the parasitoid.

The number of *O. sokolowskii* emerged per *P. xylostella* pupa increased from the first to second generation. In this context, applied aqueous extracts from *A. pyrifolium* and *A. indica* may be a useful tool to control *P. xylostella* larvae and allow *O. sokolowskii* populations to augment in cabbage fields. According to Ferreira et al. (2003), at 28 and 18°C temperatures, the parasitoid larval stage duration were 12.9 and 31.6 days, 7.3 and 12.0 adult parasitoids emerged from each *P. xylostella* pupa, and the sex ratio were 86 and 91% females, respectively. Also, *O. sokolowskii* can disperse, find, and parasitize *P. xylostella* larvae up to 24 m from its release point (Silva-Torres et al., 2011). All these biological features (short development time, high reproduction rate, high rate of female emergence, and foraging behavior) make this parasitoid an ideal agent for biological control purposes.

The preference of botanical insecticides over synthetic insecticides would also allow for population increase of other natural enemies acting on the biological control of the diamondback moth. According to Goodwin (1979), only for parasitoids, over 90 species can attack *P. xylostella* in the field. Pereira et al. (2004) found respectively 86.1 and 86.7% emergence of the parasitoids *T. pretiosum* and *T. exiguum* reared on *P. xylostella* eggs whose larvae were previously fed leaves of the kale cv. Manteiga. Dadang and Prijono (2009) found that formulations of the plant species *Piper retrofractum* Vahl., *Annona squamosa* L., and *Aglaia odorata* Lour. did not affect the performance of the parasitoids *Diadegma semiclausum* (Hellen) and *Eriborus argentiopilosus* (Cameron) (Hymenoptera: Ichneumonidae) on cabbage. Therefore, applied botanical insecticides against *P. xylostella* will contribute for increased populations of several natural enemy species in cabbage fields.

In summary, the combined use of the resistant cv. Ruby Ball with *A. pyrifolium* aqueous extract increases *P. xylostella* mortality. Parasitism by *O. sokolowskii* in combination with *A. pyrifolium* or *A. indica* extracts can attain nearly total mortality of *P. xylostella* regardless of the cabbage cultivar used. Lastly, the resistant cv. Matsukase Sakata treated with *M. azedarach* or *A. indica* extracts affects adversely *O. sokolowskii* development.

Considering the promising results of our study in laboratory conditions, further experiments are encouraged to evaluate in greenhouse and field the effects of the resistant cvs. Ruby Ball and Matsukase Sakata combined with *A. pyrifolium* aqueous extract. These studies may confirm the high mortality rates of *P. xylostella* and selectivity to *O. sokolowskii*, in order to elaborate an efficient IPM program for cabbage against the diamondback moth.

## Conflict of Interest

The authors have not declared any conflict of interest.

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Vol. 10(7), pp. 596-603, 12 February, 2015
DOI: 10.5897/AJAR2014.8484
Article Number: 485980950328
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Compost of garbage and tree pruning used as substrates for production of irrigated wild poinsettia seedling

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Received 9 January, 2014; Accepted 22 January, 2015

**The high nutrient content in organic composted waste is an alternative source of fertilizer for use in agriculture and for re-establishment of native forests. This work had as an objective is aimed to evaluate the growth of *Pterogyne nitens* (wild poinsettia) seedlings, a rainforest native species, on substrates containing composts of organic garbage and tree pruning. A greenhouse experiment was conducted, in which seedlings were randomly transplanted into tubes to establish 8 treatments, 4 substrates and 2 irrigation depths, in a 4×2 factorial arrangement, with three replicates. The substrates were: S1: 80% tree pruning compost and 20% garbage compost; S2: 100% tree pruning compost; S3: 80% tree pruning compost and 20% commercial substrate; S4: 100% commercial substrate. Irrigation was applied to supply 50% (Depth 1) and 100% (Depth 2) of daily reference evapotranspiration. Plantlet growth was not affected by irrigation, but plantlets were significantly taller in the treatment with 80% tree pruning plus 20% garbage composts. It was concluded that seedling formation of wild Poinsettia in a greenhouse environment can be satisfactorily obtained by supplying half of daily reference evapotranspiration depth and a substrate consisting of 80% pruning tree plus 20% garbage composts, which is suitable to replace the commercial fertilizer product.**

**Key words:** Growing media, organic compost, re-establishment native plants.

## INTRODUCTION

According to the Brazilian Association of Special Waste and Public Cleaning (ABRELPE 2010), the country generated more than 57 million tons of solid waste in 2009, corresponding to growth of 7.7% over the previous year's volume. In this context, attitudes seeking for alternatives to minimize the volume of waste disposed are essential to mitigate the environmental problem (IBGE, 2010). The main society's challenge is to ensure access and sustainable for use of natural resources (Pigatim, 2011), because population growth leads to greater consumption of food and non-durable goods, increasing considerably the production of waste.

The public forestation generates a significant amount of green waste, because of the pruning and subsequent

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removals made. That waste end up in landfills and, in some cases, are burned in open disposal areas.

Organic agriculture has been used as a strategy for soil management in an attempt to achieve a sustainable agriculture (Goedert and Oliveira, 2007), using designed processes to mitigate the sharp increase in production of organic solid waste. Among the processes, the composting has been shown as an interesting alternative, since it has the ability to reduce volume and mass of organic waste by approximately 50%, and generate a stable product, which can be beneficial for agriculture (Raviv, 2011).

Sewage sludge, organic waste, tree pruning, garbage, orange bagasse and animal manure have been used as organic amendments in food production, with a great success when processed by composting (Fialho et al., 2010; Torri et al., 2012; De Lucia et al., 2013a), reducing input by mineral fertilizers, increasing crop productivity and avoiding improper disposal, which leads to less pollution of soil and groundwater.

The composting process aims to accelerate decomposition of organic material under optimal conditions for microbial growth. Basically, temperature, aeration, moisture, carbon, nitrogen and nutrients are the factors that interfere with the composting process (Ausina et al., 2000). In that sense, many reports have showed domestic organic waste as important source of nutrients for plant growth (Nóbrega et al., 2008; Fialho et al., 2010).

In literature, there are many reports on organic fertilizer increasing accumulation of nutrients and vigor of tree seedlings, allowing better growth after transplantation (Nóbrega et al., 2008; Stellacci et al., 2013). However, there are few studies on evaluating organic compound concentrations compost rates as substrate for development of tree seedlings (Ferrini and Nicese, 2005; Bakry et al., 2013; De Lucia et al., 2013b).

The application of urban waste compost in agriculture is advantageous due to its high organic matter and nutrients contents, absence of pathogenic microorganisms and provided benefits on conditions of cultivation (increase in organic matter content, high pH value and availability of phosphorus, potassium, calcium and magnesium), nutritional and production of plants (Mantovani et al., 2005). The use of urban waste compounds as conditioning of agricultural soils is a usual practice in many countries, because it provides high levels of organic matter and nutrients to plant, such as nitrogen and phosphorus. According to Franco et al. (2010), those are the most important minerals for plant tillering. Mantovani et al. (2006) recognized a high potential of waste compost as nitrogen source for agriculture, but pointed as a constraint its slow release by mineralization.

The frequent application of compost can increase pH (Russo et al., 2009; Krob et al., 2011), however, any benefit will depend on its composition, time of application and amount applied. Ruppentahl and Castro (2005) found adequate nutrition of gladiolus using compost in a quantity of 10 t ha$^{-1}$. Mancini and De Lucia (2011) also reported increased plant spike of gladiolus plants receiving urban sludge based compost. Oliveira Junior (2008) studied the response of application of urban waste compost, horse and cattle manure with subsoil constituents as a substrate for the production of *Pterogyne nitens* seedlings. In that research, better results were obtained by applying substrates containing 75% waste compost, 50% waste compost plus 25% horse manure and 25% waste compost plus 50% horse manure. Evaluating application of waste compost and tree pruning as a substrate, concluded as the best treatment the application 20% waste compost with 80% of tree pruning. Nóbrega et al. (2008) evaluated the effect of urban waste compost on seedlings growth of *Enterolobium contortisiliquum* (Vell.) (monkey-ear). They found improved soil fertility as a result of increased pH and also higher concentrations of P, K, Ca, Mg, organic matter and micro-nutrient, which gave thicker stem diameter, taller plant and higher dry matter. According to Nóbrega et al. (2008), the mix 80% waste compost plus 20% soil without liming was the best substrate for production of *E. contortisiliquum*.

Waste compost dose need to be evaluated for each plant species, in order to assess crop yield response and to prevent contamination by heavy metals. Evaluations of increasing waste dosage by Nobile et al. (2007) showed negative crop growth effects for substrates with concentrations above 30% of urban waste compost. Better growth of native species was found using organic waste compound as substrate, particularly for *Schizolobium parahyba* (Vell.) Blake. (guapuruvu) (Sabonaro, 2006), but not for *Tabebuia impetiginosa* (Mart.) Standl (ipe-purple) (Sabonaro and Galbiatti, 2007).

Several studies showed benefits of organic matter to improve soil physical properties and consequent positive impacts on crop yield (De Lucia et al., 2013c). Organic matter is of great importance as a source of nutrients to plants, in soil cation retention and to improve or maintain soil structure, increasing infiltration and water retention, microbial activity and other properties (Pelá 2005). Increasing soil organic matter content by application of organic waste is beneficial to soil physics and to maintain a good soil structure (Silva et al., 2002).

There a distinct effect of pH on nutrient availability in organic substrate as compared to mineral soil (Ostos et al., 2008). Stabilized organic compost is a product of a controlled process involving biochemical decomposition of organic material to a more stable product, used as a fertilizer, with pH above 6.5 and C/N ratio below 1.8, due to the soil immobilization of N. The dose should be less than the maximum total N (305 kg ha$^{-1}$) to avoid risk of contamination by $NO_3$ leaching through the soil profile (Oliveira et al., 2001). Therefore, N, $P_2O_5$ and $K_20$ soil contents have to be known before defining dose for application of organic compost. Water is of major importance for seedling development, since it is involved in several plant metabolic processes. Irrigation has to be applied properly to provide adequate water supply at the appropriate time for achieving best plant growth and development. While water stress decrease plant growth and nutrient uptake, water excess may promote nutrient leaching and can even provide a favorable microclimate to development of diseases, in addition to socio-environmental issues relating to water saving and the accumulation of leachate in the soil (Lopes, 2005).

The type of substrate used in the seedling production is crucial in determining irrigation frequency and volume of water to be applied (Wendling and Gatto, 2002). Irrigation in small containers such as tubes used for seedling growth has to be applied in a high frequency. Substrates with low water retention capacity, such as carbonized rice, sand, chaff charcoal, require more frequent irrigation, as compared to substrates with higher water retention capacity, such as subsurface soil, compost, humus, coconut fiber etc., in order to achieve uniform water distribution in the substrate and prevent buildup of salts. The risks of diseases in plants are reduced when water is applied in the morning, because it prevents high moisture in the substrate in the evening.

*Pterogyne nitens* Tul., widely known as ‘wild poinsettia’, is a specie of the family Leguminosae – Caesalpinoideae, which occurs from the Northern through Southern Brazil. It is a deciduous plant, heliophille, semidecidous, typical of broadleaf forest, blooming from December to March and ripening from May to July (Carvalho, 2003). It is an ornamental tree of a high monetary value, suitable for afforestation of urban roads and highways. Wild poinsettia has great economic and environmental potential; his wood is elastic, tough and durable, suitable for fine furniture, general carpentry, construction, manufacture of casks, barrels and tanks for beverages and acids. Due to its hardiness and fast growth, is used for mixed plantations in degraded areas of permanent preservation (Lorenzi, 2000). Its timber has characteristics of resilient, tenacious and resistant, which makes it suitable for fine furniture, general carpentry and construction. It is also considered as an ornamental tree with high economic value, recommended also for afforestation of street and roads, replacement of riparian forest in areas with flooding and revegetation in sandy and degraded soils (Ausina et al., 1994).

Therefore, the objective of this study was to compare growth of Pterogyne *nitens* seedlings (wild groundnut) on commercial substrates and substrates containing garbage and pruning trees composts, submitted to two irrigation levels, in a greenhouse.

## MATERIALS AND METHODS

The experiment was conducted from May to August 2010 in the Department of Rural Engineering of the Faculdade de Ciências Arárias e Veterinárias, Câmpus de Jaboticabal, Universidade Estadual Paulista (FCAV-UNESP), Brazil. The site is located at latitude 21º 15’ 15’’ S, longitude 48º 18’ 09’’ W and altitude around 595 m. The climate classification is Tropical wet and dry or savanna climate (Aw), according to Köppen, characterized by a subtropical climate, with hot summer and dry winter. Average temperature is about 21ºC, minimum temperature (average value about 12.5ºC) occurs on June and July, and higher temperature (average value about 30.6ºC) occurs during December to February. Mean annual precipitation value is about 1,400 mm, with 80% occurring from October to March).

The experiment was conducted in a greenhouse, covered by a plastic dark net with 50% light interception and closed on the sides by an antiaphid net. Eight treatments were arranged in a randomly experimental design, following a 4 × 2 (4 substrates by 2 irrigation levels) factorial scheme with 3 replicates. The results were submitted to an analysis of variance (ANOVA), by testing significance by the F test, and comparing means by the Tukey test at 5% probability.

The volumetric proportion of substrates row materials characteristics of the substrates used for the constitution of four compared substrates are given in Table 1.

Irrigation was applied daily manually in two levels: 50% (level 1) and 100% (level 2) of daily reference evapotranspiration estimated by an atmometer (Broner and Law, 1991). The cumulative depths of applied water for each irrigation level are presented in Table 2.

The tree pruning compost used in this research was obtained in the county of Guaíra, SP, from street pruning, after crushing the twigs and leaves for the composting process. The material was collected at random from piles previously composted, and then transported to the Laboratory of the Department of Rural Engineering of FCAV-UNESP- Jaboticabal, for final screening (mesh 5 mm). Physical and chemical analyses were performed according to the methodology of the National Reference Laboratory for Plant (1998) in the laboratory of ESALQ / USP. The same analyses were performed for the garbage compost, which was obtained from composting of organic waste collected in the county of Sao Jose do Rio Preto, SP.

The seeds for production of wild poinsettia seedlings were collected in the field of Unesp Campus, in Jaboticabal, SP, in addition to seeds collected in the rural settlement Reage Brasil of ITESP, in County of Bebedouro, SP.

Seedlings were transplanted in rigid plastic tubes (13 cm height and 160 cm³ volume) containing the different substrates (Table 1). A polypropylene net was used as support, after mixing the substrate components by hand. The chemical and physical characteristics of the substrates row materials are given in Table 3.

In each tube, two seeds of *Ptegyne nitens* were sown to leave one plantlet after thinning at 30 days of emergence. The following evaluation parameters were taken on seedling growth: (a) Plantlet height (cm), by measuring plantlet height from the surface of the substrate to the inflection of the top leaf fully expanded using a ruler graduated in millimeters; (b) stem diameter (mm), using digital caliper measuring at 2 cm of substrate surface; (c) leaves (n), counting the number of leaves, and d) plantlet dry weight (g/plant), weighing on a precision scale after drying at 70°C in an oven of forced air. Measurements a, b and c were measured every 15 days and d at the end of the experiment. No fertilizer was applied on those substrates.

## RESULTS AND DISCUSSION

The analysis of variance of treatment main effects on wild poinsettia plantlets growth showed significance for

**Table 1.** Volumetric proportion of substrates row materials (%) used for the constitution of four compared substrates.

| Substrate | Tree pruning compost | Garbage compost | Commercial substrate |
|---|---|---|---|
| S1 | 80 | 20 | 0 |
| S2 | 100 | 0 | 0 |
| S3 | 80 | 0 | 20 |
| S4 | 0 | 0 | 100 |

**Table 2.** Irrigation depths (mm) according to irrigation treatments.

| Irrigation depth | Month | | | | Total |
|---|---|---|---|---|---|
| | May | June | July | August | |
| 100 ETo | 86 | 88 | 84 | 119 | 377 |
| 50 ETo | 43 | 44 | 42 | 59 | 188 |

**Table 3**. Chemical and physical characteristics of substrates row materials used for seedlings production of wild poinsettia.

| Characteristics | Commercial substrate | Garbage compost | Tree pruning compost |
|---|---|---|---|
| pH in $CaCl_2$ 0,01 M | 5.2 | 7.8 | 7.1 |
| Density (g $m^{-3}$) | 0.64 | 0.58 | 0.68 |
| Total C (organic and mineral %) | 32 | 25 | 25 |
| Total N (%) | 1.00 | 0.72 | 2.11 |
| Total P ($P_20_5$%) | 0.12 | 0.72 | 0.41 |
| Total K ($K_2O$%) | 0.31 | 0.45 | 1.74 |
| Total Ca (%) | 2.59 | 5.04 | 4.00 |
| Total Mg (%) | 1.26 | 0.32 | 0.39 |
| Total S (%) | 0.16 | 0.28 | 0.33 |
| Total B (mg $kg^{-1}$) | 4 | 8 | 11 |
| Total Cu (mg $kg^{-1}$) | 29 | 437 | 61 |
| Total Fe (mg $kg^{-1}$) | 17423 | 18833 | 41918 |
| Total Mn (mg $kg^{-1}$) | 202 | 455 | 444 |
| Total Zn (mg $kg^{-1}$) | 47 | 519 | 87 |
| Total Mn (%) | 1,26 | 0,27 | 0,39 |
| C/N ratio ( Total C : total N) | 32 | 15 | 12 |
| C/N ratio (Organic C : Total N) | 32 | 14 | 12 |

Source: Laboratory of Soils of ESALQ-USP, Piracicaba, SP.

subtract type and no significance for irrigation level, according to the F test (Table 4). The interaction of irrigation level to substrate type had no significance, except for stem diameter (Figure 1).

The comparison of means for substrate treatments showed the substrate containing tree pruning and garbage composts in a proportion 4:1 the most effective in developing wild poinsettia seedlings, for all growth variables, except for number of leaflets, in which compost containing 100% pruning showed similar result as the treatment 4:1 tree pruning / garbage composts (Table 4 and Figure 2).

For the treatment 4:1 tree pruning / garbage composts, the results of plantlet height and number of leaflets per plantlet were adjusted to a second-degree polynomial regression, while stem diameter data were adjusted to an exponential curve (Figures 3 to 5).

Those results can be attributed to the capability of that substrate to sustain plantlets, which are essential for production of high quality tree seedlings, besides providing nutrients and increase water retention without compromising root aeration. Another important advantage

**Table 4.** Analysis of variance (ANOVA) of main effects of treatments on growth variables of *wild poinsettia*, comparison of means (MEANS) and coefficient of variation (CV%).

| Factor | Plant height (cm) | Stem diameter (mm) | Leaflet (n) | Plant dry weight (g plant$^{-1}$) |
|---|---|---|---|---|
| **Substrate (S)** | | | | |
| Tree pruning/garbage compost (4:1) | 6.02$^{a}$ | 1.60$^{a}$ | 10.50$^{a}$ | 0.48$^{a}$ |
| Commercial | 4.56$^{b}$ | 1.30$^{b}$ | 6.37$^{b}$ | 0.26$^{b}$ |
| Tree pruning | 5.03$^{b}$ | 1.41$^{b}$ | 9.93$^{a}$ | 0.28$^{b}$ |
| Commercial/tree pruning (1:4) | 4.87$^{b}$ | 1.37$^{b}$ | 6.67$^{b}$ | 0.25$^{b}$ |
| **Irrigation depth (I)** | | | | |
| 50% | 5.47$^{a}$ | 1.41$^{a}$ | 8.58$^{a}$ | 0.31$^{a}$ |
| 100% | 5.42$^{a}$ | 1.45$^{a}$ | 8.21$^{a}$ | 0.32$^{a}$ |
| **ANOVA** | | | | |
| Substrates (S) | 10.29** | 19.44** | 11.95** | 24.88** |
| Irrigation depth (I) | 0.24$^{ns}$ | 2.82$^{ns}$ | 2.02$^{ns}$ | 0.15$^{ns}$ |
| S x I | 1.25$^{ns}$ | 4.32* | 0.82$^{ns}$ | 2.08$^{ns}$ |

**; * and $^{ns}$, significant at 1%; 5% and non significant at 5% by F test, respectively. Means followed by different characters on columns are different by Tukey test (5%).

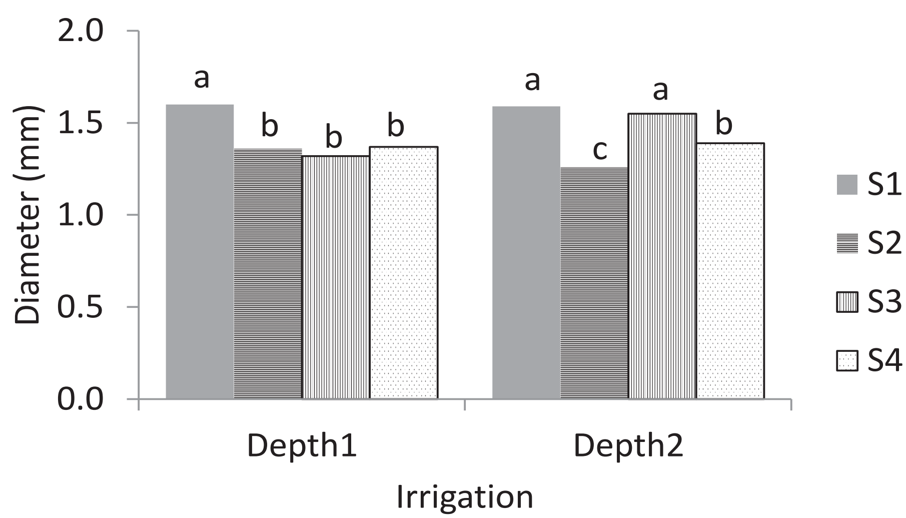


**Figure 1.** Histogram of stem diameter for the interaction substrate an irrigation depth. Substrate S1 is tree pruning/garbage compost (4:1), S2 is commercial, S3 is tree pruning, S4 is commercial/tree pruning (1:4), and depth 1 is 50% and depth 2 is100% of daily reference evapotranspiration. Means followed by different characters above the columns are different by Tukey test (5%).

was the low C/N ratio (<25) of substrate containing high portion of pruning of tree, because of faster mineralization of organic matter, increasing nutrients availability to plants (Malavolta, 2006). The chemical composition of the pruning compost used in this study (Table 3) was higher in nitrogen and potassium, as compared to other studies. The treatment with commercial subtract was supplanted by 4:1 tree pruning / garbage composts because of its beneficial effects, according Nóbrega et al. (2008), including capability to increase pH and the concentration of P, K, Ca, Mg, organic matter and micronutrient, improving soil fertility.

## Conclusions

The substrate containing 4:1 tree pruning / g arbage composts provide the best results for growth of wild

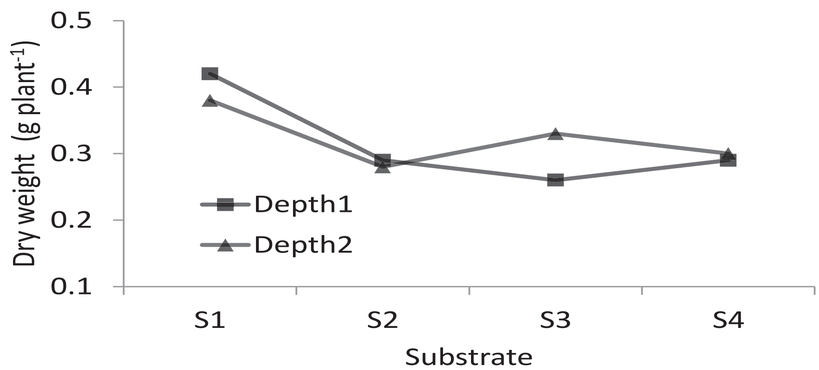


**Figure 2.** Plantlet dry weight as a function of substrate and irrigation depth. Substrate S1 is tree pruning/Garbage compost (4:1), S2 is commercial, S3 is tree pruning, S4 is commercial/tree pruning (1:4), and depth 1 is 50% and depth 2 is100% of daily reference evapotranspiration.

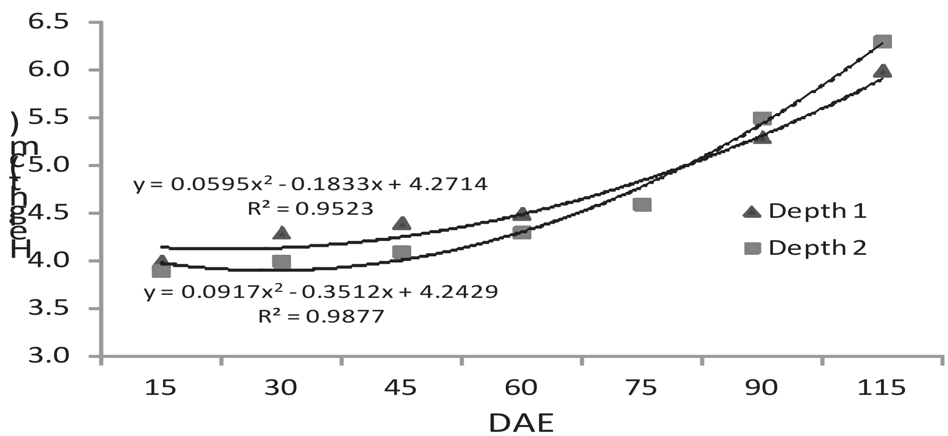


**Figure 3.** Plantlet height as a function of days after emergence (DAE) for the treatment 4:1 tree pruning/garbage composts (80% tree pruning and 20% garbage composts) under two irrigation depths (Depth 1 is 50% and depth 2 is 100% of daily reference evapotranspiration).

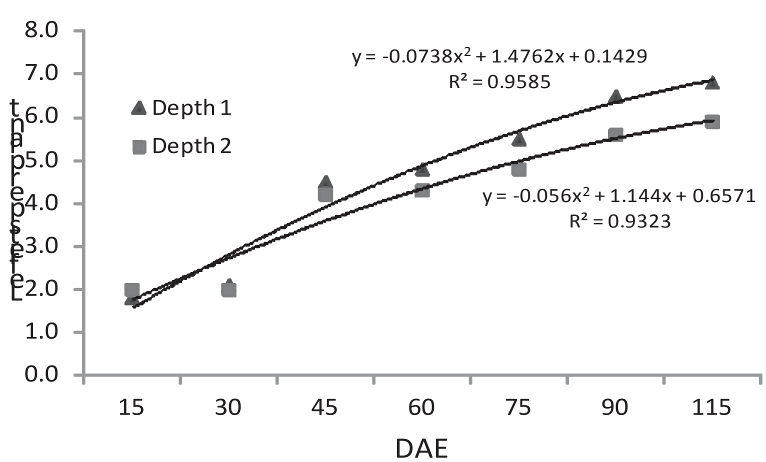


**Figure 4.** Number of leaflets per plantlet as a function of days after emergence (DAE) for the treatment 4:1 tree pruning/garbage composts (80% tree pruning and 20% garbage composts) under two irrigation depths (Depth 1 is 50% and Depth 2 is100% of daily reference evapotranspiration).

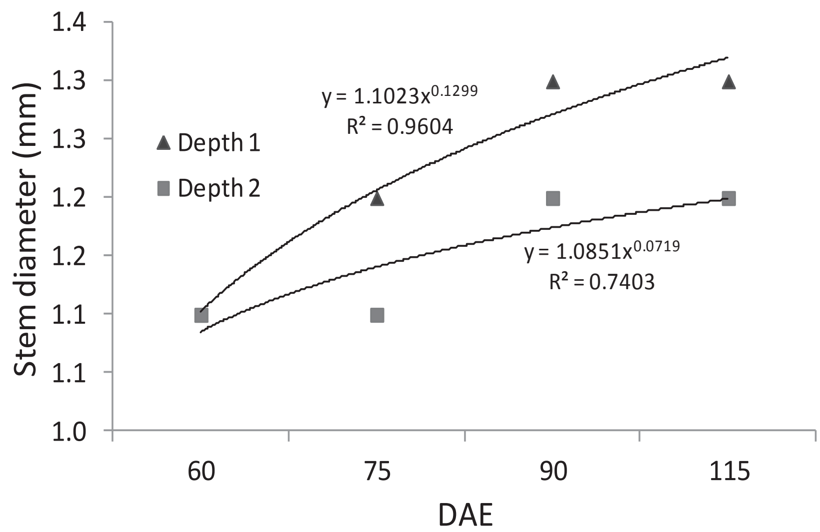


**Figure 5.** Stem diameter as a function of days after emergence (DAE) for the treatment 4:1 tree pruning/garbage composts (80% tree pruning and 20% garbage composts) under two irrigation depths (Depth 1 is 50% and Depth 2 is 100% of daily reference evapotranspiration).

poinsettia being appropriate to replace the commercial substrate. The effects of the treatment 4:1 tree pruning / garbage composts on plantlet height and leaflet number adjust to a second degree polynomial curve, while stem diameter follow an exponential response. Irrigation supplying half of daily reference evapotranspiration is sufficient for plantlet formation of wild poinsettia in greenhouse.

## Conflict of Interest

The authors have not declared any conflict of interest.

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Vol. 10(7), pp. 604-612, 12 February, 2015
DOI: 10.5897/AJAR2014. 9429
Article Number: 249038450331
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Practical tool in classification of animals for slaughter by fuzzy logic

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Received 10 December, 2014; Accepted 22 January, 2015

**This paper treats of the classification of animals for slaughter, using concepts of fuzzy logic as a tool to assist in decision making. The entries (inputs) were made by measurements of body length and weight of animals. The output values corresponded to the classification as ideal weight for slaughtering. In this paper were developed three simulations involving three lambs from a group to be sent to slaughter. The two measures mentioned above were taken before slaughtering. The results were considered good, because it was possible to classify these lambs as ideal moments to slaughter.**

**Key words:** Classification of animals, fuzzy logic, lamb slaughter, decision making.

## INTRODUCTION

Currently, as in the companies as in day-by-day of the people, it is necessary constantly to take decisions. In the companies the decisions become much more important, since the future is dependent on decisions. If a wrong decision is taken, the consequences could be disastrous, causing damages or even the death of the company. Therefore it is necessary to use the logic so that the correct decision is taken.

In the decision moment, the entrepreneur makes use of assumptions, approaches or simplification, provoking doubts regarding the validity of the results. The uncertainties can occur when the entrepreneur is facing a probabilistic problem. In general, it is not possible to describe with exactness the probability distribution of some involved important variable in the problem, consequently, not being possible to apply the correct methods for the problem analysis. In this context, it is presented fuzzy logical (or diffuse logic), which provides subsidies to solve problems with high degree of uncertainty, without losing important information during the data manipulation (Barros and Bassanezzi, 2006; Xu et al., 2008).

Usually problems using historical record of the data use a bayesian equivalent model. The advantage of the method used in this study, compared to the equivalent model bayesian, is that the solution obtained in the fuzzy case does not always occur in the baysian case that often, it must perform numerical approximations of integrals, which does not occur in the used fuzzy model. In the fuzzy approach, limited information is often sufficient to obtain satisfactory results (Santos and Rodrigues, 2004).

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The method of fuzzy logic used in this paper does not make use of the propagation algorithm of artificial neural network based on multi-layer algorithm (ANN) to the default sort using empirical mode decomposition to the feature for each classification from another one, based on EEG where mimicry of data is quite impossible because it depends on users thought. In order to do this paper we have taken four regions of the brain such as frontal, brain, parietal, occipital and we have observed each and every individual has unique pattern (Gupta et al., 2014; Kumari et al., 2014; Kumari and Vaish, 2014; Semwal et al., 2014).

There are woks, as in as in Bellustin and Kalafati (2011), that use artificial neural networks to develop algorithms for classification of gender, age and race through the image of the human face.

The fuzzy logic theory used this paper uses computing resources to provide answers to problems with the high degree of uncertainty, fast and robust and ease to simulate real situations to guide the decision. Fuzzy logic allows the development of systems that represent human decision where conventional classical logic and mathematics are insufficient or inefficient decision-making (Oliveira Jr., 1999).

This paper was carried out similarly to the Gabriel Filho et al. (2011) that developed a system based on *fuzzy* rules applied on 147 nellore beeves to determine the body mass index of ruminant animals in order to obtain the best time to slaughter. The input variables were weight and height, and as output a new body mass index which may serve as a detection system at the time of livestock slaughtering, comparing one another by the linguistic variables "Very Low", "Low", "Average ", "High" and "Very High".

There is infinity of enterprise activities where the application of fuzzy logic is possible such as: credit evaluation, cash flow control, risk analysis, supply control, marketing evaluation, suppliers evaluation, quality control, inventories optimization, classification of products and animals, etc.

With regard to the classification of products, a promising area would be to offer to the animal breeders, for example, a trustworthy method of animal classification for slaughter, since this activity is carried out by empirical methods, taking in account only physical aspect and the age of the animal.

Therefore, the aim of this study was to use fuzzy logic concepts to provide the farmer a tool to assist in decision making before slaughtering.

## Sheep farming system

Sheep breeding is, currently, a promising activity of the Brazilian agribusiness, provided by low investment in infrastructure and a good profitability to the breeders, coming meanly from meat production. As far as the sheep capacity of transforming foods of low quality into protein of high biological value as meat and milk, the animals can be reared in association with cattle in one same property, without damages for none of the species. Comparatively, this association provides a better economic return to the producers, instead of only cattle.

The growing appreciation and demand for lamb has been intensified the production systems of this animal, seeking greater flexibility in the finishing and marketing of meat, because the lamb provides one of the best carcass yield and excellent production efficiency due to its high growth rate (Hastenpflug and Wommer, 2010).

Several surveys of sheep of swamp of Mato Grosso do Sul (Brazil) have been carried out, showing that such animals have high reproductive seasonality (Santiago Son, 2010), their lambs are early and have good meat production (Pinto, 2009), have similar body biometrics to genetically improved exotic lambs, have good yield potential with respect to the characteristics of carcass and meat quality, with potential for the exploitation of the cutting sheep industry (Vargas Junior et al., 2011).

In the sheep industry is the lamb animal category that has greater acceptance in the consumer market, having better organoleptic characteristics, with lower production cycle and greater production efficiency due to its high growth rate (Cartaxo et al., 2011).

The experiment was conducted with lambs Technological Centre for Sheep (CTO), in the Farm School Três Barras (University Anhanguera –Uniderp), in Campo Grande, Mato Grosso do Sul (Brazil), in December 2011.

One of the problems that the sheep breeder faces is the decision making in relation to the correct moment in selecting the ready animals for slaughter, mainly, when there is a large number of animals in the fattening stage, needing an efficient and faster method of classification. The use of the concepts of fuzzy logic can facilitate this decision.

## Topics fuzzy logic

The fuzzy logic is based on the theory of the fuzzy sets where, if one determined element belongs to this set, it must be verified the degree of pertinence of the element in relation to the set. Differently of the classic theory, where the pertinence degree is binary, that is, it belongs or it does not belong to the set. In the fuzzy sets the pertinence degree is the reference to verify how much “this element is possible” to belong to the set. The pertinence degree is calculated by determined function that generally returns a real value that varies between 0 and 1, being 0 to indicate that the element does not belong to the set, and 1, that it belongs to the set (Barros and Bassanezi, 2006).

The results gotten for the fuzzy logic imitate a behavior based on rules (inferences) instead of results gotten through complex mathematical models. It can be said even though that the objective of the fuzzy logic is to generate a logical exit from a set of information not accurate, missing or with noises (Yen et al., 1995). Some fuzzy logic concepts are important to the development of this paper.

A fuzzy set X of a universe U is expressed as a set of ordered pairs where each element of X has its degree of pertinence to the set varying from 0 to 1, Equation (1).

$$X = \{(x, \mu(x)\} \mid x \in U \ e \ \mu(x) \in [0,1] \quad (1)$$

Like this:

$$\mu(x) \in [0,1] \text{ then } \mu(x) = \begin{cases} 0 & se \quad x \notin X \\ 1 & se \quad x \in X \end{cases}$$

As it happens with the conventional theory of sets, operations between fuzzy sets such as union, intersection, complement and algebraic product can be made.

The union of two sets A and the B, fuzzy subgroups of X, will result in a fuzzy set whose pertinences will be the maximum values of the respective pertinences of the sets in question, Equation (2).

$$(A \cup B)(x) = \max(A(x), B(x)) = A(x) \vee B(x), \forall x \in X \quad (2)$$

The intersection of two sets A and the B, fuzzy subgroups of X, will result in a fuzzy set whose its pertinence will be the minimum value of the respective pertinences of the sets in question (Equation 3).

$$(A \cap B)(x) = \min(A(x), B(x)) = A(x) \wedge B(x), \forall x \in X \quad (3)$$

The complement of a fuzzy set A, є subgroups of X, denoted for A, will result in a fuzzy set whose its pertinence will be the subtraction of 1 for the pertinence of the set in question (Equation 4).

$$A^{/}(x) = 1 - A(x), \forall x \in X \quad (4)$$

The algebraic product of two sets A and the B, fuzzy subgroups of X, denoted for A*B, will result in a fuzzy set whose its pertinence will be the product of the respective pertinences of the sets in question (Equation 5).

$$(A * B)(x) = A(x) * B(x), \forall x \in X \quad (5)$$

Other operations, such as limited products, drastic product, algebraic sum, limited sum, concentration and expansion can be found in Barros and Bassanezzi (2006).

The relations between two sets A and B, fuzzy subgroups of X, can represent associations, interactions X⊃A and X⊃B interconnections between the elements of the two sets. The difference of these relations for the classic sets is in the degree of association between the elements X and Y. In the classic sets the association is 0 or 1, while the fuzzy association varies from 0 to 1 (Equation 6).

$$R_{A\times B}(x,y) = \{((x,y), \mu(x,y)) \mid (x,y) \in A \times B \ e \ \mu_{A\times B}(x,y) \in [0,1]\} \quad (6)$$

The pertinence of the union of A and B it is given by the maximum of the relevancies between them (Equation 7).

$$\mu_{A \cup B}(x,y) = \max\{\mu_A(x), \mu_B(y)\} \quad (7)$$

The pertinence of the intersection of A and B it is given by the minimum of the pertinences between them (equation 8).

$$\mu_{A \cap B}(x,y) = \min\{\mu_A(x), \mu_B(y)\} \quad (8)$$

There are others fuzzy relations that had not been treated here, since they are outside of this paper target.

The projection is an operation that reduces the dimension of a relation. From a relation of two dimensions it is possible to obtain two relations of dimensions one. Equations (9) represent the projections on coordinates X and Y, respectively from a relation of two dimensions.

$$\mu R_1(x,y) = m\acute{a}x_y[\mu R(x,y)] \text{ And } \mu R_2(x,y) = m\acute{a}x_x[\mu R(x,y)] \quad (9)$$

In the first equation x is kept fixed and the maximum of y is determined in its entire domain, in the second, y is kept fixed and the maximum of x is determined.

Given two fuzzy relations involving the cartesian products A×B and B×C, with XEA, YEB and ZEC, it is possible to get a new A×C relation. Some versions of compositions exist and some of them will be presented as follow.

Given two relations of fuzzy pertinences, $\mu(R_1(x,y))$ *and* $\mu(R_2(y,z))$, then the pertinence of the composition $(R_1 \circ R_2)(x,z)$ is given by the Equation (10).

$$\mu((R_1 \circ R_2)(x,z)) = \vee \{\mu(R_1(x,y)) \wedge \mu(R_2(y,z))\} \quad (10)$$

Where $\vee$ indicates the maximum of the result between clasps, $\wedge$ indicates the minimum of the relevancies of the two relations between clasps. In the calculation of $\mu(R_1 \circ R_2)(x,y)$ it is used the algorithm of the multiplication of matrices.

Given two relations of fuzzy pertinences $\mu(R_1(x,y))$ *and* $\mu(R_2(y,z))$, the Max composition – Product, $\mu((R_1 \circ R_2)(x,z))$ is given by Equation (11).

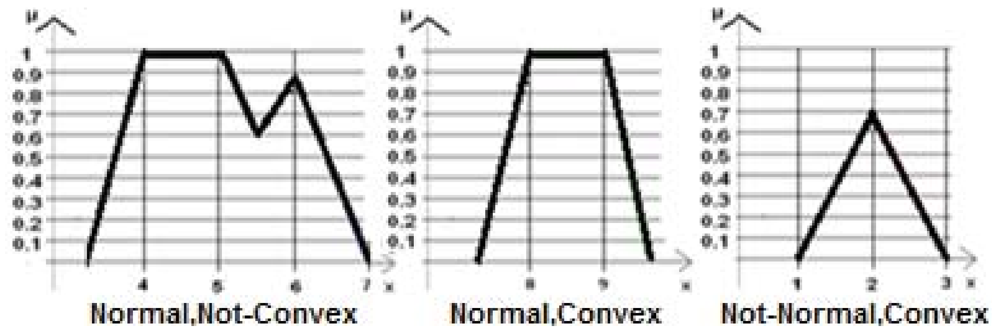


**Figure 1.** Types of fuzzy sets.

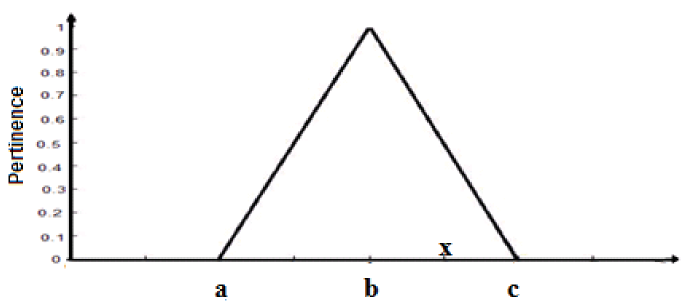


**Figure 2.** Graphical representation of the function of triangular pertinence.

$$\mu(R_3(x,z)) = \mu((R_1 \circ R_2)(x,z)) = \vee[\mu(R_1(x,y)) \times \mu(R_2(y,z))] \quad (11)$$

Other types of compositions can be found in Barros and Bassanezzi (2006) and Semwal et al. (2015).

Each fuzzy set is characterized by its pertinence function, which will determine how much one determined element belongs to the set. Different types of pertinence functions exist.

Any set of fuzzy numbers can possess a pertinence function that will represent it, since that it is *normal* and *convex*. A fuzzy set is said normal when its function of pertinence allows to classify if one definitive element belongs totally to the set, and it is called convex when its pertinence function does not have more "growth or decrease" from resultant values throughout the given universe (Rodrigues et al., 2011). Figure 1 shows the graph of fuzzy sets.

In this research the function of triangular pertinence was used, whose graph represents a normal and convex set (Equation 12).

$$\mu tri(x,a,b,c) = \max\left\{\min\left\{\frac{x-a}{b-a}, \frac{c-x}{c-b}\right\}, 0\right\} \quad (12)$$

Figure 2 shows the graph of a triangular function when a=2, b=4 and c=6.

Linguistics variables are changeable whose values are words in natural language represented in fuzzy sets. For example, the temperature of one determined process can be a linguistic variable assuming values low, high and average. These values are described for intermediary of fuzzy sets (Gomide et al., 1995, Kruel et al., 2008).

The main objective of the linguistics variables is to supply a systemic way approach for characterization of phenomena badly defined, allowing the treatment of complex systems for analysis through mathematical terms (Shaw and Simões, 1999; Tanscheit, 2007).

The first stage of the fuzzy reasoning is the fuzzification, in which is considered precise inputs (not fuzzy) resultants of measurements or comments, in which for each value of one data occurs the activation of a pertinence function, so that it is possible to make the input data mapping for the fuzzy values (Santos and Rodrigues, 2004; Tanscheit, 2007).

The fuzzification consists of transforming numerical data into a term of natural language. For example, the weight and the height of an animal are called fuzzy variables, which are attributed the sets of fuzzy values as "very", "little", "high" or "low".

Identified the fuzzy variable in a problem, it is necessary to determine the possible fuzzy values for these variables. In this case, for the fuzzy variable "weight", it can be classified in three fuzzy values that are: "Light", "Median" and "Heavy", while the fuzzy variable "body length" could be classified in "Short", "Median" and "length". For each fuzzy value will exist pertinence function so that it is possible the mapping of the input data, that are numerical values, for the fuzzy values. In this paper, it will be used the triangular function by its simplicity and easiness of understanding (Rodrigues et al., 2011).

The inference is a stage that serves of support for the decision making. In this stage, the pertinence degrees of each element are determined to the set for posterior use of the rules of the type If - Then.

According Oliveira Júnior (1999) and Shaw and Simões (1999), the rules are created of empirical form, being able to be provided by specialists in form of linguistics

**Table 1.** Relations of more used implications.

| Name | Implication of operations | Output |
|---|---|---|
| Zadeh (max-min) | máx{min{μ(A(x), μ(B(y))}; {(1-μ(A(x))}} | And |
| Mandami (min) | min{μ(A(x), μ(B(y))} | And |
| Larsen (produto) | μ(A(x)×μ(B(y)) | Or |

sentences as basic information in the development of a fuzzy inference system. The inference process makes nothing more of what to evaluate the Lights of “compatibility” of the inputs with the antecedents of some rules, being activated the consequents with proportional intensities to the same ones. The result is a fuzzy set that will be converted into scaling (condensed or defuzzified value), providing the system output.

Given two fuzzy sets A and B and respective complementary A' and B', for the accomplishment of fuzzy inference, exist two inference procedures between these sets: The Modus Ponens Generalized (MPG) and the Modus Tollens Generalized (MTG). The MPG has the following rule: if X is A then Y is B. This rule allows the implication of fuzzy values that are: If X is A' then Y is B', allowing, thus, to determining the consequent one. The MTG has the following rule: if x is A then the Y is B that allows the implication: If y is B' then x is A', determining the antecedent.

Therefore, the first stage is to determine the pertinence function $\mu(B^{'}(y))$ through of exit rules of the type “If - Then” (Equation 13):

$$\mu(B^{'}(y)) = \vee_x \{\mu(A^{'}(y)) \wedge \mu(x, y\} \quad (13)$$

Observing that $\vee_x$ means the calculation of the maximum of Y when X varies in its entire domain $\wedge$ represents the minimum of the two involved elements.

The relation of implication is a rule of the If - Then. To determine an implication relation must rather determine the type of fuzzy implication relation. The relations of fuzzy implications receive as input the values from entries (inputs) $\mu A(x)$ received from the fuzzification and the values of output $\mu(B(x))$ contained in the inference, and the result of the operation is the data of exit of the implication relation. In Table 1 some main operations types of implication are presented.

According to Shaw and Simões (1999), in fuzzification the value of the linguistics variable of inferred exit for the fuzzy rules will be translated in a number. The objective is to get only a numerical value that better represents the inferred fuzzy values of the linguistic variable of exit.

Diverse methods of defuzzification have been considered in the literature, but it is important to choose the method that better adjusts to the problem. In this paper, the method of the Center of Area (Centroid) was used for the defuzzification of the fuzzy variable which is located in the geometric center fuzzy values exits, represented for a convex polyhedral region in the pertinence graph of the inference exit (Figure 3).

The calculation of the abscissa x* of the centroid is expressed by Equation (14).

$$x^* = \frac{\sum_{i=1}^{n} x_i \times \mu_{Output}(x_i)}{\sum_{i=1}^{n} \mu_{Output}(x_i)} \quad (14)$$

Where: $x_i$ , $(i = 1, 2, \cdots, n)$ is the numerical value of the variable in each situation $i$, and $\mu_{Output}(x_i)$ is the value of the pertinence function for the value of $x_i$ in each situation $i$.

## MATERIALS AND METHODS

In this paper the concepts of the fuzzy logic was applied with the objective to classify lambs for slaughter, using measurement data of weight (kg) and body length (cm) of lambs from Farm Três Barras, University Anhanguera-Uniderp, Campo Grande, (MS), Brazil.

The first stage considers input not fuzzy, or not accurate, resultant of measurements or comments, in which, for each presented value, the activation of a pertinence function occurs, so that the inputs data mapping for the fuzzy values will be possible (Rodrigues et al., 2011).

The second stage is the inference, from which the decision making is processed taking into account the determination of the pertinence degrees of each set that, with the input data, the rules of the If-Then type are carried out. According to Shaw and Simões (1999) and Rodrigues et al. (2011), the rules are created of empirical form, being able to be provided by specialists in form of linguistics sentences, which constitutes a basic aspect in the development of a fuzzy inference system.

The third stage is the defuzzification, which in accordance with Shaw and Simões (1999) the values of the linguistics variable of exit, inferred for the fuzzy rules, will be translated for numbers (Rodrigues et al., 2011). In this paper the method of the Center of the Area (Centroid) was used in accordance with Figure 3.

## RESULTS AND DISCUSSION

With the purpose to test the methodology, its application

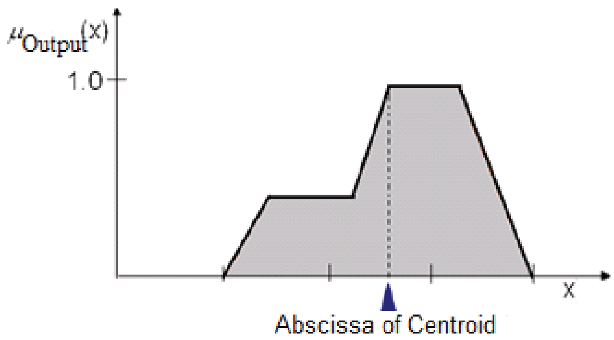


**Figure 3.** Method of defuzzification for the center of area (Centroid) Source: Adapted of Shaw and Simões (1999).

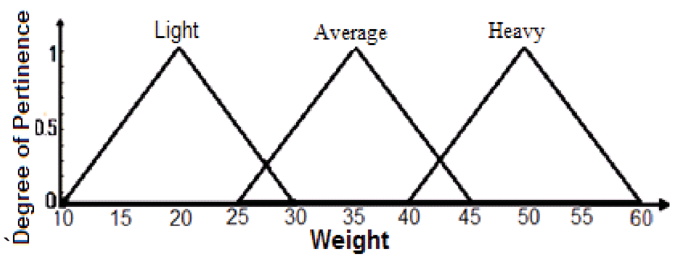


**Figure 4.** Graph of inputs triangular functions relative to the pertinence of weight variable.

**Table 2.** Pertinencies table for the variable "weight" using fuzzy set.

| Weight (Kg) | Light | Average | Heavy |
|---|---|---|---|
| 20 | 1 | 0 | 0 |
| 25 | 0.5 | 0 | 0 |
| 30 | 0 | 0.5 | 0 |
| 35 | 0 | 1 | 0 |
| 40 | 0 | 0.5 | 0 |
| 45 | 0 | 0 | 0.5 |
| 50 | 0 | 0 | 1 |

**Table 3.** Pertinences for "body length" using fuzzy sets.

| Body length (cm) | Small | Median | Great |
|---|---|---|---|
| 30 | 1 | 0 | 0 |
| 35 | 0.5 | 0 | 0 |
| 40 | 0 | 0.5 | 0 |
| 45 | 0 | 1 | 0 |
| 50 | 0 | 0.5 | 0 |
| 55 | 0 | 0 | 0.5 |
| 60 | 0 | 0 | 1 |

was proceeded in the classification of lambs for slaughter, using three common subgroups in relation to the variable "Weight" (ranging from 10 to 60 Kg); to classify a lamb at the moment of slaughter, with the use of the fuzzy sets "Light", "Average" and "Heavy", with respective pertinences (all ranging from 0 to 1), established by professionals of the study area, whose pertinencies are represented in Table 2.

Equation (15) presented the data classification for lamb weight as to inputs values:

$$\begin{aligned}
\mu tri_{Light}(x;10,20,30) &= máx\left\{\min\left\{\frac{x-10}{20-10},\frac{30-x}{30-20}\right\},0\right\}\\
\mu tri_{Average}(x;25,35,45) &= máx\left\{\min\left\{\frac{x-25}{35-25},\frac{45-x}{45-35}\right\},0\right\}\\
\mu tri_{Heavy}(x;40,50,60) &= máx\left\{\min\left\{\frac{x-40}{50-40},\frac{60-x}{60-50}\right\},0\right\}
\end{aligned} \quad (15)$$

Figure 4 presents the classification graph of the weight inputs data and respective pertinencies.

Also, using the fuzzy set, there are three subsets for the classification of lambs for slaughter in relation to "Body length" (ranging from 20 to 70 cm), such as "Small", "Median" and "Great", with respective pertinences (all ranging from 0 to 1) (Table 3).

The data classifications of body length as inputs values are presented in Equation (16).

$$\begin{aligned}
\mu tri_{Small}(x;20,30,40) &= máx\left\{\min\left\{\frac{x-20}{30-20},\frac{40-x}{40-30}\right\},0\right\}\\
\mu tri_{Median}(x;35,45,55) &= máx\left\{\min\left\{\frac{x-35}{45-35},\frac{55-x}{55-45}\right\},0\right\}\\
\mu tri_{Grat}(x;50,60,70) &= máx\left\{\min\left\{\frac{x-50}{60-50},\frac{70-x}{70-60}\right\},0\right\}
\end{aligned} \quad (16)$$

Figure 5 presents the graph of the triangular functions of body length inputs to the respective pertinences.

In this manner, for the inputs of "weight" and "body length" variables, it will be necessary to determine the fuzzy variable that will be the "states", and to choose the actions through the fuzzy values, in the case, five values as "Very lean"; "Lean"; "Ideal"; "Fat" and "Very fat", which also will have pertinences functions.

Table 4 presents the used inferences in this paper, which correspond to the biometric parameters of the lamb in relation to the inputs variables "weight" and "body length". In this paper inference function was used in the triangular form. Figure 6 presents the possible results of the defuzzification in linguistic variable ranging from -15 to 15, relative to inferences in Table 3.

In this study the inference function was used in the triangular form (Figure 6). The Table 5 shows the possible outcomes of defuzzification outs in linguistic variables relating to inferences evaluated (Table 3). For example, the input data for a lamb with weight of 25 kg and body length of 40 cm; the degrees of pertinences was calculated, making x = 25 in Equations (15) obtaining:

$$\mu tri_{Light}(25; 10, 20, 30) = máx\left\{\min\left\{\frac{25-10}{20-10}, \frac{30-25}{30-20}\right\},\ 0\right\} = máx\{\min\{1.5, 0.5\}, 0\} = máx\{0.5, 0\} = 0.5$$

$$\mu tri_{Average}(25; 25, 35, 45) = máx\left\{\min\left\{\frac{25-25}{35-25}, \frac{45-25}{45-35}\right\}, 0\right\} = máx\{\min\{0, 2\}, 0\} = máx\{0, 0\} = 0$$

$$\mu tri_{Heavy}(25; 40, 50, 60) = máx\left\{\min\left\{\frac{25-40}{50-40}, \frac{60-25}{60-50}\right\},\ 0\right\} = máx\{\min\{-1.5, 3.5\}, 0\} = máx\{-1.5, 0\} = 0$$

Making x = 40 in the Equations (16) we obtain:

$$\mu tri_{Small}(40; 20, 30, 40) = máx\left\{\min\left\{\frac{40-20}{30-20}, \frac{40-40}{40-30}\right\}, 0\right\} = máx\{\min\{2, 0\}, 0\} = máx\{0, 0\} = 0$$

$$\mu tri_{Median}(40; 35, 45, 55) = máx\left\{\min\left\{\frac{40-35}{45-35}, \frac{55-40}{55-45}\right\}, 0\right\} = máx\{\min\{0.5, 1.5\}, 0\} = máx\{0.5; 0\} = 0.5$$

$$\mu tri_{Great}(40; 50, 60, 70) = máx\left\{\min\left\{\frac{40-50}{60-50}, \frac{70-40}{70-60}\right\}, 0\right\} = máx\{\min\{-1, 3\}, 0\} = máx\{-1, 0\} = 0$$

With the calculations of the pertinences it was found in the stage of the fuzzification the fuzzy values different of zero of the weight input, with “Light” classification, degree of pertinence 0.5; body length, with “Median” classification and degree of pertinence 0.5. The results are presented in the Table 6.

Thus, the fuzzification will be activated for the rule 5 (Table 4), which will pass to be analyzed. If the weight is “Light” and the body length is “Median”, “Then” the condition is “Thin” for slaughter – if no. The weight, the body length and the state are, respectively, x, y and z, while “Light”, “Median” and “Thin” are A1, A2 and B, respectively. In the fuzzification the values of the pertinences of A'1 and A'2, representing the “Light” and “Median” are, respectively, 0.5 and 0.5, while the pertinence of B', representing the “Thin” is not known. In this in case, it is applied the rule MPG: if x is A1 “and” y is A2, then z is B, consequently, if x is A'1 “and” y is A'2, then z is B'. As “and” represents the minimum, then with the pertinence of A'1 is 0.5 and of A’2 is 0.5, then, in this case, randomly, A'1 with pertinence 0.5.

For the determination of the pertinence of B' it is necessary to apply the pertinence function of B, choosing an operation of implication that can be the Mandani operation (min) in Table 1. The values of $A1 = \{(30; 0.5); (35, 1); (40; 0.5)\}$, consequently, it is determined the values of $A'1 = \{(30; 0.5); (35, 0); (40; 0.5)\}$. Some values of B different of zero are $B = \{(4.0, 0.5); (5.0, 0.5); (6.0;, 0.5); (7.0, 0.5); (8.0, 0.5); (9.0, 0.5)\}$. Then, the relation R of the intersection of A'1 is determined with B.

$$R_{A'1\cap B}(x,y) = \left\{\begin{matrix} ((30, 4.0), 0.5); ((30, 6.0), 0.5); ((30, 8.0), 0.5); \\ ((35, 4.0), 0.5); ((35, 6.0), 0.5); ((35, 8.0), 0.5); \\ ((40, 4.0), 0.5); ((40, 6.0), 0.5); ((40, 8.0), 0.5) \end{matrix}\right\}$$

Summarizing the pertinences:

$$\mu(R_{A1\cap B}(x,y)) = \begin{bmatrix} 0.5 & 0.5 & 0.5 \\ 0.5 & 0.5 & 0.5 \\ 0.5 & 0.5 & 0.5 \end{bmatrix}$$

The pertinences of B' are calculated through the Max-min composition as follow:

$$\mu(B') = \mu(A'1 \circ R_{A1\cap B}(x,y)) = [0.5 \quad 0 \quad 0.5] \circ \begin{bmatrix} 0.5 & 0.5 & 0.5 \\ 0.5 & 0.5 & 0.5 \\ 0.5 & 0.5 & 0.5 \end{bmatrix} = [0.5 \quad 0.5 \quad 0.5]$$

If it was used other rules, others B’ would be gotten, corresponding others areas in the exit graph. As the operation of Mandani implication was used (min), the general exit of the inferences would be the union (or) of the inferences of the sets B', obtained by the rule fired. In this case, the pertinence of the exit will be equal to the pertinence of variable “Thin”, this is:

$$\mu_{Output}(u) = \mu_{Thin}(u)$$

To carry out the defuzzification, let us consider the set of points in the range (Table 5):

$$u = \{3,4,5,6,7,8,9,10\}$$

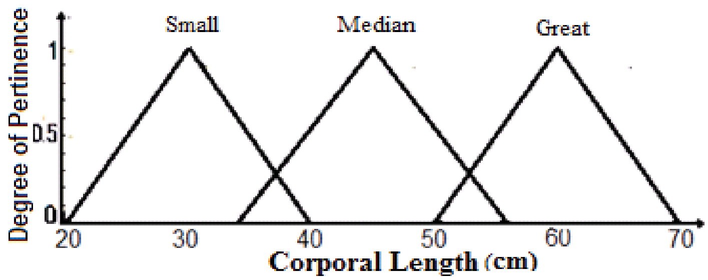


**Figure 5.** Graph of triangular functions relative to the pertinences of body length variable.

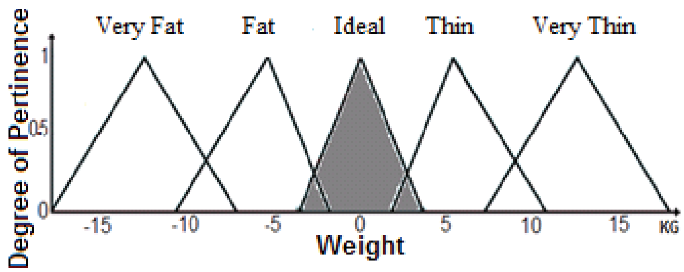


**Figure 6.** Graphs of relative exits to the evaluated inferences.

**Table 4.** Set of correspondent inferences of entries to the biometric parameters of the lamb in relation to the body length and weight variables

| Rule | If: Peso (Kg) | If: Body length (cm) | Then: Condition |
|---|---|---|---|
| 1 | Light | Small | Ideal – Else |
| 2 | Light | Median | Thin – Else |
| 3 | Light | Great | Very Thin – Else |
| 4 | Average | Small | Fat – Else |
| 5 | Average | Median | Ideal – Else |
| 6 | Average | Great | Thin – Else |
| 7 | Heavy | Small | Very Fat – Else |
| 8 | Heavy | Median | Fat – Else |
| 9 | Heavy | Great | Ideal - Else |

**Table 5.** Defuzzification in linguistic variables.

| Weigth (kg) | |
|---|---|
| -20 ≤ peso≤ -7 | Very fat |
| -10≤ peso≤ -3 | Fat |
| -3 ≤ peso≤ 3 | Ideal |
| 3≤ peso≤ 10 | Thin |
| 7 ≤ peso≤ 20 | Very thin |

**Table 6.** The fuzzification.

| Weight | Body length |
|---|---|
| $\mu tri_{Light}(25;10,20,30) = 0.50$ | $\mu tri_{Median}(40;35,45,55) = 0.50$ |

And the use of Equation (14):

$$x^* = \frac{3\times0+4\times(0.5)+5\times(0.5)+6\times(0.5)+7\times(0.5)+8\times(0.5)+9\times(0.5)+10\times0}{0+0.5+0.5+0.5+0.5+0.5+0.5+0} = 6.5$$

Thus, $B^{'} = \{(5{,}0,\ 0.5); (6.0, 0.5); (8.0, 0.5)\}$

As the result was zero, the recommendation to the breeder is of that the lamb is thin, with 6.5 kg below of the ideal weight.

One second simulation was carried through considering a lamb with 40 kg of weight and 35 cm of body length. Carrying out analogous calculations to the previous simulation, the result of the defuzzification is $x^* = -5.0$, returning to the breeder the recommendation of that the lamb is with 5 kg above of the ideal weight.

## Conclusions

The paper used fuzzy logic as tool in decision making to the farmer on the classification of lambs for slaughter, using for this rules of inferences determined by specialists in the activity of sheep industry. The results can be considered good, since it was possible to verify the power of the tool to aid in the decision.

Although the use of this tool still seems impractical for the moment due to the hard work of lamb measurement collection in the field, as would occur when the stress of the animals are being biometric measures taken, the results are promising because, with the evolution technology in the near future, they will be taken in digital form, using cameras that allow the reading of the main biometric measurements of the animals without causing any stress to them. Thus, news researches should be implemented.

Other research is required to improve decision making, considering other biometric variables, as in the present study it was decided to consider only two input variables length and weight of the body and an output variable, the animal's weight, because was done without computer assistance. These results can be implemented in computer and for ease of achieving faster results. In fact, there are some statistical packages such as Matlab, SPSS, etc., which have available fuzzy logic routines. It should be noted that this tool can be applied to a number of other sorting processes, provided that the set of rules is developed by specialists. .

## Conflict of Interest

The authors have not declared any conflict of interest.

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academicJournals

Vol. 10(7), pp. 613-622, 12 February, 2015
DOI: 10.5897/AJAR2014. 9231
Article Number: 946D8A450339
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

# Enzymes activities, hydroxymethylfurfural content and pollen spectrum of some Algerian honey

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Received 11 October, 2014; Accepted 22 January, 2015

**Forty honey samples from *Apis mellifera* were collected in different parts of Algeria during 2007 to 2010 and were analysed for parameters including hydroxymethylfurfural (HMF), invertase and diastase activities. The spectra of pollen of the honeys collected in those areas were also studied. The results show that the amylase activity ranged from 4.40 to 30.15 DN, with only one sample having a low diastase number than 8 DN. The invertase activity ranged from 0 to 138.38 UE. Invertase is generally present in small amounts and is inactivated by heating. The HMF values in our study were low (<40 mg/kg). 85% of samples (34 samples) had a HMF content less than 15 mg/kg HMF. The results of mellissopalynology show that the NPG/10 g for all samples of honey ranged from 8 × $10^3$ to 2.01 × $10^6$; all samples studied are original flower honey. We also note that the dominant pollen in the majority of samples was: pollen of *Eucalyptus, Trifolium* sp*, Echium* sp*, Hedysarium corornarium* and to a lesser extent, *Asteraceae* (mostly *Carduus*), *Apiaceae*, *Ericaceae*, *Rosaceae*are and *Rutaceae*. In general, the samples were found to meet the requirements of the international honey standards.**

**Key words:** Honey, hydroxymethylfurfural (HMF), diastase activity, invertase activity, mellissopalynology.

## INTRODUCTION

Honey, produced by the honeybee, is a natural supersaturated sugar solution, which is mainly composed of a complex mixture of carbohydrates and contains certain minor constituents like proteins, enzymes (invertase, glucose oxidase, catalase, phosphatases), amino and organic acids (gluconic acid, acetic acid, etc.), lipids, vitamins (ascorbic acid, niacin, pyridoxine etc.), volatile chemicals, phenolic acids, flavonoids, and carotenoid-like substances and minerals (Blasa et al., 2006). The composition of honey depends on the plant species visited by the honeybees and the environmental, processing and storage conditions (Bertoncelj et al., 2007, Guler et al., 2007).

Enzymes are the most important and also the most interesting honey components. They are accountable for the conversion of nectar and honeydew to honey, and serve as a sensitive indicator of the honey treatment. In some countries, the specification of enzymes is a binding legal indicator (Bogdanov et al., 1987; Oddo et al., 1999). Honey naturally contains small amounts of enzymes. The predominant enzymes in honey are diastase (amylase), invertase ($\alpha$- glucosidase) and glucose oxidase. Others, including catalase and acid phosphatase, can also be present. Honey's enzyme content can vary widely by

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floral source and region. The levels of some enzymes such as diastase are relatively easy to measure and have been used for many years to estimate the extent of heating to which a honey has been exposed. Such information has been required by some countries where heating of honey is believed to reduce or destroy potentially health-promoting properties. In fact, because the enzyme content of fresh honeys can vary widely, enzyme levels in packed honey are a poor indicator of processing and storage conditions (White, 1968).

The HMF content depends on the temperature, the duration of storage or heating, the content of various sugars, pH, the mineral content (especially that of iron) and the water content of honey (Gondarski, 1961; Ivanov, 1978; Pichler et al., 1984). According to some authors (Bogdanov, 1999), fresh honey contains practically no HMF but its concentrations increase during storage. Many studies (Ivanov, 1986; Pichler et al., 1984; Von der Oh, 1992; White, 1964) have shown that HMF levels in natural non-heated honey is almost always under 1 mg%. For 1 to 2 years, the HMF content could increase up to 3 to 4 mg% or more depending on the temperature of storage. The high HMF content in honeys is related to its long-term storage or to its overheating for liquidification of crystallized honey (White et al., 1964).

Pollen analysis has been the traditional method to determine the floral origin of the honey (Hermosin et al., 2003; Von der Ohe, 1994). Usually, honey is considered unifloral if the pollen frequency of that plant is >45%. (Terrab et al., 2003c). The identification and quantification of pollen grains in honey sediment (melisopallynological) is still the most important method for determining the botanical species that make up the pollen spectrum of honey samples. The pollen spectrum shows whether the honey samples are from different geographical and floral regions, and also the flowering time of the bee plants and their value as nectar and pollen suppliers .Through quantitative analysis of pollen grains, it is possible to establish the proportion which each plant, as a nectar supplier contributes to the constitution of the honey. However, this proportion depends on the pollen, and on the structure and biology of the different plant species (Anklam, 1998).

The objective of this study was to determine the enzymes activity of α-glucosidase (invertase), ß-amylase (diastase), the contents of hydroxymethylfurfural (HMF = 5-hydroxymethylfuran-2-carbaldehyde) and the contents of pollen spectrum for forty honey samples sorted by their botanical origins.

## MATERAILS AND METHODS

### Honey samples

The forty fresh honey samples (Table 1) were collected directly from professional beekeepers in various regions in Algeria. The vegetation in these areas can be described as being composed of a mixture of various natural plants. Honey samples were filled into glass jars after harvesting and stored at 4°C until analysis. Duplicate analyses were performed for each parameters.

### Physico-chemicals analysis

#### *Method of determination of enzymes activities*

The diastase enzymes (α- and β-amylase) were analysed with the Phadebas procedure. The determination of the honey diastase activity is a photometric method in which a blue tint insoluble cross-linked type of starch is used as a substrate. This is hydrolyzed by the enzyme, giving soluble blue fragments in water, determined photometrically at 620 nm with a Varian spectrophotometer type UV visible Cary 50. The absorbance of the solution is directly proportional to the diastatic activity of the sample.

Measurement of the invertase enzyme (α- glucosidase) was done following the method of Siegenthaler as harmonised by the International Honey Commission (Bogdanov, 1997). The activity can also be expressed as number invertase. p- nitrophenyl - α -D-glucopyranoside (pNPG) as a substrate is used for the analytical determination of the number of sucrase in honey. pNPG is divided into p -nitrophenol and glucose by α-glucosidase (invertase). By adjusting the pH value to 9.5 the enzyme reaction is stopped, and at the same time is turned into nitrophenol nitrophenolate anion, which corresponds to the amount of substrate converted and which is determined photometrically at 400 nm with a Varian spectrophotometer type UV visible Cary 50.

#### *Determination of hydroxymethylfurfural (HMF)*

The HPLC method, HMF is separated on a reversed- phase column, with water and methanol as the mobile phase, and then detected by UV absorbance. HMF was analysed by HPLC method as harmonised by the International Honey Commission (Bogdanov, 1997). One gram of sample was mixed with 9 ml of distilled water. The mixture was then centrifuged at 15,000 rounds for 10 min to remove any fine debris present in the sample. The supernatant was filtered through a 0.45 mm membrane and 20 ml of filtrate was injected to HPLC with autosampler of HPLC Agilent 1200 series, a photo diode array detector (DAD) and Nucleosil 5 C18 column. Mobile phase was a mixture of methanol/ water. The detector was set to 280 nm and duplicate analyses were performed.

### Pollen analysis

Pollen analysis was carried out using the methods established by the International Commission of Bee Botany described by Louveaux et al. (1978) and Von der Ohe et al. (2004).

#### *Quantitative melissopalynological*

Analysis was performed according to Maurizio's method (Louveaux et al., 1978) by counting microscopically the number of pollen present in the honey sediment after centrifuging a honey solution. Pollen in 400 fields of view was counted in four fold. The results were based on the average number in the 400 fields of view and expressed as the number of pollen grains in 10 g honey (PG/10 g) in thousands ($10^3$) and rounded to the nearest thousand. The honeys were placed into one of the five pollen representativity classes as distinguished by Maurizio (Louveaux et al., 1978; Von der Ohe et al., 2004). Class I includes honeys poor in pollen (PG/10 g < 20 × $10^3$), class II includes honeys with normal pollen representativity (20 × $10^3$ to 100 × $10^3$), class III honeys with over representativity pollen (100 × $10^3$ to 500 × $10^3$), class IV with

**Table 1.** The geographical origin of the honey samples.

| Sample | Geographic origin | Year collected |
|---|---|---|
| E1 | Soukahras | 2010 |
| E2 | Oum el bouaghi | 2009 |
| E3 | Soukahras | 2009 |
| E4 | Taref | 2010 |
| E5 | Taref | 2010 |
| E6 | Guelma | 2010 |
| E7 | Guelma | 2009 |
| E8 | Guelma | 2010 |
| E9 | Guelma | 2009 |
| E10 | Annaba | 2008 |
| E11 | Guelma | 2008 |
| E12 | Skikda | 2010 |
| E13 | Guelma | 2009 |
| E14 | Oum el bouaghi | 2009 |
| E15 | Taref | 2007 |
| E16 | Taref | 2010 |
| E17 | Taref | 2010 |
| E18 | Taref | 2008 |
| E19 | Soukahras | 2009 |
| E20 | Annaba | 2007 |
| E21 | Oum el Bouaghi | 2010 |
| E22 | Djelfa | 2010 |
| E23 | Skikda | 2010 |
| E24 | Guelma | 2009 |
| E25 | Khenchla | 2010 |
| E26 | Taref | 2009 |
| E27 | Taref | 2010 |
| E28 | Annaba | 2010 |
| E29 | Taref | 2009 |
| E30 | Aghwat | 2009 |
| E31 | Taref | 2009 |
| E32 | Guelma | 2010 |
| E33 | Guelma | 2010 |
| E34 | Oum el bouaghi | 2007 |
| E35 | Guelma | 2010 |
| E36 | Skikda | 2010 |
| E37 | Skikda | 2010 |
| E38 | Khenchla | 2009 |
| E39 | Taref | 2009 |
| E40 | Khenchela | 2010 |

strongly over-represented pollen ($500 \times 10^3 - 10^6$ ) and class V includes pressed honeys (PG/10 g > $10^6$ pollen).

#### *Qualitative melissopalynological analysis*

The types of pollen grains with their percentages in the pollen sediment was carried out by dissolving the honey in dilute sulphuric acid, centrifuging the solution and mounting the sediment in Kaiser's Glycerol Gelatine (glycerine jelly). For each sample, pollen were counted and their relative frequency classes were determined, using the terms predominant (> 45%) secondary pollen (16 to 45%), pollen occurring rarely and sporadically are called important minor pollen (3 to 15%) and minor pollen (< 3%) (Louveaux et al., 1978). For all pollen species in the 40 samples the individual occurrence was calculated and expressed as percentage of the total studied samples in which the determined pollen type was found.

## RESULTS AND DISCUSSION

Tables 2, 3 and 4 shows the mean values of the different parameters analysis and the result of pollen spectrum.

**Table 2.** The results of diastase number (ND) and invertase activity (IS) of honey samples.

| Sample | DN(UE) m±SD | IS(UE) m±SD |
|---|---|---|
| E1 | 15.56±0.11 | 42.26±0.57 |
| E2 | 11.80±0.39 | 11.24±0.39 |
| E3 | 4.40±0.26 | 42.83±0.68 |
| E4 | 30.15±0.17 | 37.43±0.06 |
| E5 | 18.13±0.26 | 72.01±0.95 |
| E6 | 19.13±0.39 | 45.58±0.07 |
| E7 | 8.66±0.13 | 0.00±0.00 |
| E8 | 12.41±0.50 | 12.44±0.10 |
| E9 | 8.20±0.31 | 0.00±0.00 |
| E10 | 20.82±0.57 | 27.16±0.05 |
| E11 | 9.31±0.25 | 0.00±0.00 |
| E12 | 17.52±0.16 | 103.57±0.02 |
| E13 | 17.72±0.13 | 41.93±0.11 |
| E14 | 8.17±0.45 | 0.00±0.00 |
| E15 | 14.12±0.24 | 12.49±0.00 |
| E16 | 25.49±0.38 | 35.82±0.51 |
| E17 | 16.13±0.04 | 10.25±0.06 |
| E18 | 21.70±0.44 | 23.17±0.52 |
| E19 | 16.29±0.26 | 37.81±1.01 |
| E20 | 20.90±0.08 | 24.19±0.16 |
| E21 | 11.47±0.10 | 0.00±0.00 |
| E22 | 28.94±0.11 | 107.66±0.51 |
| E23 | 18.78±0.39 | 105.02±1.00 |
| E24 | 16.29±0.26 | 29.43±0.12 |
| E25 | 17.10±0.17 | 90.50±0.15 |
| E26 | 18.53±0.26 | 78.75±0.15 |
| E27 | 15.62±0.39 | 72.711.00± |
| E28 | 20.70±0.13 | 31.65±0.10 |
| E29 | 17.40±0.50 | 16.23±0.08 |
| E30 | 23.14±0.31 | 138.38±0.60 |
| E31 | 18.84±0.57 | 138.25±0.29 |
| E32 | 14.74±0.25 | 3.48±0.40 |
| E33 | 14.41±0.16 | 5.81±0.13 |
| E34 | 10.34±0.13 | 10.47±0.35 |
| E35 | 18.57±0.45 | 12.65±0.27 |
| E36 | 20.72±0.24 | 47.03±0.06 |
| E37 | 17.10±0.11 | 105.53±0.39 |
| E38 | 17.00±0.12 | 110.14±0.07 |
| E39 | 24.11±0.12 | 111.52±0.19 |
| E40 | 17.56±0.28 | 30.67±0.34 |

**Diastase**

Diastase is the common name for the enzyme α-amylase. It is found in nectar and is also added by the honeybee during the collection and ripening of nectar. Diastase digests starch to simpler compounds. The amylase activity ranged from 4.40 to 30.15 DN (Table 2); only one sample had a low diastase number than 8 DN. The floral origin of honey also influences its diastase content. For example, citrus and clover honeys tend to contain less diastase. Other factors may affect diastase values: the natural difference in pH among honeys, nectar flow and foraging patterns of the bees. Long storage at moderate temperatures and exposure to high temperatures will inactivate diastase in honey. Diastase levels do not correlate with honey quality. Therefore, specifying the diastase level will not guarantee quality (Babacan et al., 2002). Numerous studies also indicate that honey shows significant variations in amylase content based on composition, pH value and floral source. In fact, research reveals that heating is not the only factor influencing amylase content in honey (White, 1992; Crane, 1980; Low, 1988; Babacan and Rand, 2007).

### Invertase

The invertase activity ranged from 0 to 138.38 UE (Table 2). Invertase is the enzyme that hydrolyzes sucrose to fructose and glucose. It is added to the nectar by the bee. The resulting chemical reaction is a key step in the ripening of nectar to honey. Invertase has been considered responsible for most of the chemical changes that take place during the conversion of nectar to honey. Invertase is generally present in small amounts and is inactivated by heating (Babacan et al., 2005).

### Hydroxymethylfurfural (HMF)

Since HMF can be formed either by Maillard reaction (heating of reducing sugars in the presence of proteins), or by dehydration under acidic conditions. The HMF values in our study were low (<40 mg/ kg) (Table 3), which is fixed at 40 mg/kg in the honey standards (Codex Alimentarius Commission, 2001; European Commission, 2002). An exception has been made for honeys from tropical regions for which this limit is 80 mg/kg. 85% of samples (34 samples) had a HMF content less than 15 mg/kg. HMF content are widely recognized as parameters indicating the freshness of honey (Mendes et al., 1998; Terrab et al., 2002).The presence of HMF is an indicator for spoiled, adulterated or products that were exposed to heat stress or bad storage conditions. On the other hand, HMF is considered an irritant and is irritating to eyes, upper respiratory tract, skin and mucous membrane. No positive or negative definite reports associating HMF with a cancer risk in humans were identified in available literature (FPA, 2006). However the National Institute of Environmental Health Sciences nominated HMF for testing based on the extensive human exposure, lack of adequate data characterizing its toxicity and carcinogenicity. Miller (1994) in studies based on mice and rats, proposed that sulphonation of HMF may lead to multagenicity and carcinogenicity. Janzowski et al. (2002) studied the DNA damaging potential and reactivity of HMF towards cellular glutathione as an assessment of multagenicity of HMF. It is also reported that HMF damages striated muscles and viscera by combining with protein and thus causing the accumulation of poisons in the body (Pamplona et al., 1995; Chi et al., 1998).

### Pollen analysis

The results from quantitative melissopalynological analysis, summarised in Table 3, show that the NPG/10 g for all samples ranged from $8 \times 10^3$ to $2.01 \times 10^6$. 22 of the 40 samples were poor in pollen ($< 20 \times 10^3$ in 10 g) and belonged consequently to class I; 14 samples belonged to class II, 3 samples were in class III and one sample in class V; they contained more than $10^6$ pollen in 10 g. The observed that pollen distribution is quite normal for Mediterranean honey (Persano Oddo and Piro, 2004) and also corresponded with the results of published study of Ouchemoukh et al. (2007), who found in their study of 11 Algerian samples, lower PG/10 g values ranging from $20 \times 10^3$ till $40 \times 10^3$ and a study of Makhloufi et al. (2007). However many factors influence the number of pollen in honey. It is known that the pollen richness depends upon the pollen production of the plant, the weather conditions, the distance of the beehive to the flower field, the filtering by the bee's proventriculus and consequently the pollen's diameter, and the mode of honey extraction (Von der Ohe, 1994).The results from qualitative melissopalynological analysis, summarised in Table 4, show that predominant pollen is found in 9 samples. It is generally accepted that a minimum content of 70% *Eucalyptus* pollen is necessary to classify *Eucalyptus* honey as unifloral. *Eucalyptus* honeys are considered among the best honeys and are very valuable from a consumer's point of view (Terrab et al., 2003a). The results show that all honey samples studied are original flower honey. We also note that the dominant pollen in the majority of samples are: pollen of *Eucalyptus, Trifolium* sp*, Echium* sp *and Hedysarium corornarium,* Brassicaceae, Asteraceae (mostly Carduus) and to a lesser extent, Rubus and Citrus. Our results of pollen analysis are consistent with Louveaux and Abed (1984), Chefrour et al. (2007), Ouchemoukh et al. (2007) and Makhloufi et al. (2007, 2010). The distribution of observed pollen is quite normal for honey of the Mediterranean (Persano Oddo and Piro, 2004). Also, Louveaux and Abed (1984) found that eucalyptus is one of the most important honey plants in Algeria and Terrab et al. (2003c) concluded that the single-flower honeys from *Eucalyptus camaldulensis* Dehnh are very common in northern Morocco. They mentioned *Plantago* sp. *Thymelaceae* as accompanying pollens while Ricciardelli and Vorwohl (1980) found the *Acacia* and *Gleditsia* species *H. coronarium* as pollens companions for Libya. According to the same authors, Tunisian *eucalyptus* honeys were characterized by *Citrus species, Acacia and Erica, Olea europaea*, and *H. coronarium* as pollens carers (Seijo et al., 2003). We also found a pollen of *Citrus* in our honey in the important minor pollen case. Pollen Citrus is generally under-represented in honey. Unifloral honey citrus were also collected in northwestern Morocco (Terrab et al., 2003b), Spain, *Cyprus* (Ricciardelli and Vorwohl, 1980) and Tunisia (Louveaux and Abed, 1984). Analysis of pollen honey (melissopalynology)

**Table 3.** The results of HMF and pollen number (NPG) of honey samples.

| Sample | HMF (mg/kg) m±SD | Number of pollen in 10 g m±SD | Pollen class |
|---|---|---|---|
| E1 | 10.99±0.67 | 42600±23 | II |
| E2 | 21.89±0.35 | 800±321 | I |
| E3 | 12.99±0.84 | 205000±220 | III |
| E4 | 12.56±0.25 | 17700±111 | I |
| E5 | 8.77±0.29 | 15400±3 | I |
| E6 | 1.62±0.01 | 5810±321 | I |
| E7 | 11.67±0.90 | 200000±24 | III |
| E8 | 7.04±0.74 | 8600±219 | I |
| E9 | 12.08±0.12 | 14000±211 | I |
| E10 | 33.96±0.23 | 10000±36 | I |
| E11 | 12.56±0.43 | 17800±24 | I |
| E12 | 1.72±0.25 | 83600±90 | II |
| E13 | 1.99±0.92 | 57900±86 | II |
| E14 | 36.31±0.44 | 30100±287 | II |
| E15 | 8.49±0.51 | 50000±221 | II |
| E16 | 14.41±0.33 | 40600±32 | II |
| E17 | 10.09±0.72 | 16200±21 | I |
| E18 | 14.26±0.22 | 32400±230 | II |
| E19 | 12.60±0.78 | 28200±100 | II |
| E20 | 38.84±0.39 | 14800±36 | I |
| E21 | 37.36±0.45 | 29600±287 | II |
| E22 | 1.64±0.59 | 16000±310 | I |
| E23 | 2.67±0.29 | 22000±400 | II |
| E24 | 16.99±0.01 | 10400±18 | I |
| E25 | 5.72±0.23 | 18400±190 | I |
| E26 | 7.34±0.59 | 18800±98 | I |
| E27 | 6.50±0.31 | 17600±148 | I |
| E28 | 32.85±0.90 | 12800±226 | I |
| E29 | 7.83±1.14 | 8000±118 | I |
| E30 | 3.33±0.05 | 33700±216 | II |
| E31 | 4.42±0.04 | 115400±221 | III |
| E32 | 6.64±0.70 | 18100±614 | I |
| E33 | 10.52±0.02 | 2010000±513 | V |
| E34 | 14.09±0.55 | 18600±107 | I |
| E35 | 8.61±0.29 | 3400±105 | I |
| E36 | 0.86±0.77 | 4000±125 | I |
| E37 | 0.90±0.01 | 67800±22 | II |
| E38 | 2.70±0.56 | 36000±203 | II |
| E39 | 4.32±0.18 | 17900±201 | I |
| E40 | 3.66±1.01 | 30100±115 | II |

is very important to the quality control of honey. However, the wealth of pollen depends on the production of plant pollen, weather conditions, distance from the hive to flower field, filtering by glandular of the bee and the method of extraction of honey (Von der Ohe, 1994).

## Conclusion

On the basis of HMF and enzymes activities of forty Algerian honey samples we can note that the results obtained agreed with requirements of international and European Community Directives. Although the enzymes activities and the HMF content of honey usually bear no direct relationship to the botanical origin of the product of some honey types; like *Citrus* honey, they are characterized by naturally low enzyme content. In general, these tree parameters are used as quality criteria. The strong heating and too long storage damage the enzyme activity

**Table 4.** Pollen types present in the honey samples (in percentages).

| Sample | Predominant pollen (>45%) | Secondary pollen (16–45%) | Minor pollen (3–15%) | Important minor pollen (<3%) |
|---|---|---|---|---|
| E1 | | *Echium (29%), Eucalyptus (18%)* | *Hedysarium coronarium (10%), Trifolium sp (7%)* | *Carduus, Apiaceæ, Asteraceæ, Mentha spp, Arbutus unedo, Erica arborea, Lavandula stoechas* |
| E2 | | *Trifolium sp (25%), Eucalyptus (19%)* | *Hedysarium coronarium (4%)* | *Raphanus, Asphodelus, Papilionaceae, Lotus, Cistus, Citrus, Ribus, Erica, Borrago, Apiaceae* |
| E3 | *Echium (49%)* | *Eucalyptus (18%), Trifolium sp (17%)* | *Hedysarium coronarium (3%), Lavandula stoechas (3%)* | *Cistus, Mentha, Erica arborea, Carduus, Rhamnaceæ, Citrus, Apiaceæ, Acacia spp, Fabaceae* |
| E4 | *Eucalyptus (50%)* | *Trifolium sp (23%)* | *Hedysarium coronarium (7%), Echium (4%)* | *Carduus, Apiaceæ, Asteraceæ, Mentha spp, Arbutus unedo, Erica arborea* |
| E5 | | *Hedysarium coronarium (21%), Echium (16%)* | *Brassicaceæ 7%), Trifolium sp (6%), Eucalyptus (6%), Fabaceæ (5%), Carduus (5%), Asteraceæ (3%)* | *Rhamnaceæ, Asteraceæ, Erica arborea, Prunus/Pyrus, Mimosa pudica, Lamiaceæ, Helianthus, Apiaceæ* |
| E6 | | *Eucalyptus (16%), Echium (19%)* | *Hedysarium coronarium (10%), Fabaceæ (6%),* | *Carduus, Apiaceæ, Asteraceæ, Mentha spp, Arbutus unedo, Erica arborea* |
| E7 | | *Trifolium sp (33%), Eucalyptus (16%)* | *Echium (7%), Hedysarium coronarium (4%)* | *Cistus, Mentha, Erica arborea, Carduus, Rhamnaceæ, Citrus, Apiaceæ, Acacia spp, Fabaceæ* |
| E8 | *Echium (55%)* | *Eucalyptus (20%), Trifolium sp (16%)* | *Hedysarium coronarium (3%), Fabaceæ (3%)* | *Cistus, Mentha, Erica arborea, Carduus, Lavandula stoechas, Myrtus, Rubus, Citrus, Apiaceæ* |
| E9 | | *Eucalyptus (20%), Echium (16%)* | *Trifolium sp (11%), Hedysarium coronarium (10%), Fabaceæ 7%), Carduus (3%), Erica arborea (3%)* | *Apiaceæ, Lavandula asphodelus, Lavandula stoechas, Lamiaceæ, Brassicaceæ, Taraxacum, Euphorbiaceæ* |
| E10 | | *Eucalyptus (21%), Trifolium sp (17%)* | *Echium (12%), Hedysarium coronarium (11%), Prunus/Pyrus (9%), Fabaceæ (6%), Carduus (5%), Erica arborea (5%)* | *Allium spp, Apiaceæ, Lavandula asphodelus, Lavandula stoechas, Brassicaceæ, Myrtus, Erodium sp, Euphorbiaceæ, Daucus carota* |
| E11 | | *Eucalyptus (40%)* | *Trifolium sp (10%), Erica arborea (9%), Erica sp (3%), Hedysarium coronarium (3%)* | *Cistus, Mentha, Erica arborea, Carduus, Lavandula stoechas, Rhamnaceæ, Citrus, Apiaceæ, Acacia spp, Lavandula asphodelus, Lamiaceæ, Brassicaceæ* |
| E12 | *Eucalyptus (63%)* | *Hedysarium coronarium (17%)* | *Echium (6%), Carduus (5%)* | *Acacia spp, Trifolium sp, Asteraceæ, Lavandula stoechas, Olea, Cistus, Helianthemum* |
| E13 | | *Trifolium sp (21%), Eucalyptus (17%), Hedysarium coronarium (19%)* | *Erica arborea (9%), Erica sp (3%)* | *Adonis sp, Cistus, Mentha, Carduus, Lavandula stoechas, Rhamnaceæ, Citrus, Apiaceæ, Acacia spp, Lavandula asphodelus* |
| E14 | | *Hedysarium coronarium (25%), Trifolium sp (18%)* | *Eucalyptus (10%)* | *Rubus, Asphodelus, Lotus, Lyptus, Citrus, Cistus, Rosaceae, Mentha, Erica, Borrago* |
| E15 | | *Eucalyptus (40%), Echium (17%)* | *Hedysarium coronarium (6%), Rubus (5%)* | *Citrus sp, Apiacea, Lavandula asphodelus, Lamiacea, Acacia sp, Carduus, Erica arborea, Lavandula stoechas* |
| E16 | *Eucalyptus (66%)* | *Echium (17%)* | *Trifolium sp (14%), Borago officinalis (3%)* | *Acacia spp, Asteraceæ, Lavandula stoechas, Molva* |
| E17 | | *Eucalyptus (32%), Echium (20%)* | *Trifolium sp (12%), Rubus (10%), Erica arborea (8%)* | *Cistus, Mentha, Carduus, Lavandula stoechas, Pyrus/Molus, Citrus, Apiaceæ* |
| E18 | | *Eucalyptus (29%), Echium (25%)* | *Trifolium sp (15%), Liliaceae (7%), Citrus (3%)* | *Asteraceæ, Lavandula stoechas, Cistus, Mentha, Erica arborea* |
| E19 | | *Eucalyptus (35%), Hedysarium coronarium (20%)* | *Trifolium sp (15%), Lavandula stoechas (3%)* | *Cistus, Mentha, Erica arborea, Carduus, Rhamnaceæ, Citrus, Apiaceæ, Acacia spp, Fabaceæ* |

**Table 4.** Contd.

| | | | | |
|---|---|---|---|---|
| E20 | *Eucalyptus* (69%) | *Hedysarium coronarium* (20%) | *Trifolium sp* (16%), *Hedysarium coronarium* (14%), *Rubus* (5%) | *Lamiaceæ, Mentha,, Erica arborea, Carduus, Rhamnaceæ, Malva, Salix, Allium, Citrus, Cistus, Apiaceæ, Acacia spp, Fabaceæ* |
| E21 | | *Hedysarium coronarium* (22%), *Eucalyptus* (18%) | *Echium* (6%) | *Trifolium sp, Fabaceæ, Carduus, Rosaceae, Apiaceæ, Asteraceæ, Erica arborea* |
| E22 | | *Eucalyptus* (42%) | *Rubus* (15%) | *Trifolium, Tamarix, Carduus, Rosaceae, Lamiacea,sp, Mentha sp.* |
| E23 | *Eucalyptus* (59%) | *Trifolium sp* (18%), *Echium* (17%) | *Hedysarium coronarium* (4%), *Lavandula stoechas* (4%) | *Lamiaceæ, Mentha, Erica arborea, Carduus, Rhamnaceæ, Citrus, Apiaceæ, Acacia spp, Fabaceæ* |
| E24 | | *Eucalyptus* (20%), *Trifolium sp* (16%), *Echium* (16%) | *Hedysarium coronarium* (6%), *Fabaceæ* (3%) | *Cistus, Mentha, typeGenista, Lotus sp, Carduus, Lavandula stoechas, Rosaceae, Rhamnaceæ, Citrus, Apiaceæ, Acacia spp* |
| E25 | | *Eucalyptus* (29%) | *Echium* (14%), *Trifolium sp* (11%), *Hedysarium coronarium* (4%) | *Asteraceæ, Borago officinalis, Lavandula stoechas, Rubus sp, Rosaceae, Menth* |
| E26 | | *Eucalyptus* (32%), *Trifolium sp* (18%) | *Echium* (12%) | *Citrus, Cistus, Mentha, typeGenista, Erica, Borago officinalis, Arborea, Carduus, Lavandula stoechas, Rhamnaceæ, Lotus, Rosaceae, Apiaceæ, Acacia spp* |
| E27 | | *Eucalyptus* (38%), *Echium* (20%) | *Hedysarium coronarium* (13%), *Carduus* (7%) | *Citrus sp, Apiacea, Lavandula asphodelus, Lamiacea, Erica sp, Acacia sp, Arborea, Apiaceae, Myrtus communis, Lavandula stoechas* |
| E28 | *Eucalyptus* (69%) | *Trifolium sp* (19%) | *Hedysarium coronarium* (11%), *Salix* (4%), *Sinapiss sp* (3%) | *Carduus, Apiaceæ, Malva, Pyrus, Citrus, Rosaceae, Medicago, Asteraceæ, Mentha spp, Arbutus unedo, Erica arborea, Lotus, Lavandula stoechas* |
| E29 | | *Hedysarium coronarium* (21%), *Echium* (16%), *Eucalyptus* (16%) | *Trifolium sp* (6%), *Fabaceæ* (5%), *Carduus* (5%) | *Brassicaceæ, Mentha sp, Borago officinalis, Lotus, Rosaceae, Rhamnaceæ, Asteraceæ (échinulé), Erica arborea* |
| E30 | | *Eucalyptus* (37%) | *Hedysarium coronarium* (14%) | *Rubus, Rosaceae, Carduus, Rosaceae, Lamiacea sp, Acacia sp* |
| E31 | | *Echium* (19%), *Trifolium sp* (18%), *Eucalyptus* (16%) | *Hedysarium coronarium* (11%), *Fabaceæ* (5%), *Rosaceae* (3%) | *Erica arborea, Carduu, Citrus, Rosaceae, Asterace, Prunus/Pyrus, Mimosa pudica, Lamiaceæ, Helianthus, Apiaceæ* |
| E32 | | *Eucalyptus* (16%), *Echium* (19%) | *Hedysarium coronarium* (10%), *Fabaceæ* (6%) | *Carduus, Apiaceæ, Asteraceæ, Mentha spp, Arbutus unedo, Erica arborea* |
| E33 | | *Eucalyptus* (20%) | *Echium* (14%), *Trifolium sp* (13%), *Hedysarium coronarium* (4%) | *Cistus, Mentha, typeGenista, Ericaarborea, Cistus, Rosaceae, Boragoofficinalis, Carduus, Rhamnaceæ, Citrus, Apiaceæ, Acacia spp, Fabaceæ* |
| E34 | *Neant* | *Hedysarium coronarium* (22%), | *Eucalyptus* (11%), *Echium* (7%), | *Trifoliumsp,Fabaceæ,Carduus,Rosaceae,Apiaceæ,Asteraceæ,Menthaspp,Arbutusunedo,Ericaarborea,* |
| E35 | | *Eucalyptus* (45%) | *Trifolium sp* (15%), *Erica arborea* (4%), *Hedysarium coronarium* (3%) | *Erica sp, Echium, Cistus, Mentha, typeGenista, Carduus, Asteracea, Lavandula stoechas, Rhamnaceæ, Citrus, Apiaceæ, Acacia spp, Lavandula asphodelus, Lamiaceæ, Brassicaceæ* |
| E36 | | *Eucalyptus* (33%), *Hedysarium coronarium* (18%) | *Echium* (14%), *Carduus* (5%) | *Acacia spp, Trifolium sp, Asteraceæ, Mentha sp, Rosaceae, Citrus, Lavandula stoechas* |
| E37 | *Trifolium sp* (51%) | *Eucalyptus* (23%) | *Hedysarum coronarium* (8%) | *Erica sp, Citrus, Cistus, Boraginoceae, Arborea, Carduus, Rhamnaceæ, Apiaceæ, Acacia spp, Fabaceæ* |
| E38 | | *Eucalyptus* (32%) | *Trifolium sp* (13%), *Hedysarium coronarium* (10%) | *Erica sp, Echium, Erica arborea, Cistus, Citrus, Apiaceæ, Acacia spp, Lamiaceæ, Brassicaceæ* |

**Table 4.** Contd.

| | | | |
|---|---|---|---|
| E39 | *Eucalyptus (35%), Trifolium sp (18%)* | *Hedysarium coronarium (15%)* | *Citrus sp, Apiacea, Mentha, Cistus, Carduus, Lavandula asphodelus, Rosaceae, Lamiacea sp, Acacia sp, Erica arborea, Apiaceae, Myrtus communis, Lavandula stoechas* |
| E40 | *Hedysarium coronarium (35%), Eucalyptus (22%)* | *Trifolium sp (15%), Erica arborea (9%)* | *Cistus, Mentha, typeGenista, Erica sp, Carduus, Rhamnaceæ, Citrus, Lavandula asphodelus, Brassicaceæ* |

and increase the HMF content. However, honey samples differ in quality on account of various factors such as season, origin of honey, activity of the bee, food of the bee, period and technique of extraction of honey, conditions of storage and the freshness of honey. The analysis of palynological results therefore revealed that the dominant pollen in the majority of samples are: pollen of *Eucalyptus, Trifolium sp, Echium sp and H. corornarium,* Brassicaceae, Asteraceae (mostly Carduus) and to a lesser extent, Rubus and Citrus, Apiaceae and Ericaceae are most frequently found in the pollen spectrum of Algerian honeys.

## Conflict of Interest

The authors have not declared any conflict of interests.

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academicJournals

Vol. 10(7), pp. 623-630, 12 February, 2015
DOI: 10.5897/AJAR2014. 9322
Article Number: D30183450342
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Operation, facilities and management in public and private abattoirs in Ethiopia

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Received 11 November, 2014; Accepted 22 January, 2015

**This study was conducted to evaluate the operation, facilities and management of public (Adama, Hawassa and Mekelle) and private (Elfora Kombolcha) abattoirs in Ethiopia. Direct observation, photograph and discussion with the workers were used to collect information. The results of this study revealed that lairage was not divided into compartments to accommodate different classes and types of slaughter cattle in two of the four abattoirs visited. Stunning boxes were not used at any of the abattoirs investigated, enervation method of stunning was practiced and there were no means of sterilizing cutting equipments. Even though anti- and post mortem inspection were conducted properly at all abattoirs, findings were not regularly recorded in public abattoirs. Weighing scales were not available at the public abattoirs while live and carcasses weights were regularly recorded at the private abattoir. In all public abattoirs, at horizontal position while it was performed in vertical position in private abattoir. Carcass contamination occurred during processing and/or during transport in the public abattoirs. Classification of carcasses occcured not practiced in public or private abattoirs. It was concluded that the management practiced in public and private abattoirs can partly contributed to the poor beef quality produced. Hence it was recommended that the country should develop legislation governing the operation of abattoirs. Moreover, hazard analysis critical control points (HACCP) should be established in all abattoirs to ensure animal welfare, maximum efficiency and beef quality.**

**Key words:** Abattoir facilities, slaughter procedure, beef, carcass, Ethiopia.

## INTRODUCTION

Proper handling of animals is not only a matter of welfare but also an issue of meat quality. Improper handling of animals yield poor meat quality; and poor meat quality result in poor processing properties, functional and eating qualities and is less likely to be accepted by consumers (Ferguson and Warner, 2008). Carcass and meat quality defects such as pale soft exudates, dark firm dry, skin blemish, blood splash, bruising, cyanosis, high microbial load, spoilage of meat, broken bones and death may occur from improper animal handling (Warriss, 2000; Forrest, 2010; Adzitey et al., 2011). Pre-slaughter animal handling starts from the farm, through marketing and end at the abattoir activities (Adzitey, 2011). Moreover, handling of animals during slaughter can also influence the quality of meat (MLA, 2011). Imperfect bleeding affects the quality of meat as more blood in the meat makes it more prone to microbial spoilage which ultimately reduces the quality of meat. Furthermore,

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**Table 1.** Descriptions of the study area.

| Abattior | Region | Distance from Addis Ababa (km) | Global position | Altitude (masl) | T°C | RF (mm) |
|---|---|---|---|---|---|---|
| Adama | Oromiya | 99 east | 8°32'N39°16E | 1712 | 13-27 | 809 |
| Hawassa | SPNN | 250 south | 7°03'N38°28E | 1500-2000 | 20-25 | 800-1000 |
| Elfora Kombolcha | Amhara | 375 north east | 11°4'N39°44E | 1842 - 1915 | 11 - 26 | 750 - 900 |
| Mekelle | Tigray | 783 north | 7°13'N 5°52E | 2000-2200 | 11- 24 | 579-650 |

SPNN- Southern people national and nationalities.

stunning methods affects the bleeding process (Gracey et al., 1999). Carcass handling can also affect meat quality significantly (Adzitey and Huda, 2012). During processing of carcasses, contamination can occur from slaughter facilities, equipment, workers, and environment (Jay, 1992). Different abattoirs have different facilities and management systems which can affect the quality of meat differently. In the developing countries, commercial abattoirs have sophisticated machinery (Gregory, 2005) while most municipal abattoirs have poor handling facilities (Ndou et al., 2011). These differences are thought to have an effect on animal behavior at slaughter and the quality of the product. Animals' reactions differ with different handling techniques and systems (Grandin, 1999). Slaughtering technology is becoming more important as it has a large influence on meat quality (Swatland, 2000). Animal welfare problems are related to inadequate facilities and equipment, lack of personnel training and improper animal handling (Grandin, 1996). It is the responsibility of the abattoirs to ensure minimal stress and good animal welfare from the time the animals arrive at the abattoir to the time of slaughter (RMAA, 2011). Animals which are well looked at slaughter provide good quality meat products. In less commercial abattoirs with little machinery available, there is high human-animal interaction which can be a cause of stress to the animals due to fear of humans (Breuer et al., 2000; Hemsworth, 2003; Waiblinger et al., 2006).

Research has shown that better quality meat with a longer shelf life can be produced if animals are handled with greater patience, understanding and care at slaughter (RMAA, 2011). Hence it is important to assess the level of facilities and management system practiced in public/municipal abattoirs to identify the impact of operation on meat quality. There is no documented information on operation, facilities, managements systems practiced in public and private abattoirs in Ethiopia. This study therefore conducted to assess the level of operation; facilities and management at public and private abattoirs in Ethiopia and suggest a possible improvement strategy.

## MATERIALS AND METHODS

### Study abattoirs

The study abattoirs are located in the capital cities of Oromiya, Amhara, SPNN (Southern people national and nationalities) and Tigray regional state of Ethiopia which contained more than 95% of cattle population of the country. Descriptions of the study areas and abattoirs are shown in Table 1.

### Data collection and analysis

Information on lairage management, stunning method, bleeding, carcass processing and transporting was collected by direct observation, photograph and discussion with workers from public (Adama, Hawassa and Mekelle) and private (Elfora Kombolcha) abattoirs in Ethiopia between August 2013 and January 2014. To identify the causes of inferior quality of carcasses, the presence/absence of basic slaughter facilities, equipment and slaughter procedure were compared between abattoirs.

## RESULTS

Capacity, end product and working time of public and private abattoirs are presented in Table 2. The public and private abattoirs studied had a slaughter capacity of 100 to 300 cattle per day. Adama, Hawasa and Mekelle are public abattoirs while Elfora Kombolcha is private. Public abattoirs provided slaughter service to butcheries. They distribute quartered carcasses to their clients. The private abattoir purchased cattle, process and distribute meat to clients (hotels and university cafeterias). Moreover, the private abattoir process corned beef for local and international market. Public abattoir worked during the night, early in the morning and late in the afternoon. However, the private abattoir worked during the day time. Two of the four abattoirs visited are located in the community while others are located outside the community.

Facilities available at public and private abattoirs are presented in Table 3. All abattoirs have lairage, stunning boxes, hoisting facilities and vehicle to transport carcasses and meat. However, it was only at Adama and Elfora Kombolcha abattoirs that lairage was divided into compartments to accommodate different classes and types of animals. In the other abattoirs, the lairage was constructed as a unit to accommodate all classes and types of cattle together (Figure 1).

Watering trough was available only at the lairage at Kombolcha abattoir. Information obtained from the workers in public abattoirs revealed that cattle were slaughtered in 2 to 3 h after arrival at the lairage while a private abattoir cattle were required to stay in the lairage for 12 to 24 h before slaughter. During this time, cattle had an access to water but not to feed.

**Table 2.** Capacity, end product and working time of public and private abattoirs.

| Abattoir | Capacity | Ownership | Location | Output | Working time |
|---|---|---|---|---|---|
| Adama | 100-300 | Public | Outside city | Carcass | 20:30-06:00 |
| Hawasa | 100-150 | Public | Outside city | Carcass | 20:30-06:00 |
| Elfora Kombolcha | 250-300 | Private | Inside city | Meat and corn beef | 06:00-16:00 |
| Mekelle | 100-150 | Public | Inside city | Carcass | 05:00-09:00, 14:00-20:00 |

**Table 3.** Facilities available at public and private abattoirs.

| Abattoirs | Lairage | Stunning box | Stunning | Hoisting | Knife and axes sharpening facilities | Sterilization facilities for equipment | Hot water | Refrigeration section | Deboning room | Carcass quartered | Laboratory | Vehicle |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Adama | Yes | Yes | Knife | Electrical | No | No | Yes | No | No | Manual axe | No | 2 |
| Hawasa | Yes | Yes | Knife | Electrical | No | No | Yes | No | No | Manual axe | No | 2 |
| Elfora Kombolcha | Yes | Yes | Knife | Electrical | Yes | No | No | Yes | Yes | Electrical saw | Yes | 2 |
| Mekelle | Yes | Yes | Hammer and Knife | Manual | Yes | No | Yes | No | No | Manual axe | No | 2 |

Stunning boxes were available in each abattoir (Figure 2). The boxes were properly designed in all abattoirs except for Mekelle. However, in all abattoirs, boxes were not on use as cattle were not willing to enter in to the boxes (based on information from the workers). In all abattoirs, enervation method of stunning was practiced. This method was conducted by thrusting sharp knife to the atlanto-occipital space of the cattle (Figure 3).

There were no knife and axe sharpening machine in Adama and Hawasa abattoirs (Table 3). In these abattoirs, workers sharpen these equipments outside the abattoir by their own means. There were no means of sterilizing equipments in all abattoirs visited. Hot water was available during working time in all abattoirs except for Mekelle. Carcasses were manually quartered using axes in the public abattoirs while electrical saw was used in the private one. Vehicles to transport carcasses were available in all abattoirs visited (Table 3).

Inspection, recording, weighting and grading practices at public and private abattoirs are presented in Table 4. In all abattoirs visited, veterinarians inspect live animals some hours or a day before slaughter. Based on anti-mortem inspection, animals were accepted, condemned or remained for some more days of observation in the lairage. Similarly, there were good practices of inspecting carcasses in all abattoirs visited. However, recording of anti- and post mortem findings were regularly conducted only in Kombolcha abattoir. Moreover, this abattoir reports the causes of condemnations of live animals and carcasses every 3, 6 and 12 months to regional agricultural bureau. This practice of reporting causes of condemnations to responsible offices was not practiced by public abattoirs.

Weighing scale for live animals and carcasses were available only in Kombolcha abattoir. In this abattoir, live weight, carcass weight and meat yield were measured on daily basis. This facility was not available in the public abattoirs and hence there was no practice of recording live and carcass weight of cattle. Recording the origins of cattle was practiced by Hawasa abattoir. This experience was not available in other abattoirs visited. Classifying carcasses was not practiced in all abattoirs (Table 4).

Bleeding was conducted on the floor at all public abattoirs. In these abattoirs, evisceration was conducted on horizontal position on the floor by incising the hide at the bottom of the abdomen without flying the skin. At Kombocha abattoir, both bleeding and evisceration was conducted on vertical position after hoisting the carcasses (Figure 4).

**Figure 1.** Lairage: Elfora-Kombolcha(left), Adam (middle) and Hawassa ( right).

**Figure 2.** Stunning box at Elfora-Kombolcha (left), Mekelle (middle) and Adama (right).

**Table 4.** Inspection, recording, weighting and grading practices at public and private abattoirs.

| Abattoir | Anti- and postmortem inspection | Recording disease finding | Live and carcass weight | Record source of cattle | Report of causes of condemnation to regional office | Classification of carcasses |
|---|---|---|---|---|---|---|
| Adama | Yes | Occasional | No | No | No | No |
| Hawasa | Yes | Occasional | No | Yes | No | No |
| Kombolcha | Yes | Always | Yes | No | Yes | No |
| Mekelle | Yes | Occasional | No | No | No | No |

Carcasses were hoisted using mechanized hoisting system in all except Mekelle abattoir where workers hoisted carcass manually using chained pulley system after flying the skin and evisceration on the floor (Table 3). The hides were flayed after hoisting the carcasses at Adama, Hawassa and Kombolcha abattoirs. In these abattoirs, carcasses were hoisted higher above the ground, creating less chance of contamination of carcasses by filth and blood on the floor. At Mekelle abattoir, carcasses were not raised high enough from the ground and they touch the floor during processing (Figure 5).

Carcasses were quartered immediately before being loaded on the vehicles. The distance between conveyer bar and the vehicle was 1 to 10 m. The distance between conveyer bar and the vehicle were relatively longer at Hawassa abattoir (about 10 m) and relatively shorter at Adama abattoir (about 1 m). Between the two points, workers transport carcasses on their shoulders. Carcasses were suspended in the vehicle to be transported to butcheries. In most cases, carcasses were touching the floor of the vehicle during transport (Figure 6).

Separate rooms from the carcasses were used to process rumen and intestine in all abattoirs. Bones, hoofs and hides were semi-processed for supply to respective companies in the private abattoirs while only hides were considered as valuable product in public abattoirs. Horns and hoof were wasted without being marketed in the latter abattoirs.

Wearing of protective clothes was practiced in both public and private abattoirs. However, at private abattoirs,

**Figure 3.** Stunning using sharp knife at atlanto-occipital space at Kombolcha (left) and Adama (right) abattoirs.

**Figure 4.** Sticking of cattle at Kombolcha (left) and Adama (right) abattoir.

workers wear clean protective clothes while those at public ones were not at the standard.

## DISCUSSION

All food animals suffer from stress following transport. Therefore, it is important that lairage should provide comfortable environment to relief animals from stress. Among the abattoir visited during the study period, Adama and Elfora Kombolcha abattoirs have well designed lairage which are well ventilated and have accommodations for different classes and types of slaughter animals. The lairage in the other abattoirs were constructed as one to accommodate all classes and types of slaughtered cattle together. Lairages should be well ventilated and provided with adequate day and night lighting (Cortesi, 1994). Animals need to be separated based on their sex, ages and origin. Mixing different classes and types of animals are a source of physical and psychological stress (Gracey, 1981). In all abattoirs visited, there were no feeding troughs in the lairage. Watering trough was available only in the private abattoir. Well designed watering and feeding troughs should be placed along the walls of the lairage in adequate number (Cortesi, 1994). Drinking water must be constantly available throughout the waiting period till slaughter (Grandin, 2003). Feed must also be provided if slaughter does not take place within twelve hours (Ledger and Payne, 1990). Availability of water at all times in the lairage will make processing of rumen and intestine easier; it promotes proper bleeding and makes flaying very easy. At Kombolcha abattoir, slaughter cattle were required to pass at least 12 h in the lairage to make sure that they do not take any solid feed before slaughter. In the public abattoirs, animals reach abattoirs 2 to 3 h before slaughter. This makes it difficult to know whether cattle were starved for at least 12 h before slaughter. FAO (1991) specifies the withdrawal of feed for 12 to 24 h before slaughter. This will reduce the risk of contaminating the carcass with the gut content during evisceration, and reduce processing time and cost. Cattle were slaughtered in most public abattoirs during the night and early in the morning. This was to provide fresh meat early in the morning to the consumers.

For the health of the environment and community, abattoirs should be constructed outside residence. Large amounts of wastewater, solid waste, bad odor and fuel burning emission can be produced from processing operations which can affect the health of people living in the surrounding (DARD, 2009). However, two of the four abattoirs visited in the present study are located in the

**Figure 5.** Carcass processing at Mekelle (left), Kombolcha (middle) and Adama (right) abattoir.

**Figure 6.** Vehicle (left) and carcass suspended in the vehicle for transport to butcheries (middle and right).

community residence. Hence it is important to take strong treatment measures against by-products polluting the environment as relocating these abattoirs might require large financial resource. However, appropriate site selection for abattoir construction should be given primary importance in the future. Good manufacturing practice emphasizes the need to establish abattoirs outside the community residence (Thai Agricultural Standard, 2005).

Anti-mortem examination of animals and post mortem inspection of carcasses and organs were conducted in all abattoirs visited. However, the causes of condemnations were regularly recorded in the private abattoir. The record book in the public abattoirs revealed that there was no practice of daily recording on causes of condemnations of live cattle. Moreover, the private abattoir provides quarter, semi-annual and annual reports on causes of condemnations of live animals, carcasses and organs to regional Bureau of Agriculture. This practice was not observed at public abattoirs. All abattoirs should be able to report their finding to the responsible sector in the Ministry of Agriculture so that the latter body will develop integrated preventive and control strategy on major animal and public health important diseases.

Recording the origin of slaughter animals were not practiced in all but Hawassa abattoir. This experience must be shared by other abattoirs so that quality, yield and disease problems can be traced to the origin thereby taking appropriate measure to improve the situations. Slaughtering is a stressful process and hence must be efficient to minimize fear, excitement, pain or suffering of animals before slaughter. Unstressed animals before slaughter make slaughter operations easier and safer (Cortesi, 1994). However, what was practiced at the abattoirs in the present study was different from this reality. A group of cattle were allowed to enter into slaughter floor at a time. In this part of the slaughter house, they wait for their turn for stunning and sticking, watching all activities of slaughter. The stunning boxes in each abattoir were not in use as information from the workers revealed that cattle were not willing to enter into this box. The reasons for this must be sorted out and appropriate measure must be taken in the future. Cattle were stunned by workers by holding their horns and/or tying on any available poles. Stunning cattle without stunning boxes would compromise the safety of the worker. Moreover, it increases the level of stress on animals. Enervation method of stunning was practiced in all abattoirs. Enervation was reported the least effective methods of stunning known till date (Gracey, 1981). This method was reported to paralyse the animal but does not produce loss of consciousness, as blood supply to the brain does not stop (Leach, 1978). This method was banned from European community long ago. Efficient stunning methods are well defined in European Union (formerly Economic Community, EEC), Directive 74/577 (Council of Europe, 1974). According to this Directive, "stunning means a process effected by a mechanically operated instrument, electricity, or gas anesthesia without adverse effects on the condition of the meat or the offal, which when applied to the animal puts it into a state of insensibility which lasts until it is slaughtered, thus sparing it in any event needless suffering." Similarly, for abattoirs in Ethiopia, stunning methods should be defined that minimize suffering of animals, maximize safety of workers and improve quality of meat product.

It is important that each abattoir should have its own sharpening machine and sterilizers to avoid the use of blunt knife and unhygienic equipments. Given the responsibility of sharpening knife for each worker will compromise the sharpness of the knife and hygiene of equipments. The knife that is used for slaughter purpose must be clean and sharp (FAO, 2004).

Even though proper equipment for hanging carcasses was found in each abattoir, it was not properly used. Proper equipment for handling carcasses includes manual or electric hoists for lifting up the carcass – getting it off the floor for flaying, eviscerating and splitting (FAO, 2008). In all public abattoirs, bleeding was conducted on the floor on horizontal position. Even though horizontal bleeding promotes faster bleeding rates (RMAA, 2011), it is not as hygienic as vertical bleeding. Moreover, in the pubic abattoirs evisceration was made on the filthy floor without flying the skin. This might expose carcasses for contamination by blood and mud from the skin. At one of the public abattoirs, it was observed that flaying of the skin was conducted on the floor. This would further contaminate the carcasses and compromise the quality of meat. This might be the reason for poor quality of beef reported at local markets in Ethiopia (Kumar et al., 2010).

At public abattoirs, workers transported carcasses from conveyer bar to the vehicle on their shoulders. They used plastic gowns which covered their head and their back. However, the hygienic condition of these clothing was not up to the standard required for abattoir personnel. Personnel at the abattoirs did not wear clean aprons, clothing, boots, mesh gloves and hair caps during meat processing. This might be the reason for high aerobic plate count (APC) in beef sold at local markets in Ethiopia (Kumar et al., 2010). For good hygienic practices and production of high quality meat, workers should ensure their hands are always clean, and also wear clean protective clothing to cover both their body and hair.

During transporting of carcasses to butchery, quartered carcasses were suspended in the vehicle from touching the floor of the vehicle. The rumen, intestines and head were placed on the floor under suspended carcasses. This might further increase the chance of microbial contamination due to the contact between carcasses and organs.

The tendency to pay beef producers based on carcass yield and quality traits is increasing (Lazzaroni, 2007). Hence it is important to measure the live weight, carcass weight and evaluate quality of beef slaughtered in each abattoir. The absence of weighing scale in all public abattoirs needs considerable attention. Live and carcass weight of cattle slaughtered in public abattoirs should be identified. Beef carcass classification system developed by the country (ES, 2012) must be implemented in each abattoir. Implementing this program will help identify the quality and yield problems of beef in the country and develop improvement strategy in the future.

A country like South Africa has developed legislations governing abattoir operations which includes; The Meat Act, 2000, and the Animal Protection Act, 1962 and 1935 for Animal Welfare Maintenance (RMAA, 2011). This kind of legislation should be developed for public and private abattoirs in Ethiopia to ensure public health safety, welfare of animals, maximize efficiency and quality of meat. Hazard analysis critical control points (HACCP) system is strongly recommended in all abattoirs. By regularly reporting measurements of critical control points (CCPs), various critical operations that are carried out by workers, handling and slaughtering of animals can be monitored to ensure that they are done properly, leading to steady improvements in welfare and operational quality. Monitoring and evaluation of the CCPs should be conducted on a regular basis (FAO, 2004).

## CONCLUSION AND RECOMMENDATIONS

Management practiced in public and private abattoirs can partly contribute to the poor quality beef. Hence it is important that the country should develop legislation governing abattoirs operation. Moreover, hazard analysis critical control points (HACCP) should be established in all abattoirs to maintain welfare of animals, maximum efficiency and quality of beef.

## ETHICAL APPROVAL

Permission was obtained from Ethical Committee of University of Pretoria to carry out the present study.

### Conflict of Interest

The authors declare that there is no conflict of interest between authors and organizations.

## ACKNOWLEDGEMENTS

The authors wish to thank the University of Pretoria for UP Post graduate Bursary and Research Office of University of Haramaya for partially financing data collection. Mr. Driba Bayicha, Mr. Belayneh Fekede, Dr. Tekele Birhan and Mr. Mohammed Hassen who were supervisors at Adama, Hawassa, Mekelle and Kombolcha abattoirs, respectively, are highly appreciation for their facilitation in data collection.

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academicJournals

Vol. 10(7), pp. 631-636, 12 February, 2015
DOI: 10.5897/AJAR2014. 9323
Article Number: F4EAD2150350
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Biotechnology in agriculture: The perception of farmers on the inclusion of Genetically Modified Organisms (GMOs) in agricultural production

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Received 11 November, 2014; Accepted 22 January, 2015

**The aim of this study was to determine the perceptions and attitudes towards biotechnology in the insertion of genetically modified (GM) crop production. The data analyzed in this article were obtained through qualitative research, via a semi-structured questionnaire administered in June 2014, with 20 associated cooperatives of farmers at Campos Gerais region. It was found, from the speech of farmers, there are advantages and disadvantages of biotechnology in agriculture, and all point to transgenic technology as a necessary and essential for increasing productivity and reducing the cost of production. On the other hand, the monopoly of seeds and inputs companies was identified as the main disadvantage of the insertion of biotechnology in agriculture. All farmers pointed insurance transgenic and research that prove the risks to human health are few and delayed.**

**Key words:** Biotechnology, farmers, perception.

## INTRODUCTION

Since the biotechnology term is recent, reports of its application have been appointed for six thousand years, where microorganisms were used in fermentation processes to produce beer and bread, among other products. Whereas the modern biotechnology has advanced, many development opportunities in various sectors of the economy were created, stands out in agriculture, which has the challenge to increase food production with sustainable use of the current biodiversity (Gomes and Borém, 2013).

Through the current biotechnology, it was possible to modernize agriculture with the new discoveries of plant breeding. Thus, traditional crops are being replaced by improved cultivars and transgenic plants to increase crop productivity to meet the demand for food (Leite and Munhoz, 2013).

According to Leite and Munhoz (2013), modern biotechnology is marked by attribution of characteristics from different species to another receptor without sexual reproduction and through human intervention.

Genetically Modified Organisms (GMOs) are those with genetic material altered by man through transferring a

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gene from one species to another. 1971 was the landmark of technological advancement, when the first GMO, mainly food was patented in the United States, and rapidly reached the world (Alves, 2004).

Among the applications of biotechnology applied to production, the insect resistance and herbicide tolerance stood out. Although commercial use of this seed started in USA in the 1980s; in Brazil, the authorization to plant genetically modified (GM) soybeans occurred after a long period of conflict and uncertainty involving an aggressive strategy of the companies, institutional uncertainties in the regulatory plan and resistances formed in the domestic market between producers and their organizations. In spite this fact, adoption of the new law on Biosafety, in March 2005, has opened the way for release of the planting and sale of GMO varieties of soybeans in Brazil (Vercesi et al., 2009; Schioschet and Paula, 2013).

In a bid to achieving higher productivity, lower production costs, reduce need for labor and ensure easy control of weeds by herbicide use, glyphosate resistant transgenic crops have being grown in larger areas. In fact, the creation of GM plants can be declared as a scientific breakthrough and a certainty of profit for major centers of biotechnology and for farmers. Since the growing of these plants by means of recombinant DNA technology, there have been present characteristics that would not have been acquired through conventional breeding (Andrioli, 2013; Ribeiro and Marin, 2012).

Biotechnology, including transgenic crop development, is contributing to alleviation of hunger; however, FAO commented that 'there is still a need to step up investment in agriculture with the dual purpose of stimulating sustainable productivity increases to expand supply and of exploiting the potential of agriculture to contribute to economic development and poverty alleviation' (Park et al., 2011).

The impact of biotechnology on agricultural productivity in developing countries, as well as national and international standards of biosafety and potential risks to the environment stood out as principal points of the incipient debate on GMO crops (Massarani et al., 2013).

In that sense, Brazil has been substantially growing its food production by means of biotechnological processes and will play a key part in supplying considerable portion of food that the world will demand.

In just eight years, the country already has the second largest area of GMO crops planted worldwide. And for the fifth consecutive year, Brazilian agriculture experienced the most boosted global growth in planted areas of GM varieties, with expansion of 12% compared to 2011, reaching a record of 36.6 million hectares, an increase of 4 million (James, 2012). According to the International Service for the Acquisition of Agri-Biotech Applications- ISAAA (2013) report, Brazil is emerging as a global leader in biotech crops, and is only behind the USA in planted area, with 36.6 million hectares. For four consecutive years, Brazil was the global growth agent, increasing its acreage of transgenic crops more than any other country in the world, growing 21% of the global area and is stabilizing its position consistently to reach the USA.

Paraná has a very particular history in relation to GMOs. The state government, in 2003, at the height of debate on the subject in Brazil, has always been opposed to GM crops. Even after the passage of the Biosafety Law, a series of legal impediments and structural obstacles was created to the cultivation of GMO crops in Paraná. In 2006, transgenic soybeans still represented less than half of the soybean production in the region. Monsanto's RR soya resistance to glyphosate had been released for commercial cultivation in the previous year; however, most farmers had not yet acceded to these seeds; most local cooperatives did not receive transgenic soybeans, and the state government continued to put pressure on farmers not to plant GM seeds (Almeida and Massarani, 2011).

Farmers had an active role in the introduction of this new technology. The objective of this research was to investigate the perceptions and attitudes toward biotechnology in the insertion of GMOs in agricultural production.

## MATERIALS AND METHODS

The approach of this paper is based on the qualitative method in order to verify the perception of farmers about the cultivation of GM crops. Based on an exploratory research by Lakatos and Marconi (2003, p. 188), "exploratory research is understood as an empirical investigations of research which goal is the formulation of questions or a problem with triple aim: to develop hypotheses, increase the familiarity of the researcher about an environment, fact or phenomenon for conducting more precise future research and modify and clarify concepts."

From the definition of a qualitative methodological approach were chosen complementary procedures as an interview and also the choice of interviewees.

A semistructured interview script was followed to the interviews. The questionnaire was applied in the first half of 2014, with associated farmers from cooperatives in the region of Campos Gerais. There was no selection of people to be interviewed, because despite the region presents a significant number of producers of GMOs, part of them did not answer the questionnaire. There were a total of 20 interviewees in the region.

An explanation of the research was made, exposing the objectives to be achieved, clarifying that there would be guaranteed anonymity of 20 interviewees and then, the questionnaire was applied.

The questionnaire was based on the study of Lima (2005) and consisted of three sections:

Section I - General questions aiming to elicit information about the crop practices of the farmers;
Section II - Questions related to the knowledge of the farmers about GM;
Section III - Questions regarding of the advantages and disadvantages of growing GM crops and their health risks.

## RESULTS AND DISCUSSION

Interviews were conducted with 20 GM producers in the

**Table 1.** The profile of interviewees and their properties.

| Interviewees | Property type | Property size (hectares) | Area for GMOs cultivation (hectares) | Time of agricultural (years) | Time of GMOs agricultural (years) |
|---|---|---|---|---|---|
| Interviewee 1 | Owned | 142 | 80 | 2 | 2 |
| Interviewee 2 | Owned | 36 | 36 | 9 | 5 |
| Interviewee 3 | Owned | 224 | 120 | 20 | 10 |
| Interviewee 4 | Owned | 80 | 80 | 25 | 20 |
| Interviewee 5 | Owned | 100 | 100 | 5 | 5 |
| Interviewee 6 | Mixed | 50 | 50 | 35 | 8 |
| Interviewee 7 | Owned | 12 | 12 | 40 | 5 |
| Interviewee 8 | Mixed | 10 | 10 | 8 | 8 |
| Interviewee 9 | Mixed | 100 | 100 | 40 | 9 |
| Interviewee 10 | Owned | 1100 | 1000 | 30 | 7 |
| Interviewee 11 | Owned | 1500 | 1200 | 17 | 5 |
| Interviewee 12 | Mixed | 135 | 135 | 1 | 1 |
| Interviewee 13 | Leased | 60 | 40 | 25 | 4 |
| Interviewee 14 | Mixed | 300 | 250 | 19 | 10 |
| Interviewee 15 | Mixed | 156 | 90 | 3,5 | 3,5 |
| Interviewee 16 | Leased | 50 | 50 | 3 | 3 |
| Interviewee 17 | Owned | 900 | 900 | 40 | 7 |
| Interviewee 18 | Leased | 77 | 77 | 26 | 2 |
| Interviewee 19 | Leased | 40 | 30 | 20 | 12 |
| Interviewee 20 | Leased | 50 | 50 | 10 | 8 |

region of Ponta Grossa, Castro and Palmeira. Regarding the level of education, one (1) respondent had incomplete elementary school; three (3) had complete elementary school; one (1) producer did not have complete high school, and four (4) of them has finished high school; eleven (11) present a college degree and one (1) holds a post-graduation, showing a diverse school level, which did not interfere in a general cultural level, since on the subject all producers showed similar level of knowledge.

Most (9) of the interviewees farmers own their land, five (5) produce in leased areas and six (6) cultivate GMOs in mixed areas (leased and owned). All interviewees use more than 50% or even 100% of farmland to GM production, which demonstrates the expansion of cultivation of GMOs in the region. Among farmers who do not cultivate GM crops on 100% of the cultivation area are those that produce oats, wheat and beans. Among the existing GM crops that the farmers cultivate stand out the soybeans and corn (Bt).

The areas of conventional crops, as well as GM crops found in this study, range from 10 acres to a maximum area of 1500 ha, demonstrating that the cultivation of GM crops occurs in all types of farms, whether small, medium or large.

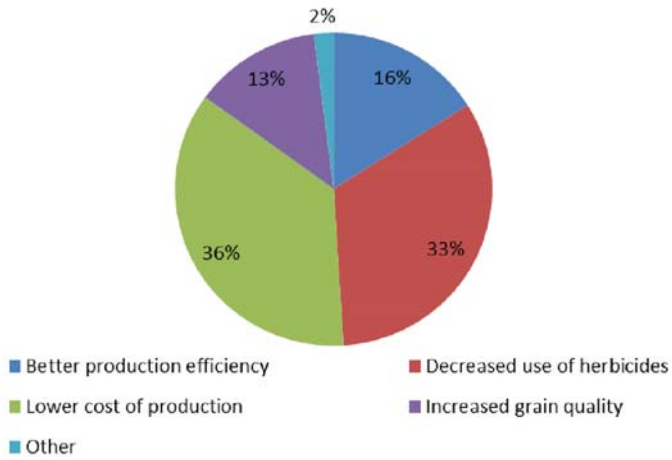
Of twenty (20) farmers interviewed, five (5) have worked in this business for 30 years or more, five (4) between 20 and 30 years, three (3) between 10 and 20 years and eight (8) have been working between 1 and 10 years. This last group, though has little time of individual farming, come from family farmers, and their knowledge and perceptions comes from when they accompanied their family on the field activities (Table 1).

The questionnaires aimed to verify the perceptions and attitudes toward biotechnology in the insertion of GM in agricultural production.

Producers most often had told what a GM is at least generally. All of them provided a clear definition regarding GMO crops, explained in their own words the general characteristics and type of resistance obtained and, in some cases, used basic scientific concepts. Among the words mentioned in most settings were the terms "technology", "modification" and "gene".

When they talk about GMOs, farmers have based their knowledge on different means; 37% of interviewees indicated the cooperative meetings as a primary means of information, followed by the media, such as television, radio and newspaper; 26% indicated the advertisements of companies. Almeida and Massarani (2011) also defined as important information about GMOs, interaction of farmers with other farmers, with agricultural experts and representatives of agricultural products.

Among the farmers interviewed, answers about the main benefits were highlighted when they choose to plant GM crops; there was ease of cultivation and crop management, higher productivity, greater weed control, reduction of the use of herbicides resulting in an economy of the use of pesticides and increased strength and durability of storage. Similar result to these was




**Graph 1.** Advantage of the cultivation of GM.

found by Mewius (2011). Among reasons for planting GM seeds are increase of productivity, reduced pesticide use against caterpillars and other plagues, obtaining a higher quality product and achieving better financial results.

In a study that focused on farmers in South Africa, Kruger et al. (2012) indicated the two greatest advantages associated with Bt maize to be convenient management (65%) and increased productivity (64%). Although Bt maize seed is more expensive than conventional maize seed, more than 84% of farmers interviewed still considered it economically worthwhile to plant Bt maize.

The insertion of GM seed in the production aroused intense controversy regarding the positive and negative issues related to them.

From an economic point of view, GM became a strong ally of the agricultural sphere, especially for farmers and providers of technology companies.

The benefits associated with its introduction were closely related to the promise of huge profits from transformative biotechnology (Massarani et al., 2013). Among the farmers interviewed, the views are linked to different experiences of each one with applications of GM crops. In this group, the benefits were set up as possible solutions to problems and difficulties in daily activities, in which this technology is seen as a tool to help growers improve the quality of their products. The production cost was highlighted among the main advantage of the cultivation of GM as shown in Graph 1.

The cultivation of GMOs aims to increase food production because in organic agriculture, which is when plants are grown without the aid of science, the process becomes more expensive and limited due to the immense difficulty with pests, as such the agriculture production was necessary to create a method that would improve the "strength" of the plants, so that an overproduction becomes possible (Leite and Monhoz, 2013).

In a research with farmers in Argentina, Massarani et al. (2013) obtained as response the benefits of the inclusion of GMOs in production that GM soy is a dividing line, because prior to its application, a large quantity of pesticides was required to eliminate as many weeds and it was not possible to achieve total elimination. Now with only glyphosate, all of these weeds are being eliminated. Production is simplified compared to before which results in a difference in the cost of farm work.

In a study developed by Céleres Consulting at the request of the Brazilian Association of Seeds and Seedlings, it was revealed that the economic benefits of using biotechnology in Brazilian agriculture reached $18.8 billion in 16 years and 81% of this amount remained with farmers, leaving 19% for the industry. As examples of approximate real values, the return on corn was at R$3 and in soya R$2.1 for every R$ 1 invested by the producer. This cost reduction with little loss in agriculture is about 30 and 51% of the $18.8 billion, respectively (Gomes and Borém, 2013).

Małyska et al. (2014) notes that farmers expressed some concerns about GMOs, such as: long-term effects of consuming GMOs, monopolistic practices of international concerns, potential risks to human health and the environment. Once again, the biggest concern was the lack of trust of public institutions and scientific research; however, in this case the only reliable source of information would be other farmer – producer of GMOs.

When asked about the disadvantages caused by the cultivation of GM crops, the increased resistance of weeds to herbicides was noted in 34% of responses. There is a growing concern about the resistance of weeds to glyphosate. This herbicide was already used before the introduction of GM crops to clear the plant area, and in some locations, the recommended doses of glyphosate were no longer sufficient to kill the weeds. With the introduction of GM crops and increased use of glyphosate, producers fear that this resistance increases, killing weeds infeasible with glyphosate (Almeida and Massarani, 2011).

Another disadvantage that was noted is the monopoly on producing industry technology which appears at 29% of the interviewees responses. The cultivation of GM reinforces the dependency with the producers of inputs, allowing the threat of a growing monopoly of multinational producers of technology on the seed market. Monsanto in Brazil obtained a monopoly on seed sold. In spite the company does not retain the right to patent its genes in Brazil, it has a monopoly over trade agreements. Worldwide, Monsanto is the largest seed company and the fifth largest of pesticides (Leite and Munhoz, 2013; Lima, 2005).

Some farmers in the study of Almeida and Massarani (2011), proved to be concerned with the possibility of greater control of agricultural production by multinationals that supply GM seeds combined with herbicide, resulting in greater reliance on producers in these companies. Although this is a social discussion, some producers demonstrate a concern with the fact that the same company was providing the seed and the herbicide and does not allow the farmers replant the seeds in subsequent years, that is, the producer must purchase certified seed and pay their royalties during each harvest.

The resistance of the consumer market was identified in only 16% of the farmers' responses. Propagation of a new product is not sufficient to just lower production costs or higher yields, it is also necessary that the product be accepted by the consumer market. In the case of GM crops, market acceptance is related not only to the preference of the consumer, but also with existing regulations in the buyer countries (Silveira et al., 2005). Although there are still doubts and disputes about the criteria used to define the quality, consumer interest in the origin of the agricultural product is no longer treated with contempt by farmers. According to the study by Lima (2005), the population is against the cultivation of GM crops, which is of serious concern and do not allow a differentiated market.

Aspects involving consumers are increasingly gaining importance. Consumer behavior becomes crucial when it comes to food safety in relation to both human health as the environment, in production control, quality certification, traceability, labeling, among others.

When asked about the risks of GM insertion in food, all farmers surveyed (20) regarded this technology as safe, noting the lack of research demonstrating the health consequences and citing the reduction of cases of poisoned employees by excessive use of pesticides in conventional culture. In their study, Massarani et al. (2013) found that majority of the sample demonstrated a pragmatic approach: they are profitable and require less work, thus, in general, there is not a dilemma as far as cultivating them. The generally favorable attitude is consistent with other attitudes related to GMOs, like human consumption of genetically modified foods or the use of GM technology for research in medicine, provided they were expanded control procedures and access to clear information.

## Conclusion

The present study aims to verify the perceptions and attitudes towards biotechnology in the insertion of GM crop production.

It was found, from the speech of farmers, that there are advantages and disadvantages of biotechnology in agriculture, and all point out transgenic technology as necessary and essential to increasing productivity, production cost, including expenses for machinery, labor and herbicides. On the other hand, monopoly of seeds and supplies by a company was cited as the main disadvantage of the inclusion of biotechnology in agriculture.

It is important to notice that all farmers pointed GMOs As safe and researches that prove the risks to human health are few and late.

For ecological and social advocates, the biggest problem in risk analysis of GMOs is that their effects cannot be predicted in its entirety. The human health risks include those unexpected, like allergies, toxicity and intolerance. At the environment, the anticipated consequences are lateral or horizontal gene transfer, genetic pollution and harmful effects on non-target organisms (Nodari and Guerra, 2003).

There was a resulting controversy between speeches of social agents and farmers, probably because each one of them defends their interests, as for farmers GMOs bring benefits and their goal is to sell their product.

## Conflict of Interest

The author(s) have not declared any conflict of interest.

## ACKNOWLEDGEMENT

The authors acknowledge CAPES for financial support.

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academicJournals

Vol. 10(7), pp. 637-644, 12 February, 2015
DOI: 10.5897/AJAR2013. 8229
Article Number: 44C682050353
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

# Technical efficiency of wheat and paddy farms in irrigated saline environment in Haryana State, India: An assessment

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Received 13 November, 2013; Accepted 22 January, 2015

**The farmers in certain areas of Western Yamuna Canal Command in Haryana State, India, face problems of water logging and salinity in the absence of adequate drainage; and sustainability of their farm operations is highly vulnerable due to fluctuations in rainfall. A study was undertaken to analyse the farm specific production processes and productivity in paddy and wheat farms and find out effect of socio-economic factors under the control of farmers to achieve the maximum output in adverse circumstances. A stochastic frontier production function incorporating a model for technical inefficiency was estimated. The results indicated that farmers combat the adverse situation by incurring higher expenses, in case of paddy, on transplanting operations, seed material and capital input and, in case of wheat cultivation, on fertilizer, irrigation and capital input. However, production function coefficients associated with number of ploughing and plant protection cost, in case of wheat, and seed and fertilizer cost, in case of paddy, were found to be negative indicating their overuse in cultivation. The inefficiency model further indicated that technical inefficiency tend to decline with increase in family size and access to both canal and tube-well water for irrigation in both wheat and paddy cultivation. The mean technical efficiency was found to be 0.84 in case of wheat and 0.93 in paddy. It indicated that there was a scope to increase productivity in wheat with the existing level of technology by improving the technical efficiency of the inputs used while productivity in paddy do not have much scope to increase through improvement of technical efficiency of inputs alone.**

**Key words:** Paddy, saline environment, stochastic frontier, technical efficiency, wheat.

## INTRODUCTION

Crop production is a very complex process involving both socio-economic conditions of the farmers and bio-physical environment where they operate. Many of the factors, like land topography, rainfall events, canal running operations and pest and diseases incidence, etc. are not under the control of the farmers and they are always found to combat these situations based on their experiences and collective wisdom at village level. In

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these circumstances, estimation of productivity only in terms of ratio of input quantities, like land, labour, fertilizers, irrigation, seeds etc. to the output and finding sources of inefficiency are very difficult. It is more difficult at village level where farmers follow almost similar practices in terms of farm operations and input quantities. However, the same quantities of input factors used by different farmers have different costs due to quality differences which led to changes in the levels of output. Thus, the quality of inputs in terms of costs is also important along with the conventional indicators of input quantities in explaining observed cross sectional differences in productivity and shortfall from potential yield. Available literature suggests that farmers in the developing countries fail to exploit the full potential of a technology or practice and make allocative errors (Kalirajan and Shand, 1989; Bravo-Ureta and Evenson, 1994; Shanmugam and Palanisami, 1994; Thomas and Sundaresan, 2000). Thus, increasing the efficiency in production assumes greater significance in attaining potential output at the farm level. Embarking on new technologies is meaningless unless the existing technology is used to its full potential (Kalirajan et al., 1996). Further, the analysis of variations between the potential and actual yields on the farm, given the technology and resource endowment of farmers, provide better understanding of the yield gap. Thus, technical efficiency is an indicator of the productivity of the firm and the variation in technical efficiency can reflect the productivity difference across firms.

Investigating the potential sources of TE in rural economies is important from a practical as well as a policy point of view. Bravo-Ureta and Pinheiro (1993) and Coelli and Battese (1996) identified a number of variables which influence TE in agriculture. Gorton and Davidova (2004) opined that there are two types of variables, viz., human capital and structural factors. Human capital includes variables such as formal and informal education, literacy, agricultural experience, training and farmer's age. The structural factors cover family income, family size, access to credit, land tenure status, gender composition of the labour force, off-farm employment and environmental variables. The impact of agricultural extension and training, education and agricultural experience on efficiency has been evaluated in several efficiency studies. For example, Stefanou and Saxena (1988) found that education and experience have significant positive effects on the level of efficiency, and in some cases these two variables can be treated as substitutes in explaining farm performance. Furthermore, O'Neill and Matthews (2000) studied the role of agricultural extension on farm efficiency in Ireland and found a positive relationship between these two variables. Kalirajan and Shand (1985) indicated that education and training have a strong and positive relationship with TE, especially among low-income farmers. Hence, the identification of those factors, which influence the technical efficiency of farming, is undoubtedly very significant for policy makers.

The Western Yamuna Canal (WYC) Command has a geographical area of about 13,543 km$^2$ and is located between 28° 20' to 30° 29' N latitude and 75° 48' to 77° 35' E longitude. The Command is spread mostly over the Haryana State and certain areas of Command have developed the twin problems of secondary soil salinization and waterlogging due to multiplicity of factors like, unlined canal system, excessive irrigation, shallow ground water depths and lack of adequate drainage in the Command area. The phenomena of water logging and salinization have led to substitution of paddy crop in k*harif* season (main rainy season, July to September) but the yield level always remain low with lower productivity of resources and high cost of production. Similarly, wheat is grown during the *rabi* season (mostly dry winter season, November to April) which is sown immediately after paddy.

In this background, the present study aimed to i) estimate technical efficiency (inefficiency) of individual farms related to paddy and wheat cultivation, which are the two important crops cultivated in two major crop seasons in a year in this region and ii) investigate influence of farmer-specific attributes on inefficiency in irrigated saline area of Haryana State.

## MATERIALS AND METHODS

### Study domain and data

The study area comprises the Western Yamuna Canal Command area in Haryana State of India. The Western Yamuna Canal takes off from River Yamuna and the main canal traverses eastern, central and southern parts of the State. A district, namely; Sonepat, located in this area was selected purposely as it has shallow groundwater depth and faces the problems of water-logging and secondary soil salinization. Thereafter, two villages, viz., Lath and Katwal were chosen randomly and 45 farmers cultivating paddy and the same number cultivating wheat were selected for detailed study. Information were collected through personal interviews of the respondents using structured and pre-tested interview schedule pertaining to the farm-specific socio-economic variables as well as crop cultivation practices during *kharif* (2010) as well as *rabi* (2010-11) season.

### Theoretical framework

Since 1957, when Farrell (1957) published his seminal article on efficiency measurements, frontier techniques have been widely used in determining the farm-level efficiency in agriculture in developing countries. Production frontiers can be mapped (statistically or non-statistically, parametrically or non-parametrically) to find the locus of maximum output levels associated with given input levels, and estimate of farm specific TE as a deviation from the fitted frontier can be obtained. The stochastic frontier production function approach involving econometric estimation of parametric function (Aigner et al., 1977; Meeusen and Broeck, 1977) and non-parametric programming, known as data envelopment analysis (DEA) (Charnes et al., 1978), are the most popular among different major approaches followed to measure and estimate efficiency. The stochastic frontier approach is considered more appropriate for assessing TE in a developing country agriculture, where data are often heavily influenced by measurement errors and other stochastic factors such as weather conditions, diseases, etc (Fare and Lovell, 1985; Kirkley et al., 1998; Dey et al., 2005). To analyze determinants of technical efficiency or inefficiency traditionally, a stochastic production frontier is estimated first for measuring farm-level TE and then a second stage analysis (Lingard et al., 1983; Bravo-Ureta and Pinheiro, 1993) is performed where separate two-limit Tobit equations for TE are estimated as a function of various attributes of the farms/farmers in the sample. However, there is also argument that the socio-economic variables should be incorporated directly into the estimation of production frontier model because such variables may have a direct influence on the production efficiency. Keeping in view these advantages, stochastic production frontier approach have been employed in this study to obtain the farm-specific technical efficiency estimates.

**Stochastic production frontier model**

A stochastic production frontier model was used to measure the farm level technical efficiency (Aigner et al., 1977; Meeusen and van den Brock, 1977). The frontier production is the maximum feasible output which could be produced (of each firm) with a given level of input use and technology and measures efficiency of farms relative to their own frontier.

A stochastic production frontier with Cobb-Douglas functional form for the individual farms and crops is stated as follows:

$$\ln Y_i = \alpha + \sum_{j=1}^{5} \beta_j \ln X_{ij} + v_i - u_i$$

where, $Y_i$ represents the actual output for the $i^{th}$ sample farm unit; $X_i$ is a vector of inputs and β is a vector of parameters to be estimated by the model which describe the transformation process, and $v_i$ is random error term with normal distribution having mean zero and constant variance; $u_i$ is the one sided error term reflecting technical inefficiency.

The variance parameters $\sigma_u^2$ and $\sigma_v^2$ were expressed in terms of parameterization (Battese and Corra, 1977): $\sigma_u^2 + \sigma_v^2 = \sigma^2$; $\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$ and $\lambda = \sigma_u/\sigma_v$ (>0). The parameter γ can take values from 0 to 1. A zero value of γ would indicate that the deviations from the frontier are entirely due to the noise and, in this case, the ordinary least squares (OLS) estimates of the model are equivalent to the MLE results. A value of one would indicate that all deviations are purely due to differences in TE across farms. The λ term with value above one would indicate that output variations due to inefficiency are higher than that due to random factors.

The dependent variable was the output or the yield obtained. The independent variables ($X_j$'s) included in the model were number of ploughing, land preparation cost (that is, cost of ploughing), seed quantity (kg), cost of seed, transplanting cost (sum of cost of water supplied in puddled land and transplanting labour cost), quantity of fertilizers (nitrogen equivalent quantity of various types of chemical fertilizers and manures), inter-culture (man-days), irrigation (numbers), irrigation cost and the capital cost. Farmers use many sources of water, that is, canal water, electric tube-well, diesel pump-sets and buying water from the neighbor farmers. Cost of irrigation and quantity of water applied in each case differ vastly due to different costs and availability associated with each source. The capital cost represented the interest on the fixed capital like tractor, other machinery and water conveyance measures employed on the farms by the farmers. Mixed use of own resources and custom hiring is widely practiced in all types of farm operations which results in large variations in the cost. The flexibility in the use of resources helped in timely and better management of problem soils to the satisfaction of the farmers. In fact, the cost variables are the proxy for better management practices.

**Inefficiency and its determinants**

A farm unit with its actual output below the level given by the production frontier is termed inefficient and, therefore, the ratio of actual output of the farm unit to the potential output is the measure of technical efficiency of the individual farm unit. An inefficiency model was fitted and estimated simultaneously with the estimation of parameters of stochastic production frontier. The model for estimating technical inefficiency (TI) was specified as:

$$TI = u_i = \delta_0 + \sum_{j=1}^{7} \delta_j Z_{ij}$$

where, $Z_{ij}$ is the vector of farm and farmer-specific characteristics, which included age, education of the head of the household, family size, total operational holding size (including leased in land) and access to irrigation sources. δ's are unknown parameters to be estimated for each $Z_{ij}$.

The above model for the inefficiency effects can only be estimated if the inefficiency effects are stochastic and have a particular distributional specification. This is ascertained by testing the following hypotheses: $H_0$: γ = 0, that is, inefficiency is absent and is not stochastic. If the null hypothesis ($H_0$) is rejected, it means that there are inefficiencies and the function could be estimated using maximum likelihood estimation method. If $H_0$ is not rejected, ordinary least squares method gives the best estimation of the production function.

The tests of these hypotheses for the parameters of the frontier are conducted using the generalized likelihood ratio statistics. The test statistic g is defined as:

$$g = -2[\ln(H_0) - \ln(H_1)]$$

where, ln ($H_0$) is the log-likelihood function of a restricted frontier model as specified by null hypothesis $H_0$; and ln($H_1$) is the log-likelihood function of unrestricted model (alternate hypothesis). The test statistic (g) has a $\chi^2$ or a mixed-$\chi^2$ distribution with degrees of freedom equal to the difference between the parameters involved in $H_0$ and $H_1$.

The variables on farmers' characteristics included in technical inefficiency model were age (years), education (years of schooling/higher education), family size (number of family members), operational holding size (net area cultivated) and access to irrigation sources (dummy variable, which assumes a value 1, if the farmer has access to both canal water and tubewell and 0 if it has access to any one of these sources).

**Estimation of the model**

Given the assumptions of the above stochastic frontier models, the inference about parameters of the model can be based on maximum likelihood estimation (MLE) method (Aigner et al. (1977). The likelihood function for this model is:

$$\ln (L) = -N/2 \ln(\pi/2) - N/2 \ln(\sigma^2) + \Sigma [\ln \Phi (-\varepsilon i \lambda / \sigma) - 1/2 (\varepsilon_i / \sigma)2]$$

where, $\lambda = \sigma_u/\sigma_v$, $\sigma^2 = \sigma_v^2 + \sigma_u^2$, and Φ is the cumulative standard normal distribution function and $\varepsilon i = (v_i - u_i)$; $\sigma_u$ and $\sigma_v$ are standard deviations of the residuals u and v, respectively. The maximum likelihood estimation (MLE) method can provide the estimates of

**Table 1.** Summary statistics for variables in the stochastic frontier model for paddy and wheat farms.

| Variables | Parameter | Paddy | | Wheat | |
|---|---|---|---|---|---|
| | | Mean | Std. deviation (s.d.) | Mean | Std. deviation (s.d.) |
| Output (q/ha) | | 37.4 | 4.8 | 39.0 | 8.4 |
| Number of ploughing | $\beta_1$ | 6.0 | 1.5 | 6.5 | 1.5 |
| Land preparation cost (INR/ha) | $\beta_2$ | 3829 | 1289 | 3600 | 478 |
| Transplanting cost (INR /ha) | $\beta_3$ | 4753 | 428 | - | - |
| Seed quantity (kg/ha) | $\beta_4$ | 12.45 | 0.50 | 106.5 | 11.6 |
| Seed cost (INR /ha) | $\beta_5$ | 654 | 68.9 | 2150 | 207 |
| Fertilizer (nitrogen equivalent) (kg/ha) | $\beta_6$ | 132 | 42.3 | 139.8 | 51.8 |
| Inter-culture/plant protection (man days/ha) | $\beta_7$ | 20.3 | 9.6 | 7.8 | 4.3 |
| Number of irrigation | $\beta_8$ | 17.5 | 5.9 | 3.8 | 0.6 |
| Irrigation cost (INR /ha) | $\beta_9$ | 6005 | 2015 | 3252 | 1097 |
| Capital cost (INR /ha) | $\beta_{10}$ | 11317 | 4585 | 9400 | 3517 |
| **Inefficiency variables** | | | | | |
| Age of the farmer (years) | $\delta_1$ | 47.4 | 15.0 | 47.3 | 15.4 |
| Education (years of schooling) | $\delta_2$ | 8.0 | 3.6 | 8.0 | 4.0 |
| Family size (number of adult members in the family) | $\delta_3$ | 7.4 | 3.9 | 8.2 | 4.2 |
| Operational holding size (ha) | $\delta_4$ | 3.7 | 2.8 | 4.5 | 3.5 |
| Access to irrigation sources* | $\delta_5$ | | | | |

INR: Indian National Rupees, *Dummy variable, value = "1", if the farmer has access to both canal water and tube-well and "0" if it has access to any one of these sources.

the stochastic frontier production equation. The individual specific TE is given by the conditional mean of exp ($-u_i$), given the distribution of the composite error term, $\varepsilon_i$. Hence, the technical efficiency of the farmer, given the specification of the model, is defined by $TE_i = \exp(-u_i)$. The technical efficiency of farmer is between zero and one and is inversely related to the inefficiency model. The parameters of the stochastic frontier production function model are estimated by the method of maximum likelihood using the Computer Programme FRONTIER Version 4.1 (Coelli, 1996).

## RESULTS AND DISCUSSION

### Description of variables used

The descriptions of variables considered in the stochastic frontier model (Table 1) for paddy and wheat farms are subsequently provided in the paper.

#### *Paddy*

The mean output level of paddy was 37.4 q/ha in the study area with a standard deviation (s.d.) of 4.8 q/ha indicating not very large variations in output among the farms. On an average, farmers carried out 6 dry ploughing before puddling of the fields with s.d. of 1.5. However, the land preparation cost was INR3829 which varied highly across the farms as indicated by the high s.d. of INR1289. Transplanting cost, which included labour and water charges, was INR4753 with standard deviation of INR428. On an average of 12.45 kg per ha (s.d. of 0.5 kg per ha), seed valued at INR654 (s.d. of INR68.9) and 132 kg nitrogen equivalent (s.d. of 42.3 kg) was used. Labour engaged for inter-culture operations were 20.3 man days (s.d. of 9.6 man days). Total number of irrigations provided were 17.5 (s.d. of 6) and the cost of irrigation was INR6005 per ha. The capital cost worked out to be INR11317 with s.d. of INR4585.

Under inefficiency variables, the average age of the farmers was found to be 47.4 years s.d. of 15.0 years) with average of 8 years (s.d. of 3.6 years) of schooling. The average family size was 7.4 (s.d. of 3.9) and average operational holding was 3.7 ha (s.d. of 2.8 ha). Nearly 72% farmers were found having access to both canal and tube-well water for irrigating their paddy crop.

#### *Wheat*

The mean output level of wheat was 39 q/ha in the study area with a standard deviation of 8.4 q/ha indicating large variations in output among the wheat farms. On an average, farmers carried out 6.5 ploughing with s.d. of 1.5 implying there was not much variation among the farms. However, the land preparation cost was INR3600 with s.d. of INR478. On an average, seed cost was INR2150 (s.d. of INR207) and 140 kg nitrogen equivalent fertilizers (s.d. of 51.8 kg) were used. Labour engaged for

**Table 2.** Maximum likelihood estimates of parameters of the stochastic frontier production function and inefficiency model (paddy).

| Variables | Parameters | Coefficient | Standard error | t-ratio |
|---|---|---|---|---|
| Constant | $\beta_0$ | 1.374* | 0.381 | 3.602 |
| Number of ploughing | $\beta_1$ | -0.032 | 0.033 | -0.975 |
| Land preparation cost | $\beta_2$ | -0.005 | 0.014 | -0.392 |
| Transplanting cost | $\beta_3$ | 0.622* | 0.114 | 5.426 |
| Seed quantity | $\beta_4$ | -0.436** | 0.203 | -2.149 |
| Seed cost | $\beta_5$ | 0.157** | 0.063 | 2.472 |
| Fertilizer (nitrogen equivalent) | $\beta_6$ | 0.010 | 0.024 | 0.425 |
| Inter-culture/plant protection cost | $\beta_7$ | 0.008 | 0.013 | 0.642 |
| Number of irrigation | $\beta_8$ | 0.017 | 0.029 | 0.584 |
| Irrigation cost | $\beta_9$ | -0.060** | 0.025 | -2.413 |
| Capital cost | $\beta_{10}$ | 0.154* | 0.014 | 10.447 |
| | | | | |
| **Inefficiency model** | | | | |
| Age | $\delta_1$ | 0.001*** | 0.001 | 1.369 |
| Education | $\delta_2$ | 0.006* | 0.002 | 2.918 |
| Family size | $\delta_3$ | -0.006** | 0.003 | -1.774 |
| Operational holding size | $\delta_4$ | 0.002 | 0.002 | 1.216 |
| Access to irrigation sources | $\delta_5$ | -0.037*** | 0.026 | -1.407 |
| | | | | |
| ***Variance parameters*** | | | | |
| $\sigma^2$ | | 0.002 | 0.001 | 4.225 |
| $\gamma$ | | 0.999 | 0.001 | 1411.90 |

*. **, ***: Significant at 1, 5 and 10% level, respectively; Log likelihood function = 95.764; Mean efficiency = 0.93.

inter-culture/plant protection was 7.8 man days (s.d. 4.3 man days). Total average number of irrigations provided were 3.8 (s.d. of 1.3) and the capital cost worked out to be INR11317 (s.d. of INR4585).

Under inefficiency variables, the average age of the farmers was found to be 47.3 years (s.d. of 15.4 years) with average of 8 years (s.d. of 4.0 years) of schooling. The average family size was 8.2 (s.d.of 4.2) and average operational holding was 4.5 ha (s.d. of 3.5 ha). Nearly 52% farmers were found having access to both canal and tube-well water for irrigating their wheat crop.

## Parameter estimates of stochastic frontier production function and determinants of technical inefficiency

### *Paddy*

Table 2 depicts the maximum likelihood estimates of stochastic production function frontier in case of paddy crop. The variables having significant positive coefficients were transplanting cost, seed cost and capital cost. Seed cost was considered separately from seed rate as some enterprising farmers tend to purchase good quality seed at higher costs from reliable quality stores. The use of these inputs indicates potential of increasing the level of production through raising their usage. However, the effect of seed (kg) and irrigation cost was found negative which indicates their over-use in production of paddy.

The estimated significant coefficients in the explanatory variables in the model for technical inefficiency indicate that inefficiency tend to decline as the family size and access to irrigation sources increases. The effect of age and education was found to be positive to the inefficiency, that is, inefficiency tended to increase with the higher age and education level. The younger farmers are more likely to tap the scientific knowledge in paddy cultivation. The results supports the findings of Singh (2008) who also reported positive relationship with the age and technical inefficiency of the wheat farmers in Haryana and argued that as the age increases the farmers tends to be more risk averter and hesitate to adopt new technologies making the production process inefficient. However, the results contradict the findings of Coelli and Battese (1996) who reported from a study of two villages in India that older farmers are relatively more efficient. However, the positive association of education and technical inefficiency is not in line with general perception. This phenomenon may be linked to the more employment opportunities available to educated people in the nearby metropolitan city of New Delhi and consequent neglect of agriculture. However, this needs to

**Table 3.** Maximum likelihood estimates of parameters of the stochastic frontier production function and inefficiency model (wheat).

| Variables | Parameter | Coefficient | Standard error | t-ratio |
|---|---|---|---|---|
| Constant | $\beta_0$ | 9.99* | 0.973 | 10.273 |
| Number of ploughing | $\beta_1$ | -0.083*** | 0.056 | -1.481 |
| Land preparation cost | $\beta_2$ | 0.215 | 0.395 | 0.544 |
| Seed cost | $\beta_3$ | -0.033 | 0.142 | -0.234 |
| Fertilizer (nitrogen equivalent) | $\beta_4$ | 0.013** | 0.006 | 2.236 |
| Plant protection cost | $\beta_5$ | -2.075* | 0.594 | -3.489 |
| Irrigation cost | $\beta_6$ | 2.259* | 0.577 | 3.912 |
| Capital cost | $\beta_7$ | 0.263* | 0.037 | 6.960 |
| ***Inefficiency model*** | | | | |
| Age | $\delta_1$ | 0.001 | 0.006 | 0.241 |
| Education | $\delta_2$ | 0.043** | 0.025 | 1.713 |
| Family size | $\delta_3$ | -0.061*** | 0.043 | -1.407 |
| Operational holding size | $\delta_4$ | 0.005 | 0.014 | 0.366 |
| Access to irrigation sources | $\delta_5$ | -0.324 *** | 0.226 | -1.430 |
| ***Variance parameters*** | | | | |
| $\sigma^2$ | | 0.099 | 0.036 | 2.740 |
| $\gamma$ | | 0.999 | 0.000 | 3505.5 |

*. **, ***: Significant at 1, 5 and 10% level, respectively. Log likelihood function = 26.504. Mean efficiency = 0.840.

be looked into and tested separately for more evidences. The mean technical efficiency was 0.93 in paddy cultivation which indicates that the selected farms remained near the frontier and there is less scope to further increase the productivity at the existing technology.

### *Wheat*

Table 3 depicts the maximum likelihood estimates of stochastic production function frontier in case of wheat crop. The variables having significant positive coefficients were fertilizer (nitrogen equivalent), irrigation cost and capital cost. The use of these inputs indicates potential of increasing the level of production through raising their usage. However, irrigation and capital costs included market based components like use of diesel pump sets and purchase or hiring of irrigation water from neighbour farmers and investments in water conveyance methods and other machinery. These activities help raise productivity by having more controls over farm operations and timely applications. The effect of number of ploughing and plant protection cost (including inter-culture) was found negative which indicates their over use in production of wheat. These point towards the need for more intensive knowledge dissemination on input use in the current technologically advanced cultural practices scenario.

The estimated coefficients in the explanatory variables in the model for technical inefficiency indicate the association between various farm specific socio-economic characteristics and inefficiency effects. It was observed that inefficiency tend to decline as the family size and access to irrigation sources increases. The effect of education was found to be positive to the inefficiency which indicated inefficiency tended to increase with the higher level of education. The findings need to be investigated further as it contradicts with the hypothesis of Schultz (1964) that education increases the ability to perceive, interpret and respond to new events and enhances farmers' managerial skills, including efficient use of agricultural inputs. However, it is very plausible that the farmers with education may be attracted/associated with other employment opportunities and consequently offers less attention to the agricultural operations.

The mean technical efficiency was 0.84 in wheat cultivation which implies that the farmers can increase their output by 16% without additional resources through more efficient uses of existing inputs and technology. Frequency of occurrences of farmers indicates that 33% farms have technical efficiency below 0.80 and 22% of sample farms were operating close to the frontier with technical efficiency estimate of more than 0.95.

### Frequency distribution of technical efficiencies

Table 4 presents the distribution of estimated technical

**Table 4.** Frequency distribution of technical efficiencies.

| TE ranges | Paddy | | Wheat | |
|---|---|---|---|---|
| | No. of farms | % | No. of farms | % |
| <0.70 | 0 | 0 | 6 | 13.3 |
| 0.71-0.80 | 0 | 0 | 9 | 20.0 |
| 0.81-0.85 | 0 | 0 | 3 | 6.8 |
| 0.86-0.90 | 6 | 13.3 | 8 | 17.8 |
| 0.91-0.95 | 21 | 46.7 | 9 | 20.0 |
| >0.95 | 18 | 40.0 | 10 | 22.3 |
| Total | 45 | 100 | 45 | 100 |

efficiencies among selected wheat and paddy farms. The technical efficiency values were grouped into six categories, that is, below 0.70, 0.70 to 0.80, 0.81 to 0.85 and 0.86 to 0.90, 0.91 to 0.95 and above 0.95. The result shows that, in case of wheat, the farms were fairly distributed among the selected categories. Six farms (13.3%) were having technical efficiency below 0.70. The number of farms in the ranges 0.71 to 0.80, 0.81 to 0.85, 0.91 to 0.95 were 9 (20.0%), 3 (6.8%) and 8 (17.8%), respectively. The number of farms in technical efficiency ranges from 0.91 to 0.95 and 0.96 to 1.0 were 9 (20%) and 10 (22.3%), respectively.

In paddy cultivation, no farm was having technical efficiency below 0.86. The number of farms in the ranges 0.86 to 0.90 and 0.91 to 0.95 were 6 (13.3%) and 21 (46.7%), respectively. The numbers of farms in technical efficiency range above 0.96 were 18 (40%). Therefore, paddy farms were more skewed to higher efficiency ranges due to water logging and consequent more uniform cultivation practices.

## Conclusion

The estimated mean technical efficiency of 0.93 in paddy production imply that farmers were doing their best in current situation of water logging and salinity build up in the Command area and have limited maneuverability in the prevailing conditions. The unexploited potential in paddy cultivation was only 7%. However, in case of wheat, it was revealed that realized mean technical efficiency was 83%, signifying an unused potential for productivity enhancement.

The study indicated that transplanting cost, seed cost and capital cost in paddy cultivation positively influenced the output level indicating their under use and scope to further increase the output by enhancing their quality. Similarly, in wheat cultivation, fertilizer (nitrogen equivalent), irrigation cost and capital cost positively and significantly influenced the level of output with an indication of their further enhancement. So, the results revealed a significant association between the output levels, and the cost parameters which are the proxies for the quality of inputs. Hence, the farmers need to have state support in terms of availability of quality inputs and appropriate knowledge for enhancing their efficiency level to realize higher yields. The existing negative coefficients of seed rate and irrigation cost, in case of paddy and number of ploughings and plant protection cost (including inter-culture), in case of wheat, indicate their over-use in the cultivation process.

## Conflict of Interest

The authors have not declared any conflict of interest.

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academicJournals

Vol. 10(7), pp. 645-652, 12 February, 2015
DOI: 10.5897/AJAR2014. 9330
Article Number: A0816B950356
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Factors influencing agricultural credit demand in Northern Ghana

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Received 13 November, 2014; Accepted 9 January, 2015

**The greatest challenge to food security is low productivity emanating from slow growth in the agricultural sector and one of the reasons for this is little or no access to financial resources by producers. Credit is one of the empowerment tools that have the potential to boost the productivity, increase food security and change the life of farmers from a situation of abject poverty to a more dignified life in the long run. Using a household survey data from United State Agency for International Development's feed the future initiative; this study employed the logistic regression model to investigate the factors influencing households' demand for agricultural credit placing much emphasis on membership to organization. A total sample size of 2,330 farm households selected from Northern Ghana was used. The results of the logistic regression model revealed significant and positive variables such as age, education, group membership and source of credit. We therefore call on stakeholders to encourage formation of cooperative groups to enable farmers pull resources together or streamline loan application procedures, intensify education of farmers on loan procedures and promote flexibility in types of collateral demanded by financial institutions in order to enhance access.**

**Key words:** Credit access, farmers, food security, Ghana, logit model.

## INTRODUCTION

Declarations from the various international conferences, since 1992, identified food security as one of the underlying and cross-cutting issues that require concerted action in order to ensure the sustainable reduction of absolute poverty and thus achieve the Millennium Development Goals (MDGs) in Africa (MoFA, 2007). Undoubtedly, the food and agriculture has been recognised as the simple and most influential sector with greater impact on poverty reduction and achieving the Millennium Development Goals (MDGs) in Africa. It is for these reasons that in 2003, the African Heads of State and Government adopted an Africa-owned and Africa-led initiative, namely the Comprehensive Africa Agricultural Development Program (CAADP), to assist African countries to revitalize agricultural growth as a strategy to combat poverty and hunger, and in the end accomplish

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the MDGs (ECOWAP, 2009).

Unfortunately, the agriculture sector in Ghana is plagued with challenges such as credit access which is one of the most prevalent tools for spinning agricultural development (MoFA, 2007). For instance, the share of agricultural credit in total bank lending initially fell from the mandatory 25% to about 10% before recovering to 12% in 1998 following the liberalisation of the financial sector in the early 1990s. According to the Bank of Ghana Statistical Bulletin, share of agriculture and forestry in the outstanding credit balance of money deposit banks (MDBs) in December 2009 and 2010 were 4.5 and 5.5% respectively (MoFA, 2011) and hence an indication of a low and deteriorating level of credit supply to the agricultural sector. This challenge is confirmed in the study by Nankani (2008) in which agriculture is reported to be largely excluded from the formal banking system, with only 9% of credit going to the sector. Ghana therefore faces the challenge of making substantial progress in food security resulting from lack of credit to boost production. Progress in achieving MDGs is therefore reported to be slow and projections are that the targets may not be realized by 2015 (Amponsah, 2012). The low and deteriorating level of credit supply by financial institutions stems from the fact that physical assets that the lender can seize if the individual borrower defaults are usually hard to come by. Agricultural credit suppliers are therefore not willing to extend credit which is not fully secured.

A consensus reached by the financial institutions and famers is the group approach in which institutions focus on groups rather than on individual farmers. In this way, credit is extended to farmers who form some sort of associations, credit unions and cooperatives. Such organizations play the role in the securing, sharing and repayment of such funds and at the same time lower interest charges and make loans better secured as it is believed. As observed by Mohammed et al. (2013), when a farmer is not a member of any organization, his main source of collateral is from his own physical capital assets which are often difficult to produce by smallholder farmers as compared to a farmer who is a member of a social network.

Several studies have analyzed the use of credit among resource-poor rural dwellers and concluded that credit was allocated mainly for agricultural and non-agricultural productive activities as well as for consumption purposes though at varying allocative proportions see for instance Zeller et al. (1996) and Schreider (1995). Olatunbosun (2012) also concluded that constraint to agriculture financing is due to lack of access to credit. Our study is unique in a sense that, it looks at the factors that influence accessibility of agricultural credit by famers with much emphasis on the effect of group membership on credit access. Consequently, this study would contribute to the literature on the factors influencing farmers' access to credit.

## LITERATURE REVIEW

Agricultural credit has been defined as the present and pro tem transfers of purchasing power from a person who owns it to a person who wants it, allowing the latter the opportunity to command another person's capital for agricultural purposes but with confidence in his willingness and ability to repay at a specified future date (Kuwornu et al., 2013). In other words, a transaction between two parties in which one, acting as creditor or lender, supplies the other, the debtor or borrower, with money, goods, services, or securities in return for the promise of future payment is known as credit (Kosgey, 2013). A household is therefore said to have access to a type of credit if at least one of its members has a strictly positive credit limit for that type of credit. Credit can be in cash or in kind. However, this study dwelled on both cash and formal source of credit.

Several studies in developing countries on credit access by farmers have considered a broad range of factors and concluded that factors that determine farmer credit access vary from one geographical area to another. For instance, using a stepwise linear regression analysis to determine the relationship between socio-economic characteristics of farmers and their rate of accessibility to agricultural credit, Etonihu (2013) concluded that education, distance to source of credit and types of credit source were significant factors affecting farmers' accessibility to agricultural credit in Nigeria.

Schmidt and Kropp (1987) revealed that the type of financial institution and its policy will often determine access. They further revealed that where credit duration, terms of payment, required security and the provisions of supplementary services do not fit the needs of the target group, potential borrowers will not apply for credit even where it exists and when they do, they will be denied access. Bigsten et al. (2003) and Fleisig (1995) stated that in developing countries asymmetric information, high risks, lack of collateral, lender-borrower distance, small and frequent credit transactions of rural households make real costs of borrowing vary among different sources of credit.

In addition, Okurut et al. (2005) employed a logit model to investigate factors that influence both credit demand and supply in Uganda by using observed household and individual characteristics. The household characteristics that influenced demand included age, education, and household expenditure per adult equivalent. They further argued that, household composition, migration status and credit demand is higher for males than females and for households with a higher dependency ratio. Demand for credit is less in households with sick members and more land assets per adult equivalent, while gender does not play a significant role in the demand for credit.

Atieno (2001) did an empirical assessment on the formal and informal institutions' lending policies and access to credit by small-scale enterprises in Kenya. The findings showed that income level, distance to credit sources, past credit participation and assets owned were significant variables that explained participation in formal credit markets. Indeed, the study dealt with both formal and non formal lending institutions in relation to small scale enterprises in accessing general credit. Kimuyu and Omiti (2000) and Lore (2007) demonstrated that age is associated with access to credit and that older entrepreneurs were more likely to seek out for credit. Further, they asserted that age is an indicator of useful experience in self selecting in the credit market.

In an empirical study of repayment performance in group–based credit programmes in Bangladesh, Zeller et al. (1996) found that social capital results in very high repayment rates compared to traditional physical-collateral-based financial institutions. Their study further revealed that high repayments were registered in cases where farmers arranged for a flexible repayment schedule with financial institutions as opposed to fixed one. A recent and similar study by Mohammed et al. (2013) on social capital and access to credit by farmer based organizations in the Karaga District of northern Ghana deduced that the positive effect of the FBOs' social capital on access to credit calls for conscious effort to strengthen FBOs along the social capital dimensions.

Estimating the determinants of credit demand by farmers and supply by Rural Banks in the Upper East Region of Ghana using Logit and Tobit respectively, Akudugu et al. (2012) pointed out age of farmers, gender and political affiliations among others as the main determinants of credit demand by farmers while type of crop grown, farm size and the amount of savings are the main determinants of credit supply by the Rural Banks.

Similarly, results of Dzadze (2012) on factors determining access to formal credit in the Abura-Asebu Kwamankese District of Central Region of Ghana using the logistic regression model revealed extension contact, education level and saving habit as the significant and positive factors influencing farmers' access to formal credit. The study called on Ministry of Food and Agriculture (MoFA) to enhance farmer-extension agent contact by providing logistics on time for Agricultural Extension Agents (AEAs) to make periodic visits to farmers in their communities.

Chauke et al. (2013) also replicated the study by Dzadze et al. (2012) in the Capricorn District of South Africa varying the factors hypothesized to have effect on credit access and concluded that the need for credit, attitude towards risk, distance between lender and borrower, perception on loan repayment, perception on lending procedures and total value of assets are the main determinants of farmers' access to agricultural credit. The study therefore called for government policies that intend to improve the accessibility to agricultural credit by farmers.

Examining the determinants of credit access by rural farmers in Oyo state in Nigeria (Ololade and Olagunju, 2013), the Binomial Logit model revealed that significant relationship existed between sex, marital status, lack of guarantor, high interest rate and access to credit. The need for financial institutions to help look into the conditions for obtaining credit by farmers was obvious.

In the study of agricultural credit access by Grain Growers in Uasin-Gishu County, Kenya, Kosgey (2013) also found that agricultural credit access is influenced by farmers' age, education level, family size, household size, repayment period and loan amount were highly important in influencing access to agricultural credit.

Using the Probit and Tobit regression with robust standard errors to control for heteroskedasticity, Kuwornu et al. (2012) analysed allocation and constraints of agricultural credit of selected maize farmers in Ghana. The empirical results of the Probit model revealed that gender, household size of farmers, annual income of farmers and farm size have significant influence on credit constraint conditions of the farmers while that of the Tobit regression model revealed age, bank visits before credit acquisition and the amount (size) of credit received as the significant factors influencing the rate of agricultural credit allocation to the farm sector.

Selecting farmers randomly from twenty villages in Surulere Local Government area of Oyo State in Nigeria, Adebayo and Adeola (2008) investigated the sources and uses of agricultural credit by small scale farmers. Their study revealed that majority of the farmers relied on co-operative societies for agricultural credit, thus necessitating a call on government agencies to mobilize the rural farmers to form themselves into formidable groups in order to derive maximum benefit of collective investment of group savings. From the foregoing discussions, it is clear that different factors determine the access to agricultural credit by famers in different parts of the world or even in different locations within a given country due to differences in agro-ecological as well as socio-economic setting under which production takes place. Conclusions emanating from most of the studies have tended to be case-specific and in some cases contradictory thereby justifying the proposed study. Though, a number of studies have been conducted across the world on credit, there is dearth of literature on the effect of group membership on credit access, especially among small scale farmers in Ghana. This is a serious gap that must be bridged if the problem of low credit among farmers is to be addressed and agricultural productivity improved.

## MATERIALS AND METHODS

The study employed the logistic regression model for analyzing households' access to agricultural credit considering the dichotomous nature of the dependent variable. In other words households' access to agricultural credit was expressed in two categories: "have access to credit" and "do not have access credit", thus placing the analysis within the framework of binary choice models and hence restricting the use of Ordinary Least Squares (OLS) because of the normality and homoscedastic assumptions of the error term. Moreover, the computed probabilities may lie outside the 0-1 range (Goldberger, 1964; Maddala, 1983; Greene, 2003), thus limiting the use of the Linear Probability Model (LPM) which is reported to have non-normal and non-constant error terms and possesses constant effect of the explanatory variable. Probit and logit models which provide equally efficient parameters are therefore the most popular statistical methods developed to analyze dichotomous response dependent variables (Demaris, 1992; Goldberger, 1964). However, our choice of the logit model over the probit model is based on Peng et al. (2002) who argued that when a continuous dependent variables are included in the model, logit model is well suited for explaining and testing the hypothesis about the relationships between a categorical outcome variable and one or more categorical or continuous variable. It is also worth noting that use of the logit model for this analysis is consistent with the literature on credit access (Ololade and Olagunju, 2013; Akudugu et al., 2009; Ayamga et al., 2006).

The study employed the threshold decision-making theory proposed by Hill and Kau (1973) and Pindyck and Rubinfeld (1998) to analyse the determinants of credit access by farmers. The theory points out the fact that when farmers are faced with a decision to adopt or not to adopt an innovation, in this case access to credit, every farmer has a reaction threshold, which is dependent on a certain set of factors. This being the case, at a certain value of stimulus below the threshold, no adoption is observed while at the critical threshold value, a reaction is stimulated by certain factors which can be household, socioeconomic and institutional characteristics of the respondent. Such phenomena are generally modeled using the relationship:

$$Y_i = X_i'\beta + \varepsilon_i \qquad (1)$$

Where Yi is equal to one (1) when a choice is made to adopt and zero (0) otherwise; this means:

Yi = 1 if Xi is greater than or equal to a critical value, $X^*$ and Yi = 0 if Xi is less than a critical value, $X^*$. Note that $X^*$ represents the combined effects of the independent variables ($X_i$) at the threshold level. Equation (1) represents a binary choice model involving the estimation of the probability of adoption of a given technology (Y) as a function of independent variables (X). Mathematically, this is represented as:

$$Prob(Y_i = 1) = F(\beta' X_i) \qquad (2)$$

$$Prob(Y_i = 0) = 1 - F(\beta' X_i) \qquad (3)$$

Where $Y_i$ is the observed response for the $i^{th}$ observation of the response variable, *Y*. This means that $Y_i = 1$ for an adopter (that is, farmer's decision to demand for farm credit) and $Yi = 0$ for a non-adopter (that is, farmer's decision not to demand for credit). *Xi* is a set of independent variables associated with the $i^{th}$ individual, which determine the probability of adoption (that is, farmer's decision to demand for credit), (P). The function, F may take the form of a normal, logistic or probability function. The logit model uses a logistic cumulative distributive function to estimate, P as follows (Pindyck and Rubinfeld, 1998):

$$Prob(Y_i = 1) = \frac{e^{\beta' X}}{1 + e^{\beta' X}} \qquad (4)$$

$$Prob(Y_i = 0) = 1 - \frac{e^{\beta' X}}{1 + e^{\beta' X}} = \frac{1}{1 + e^{\beta' X}} \qquad (5)$$

The implication for applying the logit model in this paper is that, the farmer would decide to demand credit at a given point in time when the combined effects of the factors assumed to influence farmers' decision to demand for credit exceed the reaction threshold. Based on the conceptual framework, the empirical model is estimated using the farmers' characteristics plausibly assumed to influence their credit decisions. The covariates include farm and farmer characteristics such as sex, age, age squared, education, farm size, household size, income, group membership and source of credit. The empirical model for access to agricultural credit is specified below:

$$Y = (\beta_0 + \beta_1 Sex + \beta_2 Age + \beta_3 Age^2 + \beta_4 Education + \beta_5 Farm\_size + \beta_6 Household\_size + \beta_7 Income + \beta_8 Group\_membership + \beta_9 Source\_credit + \varepsilon_1)$$

Where, Y = the dependent variable defined as the access to credit by smallholder farmers = 1 and 0 no access to credit; $\beta_0$= constant and intercept of the equation. The definition/measurements and a priori expectations of the variables used in the logit model are presented in Table 1. Our choice of variables for this study is based on intuition and literature (Ololade and Olagunju, 2013; Chauke et al., 2013; Dzadze et al., 2012 Kuwornu et al., 2012; Akudugu et al., 2009; Ayamga et al., 2006; Demaris, 1992).

## DATA

The data use for this study is from the United States Government's Feed the Future (FTF) initiative that aims to support growth of the agricultural sector and promote good nutrition to attain its key goal of sustainably reducing global hunger and poverty. The survey was implemented in the three northernmost regions of Ghana namely: Upper West, Upper East, and Northern Region, as well as some selected areas in Brong Ahafo Region, to provide baseline data on the prevalence of poverty, per capita expenditures, nutritional status, women's empowerment, household hunger, dietary diversity and infant and young child feeding behaviours. The survey was funded by USAID and implemented by USAID-Ghana Monitoring Evaluation and Technical Support Services (METSS), Kansas State University (KSU), University of Cape Coast (UCC), the Institute of Statistical, Social and Economic Research (ISSER) at the University of Ghana, and the Ghana Statistical Service (GSS) with US Department of Agriculture (USDA) and USAID providing technical support.

Multistage sampling procedures were applied and carried out in the three northern regions of Ghana as well as areas above the $8^{th}$ Parallel in the Brong Ahafo Region of Ghana. In the first stage, a probability sampling methodology was employed to select two hundred and thirty EAs from all the EAs within the ZOI based on the Ghana 2010 Census data. The areas in the ZOI were then divided into two strata (that is, agriculture-nutrition intervention area as Strata I and agriculture only intervention area as Strata II) in the second stage to ensure an adequate number of respondents for the two strata. This resulted into an effective sample size of 4580 and was rounded up to 4600 to give further cushion for the likelihood of non-response. Maize farmers were then excised from the total sample for the purpose of this study. On the basis of predominance of maize farmers, the Northern region was selected for the study. The data set (which was used for the analysis in this study) is therefore made up of 2330 maize farmers from Northern Region.

**Table 1.** Definition/measurements and the expected signs of the variables used in the logit.

| Model variable | Definition/measurements | Expected sign |
|---|---|---|
| Demand for Credit | Dummy (1 = if household has access to credit and 0 if otherwise) | |
| Sex of the farmer | Dummy (1 = male; 0 otherwise) | + |
| Age of the farmer | Number of years | + |
| Level of education | Dummy (1 = formal education; 0 otherwise) | + |
| Farm size | In acres | + |
| Household size | Number of people | + |
| Income | Amount in Ghana Cedis | + |
| Group membership | Dummy (1 if the farmer is a member of a group and 0 otherwise) | + |
| Source of credit | Dummy (1 if the farmer access credit from informal source and 0 otherwise) | - |

**Table 2.** Summary statistics of variables.

| Variable | Mean | Standard deviation |
|---|---|---|
| Demand for Credit | 0.4925 | 0.5001 |
| Gender of the farmer | 0.3104 | 0.4628 |
| Age of the farmer | 42.9768 | 15.9056 |
| Level of education | 0.5006 | 0.5001 |
| Farm size | 3.9659 | 4.9603 |
| Household size | 6.0125 | 3.5232 |
| Income | 459.0382 | 1396.1240 |
| Group membership | 0.4981 | 0.5001 |
| Source of credit | 0.4963 | 0.4388 |

Source: Authors' computation, 2013.

**Table 3.** Logit regression results of the factors influencing access to agricultural credit.

| Variable | Coefficient | Standard Error | Z |
|---|---|---|---|
| constant | -1.9422 | 0.3915 | -4.96*** |
| Sex | -0.7044 | 0.1193 | -5.91*** |
| Age | 0.0384 | 0.0174 | 2.20 ** |
| Age square | -0.0003 | 0.0002 | -1.74* |
| Education | 1.9523 | 0.1027 | 19.02*** |
| Farm size | 0.0147 | 0.0122 | 1.21 |
| Household size | -0.0522 | 0.0150 | -3.48*** |
| Income | -0.0001 | 0.0000 | -2.33** |
| Group membership | 0.2159 | 0.1000 | 2.16** |
| Source of credit | 1.2352 | 0.1121 | 11.02*** |
| Number of observations | 2329 | | |
| LR Chi-square (9) | 754.35 | | |
| Probability Chi-square | 0.0000 | | |
| Log likelihood | -1236.903 | | |
| Pseudo $R^2$ | 0.2337 | | |

*, **, *** denote significance at 10, 5 and 1% respectively. Source: Authors' computation, 2014.

## RESULTS AND DISCUSSION

Here summary statistics of the variables used in the study (Table 2) as well as results of the estimation of logistic regression model (Table 3) is presented. Results from study reveal that less than 50% of households have access to credit where male household comprised of 31% of the sample. The average age of a household head was found to be 43 years ranging from 14 to 100 years. The level of educational among households was encouraging considering the fact that 50% of the farmers were educated. Further findings revealed that on the average, 4 acres of land is being managed by 6 people with an average monthly income of GH¢ 459.04. Almost 50% of the farmers participated in group activities. Less than 50% of the farmers got farm credit from informal sources such as friends, relatives, NGOs, informal lenders, village savings and loans associations.

**Determinants of households' access to agricultural credit**

The significant determinants of factors affecting access to credit by farmers are sex, age, age square, education, household size, income, group membership and source of credit. Though the estimated Pseudo R-squared value was low (23.4%), the log likelihood ratio (LR) statistic is significant at 1 percent, meaning that the explanatory variables included in the model jointly explain the probability of farmers' decision to access credit from the formal.

Gender was found to be negatively related to decision to access agricultural credit by farm households (Table 3). This was found to be significant at 1% level. This means that female farmers are more likely to access agricultural credit from formal institutions than their male counterparts. This is understandable given that most credit schemes designed by banks and other development institutions such as NGOs focus more on women. The result is consistent with the findings of Akudugu et al. (2012) who argued that females are considered the most disadvantaged, vulnerable and above all, credit worthy and are therefore likely to opt for credit than their male counterparts. Age of the famer was also found to be significant 5% and positively related to households' decision to access credit. This implies that the probability of households' decision to access credit from both formal institutions increases with age of the farmer. This result is plausible for the fact that experience which increases with age is an important aspect of decision making styles in the credit market. Previous experience with lenders is an important predictor of outcomes. This experience can be gained hands-on from having started previous ventures. Experience of previous start-ups help provide farmers with considerable motivation for venturing again, opens new opportunities, links them to important resource providers and develop key competencies. Experience which increases with age, reduces the aversion to risks by farmers. Therefore, older farmers are expected to have higher probability of accessing credit from institutions than younger farmers. This result is consistent with the findings of other studies (Akudugu et al., 2012) and yet contrary to the finding of Mohammed et al. (2013).

The level of education attained by a farmer was significant at 1% significance level and showed a positive relationship with formal credit access. The result implies that level of education influences a farmer's chances of accessing credit. This is because higher level of education is associated with the ability to access and comprehend information on credit terms and conditions, and ability to complete loan application forms properly. This finding regarding education is consistent with the findings of Ayamga et al. (2006); Thaicharoen et al. (2004) and Arvai and Toth (2001) who also found that education significantly influences the decision to participate in formal credit schemes.

Surprisingly, household size was found to be significant at 10% but negatively related to agricultural credit access. This implies that the probability of households sourcing agricultural credit from formal institutions is lower for larger households but higher for smaller households. Though contrary to our expectation, the result is reasonable because credit is used for purchase of inputs and hiring of labour and therefore needed in smaller households to supplement farmers, who are labour and input constrained, thus explaining why smaller households have higher probability of sourcing credit from lenders.

Annual income was found to be a significant variable which influences household to access credit from lenders. The negative sign for the coefficient of this variable suggests that farmers with low annual income are more credit constrained than farmers with high annual income. This finding conforms to our expectation and consistent with the study of Akram et al. (2008) who observed a negative relationship between annual income and credit constraint condition of farmers.

Turning to our major variable of interest, the result revealed that membership to social group is significant at 5% and positively related to the probability of household access to agricultural credit. This conforms to our a priori expectation and consistent with the findings of Akudugu et al. (2009), Armendariz and Morduch (2005), and Kah et al. (2005) who explained that formation of economic and social associations helps improve access to credit since there is a joint guarantee by association members. This implies that when farmers joined social groups, then, the probability that they will access credit from the Banks to support their farming activities is most likely to increase. This is because the decision to join such social groups is mostly driven by the desire to access financial services, particularly credit from the Banks.

The relationship between source of credit by farmers and access to credit (in this case, demand for credit) was amazing. This variable was found to be significant at 1% and positively related to households' access to credit. This implies that the probability of households accessing credit from informal sources like friends, relative, NGOs or village savings and loans association is higher than in formal sources such as banks. Though surprising, the result is plausible for two reasons. First, credit obtained from the informal sector entails no or low interest rate, thus making it less costly as compared to the formal sectors. Secondly, farmers incur additional transaction cost as a result of conditions involved in applying for a loan from the financial institutions. For instance, banks normally give loans to farmers on group basis. This means that in order to apply for a bank loan, the prospective borrower has to look for other farmers to form a credit group. The farmer therefore incurs transactions cost in the process of looking for the eligible farmers. Farmers who cannot afford the additional cost finally opt for informal sources.

## CONCLUSIONS AND RECOMMENDATIONS

The role of agricultural credit in the development of agricultural sector is magnificent. Accessible credit enhances farmers' purchasing power to enable them acquire modern technologies for their farm production. Access to the credit however, seems to be limited among smallholder farmers due to certain constraints. Using the Logistic regression model, the study sought to analyse the factors that influence households' access to credit from both formal and informal sectors in Northern Ghana with much emphasis placed on the membership to farmers' associations. Results from the study showed that almost 50% of households have access to credit and that decision to access agricultural credit is positively and significantly determined by age, education, group membership and source of credit. Sex, age square, household size and income though significant, have negative impact on probability of households' credit access. We therefore call on stakeholders to streamline loan application procedures, intensify education of farmers on loan procedures and promote flexibility in types of collateral demanded by financial institutions in order to enhance access. In case of collateral security, farmers should be encouraged to form cooperative groups to enable them pull resources together or form groups to access loans from financial institutions since the group lending scheme ensures higher repayment rate as the leader of the group serves as a guarantor to the bank.

### Competing Interest

Authors have declared that no competing interest exist.

## ACKNOWLEDGEMENTS

The authors are grateful to the USAID-Ghana, the Kansas State University (KSU), University of Cape Coast (UCC), the Institute of Statistical, Social and Economic Research (ISSER) at the University of Ghana, the Ghana Statistical Service (GSS) and the US Department of Agriculture (USDA) for their collaborative efforts in implementing the survey and making the data available for this study.

**Abbreviations: AEAs**, Agricultural Extension Agents; **CAADP**, Comprehensive Africa Agriculture Development Programme; **ECOWAP**, ECOWAS Agricultural Policy; **FTF**, Feed the Future; **GSS**, Ghana Statistical Service; **ISSER**, Institute of Statistical, Social and Economic Research; **KSU**, Kansas State University; **LPM**, Linear Probability Model; **METSS**, Monitoring, Evaluation and Technical Support Services; **MDBs**, Money Deposit Banks; **MDGs**, Millennium Development Goals; **MoFA**, Ministry of Food and Agriculture; **OLS**, Ordinary Least Squares; **UCC**, University of Cape Coast; **USAID**, United States Agency for International Development; **USDA**, United States Department of Agriculture.

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Vol. 10(7), pp. 653-659, 12 February, 2015
DOI: 10.5897/AJAR2014. 9331
Article Number: 3943BE650358
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Climate change impacts on South African hop producer prices

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Received 13 November, 2014; Accepted 22 January, 2015

**Climate change impacts caused South Africa to breed unique hop cultivars which are adapted to shorter and warmer winters and shorter day length in summer. However, climate change impacts in South African include further increases in temperature along with noticeable inter-seasonal variation in rainfall patterns. These changes have demanded a re-evaluation of the ability of South African hop farmers to adapt to climate change impacts. In order to assess the adaptive capacity of hop farming operations from a financial perspective, the study assessed the potential inflationary impacts of climate induced water related risk on the production cost of South African commercial hop operations. It was found that the South African hop price model is a cost-based model with fixed returns, which aims to maintain the gross margin above specified cost for hop farmers. This rather unique setup implies that returns on investment are fixed and that inflationary pressure cannot erode the profitability of hop farming operations. Climate induced inflationary impacts will therefore inflate the consumer price of hops since it is almost certain that breweries will pass on any inflationary impacts to the final consumer. We have distinguished between a temperature effect and a rainfall effect of climate change. Given an average dry yield of 1 739 kg of hops per hectare for the study area and a current market price of R51.39/kg for dry hops, the temperature effect will inflate the market price for hops with R1.03/kg, while the rainfall effect will inflate prices with R0.31/kg. The study found that a total increase of R1.34/kg (that is, a 3% increase) in the producer price of hops is therefore required to offset climate induced water-related risk on hop cultivation in the study area.**

**Key words:** Climate change, hop farming, production cost model, South Africa.

## INTRODUCTION

Between the late 1990s and early 2000s, the international hops market was over-supplied, causing a worldwide decrease in the price of hops. Consequently, the area under cultivation decreased steadily; falling by approximately 50% during this time (Mozny et al., 2009). This was followed by a volatile price period characterized by stockpiling and speculation. More recently, the market has stabilized and is set for a period of growth; unless the demand for beer decreases significantly; or, more relevant for the current paper, external factors such as climate change induce water-related risks that threaten the production and supply of hops.

A focused effort was made during the 1980's to grow the South African hops industry because of its strategic

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**Figure 1.** Water management areas in South Africa (provincial boundaries are shown in grey and study area is indicated with arrow).

importance for the South African beer industry. It was expected that the drier South African climate would not only lead to fewer pests as compared to Europe and the United States, but being a labor intensive industry, create much needed job opportunities while savings on foreign exchange (all South African hops was imported at that time). Consequently, an active breeding programme has resulted in some unique South African hop cultivars with unique terroir properties which are sold on the international market. Today, 75% of the area under cultivation is grown by private growers who are contracted to single beer brewing company. This arrangement effectively cancels out marketing risk from the producer side. Producers therefore have a guaranteed buyer for their produce, which implies that producers are not vulnerable to international price variation. This low-risk proposition has been an important consideration for private land owners when considering growing hops under contract.

The South African producer price for wet hops is based on a fixed margin above specified costs, which is reviewed and adjusted on an annual basis. Climate change impacts can affect the cost structure of hop farming operations, but not producer's profitability. This is the first study focusing on quantifying the inflationary impact on input cost specifically due to climate induced water related-risk on the industry. We present the required adjustments in producer price to maintain the profitability of hop farming operations and recommend changes to hop cultivation practices to better manage climate induced water-related risk on hop farming by applying a pragmatic approach as far as possible to maintain practical relevance. Data were mainly derived from a hop farm survey conducted by the researchers (De Lange and Mahumani, 2010), while industry data was obtained from a leading South African beer company (Conway, 2010; Brits, 2010) and previous reports on hop farming operations in the study area (Kleynhans, 1991; Kassier and Spies, 1988).

## STUDY AREA AND CLIMATE CHANGE MODELLING

Hops require a cool, moist climate, preferably with summer rainfall, low winter temperatures (about 5 weeks at temperatures below 4°C) to encourage full dormancy, and a frost free growing season with long daylight hours. In addition, winds can cause both delay in growth and physical damage to the ripening cones. Hot gusts around harvest time also cause yield losses because hops become dry and brittle, which causes the cones to shatter in the picking machines. Hop farming operations in South Africa are primarily located in the Waboomskraal area (33°52'20.64"S, 22°21'15.14"E) which is situated in the Outeniqua Mountains, inland of the south coast town of George in the Western Cape Province of South Africa (Figure 1).

The Waboomskraal area is considered a spring rainfall region, with the bulk of its rainfall between September to November; while the driest period is June to July. Average rainfall is 691 mm per year with a standard deviation of 140 mm per year (De Lange and Mahumani, 2010).

Given that hops require approximately 900 to 1000 mm water per year to serve growth requirements and to account for evaporation losses, the Waboomskraal is therefore considered a marginal area for growing hops compared to most northern hemisphere growing regions where there are ample cold units in winter and long daylight hours in summer. Farmers manage these requirements using supplemental irrigation (a typical irrigation season varies between 16 and 18 weeks, during which farmers irrigate between 25 and 30 mm per week), cultivar selection and breeding programmes, and artificial lighting. There are 13 commercial hops growers cultivating 483 ha of hops in the Waboomskraal district of the George area, and all of them deliver wet hops to directly to a single brewery. Some farms are diversified, but the majority (65%) has hops as a monoculture.

The Cape south coast is considered to be a climatic transition zone, located between the winter rainfall area of the southwestern Cape to the west, and the summer rainfall areas of the interior to the north. As such, the region's climate is affected by changes in the circulation systems of both of the climate regimes bordering the area, which makes it particularly vulnerable to climate change impacts (Engelbrecht, 2010).

During the past century, temperatures in the central interior of southern Africa have been increasing at about twice the global average rate of 0.8°C (Kruger, 2006; Kruger and Shongwe, 2004). This is due to the region's location in the subtropics, in combination with hemispheric changes in circulation systems, primarily the strengthening of the subtropical high-pressure belt over the region (Engelbrecht et al., 2009). In order to assess climate change risk in the Cape south coast, it was necessary to consider long-term historical rainfall and temperature data, and projections of future trends of the same variables by means of regional climate models (Peter et al., 2009).

Six climate simulations were performed by the Council for Scientific and Industrial Research (CSIR) in South Africa during 2010 (Engelbrecht, 2010; Engelbrecht et al., 2009). These experiments applied a variable-resolution atmospheric global circulation model (AGCM) as a regional climate model to simulate future climate conditions over southern Africa. The model was fed with historic (1961 to 2010) and simulated (2011 to 2050) data from six different coupled global circulation models which contributed to Assessment Report 4 of the Intergovernmental Panel on Climate Change (IPCC) (http://www.ipcc-wg2.gov/publications/AR4/index.html). The CSIR simulations were done based on the IPCC's A2 emission scenario (http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=98). The AGCM used to perform the simulations was the conformal-cubic atmospheric model (CCAM) of the Commonwealth Scientific and Industrial Research Council (CSIRO) in Australia (McGregor, 2005). The model was first applied at a resolution of 2° in latitude and longitude, whereafter the simulations were downscaled to a resolution of 0.5° for southern Africa. An important feature of the simulations was that the sea surface temperatures of the coupled global simulation models used to drive the regional climate model, were bias-corrected, an approach that leads to improvements in the simulation of regional precipitation and circulation patterns (Engelbrecht, 2010).

A general strengthening of the subtropical high-pressure belt, and southern displacement of the westerly wind regime projected for the southern African region, are expected to decrease frontal rainfall and cut-off lows over the Cape south coast (Kruger, 2006; Engelbrecht et al., 2009). Projections of maximum temperatures over southern Africa suggest that, for all seasons, the largest temperature rise will occur over the western interior, with the strongest warming projected to occur during winter. The coastal areas are expected to warm at a slower rate than areas over the interior, due to the moderating effect of the ocean.

The observed and projected trends in maximum temperature over the study area, for each of the seasons June to August (winter), September to November (spring), December to February (summer) and March to May (autumn), are presented in Figure 2. The temperature trend analysis was performed using weather station temperature data as well as the above-mentioned projections for the period 1961 to 2050. Although there is variation between models, the models suggest an expected average increase of approximately 0.6°C in the mean annual temperature. However, given that an annualized average does not reveal sufficient detail to derive the impacts on the hop growing cycle, and therefore on hop farming operations in the study area, it became necessary to present temperature changes on a monthly basis (Figure 2) (De Lange and Mahumani, 2010). Of particular interest was a projected increase in the average maximum temperature over the irrigation season (September/October through to February/March) of 0.7°C, while the average minimum temperature is projected to increase by 0.79°C.

Figure 3 presents observed and projected monthly average rainfall totals for the period 1961 to 2050. It is expected that both the total rainfall and standard deviation in rainfall will remain constant at an average of 639 and 116 mm per year respectively (Engelbrecht, 2010). However, certain months will become drier, whilst other will become wetter (Figure 3). The relevance of these expected changes to the hops industry is determined by the impacts of such events on the growing cycle of hops. For example, the expected decrease of 9 mm in October is considered more important ascompared to the decrease of 6 mm for May, because the former falls within the beginning of the annual growth cycle, whilst the latter occurs after harvest time.

## RELATIONSHIPS BETWEEN CLIMATE AND YIELD/QUALITY

The relative performance of commercial hop growers is measured in terms of yield (tons harvested per hectare) and quality (α-acid percentage per unit weight, which is the generally accepted indicator of quality for hops). Growers thus aim to optimize growing conditions to maximize performance. Hops is particularly vulnerable to an increase in air temperature during the onset of the reproductive phase, as this not only leads to a shortening of the vegetative period, but also has negative impacts on the yield (quantity) and α-acid (quality) of the harvest (Brits, 2010). Furthermore, although no field trials are currently available to enable estimation of the exact crop-water production function for hops, it has been reported that hop plants in the Waboomskraal area have a total water requirement of 1 161 to 1 271 mm per hectare per year (Brits, 2010). This implies an irrigation requirement of between 470 to 580 mm per hectare per year (De Lange and Mahumani, 2010) to supplement the average 691 mm of rainfall (Engelbrecht, 2010). Given that 483 ha are currently under commercial hop production, the total water requirement for the industry is estimated at 5.6 to 6.1 million cubic meters per year, of which 2.3 to 2.8 million cubic meters needs to be irrigated. It is clear that hop farming is highly dependent on irrigation, which implies that irrigation management can be used to increase the adaptive capacity of hop farming.

In the absence of field trial data for South African conditions, we turned to international data to establish the relationship between climate change, yield and quality of hops. Surprisingly, few studies were found on this subject, which could imply that climate change is not yet seen as a major production risk in the prominent hop growing areas of the world (Germany, USA, China and the Czech Republic). Only one recent study was found (Mozny et al., 2009). Mozny et al. (2009) simulated the impact of changing weather conditions on yield and quality of Saaz hops in the Czech Republic with a crop production model developed earlier by the same author (Mozny et al., 1993). The model was calibrated with historical production data for a 52 year period, historical records of minimum and maximum air temperatures, relative air humidity, rainfall and solar radiation.

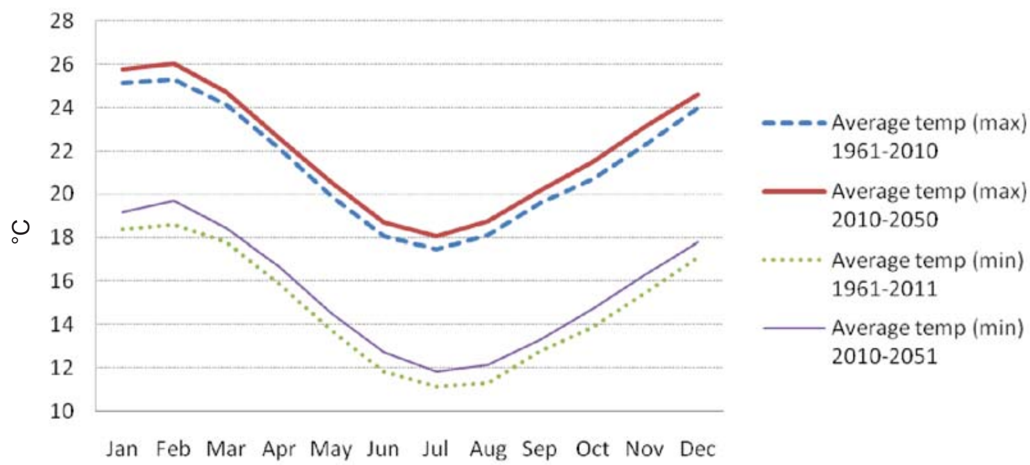


**Figure 2.** Observed and projected average maximum and minimum monthly temperatures for Waboomskraal.

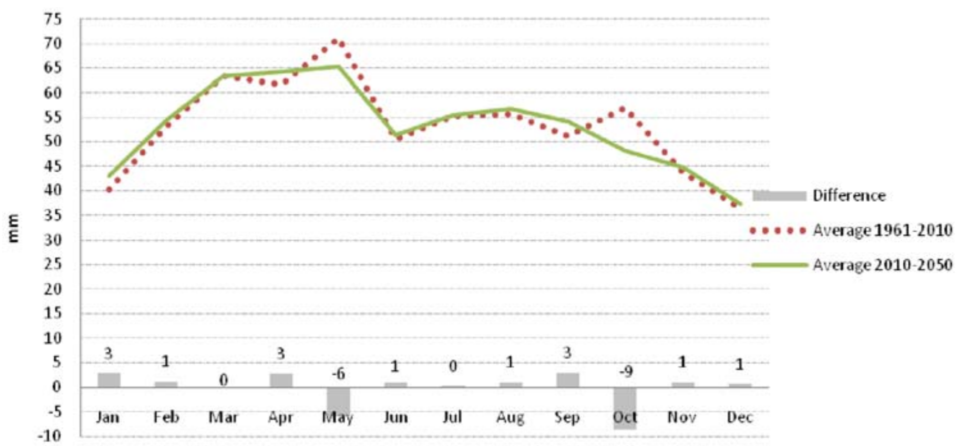


**Figure 3.** Observed and projected average total monthly rainfall for Waboomskraal.

Although this work was done in the Czech Republic, it can at least be used to qualify the relationship between expected changes in rainfall and temperature on the one hand, and the yield and quality of hops on the other. Reliable South African hop production records only go as far back as 1997 (De Lange and Mahumani, 2010), whereas climate data dates back to 1961. Research on the calibration of such a model for South African conditions and South African cultivars such as Southern Star and Southern Promise should therefore be a priority. Mozny et al. (2009) quantified the positive functional relationship between water application and yield; and establish a slope between a decrease in water application (rainfall and/or irrigation) and a decrease in yield of between seven and 10%. This relationship proved **Error! Reference source not found.**relevant to our study area, because an extrapolation of this relationship towards the current average rainfall of 691 mm per annum for the Waboomskraal area closely matched the reported average yield of the area of 1.739 t/ha (standard deviation of 0.21 t/ha) (De Lange and Mahumani, 2010). However, because of higher evapotranspiration rates in South African conditions as compared to Czech conditions, it behooves growers to augment precipitation with irrigation in the former (De Lange and Mahumani, 2010). Furthermore, Mozny et al. (2009) also quantified the negative relationship between temperature and α-acid percentage (quality) and found an increase in temperature could decrease α-acids (and therefore the quality of the hops) by between 13 and 32%, depending on the baseline. We have used these outcomes to support the two working assumptions for our study. For the purpose of this study we can thus assume with a fair degree of confidence that climate changes will affect hop cultivation in the following ways, *ceteris paribus*:

i) Increasing temperatures lead to an increased water requirement which, if not managed by means of irrigation, will decrease yield;
ii) Increasing temperatures will, if not managed, decrease quality (α-acid percentage).

## RESULTS

The extent of the impacts of changes in temperature and rainfall on hop yield and quality are determined by the timing of these events within the hops cultivation calendar (Figure 4).

For example, increased temperatures during spring


**Figure 4.** South African hop growing cycle.

(September) could lead to phenological changes to the plants, which could cause an earlier onset of flowering (Brits, 2010). This could have significant impacts on the operations calendar of a farm, particularly if such farm is diversified (like most in the Waboomskraal area (De Lange and Mahumani, 2010). Furthermore, an increase in the number of hot days during the rapid growth period of early summer (November through to December) will increase the evapotranspiration rates (and hence the irrigation requirement) of the plants (Brits, 2010). Growers can respond to these impacts in various ways, including changes in cultivar selection, changes in cultivation practices (crop rotation, irrigation, soil moisture retention, and temperature control (cooling) regimes), changes in harvest practices, and diversification. The choice of strategy will depend on the expected climatic stress factors (determined by the duration and intensity thereof), and the financial implications of the different interventions.

Numerous trade-offs are present in adaptation strategies to climate changes. For example, because commercial farmers aim to provide optimum growing conditions for the hops, the probability of applying deficit irrigation as a medium to long term response strategy to a water shortage, is unlikely and farmers will rather take hectares out of production and ensure that the remaining hectares are irrigated optimally (De Lange and Kleynhans, 2007). This implies that if climate projections suggest a decrease in rainfall, the number of hectares under cultivation could decrease, as opposed to a decrease in yield per hectare. Furthermore, if a grower decides to increase water use efficiency by upgrading his irrigation system to for example drip irrigation, the benefits of overhead sprinklers in terms of countering temperature spikes (through the cooling effect of such sprinklers) will be lost. The choice between different management practices is thus determined by the risk profile of the grower, which is in turn, affected by the time frame under consideration. For example, a seasonal drought will leave little time for growers to respond to such an event. Consequently, most will cover their short term risks by means of short term crop insurance instead of changing their cultivation practice.

Medium and long term temperature forecasts suggest that daily maximum temperatures in the study area during September/October through to February/March will increase by 0.7°C on average, while daily minimum temperatures will be 0.79°C higher. This temperature increase will increase the demand for irrigation water during the irrigation season with approximately 6 mm/month (or 60 $m^3$/ha/month) to maintain field capacity, implying a total additional 30 mm (or 300 $m^3$ of irrigation water per hectare) for the five month growing cycle (Chapman, 2011). This implies an additional 144 900 $m^3$ of water on an industry level over the growing period. Furthermore, Figure 3 suggests an expected decrease in rainfall of approximately 9 mm for October (the beginning of the rapid growth period of hops). This is considered a significant change which will need to be accounted for in irrigation scheduling (a further 6 mm decrease is expected for May, but this falls outside the irrigation season). The current irrigation requirement for October is approximately 63 mm (or 630 $m^3$ of water per hectare)

**Table 1.** Production cost structure for hop farming operations in the Waboomskraal area. Data sourced from hop farms survey report (De Lange and Mahumani, 2010).

| Description | Production cost (R/ha/yr) |
|---|---|
| Annual re-plant @ 1.5% | 313 |
| Wages | 15 955 |
| Pesticide | 2 754 |
| Twine | 1 340 |
| Fertilizer | 4 530 |
| General maintenance | 10 486 |
| Fuel | 5 627 |
| Electricity | 4 437 |
| Research levy | 438 |
| Insurance | 2 636 |
| Communication | 943 |
| Manager salary | 8 420 |
| Equipment hire | 535 |
| Licenses | 331 |
| Fees | 897 |
| Interest on overdraft | 2 971 |
| Current cost depreciation | 9 350 |
| Total | 71 964 |

rainfall for October decreases by 9 mm, this deficit will need to be supplemented by irrigation, which implies that the total irrigation need for October will become 72 mm. The overall increase in the demand for irrigation water (resulting from the expected increase in temperature in addition to the decrease in rainfall) implies an increase in irrigation costs in the production budget for hops (Table 1 shows the 2010 production cost structure). Given that borehole water costs approximately R5.99/$m^3$ (as calculated in De Lange and Mahumani, 2010) (operating, maintenance and depreciation included), it is estimated that the temperature increase (above-mentioned 300 $m^3$/ha) will increase the production cost by R1 798/ha; while the decrease in rainfall in October (additional water requirement of 90 $m^3$/ha) will add R540/ha. A total additional cost of R2 338/ha over-and-above the current total production cost of R71 964/ha is expected.

Given an average yield of 1 739 kg of dried hops per hectare and a current market price of R51.39/kg for dried hops (Conway, 2010), the increase in temperature will require a price increase of R1.03/kg (that is, R1798 / 1739 kg), while the decrease in October rainfall will require an increase of R0.31/kg (that is, R540 / 1739 kg) (total price increase of R1.34/kg), to maintain the current margin above specified cost.

## Conclusion

(De Lange and Mahumani, 2010; Conway, 2010). If

Changing climate patterns have operational and structural impacts on the capacity of commercial agriculture. This changing environment implies that the adaptive capacity is determined by the flexibility of commercial agricultural production systems, and is an increasingly important component of successful commercial farming practice. This study focused on the adaptive capacity of commercial hop farming operations in South Africa and illustrates the inflationary impact of climate change impacts on hop producer prices.

The South African hop producer price model is cost-based with fixed returns, and aims to maintain gross margins above specified cost. This rather unique setup is due to the small size of the industry and the unique production and processing setup in South Africa; whereby local growers do not dry their hops but deliver wet hops directly to breweries for drying and processing. The fact that returns on investment are fixed, provides the assurance that cost increases and inflationary pressure cannot erode the profitability of hop farming operation. The study estimated that an increase of R1.34/kg in the producer price of hops is required to offset climate induced water-related risk on hop cultivation practice in the study area. This figure was estimated via a cost-based approach employing a crop production model based on crop production functions from the literature and was used to simulate the functional relationships between changes in temperature/rainfall and irrigation requirements. The changes in irrigation requirements were quantified in monetary terms and expressed in terms of required price



increase that will maintain profitability.

Crop production models are consequently useful tools for assessing the vulnerability and response of crops to climate change. This study highlighted the fact that such a model does not currently exist for the South African hops industry. The study presents the need for a dedicated study to calibrate hops production functions for South African conditions and South African cultivars which can serve as basis for regression based models for future climate change scenarios.

## Conflict of Interest

The authors have not declared any conflict of interests.

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academicJournals

Vol. 10(7), pp. 660-667, 12 February, 2015
DOI: 10.5897/AJAR2014. 9337
Article Number: 3943BE650358
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Chemistry, nitrogen and carbon stocks in different land-use systems in a tropical environment

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Received 13 November, 2014; Accepted 22 January, 2015

**Considering the occurrence of land degradation and the need for sustainable practices, it is necessary to conduct studies that evaluate the content of organic carbon and nitrogen in the soil, as well as its chemical attributes. Thus, this study aimed to evaluate the content and stock of carbon and nitrogen and the chemical attributes of soil in an area that was classified as a Typic Hapludox and was treated under different land-use systems, a native tropical forest (NF) and agricultural systems with an annual crop (AC), perennial crop (PC) and pasture (PT), located in the southern state of Espírito Santo, Brazil. The content and stock of organic carbon (OC), total nitrogen (TN), the OC/TN ratio and the chemical attributes of land fertility were analysed at depths of 0 to 10, 10 to 20 and 20 to 40 cm. The OC and TN stocks in the soil presented the following descending percentages in relation to the reference system (NF): PC > AC > PT. The percentage reductions in the stocks of OC and TN were 38 and 15%; 42 and 21%; and 8 and 3%, in the PC, AC and PT systems, respectively. Among the cultivation systems that were studied, the native tropical forest and the pasture lands presented the lowest soil fertility, which indicated acidic soils with insufficient macronutrients. Major deficiencies in the micronutrients copper, zinc and boron were observed, and the content of the latter was below a critical level in all of the systems and soil depths evaluated.**

**Key words:** Soil fertility, organic matter, coffee, sorghum, pasture.

## INTRODUCTION

The degradation of cropped soil in Brazil is concentrated on pasture lands, annual croplands and perennial plantations. Furthermore, in perennial crops, particularly coffee plantations, the main problems result from erosion caused by steep slope grading, excess weeding, ancient planting with a low density of plants and a low level of conservation practices. Conversely, on pasture lands, the degradation occurs mainly due to soil compaction, lack of

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fertilization, trampling by herds and high rates of pasture use.

The conversion of native vegetation into cropland represents a significant change to the original ecosystem because it generates alterations to the morphological, physical, chemical and biological soil attributes. Thus, some features may be eliminated because the natural mechanisms of recycling and protection are destroyed, which leads to various forms of degradation (Lima et al., 2011; Mansor et al., 2014). The incorporation of carbon (C) and nitrogen (N) into the forest soil is also associated with symbiosis among plants, diazotrophic bacteria and mycorrhizal fungi and contributes a great deal to the plant species that fix atmospheric N (Braghirolli et al., 2012). Ploughing the soil, the extraction of minerals and the imbalanced loss of nutrients from a cropping system cause reductions in the stocks of N and organic C (Nunes et al., 2011).

On cultivated land in tropical areas, organic matter losses occur intensively because their stock may be reduced by more than 50%, when compared with undisturbed areas with the same soil characteristics, in less than ten years of cultivation (Shang and Tiessen, 1997). Up to 80% reductions in carbon content were observed by Silva et al. (1994) in areas cropped with soybeans, and by Silva et al. (1999) in Ferralsols under liming and phosphate fertilisation. Reductions in the C content of agricultural areas are the result of increased organic matter decomposition, which occurs due to the increasing disturbance of soil, the increasing degree of aeration as well as a change in the terrestrial soil structure or the reduction of organic material being introduced into the soil (Dalal and Mayer, 1986).

According to Santos et al. (2008), reduction in the C content may be explained by increased erosion, fast-growing organic matter extraction processes, the organic carbon oxidation processes in the soil, and the smaller quantity of organic material introduced into managed systems, compared with native forests. Souza et al. (2012) claimed that inappropriate soil management may play a fatal role because it creates an opportunity for organic matter mineralization and the emissions of immense amounts of greenhouse gases, such as nitrous oxide ($N_2O$), carbon dioxide ($CO_2$) and methane ($CH_4$) (Cerri et al., 2007). Organic cultivation of coffee is more sustainable than conventional (Partelli et al., 2012), which is also true for sugarcane cultivation, primarily when it does not involve the burning of straw (Evangelista et al., 2013).

The total nitrogen (TN) stock of soil under natural conditions is influenced by climate factors and by vegetation. In soils under a tropical climate, the total nitrogen concentration may vary between 0.02 and 0.40% and, in extreme cases of organic soils (Histosols), it can achieve up to 2% (Stevenson, 1994). The major quantity of total nitrogen in the soil is in its organic form (more than 95%), which makes soil organic matter (OM) a very important reservoir of available forms of N for plants, mainly in the forms of nitric acid (N-$NO_3^-$) and ammonia (N-$NH_4^+$) (D'Andréa et al., 2004).

Considering the occurrence of land degradation and the need for sustainable practices, studies that evaluate the stock and content of organic carbon and nitrogen in soil, as well as soil chemical attributes are necessary. Thus, this study aimed to evaluate the content and the stock of carbon and nitrogen and the fertility attributes in a Ferralsol under different land-use systems.

## MATERIALS AND METHODS

This study was performed using soil samples from an area classified as a Typic Hapludox on the campus of the Instituto Federal do Espírito Santo (20° 45' 51" S; 41° 27' 24" W and 131 m above sea level) in the Alegre municipality, in the state of Espírito Santo. The climate in the area is considered to be a CWa based on the Köppen system, with a dry winter, an average annual temperature of 23°C and an average annual precipitation of 1,200 mm.

To determine the performance of different land-use systems, four areas were selected, which were distributed in four homogeneous sections of soil. The analysed systems included the following: native tropical forest (NF), annual cropping of sorghum (AC), perennial cropping of coffee (PC) and pasture composed of *Brachiaria* sp. (PT) (Table 1).

Samples were collected in September 2010; in each system, four rectangular blocks, measuring 15×20 m (300 $m^2$), were selected. Samples were obtained from depths of 0 to 10, 10 to 20 and 20 to 40 cm in order to evaluate the content of organic carbon (OC) and total nitrogen (TN) as well as the chemical attributes of land fertility. Furthermore, one sample from each parcel was removed, which was obtained from 15 randomly chosen subsamples. Each composite sample represented a repetition. To evaluate the soil bulk density characteristics, several undisturbed samples were obtained using a volumetric core with a capacity of 89.53 $cm^3$. In all of the systems, before collecting the samples, all of the visible plant residues on the land surface were removed.

The samples were kept in plastic bags and were taken to the laboratory. To analyse the content of organic carbon and TN, these were air-dried, ground in a mortar and filtered through a square mesh sieve measuring 0.210 mm. The samples designated for chemical analysis of fertility were air-dried, ground and sieved through 2 mm mesh to obtain the air-dried fine soil TFSA.

The organic carbon was determined using methods described by Yeomans and Bremner (1988). For measuring the NT, the method explained by Bremner (1996) was adopted, which involves the use of a mixture composed of $K_2SO_4$, $CuSO_4$ and selenium. According to these results, the content of organic carbon and total nitrogen were used to calculate the OC/TN.

The stocks of organic carbon and total nitrogen in the different systems under analysis and at each soil depth were calculated using the following formula: stock of organic carbon or total nitrogen (t ha-1) = content of organic carbon or total nitrogen (g $kg^{-1}$) × BD × e/10, where BD = bulk density at depth (kg $dm^{-3}$) (average of four repetitions); and e = the thickness of the soil layer (cm).

On the TFSA samples, the water pH, the changeable contents of Al, Ca, Mg, K, Na, Fe, Cu, Zn, Mn and B, and the available contents of phosphorus (P) (Mehlich-1) and sulphur (S) and the contents H+Al were analysed. The method used to analyse the samples was described by Embrapa (1999). Sulphur extraction was performed using a solution of calcium phosphate (500 mg $L^{-1}$ of P), where the available S was quantified by Turbiquant® turbidimetry. According to data from the fertility analysis, the values of the effective cation exchange capacity (t) and the potential capacity (T), the sum of the

**Table 1.** History of land-use systems installed in different areas in the municipality of Alegre, Espírito Santo, Brazil.

| Land-use systems | Symbol | History |
|---|---|---|
| Native forest | NF | A native tropical forest situated approximately 500 m from the other land-use systems with the same soil class. This area was used as a reference for the soil equilibrium state. |
| Annual crop | AC | This area was previously cultivated with greens for 11 years, after which, in 1994, fodder sorghum (*Sorghum bicolor)* was planted for animal feeding. This crop is planted every year with conventional planting methods and is managed according to proper crop handling protocol. The area remains fallow in the intercrop period. |
| Perennial crop | PC | This area was previously cultivated with oranges for 23 years, after which, in 2006, a coffee crop was planted (*Coffea canephora).* The crop has been cultivated according to crop handling protocol, including pruning (once a year) when the crop residues are deposited in the crop furrows. |
| Pasture | PT | This pasture was initially formed with Pernambuco grass, a native species of the region. In 1994, after 64 years, *Brachiaria decumbens* was planted, when the pasture was managed with continuous herbaceous cattle under a semi-intensive regime and with no soil fertility management. |

bases (SB), the base saturation (V), the Al saturation (m) and the Na saturation (ISNa) were calculated.

The data from the contents and stocks of organic carbon and TN, the OC/TN and the attributes of soil fertility were subjected to a variance analysis in order to verify the effects of the systems at all depths. Comparisons of the average were performed using Tukey's test, adopting a 5% probability and using the computer app SAEG.

## RESULTS

At depths of 0 to 10 cm, the organic carbon content varies from 8.0 to 14.4 g $kg^{-1}$ (Table 2). The organic carbon in the native tropical forest was significantly superior to the annual crop, perennial cropping of coffee and pasture systems. Moreover, in this system, the total nitrogen varied from 0.9 to 1.2 g $kg^{-1}$, which means a higher total nitrogen content compared with the other systems. The total nitrogen content of the soil was influenced by all of the systems, being higher on the native tropical forest and pasture, at depths of 10 to 20 and 20 to 40 cm. The OC/TN relationship in the soil varied from 9.5 (perennial cropping of coffee) to 11.9 (native tropical forest), from 7.4 (perennial cropping of coffee) to 13.1 (native tropical forest), and from 8.13 (perennial cropping of coffee) to 10.1 (pasture) for samples collected at depths of 0 to 10, 10 to 20, and 20 to 40 cm, respectively (Table 2).

The organic carbon stock was slightly altered by land use at all of the analyzed depths (Table 2). In a general way, considering all of the soil depths, the highest organic carbon stock values were observed in the native tropical forest and pasture systems, followed by the annual crop and perennial cropping of coffee systems. It was observed that the pasture system had an organic carbon stock that was significantly similar to the native tropical forest system (Table 2), according to Rangel et al. (2007).

In general, the total nitrogen stocks in the soil followed the same pattern of answers as the organic carbon stocks (Table 2). The average total nitrogen losses at different depths in the annual crop, perennial cropping of coffee and pasture systems were 19, 21 and 3%, respectively. The potential acidity (H + Al) followed a pattern in which the highest values occurred in the native tropical forest system at all of the evaluated depths, as similarly observed for the pH values. In the annual crop and perennial cropping of coffee systems, at depths from 0 to 10 and 10 to 20 cm, there was no significant difference in the levels of H + Al. Except for the perennial cropping of coffee system at a depth from 20 to 40 cm, the levels of H + Al in the annual crop and perennial cropping of coffee systems were classified as low. Regarding the native tropical forest system, the levels of H + Al were classified as high at depths from 0 to 10 and 10 to 20 cm and were average at depths from 20 to 40 cm.

The P levels at depths from 0 to 10 cm varied from 2 to 32.7 mg $dm^{-3}$. A greater availability of P at this depth was identified in the annual crop and perennial cropping of coffee systems. In the annual crop system, in which the level of loam is 49%, the P (32.7 mg $dm^{-3}$) level was high. In the coffee cultivation area (PC) where the soil had a loam level of 38.6%, the P level (23.2 mg $dm^{-3}$) was also expressed as high. The lowest levels of P were determined in the native tropical forest systems independently of their depths, indicating a generally low P level in the soil.

In the 10 to 20 cm layer in the annual crop and perennial cropping of coffee systems, the P levels were significantly higher than those in the native tropical forest and pasture systems. The same situation was observed at a depth from 20 to 40 cm, despite the lower levels observed in this depth. In all systems, the P decreased with increasing depth.

Availability of Ca and Mg presented a significant variation in the systems of soil usage at all of the

**Table 2.** Contents of organic carbon (OC), total nitrogen (TN), carbon to nitrogen ratio (C/N), the stocks of organic carbon (EstOC) and the total nitrogen (EstTN) in different land-use systems and at different depths in the municipality of Alegre, Espírito Santo, Brazil.

| Land-use system | OC | TN | C/N | EstOC | EstTN |
|---|---|---|---|---|---|
| | ($g\ kg^{-1}$) | | | ($Mg\ ha^{-1}$) | |
| **0 - 10 cm** | | | | | |
| NF | 14.4$^{a}$ | 1.2$^{a}$ | 11.9$^{a}$ | 15.8$^{a}$ | 1.3$^{a}$ |
| AC | 10.5$^{bc}$ | 0.9$^{bc}$ | 11.6$^{a}$ | 12.6$^{a}$ | 1.1$^{a}$ |
| PC | 8.0$^{c}$ | 0.8$^{c}$ | 9.5$^{a}$ | 10.8$^{a}$ | 1.1$^{a}$ |
| PT | 13.0$^{b}$ | 1.0$^{b}$ | 11.7$^{a}$ | 15.7$^{a}$ | 1.2$^{a}$ |
| **10 - 20 cm** | | | | | |
| NF | 9.0$^{a}$ | 1.0$^{a}$ | 13.1$^{a}$ | 14.8$^{a}$ | 1.1$^{a}$ |
| AC | 6.5$^{ab}$ | 0.7$^{b}$ | 8.6$^{b}$ | 7.8$^{b}$ | 0.9$^{a}$ |
| PC | 5.0$^{b}$ | 0.7$^{b}$ | 7.4$^{b}$ | 6.9$^{b}$ | 0.9$^{a}$ |
| PT | 9.3$^{a}$ | 0.9$^{a}$ | 10.0$^{b}$ | 10.8$^{ab}$ | 1.1$^{a}$ |
| **20 - 40 cm** | | | | | |
| NF | 7.7$^{ab}$ | 0.8$^{a}$ | 9.9$^{a}$ | 17.8$^{a}$ | 1.8$^{a}$ |
| AC | 5.1$^{ab}$ | 0.5$^{b}$ | 8.8$^{a}$ | 12.5$^{ab}$ | 1.4$^{b}$ |
| PC | 4.1$^{b}$ | 0.5$^{b}$ | 8.3$^{a}$ | 10.5$^{b}$ | 1.3$^{b}$ |
| PT | 8.0$^{a}$ | 0.8$^{a}$ | 10.1$^{a}$ | 18.2$^{a}$ | 1.8$^{a}$ |

Native forest (NF), annual crop (Ac), perennial crop (PC) and pasture (PT). Averages followed by the same letter in the column do not differ statistically according to Tukey's test, considering a 5% probability.

evaluated depths (Table 3). At depths from 10 to 20 and 20 to 40 cm, the levels of Ca and Mg presented similar behaviors, with higher amounts in the annual crop and perennial cropping of coffee systems, and significantly lower levels in the native tropical forest and pasture systems. At all of the evaluated depths, the levels of Ca and Mg in the annual crop and perennial cropping of coffee systems are expressed as average. If we consider 2.4 and 0.9 cmolc $dm^{-3}$ as critical Mg and Ca levels in the soil (CFSEMG, 1999), respectively, the levels of these nutrients are only close to or above the value in the annual crop and perennial cropping of coffee systems, except for the Mg level in the pasture system at a depth from 0 to 10 cm, which is a critical level.

The K levels in the annual crop and perennial cropping of coffee systems were within levels that are considered low for native tropical forest and pasture systems at all depths (Prezotti et al., 2007). In the annual cropping system (sorghum), the K level was significantly higher than in the other systems at depths from 0 to 10 cm, which did not differ from the perennial cropping of coffee system at a depth from 10 to 20 cm. From 20 to 40 cm, the highest K level was observed in the perennial cropping of coffee system. The concentrations of K in all of the systems decreased with depth (Table 3). Except for the annual crop and perennial cropping of coffee systems, at depths from 0 to 10 and 10 to 20 cm, the results for all the management systems at different depths are expressed as low (< 60 mg $dm^{-3}$) in terms of soil fertility related to K.

The results observed in the soil analysis (Table 3) were compared following the fertility patterns of the "5ª Aproximação do Manual de Recomendação de Calagem e Adubação para o Estado do Espírito Santo" (Prezotti et al., 2007) (5th Approach in the Recommendations Manual of Liming and Fertilisation of the State of Espírito Santo).

The pasture system exhibited an Fe level that was significantly higher than that of the other systems at 0 to 10 cm (Table 4), considering that at other depths, there was no consequential variation and the Fe levels were within the medium level range in all of the other systems (20 to 45 mg $dm^{-3}$) but high in the pasture system (> 45 mg $dm^{-3}$). In the systems where there was fertilization and liming management (perennial cropping and annual crop), the levels of Mn were significantly higher, with values within the high level range at all of the studied depths. At depths from 0 to 10 and from 10 to 20 cm, the levels of Mn in the native tropical forest and pasture systems did not differ and were considerably lower than those observed in areas with annual and perennial crops.

The soil exhibited a B deficiency in all of the systems and at all depths, which was below or slightly above the designated low level (< 0.35 mg $dm^{-3}$). The perennial cropping of coffee system presented a considerably higher level of Cu and Zn than the others in the layers from 0 to 10 and from 10 to 20 cm and also of Cu at a depth of 20 to 40 cm (Table 4).

**Table 3.** Chemical features and macronutrient content at depths of 0 to 10, 10 to 20 and 20 to 40 cm under different land-use systems in the municipality of Alegre, Espírito Santo, Brazil.

| Land-use system | pH | S | P | K | Na | Ca | Mg | Al | H+Al |
|---|---|---|---|---|---|---|---|---|---|
| | | (mg dm$^{-3}$) | | | (cmol$_c$ dm$^{-3}$) | | | | |
| **0 - 10 cm** | | | | | | | | | |
| NF | 4.6$^b$ | 20.6$^{ab}$ | 2.0$^b$ | 49.5$^c$ | 3.2$^b$ | 0.3$^b$ | 0.5$^b$ | 0.8$^a$ | 6.5$^a$ |
| AC | 6.0$^a$ | 25.4$^a$ | 32.7$^a$ | 144.7$^a$ | 12.0$^a$ | 2.6$^a$ | 1.1$^a$ | 0.0$^c$ | 2.0$^c$ |
| PC | 6.1$^a$ | 2.8$^c$ | 23.2$^a$ | 96.0$^b$ | 4.5$^{ab}$ | 2.3$^a$ | 0.9$^a$ | 0.0$^c$ | 2.2$^c$ |
| PT | 5.1$^b$ | 11.3$^b$ | 1.6$^b$ | 47.3$^c$ | 7.5$^{ab}$ | 0.5$^b$ | 0.9$^a$ | 0.3$^b$ | 4.1$^b$ |
| **10 - 20 cm** | | | | | | | | | |
| NF | 4.6$^b$ | 24.2$^a$ | 1.5$^b$ | 28.7$^b$ | 1.7$^b$ | 0.1$^b$ | 0.4$^b$ | 0.9$^a$ | 5.2$^a$ |
| AC | 5.9$^a$ | 33.3$^a$ | 28.3$^a$ | 63.0$^a$ | 15.0$^a$ | 2.4$^a$ | 0.9$^a$ | 0.0$^c$ | 1.7$^c$ |
| PC | 6.5$^a$ | 0.7$^b$ | 20.7$^a$ | 64.2$^a$ | 4.0$^b$ | 2.3$^a$ | 0.9$^a$ | 0.0$^c$ | 1.2$^c$ |
| PT | 5.0$^b$ | 14.9$^{ab}$ | 1.3$^b$ | 17.7$^b$ | 6.2$^{ab}$ | 0.4$^b$ | 0.5$^b$ | 0.3$^b$ | 3.2$^b$ |
| **20 - 40 cm** | | | | | | | | | |
| NF | 4.6$^c$ | 28.0$^a$ | 1.4$^c$ | 17.0$^b$ | 0.0$^b$ | 0.0$^b$ | 0.4$^b$ | 0.8$^a$ | 4.5$^a$ |
| AC | 6.0$^b$ | 25.8$^a$ | 11.7$^a$ | 22.0$^b$ | 5.2$^a$ | 2.1$^a$ | 0.9$^a$ | 0.0$^c$ | 1.5$^c$ |
| PC | 6.9$^a$ | 6.4$^b$ | 4.9$^b$ | 49.3$^a$ | 3.2$^a$ | 2.1$^a$ | 0.9$^a$ | 0.0$^c$ | 3.5$^b$ |
| PT | 5.2$^c$ | 16.8$^{ab}$ | 1.2$^c$ | 11.7$^b$ | 6.0$^a$ | 0.3$^b$ | 0.2$^b$ | 0.4$^b$ | 0.6$^d$ |

Native forest (NF), annual crop (Ac), perennial crop (PC) and pasture (PT). Averages followed by the same letter in the column do not differ statistically according to Tukey's test, considering a 5% probability.

**Table 4.** Fertility attributes at depths of 0 to 10, 10 to 20 and 20 to 40 cm under different land-use systems in the municipality of Alegre, Espírito Santo, Brazil.

| Land-use system | t | T | SB | V | m | ISNa | Fe | Cu | Zn | Mn | B |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | (cmol$_c$ dm$^{-3}$) | | | (%) | | | (mg dm$^{-3}$) | | | | |
| **0 - 10 cm** | | | | | | | | | | | |
| NF | 1.9$^c$ | 7.18$^a$ | 1.0$^b$ | 14.6$^c$ | 45.4$^a$ | 0.1$^b$ | 59.9$^b$ | 0.3$^c$ | 1.0$^b$ | 13.1$^b$ | 0.4$^a$ |
| AC | 4.2$^a$ | 6.0$^b$ | 4.2$^a$ | 69.9$^a$ | 0.0$^c$ | 0.8$^a$ | 43.9$^b$ | 1.1$^b$ | 4.1$^b$ | 83.6$^a$ | 0.1$^b$ |
| PC | 3.5$^b$ | 5.7$^b$ | 3.5$^a$ | 60.8$^a$ | 0.0$^c$ | 0.3$^{ab}$ | 40.9$^b$ | 3.6$^a$ | 17.0$^a$ | 114.2$^a$ | 0.1$^b$ |
| PT | 1.9$^c$ | 5.8$^b$ | 1.6$^b$ | 27.5$^b$ | 16.3$^b$ | 0.5$^{ab}$ | 85.2$^a$ | 0.7$^{bc}$ | 1.0$^b$ | 28.7$^b$ | 0.1$^b$ |
| **10 - 20 cm** | | | | | | | | | | | |
| NF | 1.5$^b$ | 1.5$^b$ | 0.6$^b$ | 10.5$^b$ | 60.0$^a$ | 0.1$^b$ | 48.3$^a$ | 0.3$^b$ | 0.6$^b$ | 5.0$^c$ | 0.3$^a$ |
| AC | 3.9$^a$ | 3.9$^a$ | 3.9$^a$ | 69.0$^a$ | 0.0$^c$ | 1.0$^a$ | 34.8$^a$ | 0.8$^b$ | 3.2$^{ab}$ | 56.0$^b$ | 0.1$^b$ |
| PC | 3.5$^a$ | 3.5$^a$ | 3.5$^a$ | 73.4$^a$ | 0.0$^c$ | 0.4$^b$ | 42.5$^a$ | 2.9$^a$ | 3.1$^a$ | 92.9$^a$ | 0.1$^b$ |
| PT | 1.4$^b$ | 1.4$^b$ | 1.0$^b$ | 21.9$^b$ | 25.8$^b$ | 0.6$^{ab}$ | 43.4$^a$ | 0.6$^b$ | 0.4$^b$ | 17.0$^c$ | 0.1$^b$ |
| **20 - 40 cm** | | | | | | | | | | | |
| NF | 1.3$^b$ | 1.3$^b$ | 0.5$^b$ | 9.4$^c$ | 64.2$^a$ | 0.9$^a$ | 42.5$^a$ | 0.3$^b$ | 0.4$^a$ | 3.2$^a$ | 0.3$^a$ |
| AC | 3.1$^a$ | 3.1$^a$ | 3.1$^a$ | 67.1$^b$ | 0.0$^c$ | 0.5$^a$ | 27.1$^a$ | 0.4$^b$ | 0.6$^a$ | 17.3$^a$ | 0.0$^b$ |
| PC | 3.1$^a$ | 3.1$^a$ | 3.2$^a$ | 82.9$^a$ | 0.0$^c$ | 0.4$^a$ | 35.2$^a$ | 1.3$^a$ | 1.8$^a$ | 29.5$^a$ | 0.0$^b$ |
| PT | 1.2$^b$ | 1.2$^b$ | 0.8$^b$ | 18.9$^c$ | 35.7$^b$ | 0.6$^a$ | 32.7$^a$ | 0.5$^b$ | 0.2$^a$ | 8.6$^a$ | 0.1$^b$ |

Native forest (NF), annual crop (Ac), perennial crop (PC) and pasture (PT). Averages followed by the same letter in the column do not differ statistically according to Tukey's test, considering a 5 % probability.

According to the CFSEMG (2009), the critical soil levels of micronutrients presented in the Table 4 are Fe = 30 mg dm$^{-3}$; Cu = 1.2 mg dm$^{-3}$; Zn = 1.5 mg dm$^{-3}$; Mn = 8.0 mg dm$^{-3}$; and B = 0.6 mg dm$^{-3}$. Thereafter, the evaluated soil in the different systems at several depths exhibit the following micronutrient deficiencies: Cu (in the annual crop and perennial cropping of coffee systems in the depth from 0 to 10 cm); Zn (in the native tropical forest and pasture systems at all depths, and annual crop at a depth of 20 to 40 cm); Mn (in the native tropical forest system at depths from 10 to 20 and 20 to 40 cm); and B (in all of the studied systems and depths).

The native tropical forest system presented a significantly higher value than in the annual crop, pasture and perennial cropping of coffee systems at depths from 0 to 10 cm (Table 4). At depths from 10 to 20 and from 20 to 40 cm, the annual crop and perennial cropping of coffee systems presented CEC values significantly higher than in the native tropical forest and pasture systems. The values of CEC numerically decreased in the soil profile. The saturation base (V) exhibited a significantly higher value in the annual crop and perennial cropping of coffee systems at all depths (Table 4). The values of base saturation, pH, Al, H+Al, Al saturation, Ca and Mg at depths from 0 to 10 and 10 to 20 cm were considered as expected.

## DISCUSSION

The significantly superior organic carbon (OC) in the native forest (NF) than in the annual crop (AC), perennial crop (PC) and pasture (PT) systems (Table 2) can be explained by the historically more intensive soil ploughing and consequently higher C loss by oxidation and erosion. However, when the use of the agricultural systems is balanced or organic, soil sustainability can be reached (Partelli et al., 2012; Evangelista et al., 2013).

For tropical soils that are not ploughed, there is a balance in the OC/TN relationship of approximately 10 to 15 (Stevenson, 1994). The low values in this relationship observed in the annual crop and perennial cropping of coffee systems may occur due to the high pH level and the lack of Al in the soil (Table 3), which are factors that benefit the increase in OM (Stevenson, 1994). Despite not having detailed information about handling the soil fertility in the systems that were cultivated with sorghum and coffee for a long period leading up to this experiment, it is possible to affirm that nitrogen fertilization that was performed over the years created favorable conditions for growth in the total nitrogen content and a consequent reduction in the values of the OC/TN relationship.

The systems with less intensive or no soil ploughing tended to maintain more OC, which was observed at depths of 10 to 20 and 20 to 40 cm (Table 2). According to Paul and Clark (1989), the augmentation of the organic carbon stock in soils subjected to more conservation systems may be associated with the physical protection of organic compounds against microbial decomposition, which benefit from the occlusion of organic carbon in the soil and result in the chemical protection of organic compounds due to the interaction of the latter with soil minerals and cations such as $Al^{3+}$ and $Fe^{3+}$, preventing organic carbon decomposition.

The significantly similar organic carbon stock in the pasture system to the native tropical forest system (Table 2), according to Rangel et al. (2007), may be associated with the developed root system and the well-distributed graminae under pasture, which benefits from subsurface carbon deposition in the form of roots.

In the analyzed soil depths, the lowest organic carbon stocks were generally observed in the systems that had greater soil disturbances. In the annual crop system, this was most likely the result of soil aeration and homogenization of the superficial layers by aeration and harrowing. Souza and Melo (2003), studying the impact of different systems in corn production on the dynamics of soil carbon, also observed lower organic carbon stock levels in conventional growing systems when compared to the obtained system values, in which the remains of the previous crops were the soil surface.

The generally same response pattern in total nitrogen as in organic carbon stocks (Table 2) can be explained by the greater amounts of total nitrogen in the soil (approximately 95%) found in association with organic matter. The rise in the total nitrogen stock in the native tropical forest and pasture systems was associated with the greater volume of plant debris that returned to the soil and also to the greater organic carbon stocks in these systems. In a Red-Yellow Argisol subjected to different cropping systems (mineral and organic fertilization), Leite et al. (2003) observed reductions in total nitrogen stocks by 37% in a sample without fertilization and by 15% in systems receiving organic fertilization, in relation to a reference system (native forest), indicating the occurrence of a lower loss of N in the system with greater contributions of organic matter. These results are similar to those of the present study.

For all of the analyzed depths, the active soil acidity (pH) in the native tropical forest system was expressed as ‘high,’ which was followed by the pasture system with active acidity that was expressed as ‘average’. In terms of significant differences, greater pH values were observed in the annual crop and perennial cropping of coffee systems at all of the studied depths.

The pH results reflected liming management in the different systems, which was absent on the forest and pasture lands but was regularly practiced in the annual and perennial cropping systems. The data also indicated advanced stages of weathering and low natural fertility in the analyzed soil. The Al present in the soil solution is hydrolyzed and releases ions H, which are responsible for an elevation in the soil’s active acidity. Another factor that can explain lower pH levels in the native tropical forest and pasture systems is their higher amounts of organic carbon (Table 2). Stevenson (1994) describes the ionization of hydrogen (H) in the carboxylic acid groups and mainly in the tertiary alcohols of organic matter that contribute to soil acidity.

The results of the present study are in line with those obtained by Candido et al. (2010), who evaluated the chemical characteristics of soils under coffee cultivation in the micro region of Caparaó, Espírito Santo, and who found pH values close to those presented in Table 3, in addition to low levels of soil fertility. Significantly, the data obtained indicate the need for the adoption of corrective practices on the pasture lands, which presented high acidity levels and a low Ca content.

The potential acidity (H + Al) followed a pattern similar to that observed for the pH values. The P levels in the soil were generally low. This indicates once more that the management of soil fertility in the pasture area was inappropriate, aside from the naturally low P levels in the soil. Similar results were obtained by Falleiro et al. (2003).

The significantly higher P levels in the annual crop and perennial cropping of coffee systems than in the native tropical forest and pasture systems were associated with the phosphate fertilizer applications. Tropical soils have low P levels because of weathering. In all systems, P decreased in the deeper layers, which can be explained by the greater contribution of organic matter in the surface soil depths (0 to 10 cm), which contributes to a greater availability of P at this depth, in addition to the top-dressing fertilisations and the low P mobility in the soil profile (Falleiro et al., 2003).

Given the importance of Ca and Mg for a good crop development, the results showed the need for additional inputs into the soil in the pasture systems (Table 3). Frazão et al. (2008) evaluated soil fertility in different management systems and also observed lower Ca and Mg levels in the natural and pasture systems. The low levels of these elements in the pasture soil are related to the last application of lime, occurring 18 years before at pasture planting.

The K levels in the annual crop and perennial cropping of coffee systems (Table 3) were similar to results reported in other studies, in which the greatest K concentrations were found in the surface layer of the soil (Santos and Tomm, 2003; Frazão et al., 2008). In the annual crop and perennial cropping of coffee systems, these results were directly associated with the contribution of potassium fertilisers, mainly KCl, which favoured the accumulation of K in the surface soil layers.

According to Silveira and Cunha (2002), the presence of organic matter in the soil is associated with the availability, amount and retention of micronutrients in the soil as B. The higher organic carbon levels in the native tropical forest system (Table 2) explain the higher B level in these soils. The considerably higher level of Cu and Zn in the perennial cropping of coffee system (Table 4) can be explained by foliar fertilisation and soil transport of micronutrients Cu and Zn, performed in isolation.

The significantly higher potential capacity (T) in the native tropical forest system can be explained by the greater contribution of plant residues deposited in the upper soils layers of the native tropical forest system, influencing the increase in organic matter levels at this depth and consequently the potential T. Costa et al. (2006), studying a Rhodic Ferralsol, observed that usage systems where there are greater plant residue inputs present a cation exchange capacity (CEC) that is higher compared to the others systems, which leads to better soil quality in terms of its physical and chemical attributes. The decreasing CEC values in the soil profile were in line with the results of Frazão et al. (2008).

In the annual crop and perennial cropping of coffee systems, there was no need to apply an acid soil corrective (limestone). However, in the pasture system, analyzing the same attributes as previously mentioned, there was an immediate need for intervention in the soil to correct for its acidity. Using the formula of liming need (LN) for the base saturation method and the soil data analysis at depths from 0 to 10 cm, considering that an appropriate base saturation is a good development indicator for pastures, which is expressed as 60% (Prezotti et al., 2007), a limestone with a PRNT ("Poder Relativo de Neutralização Total"; in English, Natural Power of Total Neutralisation) of 100% at a depth of limestone incorporation of 7.5 cm of the surface soil, it would be necessary to apply 720 kg of limestone per hectare on the pasture lands.

## Conclusion

The introduction of different systems culminated in the reduction of organic carbon and total nitrogen values, mainly at soil depths of 0 to 10 and 10 to 20 cm.

The stocks of organic carbon and total nitrogen in the soil at the analysed soil depths followed a descending order in relation to the reference system (NF> PC > AC > PT). On average, the percentage reductions in the organic carbon and total nitrogen stocks were 38 and 15%; 42 and 21% and; 8.3 and 3% in the perennial cropping of coffee, annual crop and pasture systems, respectively.

Among the land-use systems analyzed, the areas under native forest and pasture presented lower soil fertility.

## Conflict of Interest

The authors have not declared any conflict of interest.

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Vol. 10(7), pp. 668-676, 12 February, 2015
DOI: 10.5897/AJAR2014. 8509
Article Number: E4A4E2650370
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Engaging smallholder farmers with seasonal climate forecasts for sustainable crop production in semi-arid areas of Zimbabwe

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Received 14 January, 2014; Accepted 7 November, 2014

**Small holder farmers in the semi-arid areas have not been able to utilize seasonal climate forecasts in making crop management decisions due to limited exposure as well as failure to interpret it. Three participatory meetings were held with farmers in Lower Gweru and Lupane Districts of Zimbabwe soon after the release of the 2008/2009 and 2009/2010 seasonal climate forecast in September of each season. This was done to solicit for farmers' prediction of the coming rainy season and come up with field test crop management practices. Farmers have their sets of indicators that they rely on to forecast seasonal rainfall which are based on generations of past experience that include environmental, biological, and traditional beliefs. There is however, need to investigate how their indicators compare with the scientific forecast in making farming decisions. Farmers claimed that the rains were starting later and finishing earlier whilst analysis of the rainfall record showed that starting rains have been later by 5 to 10 days in the last five years. There was an increase in the number of dry spells in the rainy season in the last five years compared to the period 1980 to 2008. Adding recommended amounts of fertilizers resulted in yield increases of 40% compared to adding half the recommended amounts. Growing long season varieties resulted in higher yields (22%) than growing short season varieties in the 2009/2010 wetter season while growing of shorter season variety had yield advantage (36%) over the long season variety in the 2009/2010 which was relatively dry. Frequent weeding resulted in about 8% increase in maize yields compared to weeding once in a season. The study demonstrates that knowledge of the coming season assists smallholder farmers in coming up with adaptive strategies for climate variability and change.**

**Key words:** Seasonal climate forecast, agriculture, smallholder farmers, adaptation, semi-arid areas.

## INTRODUCTION

The severity, duration and frequency of droughts especially in Sub Saharian Africas' semi-arid areas is expected to increase due to climate change (Lasage et al., 2008). Climate variability and change directly affects

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agricultural production, as agriculture is inherently sensitive to climatic conditions and is one of the most vulnerable sectors to the risks and impacts of global climate change (Parry et al., 1999). Among the most vulnerable groups to the effects of climate variability and change are the small holder farmers who live in semi-arid dry communal areas and have the least ability to adapt to climate variability and change (IPCC, 2001, 2007). This makes smallholder farmers living in these marginal areas food insecure especially now with changing climate expecting to increase the frequency of droughts (Kalanda-Joshua et al., 2011). This implies that farmers have to take a number of crucial crop management decisions and land and water management decisions before and during the growing season, based on climate information (Sivakumar, 2006). It is therefore important for farmers to integrate the issues of climate variability into resource use and development decisions for a more informed choice of policies, practices and technologies that may reduce agriculture's long term vulnerability to climate variability and change (Sivakumar, 2006).

The introduction of seasonal climate forecast into management decisions can reduce the vulnerability of agriculture to droughts (Patt and Gwata, 2002) and reduce negative impacts. It is widely accepted that climate prediction information should be introduced into the planning process as an input into the design of adaptation/mitigation plans (Zievogel and Zermoglio, 2009; Sivakumar, 2006), and this should be embedded into existing strategies of individuals and communities including their use of indigenous knowledge systems in weather forecast (Prowse and Scott, 2008; Bharara and Seeland, 1994). For seasonal climate forecasts (SCF) to have an impact on decision making, they have to be reliable, timely, and appropriate in context and readily accessible (Challinor, 2008; McCrea et al., 2005). A study carried out by McCrea et al. (2005) shows that adoption and use of seasonal climate forecasts by farmers depends on the level of understanding of the forecast, the format of presentation of the forecast and the attitude of farmers towards the usefulness of the forecast as an indicator of future rainfall.

Seasonal climate forecasts have been used before to assist farmers in making appropriate crop management decisions (Patt and Gwata 2002; Carberry et al., 2002; Meinke and Hochman, 2000) including crop choice, choice of cultivar, fertiliser use, area planted to a given crop, timing and tillage type. Farmers who attended participatory training workshops on forecasts are significantly more likely to use the forecasts than those who learn of the forecasts through non-participatory channels (Ziervogel and Calder, 2003).

Some studies in Zimbabwe (Patt et al., 2005) and Brazil (Ziervogel and Calder, 2003), demonstrate that farmers who used seasonal climate forecast significantly improved their yields compared to their counterparts who did not use it.

There are several case studies where farmers have been engaged with improved management of risks under variable climate, but there has not been any quantitative evidence. Most studies report on how farmers who have undergone training on the use of SCF understand better on how to respond to SCF compared to their counterparts who did not undergo the training (Patt et al., 2005). Challinor (2008) argues that the most effective way to conduct pro-poor adaptation research may well be to take (from the onset) a holistic view that is informed by engagement and partnership with potential benefactors. Such projects should integrate indigenous knowledge systems and traditions of the benefactors (Nyong et al., 2007; Nyong and Kanaroglou, 1999).

Rainfall characteristics such as onset, ending, dry spells, rainfall intensity and rainfall amounts are showing signs of change in Zimbabwe. The smallholder farmers in Zimbabwe depend on rainfed agriculture which is vulnerable to low, erratic and variable rainfall. Decisions on crop management strategies are very important in such semi-arid areas and are potentially improved by seasonal climate forecast. The objectives of the study were to (i) compare and document farmers' perceptions of changing climatic conditions with measured weather data, (ii) compare climate predictions obtained from the scientific seasonal forecast with the indigenous seasonal prediction and (iii) come up with management options that respond to the seasonal predictions and compare the different options in field experiments.

## RESEARCH METHODS

### Study areas

The research was carried out in the 2008/2009 and 2009/2010 farming seasons in Lower Gweru and Lupane Districts in South-western Zimbabwe (Figure 1) which lie in Natural Region IV. In Lower Gweru, district, Nyama and Mudubiwa wards were chosen while in Lupane, Daluka nad Menyezwa wards were chosen. The sites were chosen on the basis that they are both in the semi-arid regions of the country dorminated by smallholder farmers. The natural regions are a classification of the agricultural potential of the country, from natural region I, which represents the high altitude wet areas to natural region V which receives low and erratic rainfall averaging 550 mm per annum (Vincent and Thomas, 1960). These two districts are located in the semi-arid areas which cover 75% of the country. These districts have an annual rainfall of less than 700 mm per year and a growing season of 90 to 150 days. Droughts occurs once in every three to five years in these districts. Rainfall is erratic and ill distributed in time and space resulting in frequent crop failures that occur three out of five years. In drier parts of Southern Africa, the coefficient of variation in annual rainfall is between 20 and 40%, while the variation in yield is from less than 15 to 60% with high implications on food security (Lumsden and Schulze, 2007). Land use in the districts is typical of communal lands with dryland crop production in the rainy season and animal rearing. Farmers are dependent on rainfed crop production. The commonly grown crops are maize, groundnuts, sorghum, pearlmillets and groundnuts.

To attest farmers' claim that climate is changing, historical rainfall data from 1980 to 2008 was obtained from Thornhill airbase in

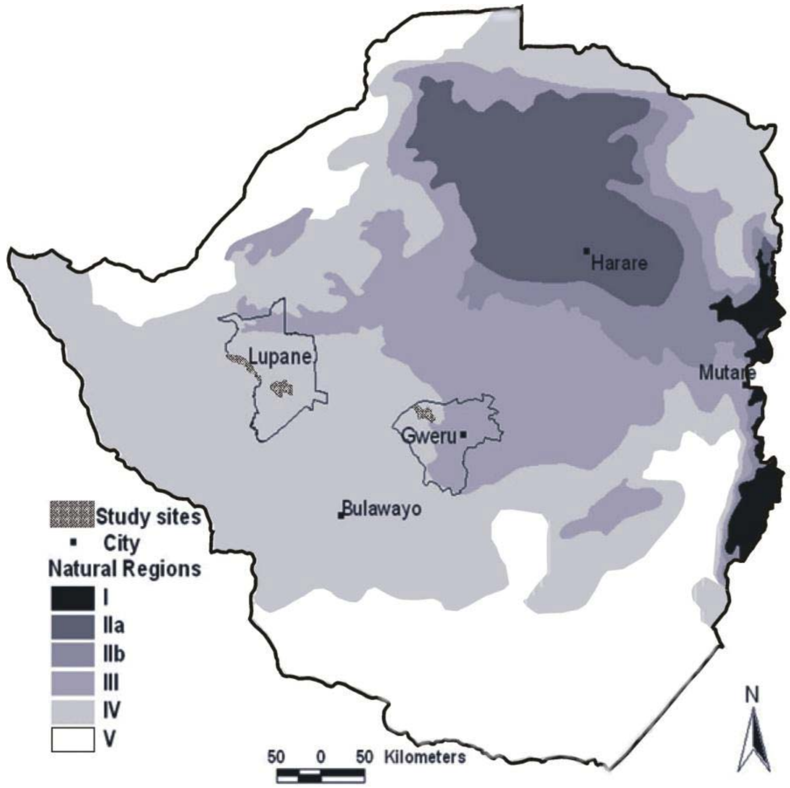


**Figure 1.** Map of Zimbabwe showing natural regions and locations of the study sites.

Gweru which is 20 km from Lower Gweru while that for Lupane was obtained from Lupani meteorological office. This data was used to determine starting dates, ending date and maximum length of dry spells within rainy seasons.

The seasonal climate forecasts of the study areas were obtained from the Zimbabwean Met department through the Southern African Regional Climate Outlook Forum (SARCOF) which coordinates the production of the SCF. The seasonal climate forecast is a product of pre-season forums that bring together climate experts involved in seasonal forecast development relevant to Southern African Development community (SADC) to develop the best forecast for the region through a consensus. The product that comes out of the SARCOFs is regional in nature covering the whole of the SADC. After the SARCOF, the national meteorological services, for example the Zimbabwean Meteorological Department downscales the regional product to their country-specific rainfall forecasts.

#### Participatory research with farmers

Three participatory workshops were held with farmers in each of the two districts to get an understanding of the farmers' perceptions of changing climate conditions, to document the indicators they use to come up with their forecast indigenous seasonal climate forecast (ISCF) and also to evaluate field experimental results based on decisions from their indigenous knowledge forecasts. The participating farmers came from two districts (Lower Gweru and Lupane), two wards per district and three villages per ward. Five farmers from each village were selected randomly making a total of 60 farmers who participated in the research. For their respective villages, farmers were asked to come up with prediction for the 2008/2009 and 2009/2010 seasons forecast using their local indicators –and their perceptions of changing climate conditions before they went into plenary to come up with a consensus of the seasonal climate forecast for the district. The indigenous seasonal climate forecast was compared with the seasonal climate forecast issued by the Department of Meteorological Services.

Farmers were then asked what management options they would take, given the seasonal climate forecast. In a participatory manner and together with the farmers, field experiments were designed with the aim of testing how farmers' variety selection, tillage method, and fertilizer type and amount decisions, based on the seasonal climate forecast, affect crop yields. Two experiments were planted out in each district for the two consecutive seasons. The 2008/2009 experiment had a split-split plot treatment structure arranged in a Randomised Complete Block Design (RCBD). Tillage was the main plot factor while variety was the sub-plot factor and fertilizer sub-sub plot factor.

The 2009/2010 experiment had a 2 x 2 x 2 x 2 factorial treatment structure arranged in a RCBD. For each treatment there were two tillage systems, two varieties, two fertilizer levels and two weeding times. The treatments were replicated three times.

## RESULTS AND DISCUSSION

### Farmers' perceptions of climate change

Farmers indicated that climate has been changing in the previous five years, in that rains start earlier, rains end latter and the maximum number of dry spells has

**Table 1.** Rainfall starting dates, ending dates and maximum length of dry spells in the last 5 years and between 1980 and 2008 in Lower Gweru and Lupane Districts.

| District | Lower Gweru | | | Lupane | | |
|---|---|---|---|---|---|---|
| (Median dates) | Rainfall onset | Rainfall ending dates | Maximum length of dry spells within rainy season | Rainfall onset | Rainfall ending dates | Maximum length of dry spells within rainy season |
| 1980-2008 | Nov 14 | Feb 22 | 16 | Nov 12 | Feb 9 | 18 |
| Last 5 years | Nov 5 | Mar 1 | 20 | Nov 22 | Mar 25 | 20 |

For dry spells: maximum length of dry spells (Dec 1 to Mar 31).

**Table 2.** Shows the indicators that farmers use to predict the rainfall season.

| Wet year | Drought year |
|---|---|
| (i) *Rhus Lancea* and *Lannea discolor* trees produces lots of fruits | (i) *Rhus Lancea* trees produces few fruits |
| (ii) *Azanza garkeana* do not fruit well | (ii) *Lannea discolor* produces fruits but aborts them |
| (iii) Heat wave experienced | (iii) Before the rains |
| (iv) Early haziness soon after winter | (iv) Extended winter period |
| (v) North easterly winds | (v) North easterly winds dominant |
| (vi) Frogs turning brownish | (vi) White frogs appear in trees |
| (vii) Water birds making a lot of noise | (vii) Lots of thunderstorm without rains |
| (viii) Butterflies seen hovering in the air from north to south starting in October | (viii) Early rains starting from early October |

increased. Comparison of the meteorological records with farmers' assessment of climate change showed a large disparity, with few of the stated changes being evident in the long term record. For example, farmers claimed that the rains were starting later and finishing earlier. Analysis of the rainfall record showed that starting rains (20 mm in 2 days) have been later by 5 to 10 days in the last five years compared to the 1980-2008 period at Lupane site but, for Lower Gweru District, it actually started earlier, by 9 days (Table 1). There was no evidence at any one site that the rain season was finishing earlier. Data on dry spells shows that there was an increase in the number of dry spells in the rainy season in both districts. This suggests that farmers might have poor memories of the rainfall variability over the longer term, and given their almost non-existent measurement of rainfall thereby highlighting the need to cross-check (with measured data) farmer derived information about perceived climate change. A similar result was obtained by Moyo et al. (2013) who observed that climatic data show no evidence that corroborates the farmers' perceptions.

## Comparison of scientific and indigenous forecasts with measured and long term rainfall records

Farmers use a variety of indigenous knowledge systems in predicting weather. Table 2 shows the various indicators used to predict whether the coming season is dry or wet in the two districts. The indicators that the farmers are using are similar to those that have been recorded by other researchers elsewhere in the country, Zambia and Malawi (Kalanda-Joshua et al., 2011; Chagonda et al., 2010; Mubaya, 2010).

The scientific seasonal forecast for Lower Gweru was Normal to Above Normal for the period October, November and December (OND) while normal rains were predicted for the period January, February and March (JFM) in the 2008/2009 season (Table 3). The forecast for Lupane was Normal to below normal for the period OND while normal to below normal rains were expected for the period JFM in the 2009/2010 season. In the 2009/2010 season, the forecasts were below normal to normal in the two districts for both periods OND and JFM.

There was impressive consistency between farmer predictions on seasonal rainfall using indigenous knowledge of environmental indicators and the actual rainfall totals. The indigenous knowledge system predicted a wetter 2008/2009 and drier 2009/2010 season while actual rainfall total was 944 mm for 2008/2009 and 562 mm for 2009/2010 season respectively. The SCF in 2009/2010 predicted normal to below normal rainfall, while farmers at Lower Gweru and Lupane also forecast a poor rainfall season using local indicators but actual rainfall totals were 505 and 617 mm at Lower Gweru and Lupane respectively for the two seasons. It is likely that the deviation of the observed and predicted rainfall could be on one hand due to the fact

**Table 3.** Comparison of scientific and indigenous forecasts with measured and long term rainfall records.

| Variables | 2008/2009 | | 2009/2010 | |
|---|---|---|---|---|
| | OND | JFM | OND | JFM |
| L Gweru | Above Normal | Normal | Below Normal to Normal | Below Normal to Normal |
| Lupane | Normal to Below Normal | Normal to Below Norma | Below Normal to Normal | Below Normal to Normal |
| Farmer | | | | |
| Prediction for both Lower Gweru and Lupane | Wet | | Dry | |
| Actual rainfall | 784 mm (Lower Gweru)<br>1105mm (Lupane) | | 505 mm (L Gweru)<br>617 mm (Lupane) | |
| Long term rainfall range | Lower Gweru 650 – 800 mm<br>Lupane 450 – 650 mm | | | |

**Table 4.** Treatments for the trials in the two districts during the 2008/2009 and 2009/2010 seasons.

| Variables | 2008/2009 | 2009/2010 |
|---|---|---|
| Tillage | CP<br>Ridge | CP<br>Ridge |
| Cultivar | SC403, SC513, OPV | SC403, SC513 |
| Fertility | 0, 4.2 tons manure,31 kg/ha N, 66 kg/ha N | 31 kg/ha N, 66 kg/haN |
| Weeding | non | 1 weeding<br>2 weeding |

CP- conventional ploughing, SC403 Very early maturing maize variety (110-120 days), SC513 early to medium maturing maize variety (120-130 days). OPV: medium to long season variety (125- 140 days).

that the scientific forecasts could not be downscaled enough to capture variation over a small area which could be too coarse to address local farmers' needs (Mahoo and Mpeta, 2010).

Scientific seasonal forecasts generally have greater accuracy for drier seasons that are associated with El Nino events in Southern Africa (van Heerden et al., 2002; Nicholson and Selato, 2000; Lindesay et al., 1986). The 2009/2010 season was El Nino and it was better predicted than the 2008/2009 season by the scientific climate forecast and therefore influenced the prediction of normal to below normal rainfall over Zimbabwe. However, the 2009/2010 season was predicted dry by the indigenous knowledge forecast and the observed rains were below the normal range which is consistent with the scientific forecast's normal to below normal rains.

## Response to seasonal climate forecasts

Table 4 shows the management options that farmers in the two districts settled in order to respond to the 2008/2009 and 2009/2010 seasonal climate forecasts. Some of the treatments are different in the two years since the forecasts were different hence different management practices were proposed by the farmers in response to the forecasts therefore inter-seasons results cannot be compared.

The 2008/2009 season was predicted to be above normal in the first half and normal to below normal in the second half of the season. Farmers decided to have fertility treatments so as to try different levels of nitrogen fertilizers and manure. The reasons for the inclusion of the manure treatment was twofold; 1) to demonstrate the usefulness of the material as a fertilizer for crop production, and 2) to demonstrate that it can be a cheaper alternative source of plant nutrients that can cut down the fertilizer cost. Farmers recognized that soil water management to retain most of the rainfall was very important so as to maximize water use efficiency they therefore decided to have tied ridges (Table 4). Since the season was predicted to be normal to above normal in

**Table 5.** OND and JFM rainfall for the 2008/209, 2009/2010 and historical records (1950-2005) for Lupane and Lower Gweru respectively.

| Variables | 2008/2009 | 2009/2010 | Long term | 2008/2009 | 2009/2010 | Long term | Long term totals |
|---|---|---|---|---|---|---|---|
| | OND | OND | OND | JFM | JFM | JFM | |
| Lupane | 331 | 231 | 208-258 | 453 | 351 | 333-385 | 450-650 |
| Lower Gweru | 445 | 222 | 201-300 | 403 | 280 | 301-401 | 650-800 |

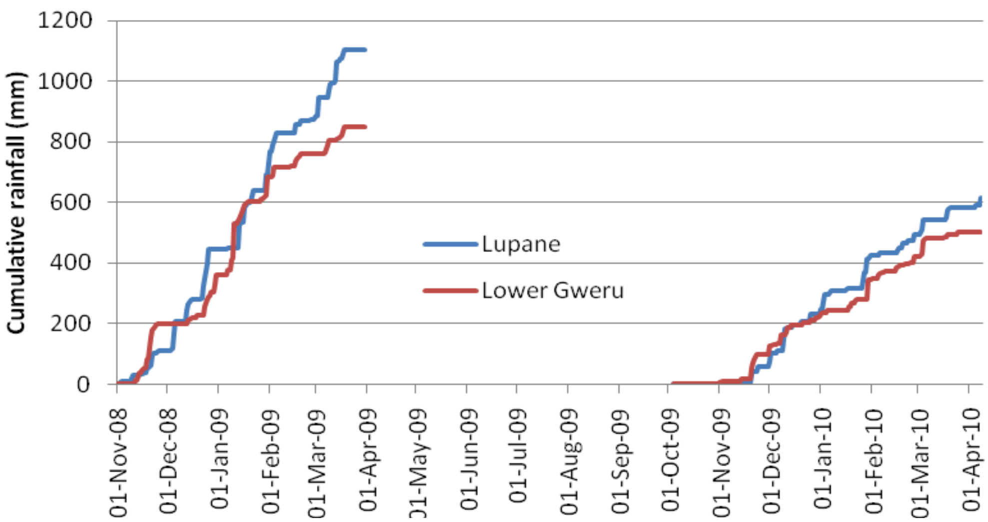


**Figure 2.** Cumulative rainfall in Lupane and Lower Gweru District.

the first half and normal to below normal in the second half of the season, a short season variety was expected to do well hence “SC403” was chosen and compared with a long to medium season variety. An open pollinated variety was chosen because farmers had poor access to hybrid seed, and because they wanted to compare its performance with the hybrids in a season that was not that good.

The 2009/2010 season was predicted to be below normal to normal in both OND and JFM. Farmers came up with varying strategies that ranges from growing of short season cultivars, small grains, water harvesting techniques, planting with the first rains, deep ploughing, stagger planting, application of lower than recommended fertilizers, thorough weed management among others. Low fertilizer levels were chosen since low rains were expected while weeding was very important to reduce moisture competition between crops and weeds. They maintained short season varieties (SC403) that mature early and compared it with a medium season variety (SC513). Tied ridging to capture *in-situ* rainfall was also recommended during this season.

Farmers came up with different management practices for the two years that were contrasting in climate. For instance the use of a short season variety irregardless of forecast outcome, would ensure that they at least are assured of some harvest. This shows that they are risk averse and would want to minimize losses. Sivakumar (2006) observed that farmers have to take a number of crucial crop management decisions and land and water management decisions before and during the growing season, based on climate information. Hansen (2005) and Huda et al. (1991) demonstrate that the ability to understand, monitor and predict weather provides an opportunity to evaluate alternate management strategies for decision-making that takes advantage of good years whilst minimizing losses during unfavorable years.

## Field experimentation

### *Recorded rainfall*

Figure 2 shows the cumulative rainfall for the two study sites. The rainfall totals for 2008/2009 were 1105 and 784 mm for Lupane and Lower Gweru respectively. The OND and JFM rainfall totals were above the long term range for both Lupane and Lower Gweru during the 2008/2009 season while they were within the long term range during the 2009/2010 season in Lower Gweru only (Table 5). In 2009/2010 total rainfall was 617 and 503 mm respectively for Lupane and Lower Gweru Districts.

**Table 6.** Effect of fertiliser levels on maize yields during the 2008/9 and 2009/10 seasons in Zimbabwe.

| Treatment | 2008/2009 | | | 2009/2010 | | |
|---|---|---|---|---|---|---|
| | Daluka | Nyama | Mudubiwa | Daluka | Nyama | Mudubiwa |
| 67 kg/ha N | 4.06[a*] | 1.60[a] | 3.82[a] | 1.446[a] | 1.900[a] | 0.331[a] |
| 31 kg/ha N | 3.34[ab] | 0.873[b] | 2.78[b] | 0.975[b] | 1.242[b] | 0.164[b] |
| Manure | 2.760[b] | 0.641[bc] | 1.50[c] | | | |
| Zero N | 2.140[b] | 0.414[c] | 1.13[c] | | | |
| *LSD | 0.898 | 0.319 | 0.595 | 0.297 | 0.390 | 0.101 |

*Number with the same letter are not significantly different, LSD: Least Significant Difference.

**Table 7.** Effect of weeding times on maize yields during the 2009/2010 season in Zimbabwe.

| Treatment | Daluka | Nyama | Mudubiwa |
|---|---|---|---|
| | 2009/2010 | 2009/2010 | 2009/2010 |
| Weed 1 | 1.033[a] | 1.567[a] | 0.193[a] |
| Weed 2 | 1.388[b] | 1.583[a] | 0.252[b] |
| LSD | 0.297 | 0.390 | 0.101 |

*Number with the same letter are not significantly different.

**Table 8.** Effect of varieties on maize yields during the 2008/2009 and 2009/2010 seasons in Zimbabwe.

| Treatment | 2008/2009 | | | 2009/2010 | | |
|---|---|---|---|---|---|---|
| | Daluka | Nyama | Mudubiwa | Daluka | Nyama | Mudubiwa |
| SC403 | 3.4[a] | 0.905[a] | 2.54[a] | 1.23[a] | 1.858[a] | 0.253[a] |
| SC510 | 2.73[a] | 0.880[a] | 2.16[a] | 1.2[a] | 1.283[b] | 0.242[a] |
| OPV | 3.1[a] | 0.861[a] | 2.22[a] | | | |
| LSD | 0.660 | 0.276 | 0.515 | 0.297 | 0.390 | 0.101 |

*Number with the same letter are not significantly different.

***Experimental results***

Adding recommended amounts of nitrogen (67 kgN/ha) gave significantly higher yields than adding low fertilizers levels, manure and no nitrogen at all in the sites except during the favorable 2008/2009 season when between 800 and 1100 mm of rainfall was received in Daluka ward (Table 6). No significant differences in yield were recorded between adding recommended amounts of nitrogen and adding low amounts of nitrogen (31 kgN/ha) during this season. 2008/2009 was a wetter year and we would have expected yield differences between adding 67 and 31 kgN/ha of nitrogen. Adding 67 kgN/ha of fertilizers gave significantly higher yields than adding 31 kgN/ha of nitrogen at all the three sites during the 2009/2010 season.

Weeding two times gave significantly higher yields than weeding once at Daluka and Mudubiwa while there were no significant differences at Nyama (Table 7). It has been observed that weed competition results in crop yield losses hence weed control improves maize yield grain (Abouziena et al., 2008; Dalley et al., 2006). There were no yield differences attributed to variety in both seasons and at all the three sites (Tables 7 and 8) during the 2008/2009 season and the 2009/2010 season accept at Nyama where the short season variety (SC403) outperformed the medium season variety (SC513).

The treatments that were recommended by farmers for adapting for below average season did not perform better than those that were meant for an above average season. For example, the recommended fertilizers levels resulted in better yields than low fertilizer levels that are meant for below average rainfall predicted in 2008/2009 season but ended up having higher than expected rainfall amounts. Studies elsewhere have demonstrated that there are no yield gains emanating from adding high amounts of fertilizers in drier seasons and differences are only obtained in wetter seasons (Mburu et al., 2011).

However, the short season varieties that are meant for below average season outperformed the long season varieties possibly because of the short length of the growing season. The suggested tied ridges and ripping that are meant to increase soil moisture under drier conditions did not give yield differences because the tied ridges were destroyed by heavy downpours during the early part of the seasons.

## Conclusions

Farmers can only forecast a wet or dry season from their indicators while the scientific SCF indicate whether is normal, below normal or above normal for two periods of the rainy season, OND and JFM. Results from this study demonstrate that, in the absence of the scientific SCF, farmers can use ISCF which has proved to be consistent with each other in the two years. It is also important that SSCF and ISCF be integrated thereby imbedding adaptation strategies in communities' existing knowledge of climate variability and indigenous prediction systems which is being recommended by Huq and Reid (2007).

The study demonstrates that seasonal climate forecast is an ideal entry point for bringing meteorological officials, researchers and extension agents together in working with the farmers in coming up with crop management practices that respond to the seasonal climate forecast thereby increasing their crop yields. From discussions held with the farmers and the nature of experiments proposed by the farmers, in response to the 2008/2009 and 2009/2010 forecasts (both modern and indigenous knowledge), it was evident that farming decisions are influenced by the seasonal climate forecast which include decisions on the following: choice of crop and variety, tillage systems to use, planting date, fertilizer amounts to use and when and how to weed.

## Conflict of Interest

The authors have not declared any conflict of interest.

## ACKNOWLEDGEMENTS

This publication is an output from a project funded by CCAA/IDRC and DFiD (Grant number 104144). The views expressed are not necessarily those of CCAA/IDRC/DFiD. The authors would particularly like to thank the communities who participated in the research for their assistance.

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Vol. 10(7), pp. 677-684, 12 February, 2015
DOI: 10.5897/AJAR2013. 7229
Article Number: 7859ACA50376
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Conservation for livelihood improvement through cooperation of rural communities and the related externalities: A case of Moepel farms in Limpopo Province, South Africa

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Received 17 April, 2013; Accepted 16 June, 2014

**Optimal use of land in rural areas has the potential to reduce poverty and attain rural economic development. Conservation with tourism benefits could potentially reduce poverty in rural areas where agricultural potential is limited. However, land use conflicts exacerbated by multiple interests for land use are prevalent and can hinder rural development. This paper explored the potential for rural communities to cooperate with each other to establish a conservation project in South Africa. Data were collected through several ways including focused groups and semi structured interviews with forty-six members of three communities which were beneficiaries of the land restitution programme. The study determined benefits from livestock and tourism land uses under different scenarios and interactions of decisions among the three communities were analysed using game theory. The analysis revealed that opting for tourism would allow the communities to earn seven times more than for livestock farming and that development of tourism through their cooperation could constitute a good option for the community development. However for cooperation to work, there would be need to address pressing issues for the communities. Such analysis can assist communities to make informed decisions on alternative sources of income and their related payoffs. Landscape scale management can also benefit from such analysis.**

**Key words:** Land use, tourism development, livestock farming, Moepel farms, game theory.

## INTRODUCTION

Rural poverty is a major obstacle to development in South Africa. The poverty head count in some rural areas is as high as 98% as compared to 44% for the national average (PROVIDE, 2009). Most rural households depend on agriculture for livelihoods and employment (Shackleton et al., 2001), relying on land classified as communal and registered in the name of the state. Communal tenure constitutes 12.2% of the total land in South Africa, with 83% of the rural population residing on it (Isaacs and Mohamed, 2000). Tenure insecurity in

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communal areas leads to problems such as inadequate legal recognition of communal tenure systems, abuse by powerful elites, and breakdown of the old permit-based system, among others (Ntsebeza, 2002; Cousins, 2002). These problems result in conflicting claims to land and bitter disputes over authority, which hampers development efforts such as infrastructure and service provisions (Cousins and Claassens, 2006; Peires, 2000). According to Cousins (2007), “the tensions normally occur between local government bodies and traditional authorities over the allocation of land for development such as: housing, irrigation schemes, business centres, and tourist infrastructure”. Moreover, tenure insecurity and lack of well-defined property rights, among others, exacerbate the land use conflicts in communal areas (Claassens, 2003).

Land use conflicts are further exacerbated by multiple interests for land use in these rural areas. Wildlife tourism is seen by many development organisations as a potential source of rural economic development and poverty alleviation, particularly in marginal rural areas where agricultural potential is limited (Barnes, 1998; Mahony and Van Zyl, 2002; Muchapondwa, 2003). Although, wildlife often has a complementary role to play in relation to agriculture when it comes to households livelihood diversification (Barnes, 1998; Ashley and LaFranchi, 1997), it directly competes with other land uses (Cousins, 2009; Skonhoft and Schulz, 1996). For this reason, various stakeholders intending to initiate any rural development projects need to reach a consensus as to what land use option is economically viable, ecologically sustainable and socio-politically acceptable given the context of the communities in question (Colyvan et al., 2011; Muchapondwa, 2003). This is vital because the solutions or strategies to rural development are context bound in most cases. Furthermore, the choice of land use option should not only be economically viable, but should also be environmentally viable in order to promote sustainable land use (Munthali, 2007).

Analysis of institutional frameworks, arrangements and decision-making in communal areas can inform land use choices made. This includes the definition of rights and obligations of different stakeholders involved. However for this to happen, the driving forces behind the use of these resources need to be well understood and the conditions under which the optimal use of these resources can be realised known prior any development of rural communities (Pearce, 1996). For wildlife tourism, the habitat needed is often much larger than the property of individual agents. As a result, people have to cooperate to get the most out of their resources. For rural communities to secure continued access to benefits and to be motivated to sustainably manage the resources, capacity of local institutions representing them need to be enhanced. Community-private partnerships which are functional and legally binding are needed to ensure tangible benefits from biodiversity conservation by these rural communities (Munthali, 2007). However, the Interaction of stakeholders (particularly rural communities) can be influenced by their location in relation to others or it can be induced by the incentive to realise economies of scale in dealing with comparable problems. Moreover, location is important because the benefits from wildlife tourism depend on the contiguity of the wildlife area (Skonhoft and Schulz, 1996). Lastly, poverty further complicates the issue because poor people may be less inclined to postpone consumption for a future benefit than less poor people.

Considering the potential of conservation through yielding of tourism benefits and the fact that often people have to cooperate to get the most out of their resources, it is necessary to understand the dilemma facing the rural communities when cooperating for establishment of conservation. Furthermore, the benefits from tourism investments require a waiting period as they do not materialise in the short term as is the case with agriculture. Previous studies on the impact of tourism development on the rural people (Ashley et al., 2001; Mahony and Van Zyl, 2001; Roe et al., 2001a, b; Mahony and Van Zyl, 2002) did not consider the dilemmas that rural communities face when they wish to cooperate to establish conservation yielding tourism benefits.

This paper explores the potential for rural communities to cooperate with each other to establish conservation projects in the presence of positive externalities. We consider the case of Moepel Farms (which are owned by three communities, namely; Motse Molekwa and Legata) in Limpopo Province of South Africa. See some background information about the Moepel Farms in the research methods section. Specifically, the study describe how the location of the different farms relative to each other influences the possibilities of cooperation and interactions of the three communities and identifies optimal land use option(s) to make the three communities realise economies of scale. The following questions are addressed: First, how does the location (that is, spatially dispersed or concentrated) of the case study farms influence possibilities for cooperation in tourism development? Second, to what extent are rural communities willing to cooperate in conservation to benefit from tourism? Last, to what extent are some communities willing to gain buy-in of 'unwilling' communities into cooperation?

## METHODS

### Study area

Whilst, the main objective of many developing countries remain to be the reduction of abject poverty, recognition of balancing this objective with natural resource conservation is on rise. Therefore, it is important for countries to strive for successful delivery of socio-economic and conservation benefits at local level. In South Africa, different instruments for landscape-scale management includes “World Heritage Sites, biodiversity initiatives transfronteir conservation areas and biosphere reserves” (Pool-Stanvliet, 2013).

This author indicates that biosphere reserve concept embraces most of the essential principles of the major landscape-scale management initiatives and is internationally designated by UNESCO. Currently, South Africa has six UNESCO designated biosphere reserves and one of them is the Waterberg Biosphere Reserves located in Waterberg District of Limpopo Province designated in 2001 (Pool-Stanvliet, 2013). Biosphere reserves are defined as "...areas of terrestrial and coastal/marine ecosystems or a combination thereof, which are internationally recognised within the framework of UNESCO's programme on Man and the Biosphere (MAB)" (UNESCO, 1996). Although, concept of biosphere reserve has the potential to allow for interconnectedness between people and nature thereby representing sites for sustainable management; there are other pressing issues like poverty, job creation, etc. that need attention in South Africa (Pool-Stanvliet, 2013). Therefore, understanding several issues to be considered as biosphere reserve and/or any other instruments becomes part of landscape-scale management initiatives in some areas is necessary.

It is within this context that that the study seek to understand the potential for rural communities to cooperate with each other to establish conservation projects in the presence of positive externalities using the case of Moepel Farms. Moepel farms are located in the Waterberg District Municipality in Limpopo Province of South Africa. This municipality covers 4 951 882 ha of land with a population of 596 104 (Waterberg District Municipality, 2010). Moepel farms belong to Motse, Molekwa and Legata communities, recent recipients of land in the Waterberg through the land restitution process. Although, these farms were previously devoted to cattle and crop farming and these communities have expressed intentions to dedicate their farms for conservation and ecotourism (De Klerk, 2002; Waterberg Meander Brochure, 2009). Different types of activities, both consumptive and non-consumptive which ranges from tourism to hunting, birds viewing and ecotourism developments have been identified (Waterberg Meander Brochure, 2009). Moepel comprises of 14 specific farms which are referred to collectively as Moepel farms throughout this paper. Twelve of these specific farms are owned independently by the three communities, namely: Motse, Molekwa and Legata; owning six, four and two farms, respectively. Figure 1 shows which community owns which farm, how these farms are located spatially and total hectares for each farm. The carrying capacity of these farms measured in large stock units (LSU) ranges from 8 to 30 ha/LSU for cattle and 11 to 40 ha/LSU for game.

As can be seen from Figure 1, the different farms are (A) Klipbank (2360 ha); (B) Schurwepoort (2110 ha); (C) Hottentots Holland (2791 ha); (D) Varkfontein (2195 ha); (E) Riebeek West (2204 ha); (F) Baklyplaats (2488 ha); (G) Zandput (2304 ha); (H) Zuurfontein (2070 ha); (I) Rhenosterfontein (2324 ha); (J) Hopefield (2753 ha); (K) St. George (2353 ha); and (L) Lusthof (2280 ha).

#### Research approach

The study used both qualitative and quantitative methods of research. The research team had a meeting with the Limpopo Department of Economic Development and Tourism (LEDET)[1] officials where the research objectives were discussed and a common understanding was reached on what was expected from the research team during the study period and at the end of the study. A general idea of what was happening within the three communities to enable preparation for the field work was established through the first visit in a workshop between LEDET, 3 communities represented by Communal Property Associations (CPAs)[2]., Limpopo Regional Land Claims Commission (LRLCC)[3], Limpopo Tourism and Parks (LTPs)[4] and Non-Governmental Organisation, Khulile Africa[5]. The communities were informed about the field study to be undertaken in their area via their CPAs committee members and the government officials. Key informant interviews was held with officials from LEDET, LDA[6], LRCC and LTP and semi-structured interviews with households within three communities who are beneficiaries of the land restitution programme[7]. The main purposes of these interviews were to explore specific experiences of individual households and to document the stories of selected households. Respondents were asked questions related to their goals and objectives in relation to Moepel farms development; rights and obligations with regard to land use decisions in Moepel Farms; and perceived opportunities and challenges with regard to Moepel Development Initiative. Two focused group discussion (one before household interviews and one after) were held to triangulate some information gathered from the semi-structured interviews. Most of the data was collected between October and December 2009. Follow up visits to fill information gaps and to verify some of the findings were done in January 2010. Interview data was analysed manually as the sample size was small and data collected was not complex and involves community perceptions on possibility of conservation and tourism land use.

In order to understand the extent to which the three communities were willing or 'unwilling' to cooperate to realize conservation benefits, game theory was applied. Game theory is defined by Mas-Colell et al. (1995) as the study of strategic decision making including the mathematical models of conflict and cooperation between intelligent rational decision-makers and is useful in analysing interactions between decision makers (that is, communities in this case) (Chew et al., 2009). The theory has been applied to conservation problems (Harsanyi, 1967; Harsanyi, 1968; Harsanyi, 1968a; Walters, 1994; Milner-Gulland and Mace, 1998; Bimonte, 2008; Magombeyi et al., 2008; Chew et al., 2009) except that the scope has been limited. Moreover, game theory has proved to be a handy tool in different biodiversity conservation planning and modelling contexts (Frank and Sarkar, 2010) and can further be used to compare different land use option scenarios (whilst taking into account the interaction among players) and the related costs and benefits. In this study, game theory was used to analyse the various strategies and resulting pay-offs of the three communities when they cooperate in establishing conservation.

## RESULTS AND DISCUSSION

### Community perceptions on possibility of conservation and tourism land use

There were differences in attitudes towards prospects for

[1] LEDET is one of the government departments in the Limpopo Province of South Africa with a mandate to develop the province's economy and to promote and manage the environmental and tourism activities

[2] CPAs which are statutory institutions associated with representing communities and their communally held assets on communal lands

[3] LRLCC is the arm of the Department of Land Affairs is responsible for the development of land and their targets are claimants of land, mainly being rural communities

[4] LTPs is a parastatal organisation and its mandate is "to promote, foster and develop tourism
to and within the Limpopo Province".

[5] Khulile Africa is an NGO which deals with rural community development

[6] LDA is one of the government departments in Limpopo Province responsible for the development Agriculture ( Mokopane branch was visited as it was closer to the study area and possibly servicing the respondents)

[7] The land restitution programme is one of the pillars of South African Land Policy which aims to restore land to those communities or people who were disposed of land after 19 June 1913 as a result of past racially discriminatory laws or practices (i.e. Native Land Act of 1913)

**Table 1.** Possible income from different land use options, minimum size of hectare required and present value income from Moepel farms at 12% discount rate and waiting period of 0 and 4 year(s) for livestock and tourism, respectively.

| Land use options | Fixed incomes R/ha | Min size of ha required | Waiting time | PV/ha for years 1-4 | PV/ha of year 5 onwards | PV/ha total |
|---|---|---|---|---|---|---|
| Livestock | 100 | 1500 | 0 | 303.73 | 529.60 | 833.33 |
| Game | 700 | 2000 | 4 | 0 | 3 707.19 | 3707.19 |
| Hotel | 2000 | 6000 | 4 | 0 | 10 591.97 | 10 591.97 |
| Reserve | 10000 | 20000 | 4 | 0 | 52 959.84 | 52 959. 84 |

development of conservation and tourism land uses in the three communities. In Molekwa and Motse, there was a general positive attitude towards the idea of developing tourism, irrespective of the waiting time for benefits to be realised. The communities indicated that conservation and tourism development was the only viable land use option in their farms. We gathered that the positive attitude was a result of a study by De Klerk (2002) which illustrated that agriculture was unsuitable in this area. The study found that only small patches in Moepel had grass suitable for cattle and the area was also mountainous making it unsuitable for cattle production. Thus, the communities were convinced that conservation and tourism development was the only viable land use at Moepel, with potential for employment creation, income generation and poverty alleviation. At the time that this study was conducted, the Motse and Molekwa communities had already removed their livestock from the concerned farms to pursue conservation and tourism development. Consequently, waiting time for tourism benefits did not seem to be a problem with this community. These two communities also had alternative land outside Moepel where they could still practise their livestock farming whilst waiting for tourism to yield benefits.

In Legata, although community members were generally aware that the benefits of conservation and tourism were greater than that of livestock, the time scale and sharing of benefits (that is, in case of cooperation with other communities) made them sceptical about the former land use practice. They raised concerns that conservation and tourism take time to show benefits in contrast to livestock benefits which could be enjoyed ‘‘now’’. Thus, this community was likely to opt for livestock in the absence of incentives to wait for tourism income. In addition, they indicated unemployment as a challenge and without alternative means to get some income were unlikely to prefer waiting for benefits.

To determine the potential gains from the different land uses, a number of land use scenarios were considered. These were; (i) Livestock only with communal grazing livestock system; (ii) Fully developed game farm with wildlife viewing options (iii) a five star fully developed ecotourism lodge with wildlife viewing and up market accommodation and; (iv) A mega reserve established in the form of private-public-community partnership involving the community, government and private companies. The plan is to transform the Moepel farms into community owned eco-tourism destination of note in the Waterberg biosphere and create a government and community conservation partnership as the basis for a successful biodiversity and tourism destination. Mr. Du Toit Malan, a Planning and Development Manager at LTP was interviewed[8] and gave official estimates of fixed incomes per ha for alternative land uses (see first 3 columns of Table 1). The table shows that income from tourism could be 7 to 100 times higher than income from livestock. The Mega Reserve had the potential to give the highest income as compared to other tourism land uses. However, in order for the mega reserve to be possible the minimum land size was 20 000 ha (LTP1), which meant the three communities individually did not qualify it.

Considering waiting period of four years, column five in Table 1 shows that there is no income from tourism land uses. Potential incomes from tourism and livestock in the beginning of year 5 are given in present value terms, using a discount rate of 12%. The sixth column shows the potential income from both livestock and tourism at the beginning of year 5 and the seventh column gives the total present value terms of the estimated potential income per ha.

Table 2 gives an overview of the potential revenues associated with different land use that the three communities are likely and able to choose given the minimum ha size of land at their disposal individually and their rationality in maximizing their incomes. The revenues used in this study were calculated by multiplying the area of the farms by the income per hectare of a particular land use. The last column of Table 2 shows the land use with the highest revenues that each community can achieve individually when other factors (that is, discount rate and waiting time) are not considered. However, time factor cannot be ignored when judging/evaluating decisions as it plays an important role in making decisions regarding whether to consider some development or project initiative over the other (Pearce and Turner, 1990). With Moepel Farms, this was largely explained by the fact that farms of these communities were not yet fully developed, hence the time

[8] Limpopo Tourism and Parks (LTP), interview with Mr Tu Toit Malan, 29-01-2010.

**Table 2.** Potential income from the farms of the three communities individually and their related possible land use options.

| Name | Size | Community | Livestock | Game | Hotel | Reserve | Best land use |
|---|---|---|---|---|---|---|---|
| Schurwepoort | 2110 | Motse | 0.21 | 1.48 | 4.22 | 21.10 | H |
| Klipbank | 2360 | Motse | 0.24 | 1.65 | 4.72 | 23.60 | H |
| Hottentots Holland | 2791 | Motse | 0.28 | 1.95 | 5.58 | 27.91 | H |
| Varkfontein | 2195 | Motse | 0.22 | 1.54 | 4.39 | 21.95 | H |
| Riebeek West | 2204 | Motse | 0.22 | 1.54 | 4.41 | 22.04 | H |
| Baklyplaats | 2488 | Motse | 0.25 | 1.74 | 4.98 | 24.88 | H |
| Zandput | 2304 | Molekwa | 0.23 | 1.61 | 4.61 | 23.04 | G |
| Zuurfontein | 2070 | Molekwa | 0.21 | 1.45 | 4.14 | 20.70 | G |
| Rhenosterfontein | 2324 | Molekwa | 0.23 | 1.63 | 4.65 | 23.24 | G |
| Hopefield | 2753 | Molekwa | 0.28 | 1.93 | 5.51 | 27.53 | G |
| St George | 2353 | Legata | 0.24 | 1.65 | 4.71 | 23.53 | G |
| Lusthof | 2280 | Legata | 0.23 | 1.60 | 4.56 | 22.80 | G |

L = Livestock, G = Game, H = Hotel, R = Reserve.

consideration was vital. Therefore for this study, waiting time was assumed to be fixed at 4 years for tourism and 0 years for livestock whilst the discount rate was varied from 12 to 0% and 12 to 24%.

Based on the results of the interviews with the three communities and analysis of benefits in Tables 1 and 2, we analyse three land use scenarios. The first scenario considers the three communities maximising revenues independently. For this scenario, it is assumed that each community maximizes its revenue irrespective of any minimum income restrictions during the waiting time, thus communities are willing and able to temporarily forgo consumption in the short term if it is compensated by higher income in the long term. Rationally, the three communities will choose the land use options as indicated in Table 2 column 8, as it is the highest each can achieve individually.

In second scenario we determined what land use option the three communities would choose to maximize revenues independently subject to the condition that income must be greater than or equal to an assumed minimum income at all times. The underlying assumption here was that these communities will opt for tourism if they are having alternative ways to obtain the minimum income whilst waiting for tourism income in four years or if they can receive some form of incentives for waiting such as some social grants. As can be seen from the interview results, Legata was one community which stated that they would prefer the land use options which will give them an income at all times (that is, not willing and able to wait).

## GAME THEORETIC ANALYSIS

### *Interactions between the three communities*

The fact that these three communities reallocate their land use practise when subjected to the condition of minimum income has implications for several things. For example, whilst pursuing conservation and tourism as land use practice will be ecologically and economically beneficial, the specific farms of Molekwa community are not located next to each other. This will pose some challenge when this community wants to fence its farms, especially if both Motse and Legata communities opt for livestock.

The location of these farms possibly call for cooperation between the two communities, Legata and Molekwa (Figure 1). Considering the preference of the Legata community for livestock, Molekwa community may consider paying Legata community to go for tourism. Alternatively, Motse and Molekwa could both opt for tourism and then further decide to disregard Legata or to pay Legata to go for tourism. Of the potential businesses or development that can be pursued in Moepel Farms, the mega reserve gives the highest income (Table 1). However, for the mega reserve to be of use, the land should be at least 20 000 ha which none of these communities have on their own.

Therefore, through interaction analysis, this paper first established how one community's decisions impact the others' payoffs for any of the two land use options; next the nash equilibrium that comes out of that, third if the nash equilibria are not yielding the largest total income how can the problem be solved and maybe in this case the last step may involve payments from one community to another. The payment decision depends on three questions: how much will Motse and Molekwa pay maximally to persuade Legata to go for tourism, how much will Legata have to be paid minimally to go for tourism instead of livestock and can Molekwa and Motse afford the payment?

For example; if we assume that Legata's coalition partner pays Legata to bridge the income gap between year 0 and 5, then the PV of the payment would yield

**Table 3.** Interactions among the three communities, strategies pursued, the potential payoffs in present value, and annual side payments.

| Coalition | Land use | PV | Annual side payment as % of livestock income |
|---|---|---|---|
| **Motse community** | | | |
| Motse; Molekwa; Legata | H | 149 855 162.89 | - |
| (Motse, Molekwa); Legata | R | 749 275 814.44 | - |
| Motse; (Molekwa, Legata) | H | 149 855 162.89 | - |
| (Motse, Legata); Molekwa | H | 148 447 958.94 | 0.33 |
| (Motse, Legata, Molekwa) | R | 748 570 617.45 | 0.20 |
| **Molekwa community** | | | |
| **Coalition** | **Land use** | **PV** | **Annual side payment as % of livestock income** |
| Motse; Molekwa; Legata | G | 35 036 641.26 | - |
| (Motse, Molekwa); Legata | R | 500 523 446.58 | - |
| Motse; (Molekwa, Legata) | H | 98 697 485.36 | 0.49 |
| (Motse, Legata); Molekwa | G | 35 036 641.26 | - |
| (Motse, Legata, Molekwa) | R | 500 052 368.21 | 0.20 |
| **Legata community** | | | |
| **Coalition** | **Land use** | **PV** | |
| Motse; Molekwa; Legata | L | 3 860 833.33 | |
| (Motse, Molekwa); Legata | L | 3 860 833.33 | |
| Motse; (Molekwa, Legata) | H | 50 479 791.57 | |
| (Motse, Legata); Molekwa | H | 50 479 791.57 | |
| (Motse, Legata, Molekwa) | R | 245 132 009.52 | |

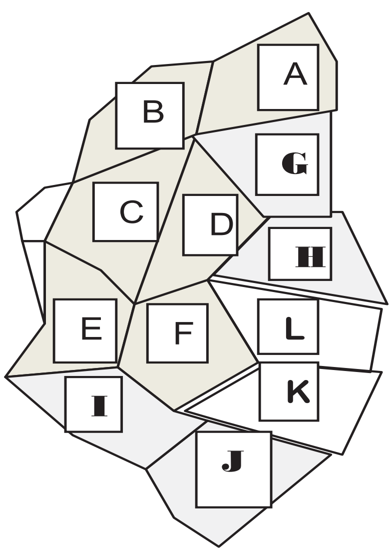


**Figure 1.** Moepel farms: Communities (Motse = A-F, Molekwa = G-J, Legata = K-L).

1407 203.93. Therefore, Motse and Molekwa can share the burden of paying Legata proportionally to their size. However, this is unrealistic since Molekwa and Motse are poor themselves. For this reason, we also calculated how much of their current livestock income they would lose if they have to fully compensate Legata for any loss of income. Table 3 presents the possible strategies that can emerge from the cooperation of the three communities and the related payoffs. This table further shows how much compensation (in the form of side payment) is needed if Molekwa and Motse need Legata's buy-in and cooperation.

The work of this paper is in line with Bimonte (2008), Magombeyi et al. (2008), Mahony and Van Zyl (2002) and Muchapondwa (2003). Bimonte demonstrated why an unsustainable path may emerge even when both players prefer preservation to exploitation and no free ride incentive exists and continued to addresses some policy issues to prevent the dreaded result that non-cooperative behaviour would yield. For instance, Legata community (despite their knowledge of tourism benefits relative to livestock) was less inclined to wait for future benefit (from tourism) and therefore indicated a preference for land use option which will give them an income at all times. Moreover, the result of this study concur with Pool-Stanvliet (2013)'s study which indicated that persistent issues like poverty, unemployment, overpopulation, etc. in South Africa demand urgent attention prior to consideration and perhaps the support of any/most sustainable land management strategies such as biosphere reserve. Magombeyi et al. (2008) explores how the application of games can be used as a tool to facilitate negotiations and rules of equal access among upstream and downstream irrigation water users in Ga-Sekororo, South Africa. The idea was that through games, communities would be able to better relate with their realities as presented by other stakeholders. From the analysis in Tables 2 and 3, the 3 communities can use those results to facilitate their negotiations on the possibility of cooperation and partnerships. Mahony and Van Zyl (2002) analysed the extent to which tourism projects in South Africa have improved the livelihoods of rural communities and contributed to rural economic development. Muchapondwa (2003) analysed the economics of wild tourism in Zimbabwe and its potential to reduce risks in agricultural production. He argued that farmers could manage risks of drought in agriculture through diversification into wild conservation whilst they contribute to efforts to conserve wildlife. The result of this study shows that the income from tourism could be 7 to 100 times higher than income from livestock. Therefore, if three communities can forge partnerships with other stakeholders and be able to cooperate with each other, successful nature-based tourism and ecotourism ventures could be established, thereby contributing to both poverty reduction and conservation.

## Conclusion

This paper explored the potential for rural communities to cooperate with each other to establish a conservation project which yields tourism benefits in the presence of positive externalities and their abject poverty in South Africa. The study achieved this by first identifying with the relevant stakeholders of the two proposed land use options (livestock and conservation which yield tourism benefits). Therefore, this study determined which of the two land use has the potential to give highest revenues (and under what conditions). From the interview results and determination of potential revenues, it was evident that opting for tourism would allow the communities to earn seven times more than by opting for livestock farming. In spite of the existing tourism potential, there is scepticism among the communities due to the fact that tourism is profitable only in the long run. The implication is that if the sceptical community cannot buy-in into cooperation, then they are likely not to cooperate and this will result in all the communities receiving lesser revenues than they would if coalitions were achieved. Game theoretic analysis of interactions of the three communities revealed that at best, if Molekwa and Motse share the burden of paying Legata to help Legata bridge the waiting period (or even lending Legata the money), they would miss one fifth of what they earned from their Moepel property as livestock farmers. Thus, it is evident that the development of tourism through a strong cooperation among the communities could constitute a good option for the community development, particularly where livestock production alone is not adequate for alleviating poverty of rural communities.

The findings of this study further pose some policy implications for government and other developmental advocates. First, it is important to enhance the participation of the main beneficiaries (that is, communities) as these communities have an imperative role to play in biodiversity conservation (Berkes, 2007); particularly making them aware of the benefits of conservation. Second, it is relevant to inform the communities on the alternative sources of income and their related payoffs so that they can make informed decisions. Finally, in areas where agriculture potential is limited, those policies and strategies that enhance wildlife conservation with social welfare should be considered.

## Conflict of Interest

The authors have not declared any conflict of interest.

## ACKNOWLEDGEMENTS

The authors gratefully acknowledge comments on earlier drafts of this article by Rolf A. Groeneveld, Wageningen University. The usual disclaimer applies.

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Vol. 10(7), pp. 685-689, 12 February, 2015
DOI: 10.5897/AJAR2014. 9084
Article Number: 2561CA250381
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Crop water requirement determination of chickpea in the central vertisol areas of Ethiopia using FAO CROPWAT model

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Received 20 August, 2014; Accepted 22 January, 2015

**Chickpea (*Cicer arntimum*) is one of the major grain legumes with an inimitable sources of dietary protein in the developing world where there is very scarce animal protein or unaffordable expensive otherwise. Ethiopia is considered as one of the secondary centers of genetic diversity for chickpea. The crop has been grown for multiple purposes since antiquity in the country. Chickpea production under residual moisture is a common practice in the central highland vertisol areas of Ethiopia. The importance of the crop in the Ethiopian diet has also been significant. Despite the huge importance of the crop as dietary item and land improvement, the yield and production of the crops is still blew the expected level in Ethiopia. Thus, producing chickpea either under full or supplemental irrigation could help in improving the productivity of the crop to contribute in increased production in the area. Determination of the crop water requirement of the crop for this particular growing area is therefore paramount importance for proper planning of chickpea production using supplemental irrigation. In view of this, the crop water requirement of chickpea was estimated using the FAO CROPWAT 8.1 Software and long term weather data record where the planting date is simulated to be 24 December. The assessment has showed that the net irrigation requirement of the crop is 37.2, 114.4, 205.2 and 79.8 mm during seedling, vegetative, late (maturity) growth stages of the crop, respectively. The irrigation requirement of the crop for a single growing season as revealed by the program is estimated to be 436.7 mm.**

**Key words:** Chickpea, crop water requirement, vertisol.

## INTRODUCTION

Chickpea (*Cicer arietinum* L.) is an ancient legume crop believed to be originated in South East Turkey, and the adjoining part of Syria (Singh, 1997; Lev-Yadun et al., 2000). It is the fourth most important food legume with a total annual global production of 9.1 million M tones from 11.2 million ha (FAO, 2009). Besides being an important source of human and animal food, chickpea also plays an important role in the maintenance of soil fertility, particularly in the dry, rainfed areas (Saxena,et al 1996, Katerji et.al., 2001). In Ethiopia, chickpea is widely grown

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across the country and serves as a multi-purpose crop. It is one of the major grain legumes with an inimitable sources of dietary protein in the developing world where there is very scarce animal protein or unaffordable expensive otherwise. Ethiopia is considered as one of the secondary centers of genetic diversity for chickpea.

In many regions where food legumes are grown, the climate is characterized by extremely variable and often chronically deficient rainfall. In such environments both agricultural scientists and farmers seek to identify crop and soil management techniques which make the maximum use of this scarce resource (Cooper et al., 1998). Major chickpea producing countries (FAO, 2003), where the crop is generally planted after the main rainy season and grown on stored soil moisture, making terminal drought stress a primary constraint to productivity (Serraj et al., 2004).

Similarly, despite the huge importance of the crop as dietary item and land improvement, the yield and production of the crops is still blew the expected level in Ethiopia (Kassie et al., 2009). Among other factors, the use of irrigation practices to grow the crop is critically low in the country. Chickpea cultivation is solely dependent on the soil moisture reserve where planting is made late during the recession of the main rainy season to escape the water lodging conditions. But, the flowering and pod setting stages appear to be the most sensitive stages to water stress (Nayyar et al., 2006). Limited irrigation to adequately meet the crop needs at critical stages of growth and development may be crucial for realization of yield potential of chickpea varieties. Thus, to match, the ever increasing national demand, growing chickpea under irrigation has to be the top and urgent priority agenda.

In any planning attempt for exercising irrigation, determination of crop water requirement of crops is the primary job in the crop production industry. As the information on crop water requirement of chickpea is severely limited, the objective of this current was to estimate the optimum crop water requirement of the crop using a model, CROPWAT model.

The latest version of model, namely CROPWAT v8 includes a simple water balance model that allows the simulation of crop water stress conditions and estimations of yield reductions based on well-established methodologies for determination of evapotranspiration (FAO, 2006) and yield responses to water. This model utilizes soil, crop, and weather databases to simulate multiyear outcomes of climate change scenarios and various crop management strategies. The model also allows the development of recommendations for improved irrigation practices.

## MATERIALS AND METHODS

This study was conducted at DebreZeit Agricultural Research Center, located at Central highlands of Ethiopia and situated between 38’051’43’.63” to 39’004’58”E and 8’046’16.20” to 8’059’16.38”N, in the Western margin of the great East African Rift Valley (Figure 1).

Long term weather record (1973-2007) from DebreZeit Agricultural Research Center’s archive for precipitation, relative humidity, windy speed, minimum and maximum temperature have been used for this study for estimating the reference evaptranspiration of the study site. The soil physical properties of the study site were determined using the proper lab procedures. The FAO CROPWAT 8.1 program was employed for estimating the daily, monthly and seasonal crop water of the crop. The irrigation scheduling scenario for the crop was also developed based on the program, the FAO CROPWAT 8.1.

## RESULTS AND DISCUSSION

The precipitation deficit during the selected (December 12 as planting date) growth stages for Chickpea is comparatively as high as 130 mm which is supposed to be more than one third of the crop water requirement of the crop (Figure 2). The least deficit in precipitation during this same period is 120 mm (in April). The model also revealed that during the main rainy season, the month of September need to be monitored as it exists moderated deficit (22 mm), that is, proper planning of agronomic practices (particularly planting date) is crucially important.

The highest crop water requirement of the crop is at around sixty days after planting (5.6 mm perday) or 56 mm perdecade (ten days sum). The crop water requirement on basis of stages: the initial stages requires 37.2 mm, while the subsequent stages, development, mid and late stages demand 114.4, 205.2 and 9.8 mm each respectively (Figure 3).

If one is to irrigate one hectare of land to grow Chickpea, the total irrigation water required will be around 4370 cubic meters of water for a single season.

Considering the planting date selected, the frequency of irrigation during initial has to be twice, three times during development, four times at mid stage and three times at late stage.

Once irrigation has started after the soil is irrigated to field capacity in this case, the soil moisture depletion level should be monitored properly. This is because lack of adequate soil moisture in the seedbed is a major hindrance to the establishment of chickpea crop. In addition, inadequate soil moisture can reduce seed germination, low down seedling growth and diminish yield in rainfed crops (Sharma, 1985). For instance, at the initial stage, the depletion level has to be as low as 40 mm per meter. In other words, after 25 days of the first cycle of irrigation, the soil moisture depletion level reaches 40 mm per meter. This corresponds to the remaining moisture in the soil is nearly 60% of the total available water. Thus, at this stage the next irrigation should be applied (Figure 4). Similarly, during flowering and yield formation, the soil moisture can be kept at 40% of the total available moisture.

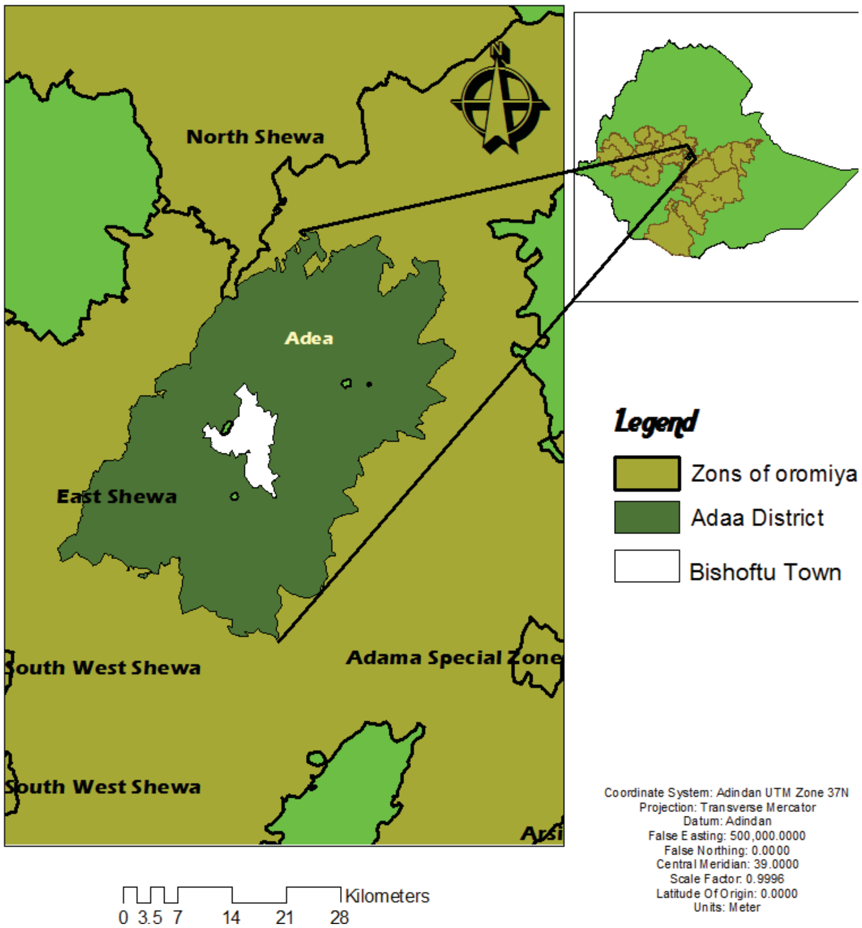


**Figure 1.** Location map of Adaa District and Bishoftu Town, West Shoa Zone, Oromia.

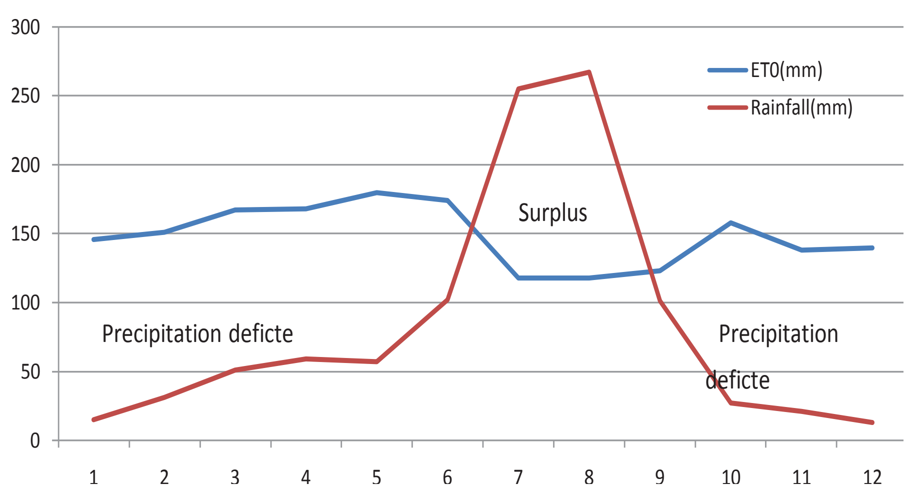


**Figure 2.** Precipitation Vs. reference evapotranspiration.

In an effort to assess the supplementary water need for the rainfed, considering the planting dates: July 1, 15, 30 and August, 1, 15, 30, the irrigation requirement varies from 134 to 372 mm in tier respective orders (Table 1).

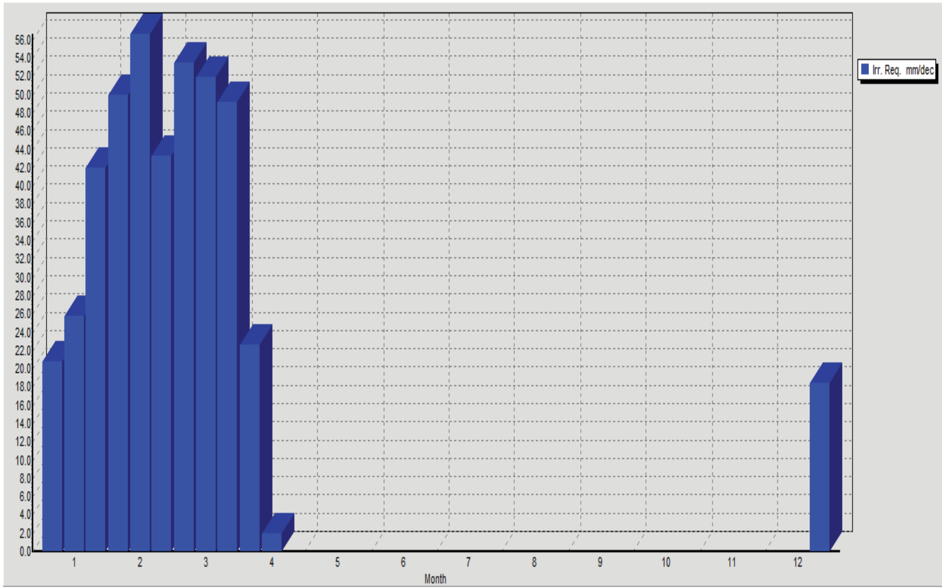


**Figure 3.** Crop water requirement of chickpea after planting (FAO CROPWAT model.

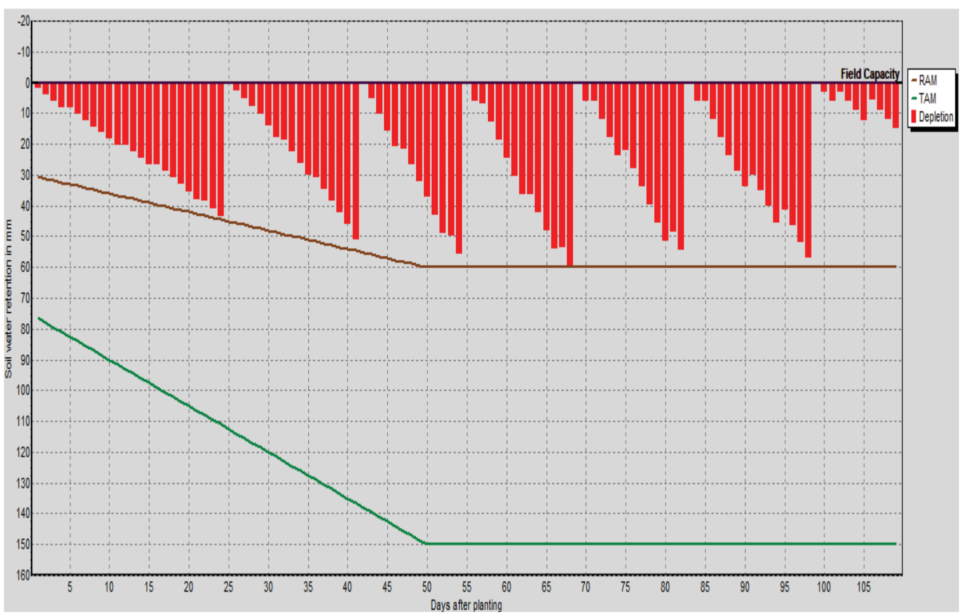


**Figure 4.** Irrigation scheduling scenarios for chickpea.

**Table 1.** Crop water requirement under different planting dates.

| Planting dates | Irrigation requirement (mm) |
|---|---|
| 01-Jul | 134 |
| 15-Jul | 212 |
| 30-Jul | 282 |
| 15-Aug | 336 |
| 30-Aug | 372 |

This result may indicate that planting after 30th July should be properly attended if the crop is to grow only under rainfed conditions.

## Conclusions

The crop water demand of chickpea for a single is season with reasonable full irrigation can be as high as

437 mm or 4370 cubic m of water for a ha. The optimum soil moisture depletion level for the vegetative stages should not exceed 60% of the total available water and 40% for flowering and yield formation. The model also reveals that irrigating twice to field capacity during vegetative; three to four times during the rest of the stages is optimum. Planting date for the main rainy season should also be monitored with possible care. Under full irrigation scenarios, the agronomic practices (planting dates) and other physiological aspects have to be integrated with either variable, particularly temperature, as some of the growth stages (flowering and grain setting) are sensitive to higher temperature. As this is only preliminary information from the model, field validation of these results should be a follow up work of this study.

## Conflict of Interest

The authors have not declared any conflict of interest.

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academicJournals

Vol. 10(7), pp. 690-696, 12 February, 2015
DOI: 10.5897/AJAR2014. 9165
Article Number: C66F66350386
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Implication of Bakolori dam irrigation activities on its physical resources

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Received 20 September, 2014; Accepted 22 January, 2015

**Amidst positive effects of irrigation, there are some negative effects which potentially appear in irrigation areas. The most important are water erosion on sloping fields; caused by depreciating irrigation structures, resulting in siltation of water canals, growth of weeds, debris and other materials that has capacity to inhibit flow of water. This in turn affects surface and ground water quality. The soil physico-chemical property analysis reveals that soil samples taken from the irrigated field contains high phosphorus and potassium. Also, the levels of copper, total nitrogen and cadmium were above the acceptable limit in all locations where samples were collected compared to others. This may be due to accumulated residues of agro-chemicals used in the irrigated fields. The water physico-chemical properties demonstrated that potassium and chemical oxygen demand concentrations are beyond the permissible limit in almost all samples collected; even with water sample collected at the reservoir, which could be the resulting effect of fertilizers from the Bakolori Irrigation project. This can be inferred from the level of algae around the river banks. This paper presents result of soil samples, surface and ground water quality in Bakolori irrigation project and recommended measures for further action to preserve its physical resources.**

**Key words:** Bakolori, irrigation, dam, surface water quality, ground water quality.

## INTRODUCTION

Bakolori is the name of a rural community in Sokoto State in North Western Nigeria. Sokoto State was one of the largest States in Nigeria until Kebbi and Zamfara States were carved out in 1991 and 1997 respectively (Mohammed, 2002). Given the abundant water resources in the country and its potential for increasing agricultural production in Nigeria, Federal Government of Nigeria established Sokoto Rima River Basin Development Authority (SRRBDA) to mitigate effects of persistent dry spells in the area, that results from too short rainy season that occur in the area. It was against this background that the Bakolori Irrigation project was commission. The original goal of the Bakolori irrigation project was to supply irrigation water to the estimated population of about forty to fifty thousand farm families in the project area. Construction work for Bakolori Irrigation Dam started on 5th June 1975 and was substantially completed and commission on 9th April, 1983. (Mohammed, 2002; Sokoto-Rima River Basin Development Authority, 1992).

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Bakolori Reservoir is being fed by Rivers N'kaba and Tarka within Niger and join river Rima after entering Nigeria. The reservoir has a capacity of 450 million $m^3$, lake area and length of 8000 Ha and 19 Km and a spillway discharge of 1650 $m^3$/s at the time of construction in 1979. The dam had 450 million cubic meters water storage capacity, was substantially completed by 1983 but its current capacity is estimated at 351,010,027 $m^3$ in 2013 (Sokoto-Rima River Basin Development Authority, 1992; Enplan Group, Nigeria, 2013; USAID, 2010; FAO, 2004).

The Bakolori Irrigation Scheme (BIP) is under the Sokoto-Rima River Basin Development Authority (SRRBDA) which is a Federal Government Agency. The Bakolori irrigation project covers three local government: Talata Mafara, Bakura and Maradun, commanding 23000 hectares; 65% irrigated by sprinkler system (15000 ha) while the gravity fed surface irrigation is used in the remaining 8,000 ha hosting more than 22,000 farmers located 110 km Southeast from Sokoto city. Presently the irrigation area under gravity is 7039 Ha for surface and converted sprinkler areas, while the non-irrigable area is 15,961 Ha which is mainly sprinkler and some surface area (Enplan Group, Nigeria, 2013; USAID, 2 010; Kebbeh et al., 2003). There are 3 Piezometric towers and 24 pumping Station which has depreciated to a state of disrepair over the last 20 years; about 3000 ha of the sprinkler irrigation scheme have been converted to surface irrigation through the provision of tube wells and intentional opening of lined canals. Therefore, a large section of the secondary canal needs rehabilitation (USAID, 2010; Kebbeh et al., 2003).

Several setbacks within the system were observed, among which are: Complete non-functioning of the hydro electric power station at the Dam. Failed sprinkler system originally covering 15000 hectares of which 3000 ha is now converted to surface irrigation through the use of tube wells. The failed dyke close to the rice area needs urgent intervention, de-silting of the drainage ditches across gravity fed areas needs to be done, because it has made the drainage ditches indistinguishable from adjacent farm lands; hence farmers now use drainage section for farming operations which was not the primary purpose which was rather to remove excess water from the system. Over-land flow is now a common site which is detrimental to crop-yield, keeping root zone too-moist for optimum performance (USAID, 2010).

Irrigation projects can fail if sediment load of water supply is higher than the capacity of irrigation canals to transport sediment; also siltation in canals shortens the active life mostly in tertiary canals as observed in the project. The gates of Bakolori Irrigation project and some sections of the secondary canals need to be rehabilitated. The drainage ditches are filled with sediments in specific areas around the system, hence increasing the salinity level of surrounding farmland which was the out-cry of farmers during consultation with farmers. The Dam, reservoir and irrigation works have suffered from lack of maintenance and currently there may be some degree of siltation of the reservoir, poorly drained areas within the command area; because of this development, the world Bank proposes to fund the rehabilitation of BIP, which has to be subjected to established Environmental procedures (USAID, 2010), pursuant to those procedures, activities that have potential for significant impact within a country require the preparation of an Environmental Assessment (EA) and subsequent approval of the EA and its recommendation to mitigate potential adverse effects. In view of these, there is need for an irrigation impact assessment (component of Environmental impact assessment) on the physico-chemical properties of farmland, surface and ground water quality, so as to ascertain the suitability in alternative uses in the project area, since there is no evidence to justify different urban and rural water quality standards ( Elizabeth et al., 2014).

## MATERIALS AND METHODS

### Topography

The project site is nearly gentle and undulating, Bakolori lies between N12.51185° and E 6.1824° at 341 m above sea level in the North Western Nigeria, shares common boundary with Niger Republic in the North and Benin Republic in the West. The 15000 ha dedicated to sprinkler irrigation seems to be at higher elevation compared to the gravity fed irrigation system. However, due to the slightly varied slope of the canal, resulting sediment transport will pose no significant impacts to topography if sediment is removed from the drains.

### Meteorological data for Bakolori irrigation project

Mean annual rainfall of the project area shows a slow but consistent increase in trend from 1981 to 2009, ranging from 500 to 1300 mm with the last few years witnessing increasing annual rainfall as shown in Figure 1. Relative humidity ranges from 40 to 80% at what times of the year? however in the last decade as shown in Figure 2. Monthly evapotranspiration reaches its peak in March 155.2 mm and begins to drop reaching its minimum at the height of the rainy season in August (88.1 mm) as indicated in Figure 3. The highest temperatures of the air are between March and May as shown in Figure 4

### Soil

Sandy loam soils (terrace) are dominant on the slopes while the floodplains are dominated by black soils originally laterized (USAID, 2010). Salinity may occur as a result of the following in the project area:

1. Salts carried in the irrigation water which are liable to build up in the soil profile
2. Solutes applied to the soil as result of fertilizers, herbicides, pesticides etc
3. Salts already in the soil profile as a result of ground water associated with water logging which is very severe in arid areas

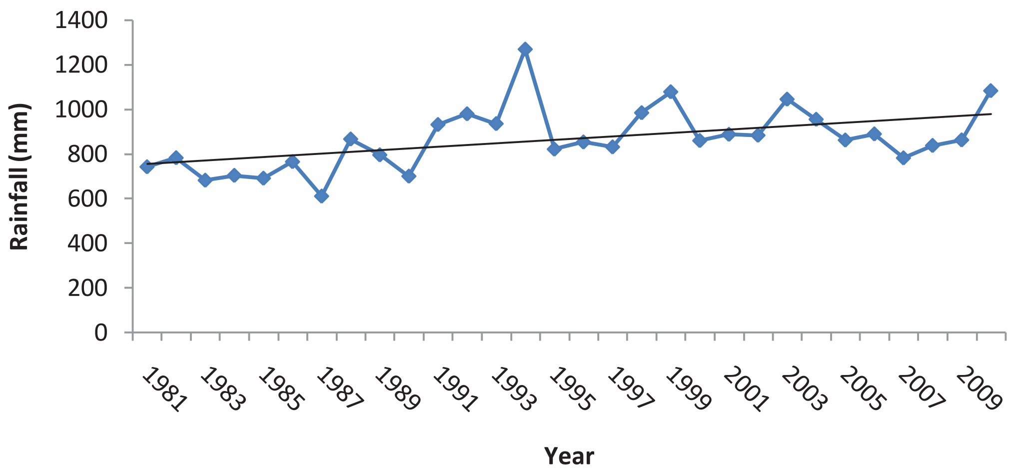


**Figure 1.** Annual rainfall for study area.

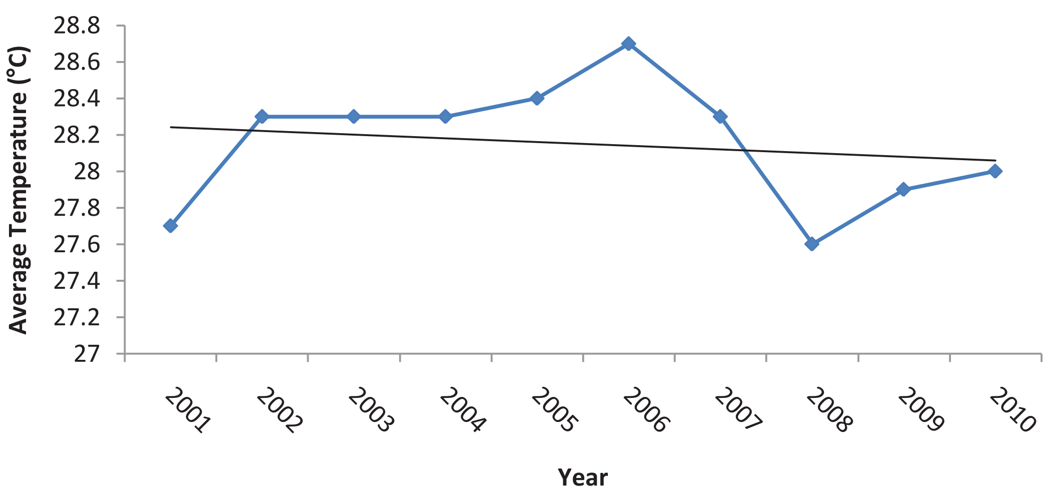


**Figure 2.** Annual average temperature for the zone.

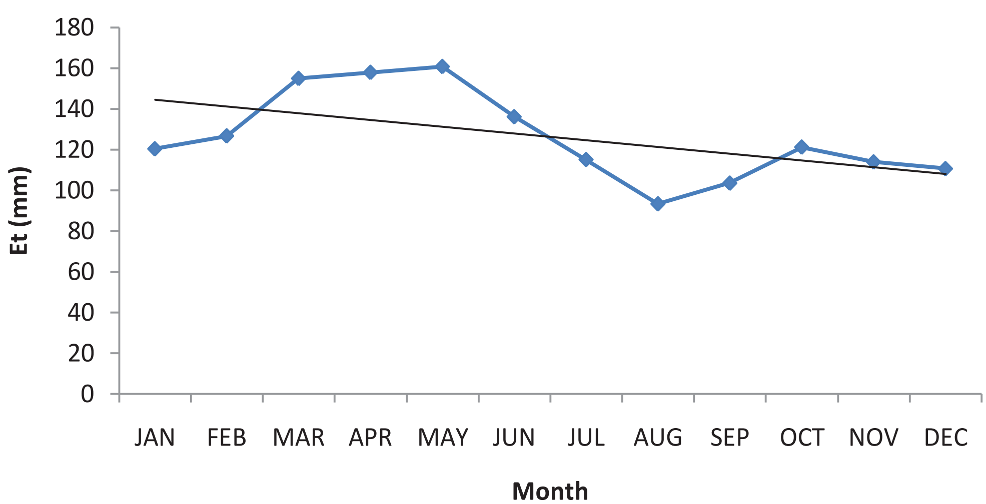


**Figure 3.** Monthly evapotranspiration values for study area.

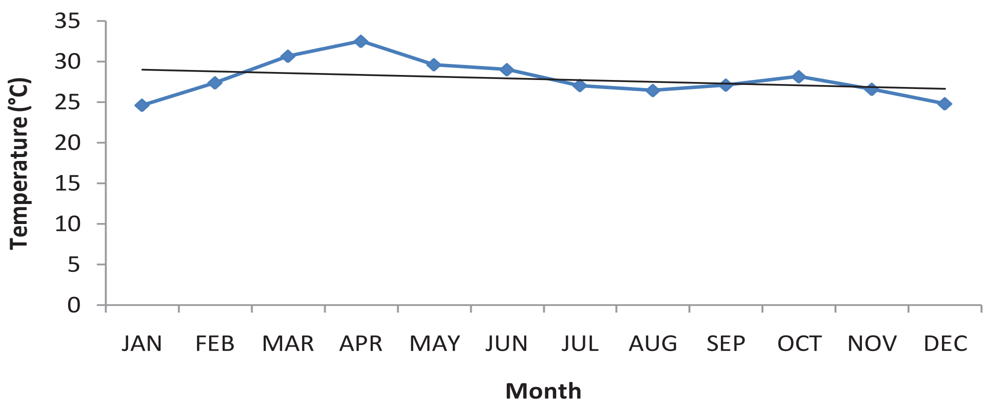


**Figure 4.** Average monthly temperature for the zone.

4. Humidity-salinity bridge when a farmer transfer from rainfed to irrigation (USAID, 2010; British Geological survey, 2003).

### Soil samples

Comprehensive soil evaluation is essential for successful management of irrigated areas. The cultural practices and farming activities carried out by farmers in the project area has altered the physico-chemical properties of the soil which may be due to the inappropriate application of organic and inorganic fertilizer to the soil during (USAID, 2010).

Investigation of the top soil physical and chemical properties is essential to establish the important factors of water retention in the study area. The field work commenced 10$^{th}$ of November 2013. A reconnaissance survey of the area was carried out with the aid of the topographic map of the study location. Soil samples in two layers 0-15 cm for surface and 15-30 cm sub-surface were taken from several locations to make a total of thirty (30) samples as recommended by Kirda (1974) was collected. The pH was determined using glass electrode digital consort pH meter, exchangeable bases (Ca, K, and Na) were extracted with 1N $NH_4OAC$ buffed at pH 7. The Ca and Mg were determined using atomic absorption spectro photometer, K and Na were read on flame photometer (Thomas, 1982). Extractable micronutrients (Fe, Cu etc) were determined by double acid method, Total phosphorus was determined by the Bray II Method; cadmium was determined using spectrophotometer. Nitrogen was extracted by macro Kjedahl method (Carter, 1993).

### Surface and ground water samples

High density PVC bottles were used for sampling. They were thoroughly cleaned by rinsing with 8N $HNO_3$ and deionized water followed by repeated washing with water sample as suggested by De (1989). Water samples were collected at hand Dug well, deep bore hole and at Bakolori Mono pump area and at different sections of the supply canals, secondary, and tertiary channel where the flow seems to be turbulent and also at all the pump stations accessible to ascertain the status of the physico-Chemical properties of surface and ground water. Twenty (20) samples were taken to Zabson laboratory Services ltd accredited by the federal ministry of Environment, Nigeria.

Hence, acceptable Standard of Federal Ministry of Environment of Federal Republic of Nigeria were employed in the interpretation of the analysis of the study parameters.

## RESULTS AND DISCUSSION

### Soil analysis

Colour of the soil sample range from grey to brown; majority of the soils observed were brown in colour with different shades. pH of the soil which depends on soil water ratio ranged between 5.5- 6.3 as shown in Table 1. The lowest pH value of 5.5 was found at irrigation left Farmland and also at 12 km of main canal and the maximum pH of 6.3 was found in subsoil (15-30 cm) of farmland at main canal. Electrical conductivity which is a measure of the amount of soluble salts present in the soil; the EC varied from 3-80 µS/cm which is within the acceptable limit. The lowest EC was found at farm land at 12 km (main canal) at the top soil (0-15 cm) and highest was noticed in the soil at Main canal 15 km from the dam. From samples of the soils collected as shown in Table 1, the sulphate concentration, chloride, phosphorus, nitrate, cyanide, chromium, iron calcium, sodium, potassium and total hydrocarbons present were within the acceptable limit which was in agreement with the report by USAID (2010). However, the levels of copper, total nitrogen and cadmium were above the acceptable limit in all the locations where samples were collected for the top (0-30 cm) soil and corresponding sub-soil (15-30 cm) which could be attributed to the use of agrochemicals and could be associated with the use of pesticide in the farms which could have be drained into ditches depending on their solubility in water. The level of available phosphorus, potassium and nitrogen caused by high rate of leaching with clayey texture developed from the river sediments because of cumulated effect of agro-chemicals applied. The level of phosphorus and potassium was beyond the acceptable limit which was at par with USAID, 2010 report.

From Table 2, it can be observed that the pH, dissolved oxygen, conductivity, salinity, turbidity, colour, total dissolve solids, sulphate, magnesium, copper, ammonium, total hardness, calcium, carbonate, bicarbonate, sodium, chloride, biological oxygen demand

**Table 1.** Physico-chemical properties of soil at project area.

| Parameter (units in mg/kg) | I/L 1 | I/L 2 | M/C 15KM 1 | M/C 15KM 2 | GIS 30 1 | GIS 30 2 | KM 12 1 | KM 12 2 | JAS 1 | JAS 2 | FME limit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature (°C) | 27.2 | 27.3 | 27.5 | 27.4 | 27.2 | 27.3 | 27.2 | 27.4 | 27.6 | 27.2 | <40 |
| pH | 5.7 | 5.5 | 5.6 | 6.3 | 5.8 | 5.7 | 5.6 | 5.5 | 5.6 | 5.5 | 6-9 |
| Conductivity | 19 | 6 | 37 | 36 | 22 | 10 | 3 | 8 | 36 | 24 | 1000 |
| Sulphate | 55.1 | 20.4 | 23.5 | 24.4 | 94.4 | 34.1 | 17.7 | 14.4 | 18.4 | 13.7 | 500 |
| Chloride | 5.49 | 40.8 | 1.2 | 1.32 | 13.13 | 2.61 | 11.7 | 7.3 | 10.8 | 6.8 | 250 |
| Phosphorus | 0.4 | 0.6 | 0.5 | 0.6 | 0.5 | 0.4 | 0.5 | 0.4 | 0.5 | 0.3 | 0.1 |
| Nitrate | 2.8 | 3.2 | 1.0 | 0.96 | 4.62 | 1.57 | 0.56 | 0.3 | 0.5 | 0.2 | 20 |
| Cyanide | 0.11 | 0.422 | 0.043 | 0.048 | 0.163 | 0.063 | 0.038 | 0.044 | 0.036 | 0.027 | 0.1 |
| Chromium | 0.048 | 0.07 | 0.084 | 0.096 | 0.035 | 0.042 | 0.07 | 0.071 | 0.062 | 0.041 | 0.1 |
| Iron | 0.183 | 0.165 | 0.126 | 0.151 | 0.122 | 0.106 | 0.192 | 0.16 | 0.18 | 0.142 | 1.5 |
| Copper | 0.72 | 0.28 | 0.24 | 0.31 | 0.18 | 0.39 | 0.19 | 0.35 | 0.13 | 0.18 | 0.1 |
| Total Nitrogen | 0.5 | 2.1 | 13.7 | 14.2 | 0.9 | 21.9 | 9.2 | 6.1 | 9.7 | 6.3 | <1 |
| Calcium | 12.52 | 12.31 | 14.10 | 13.85 | 13.77 | 13.25 | 13.93 | 13.42 | 13.97 | 13.15 | 100 |
| Sodium | 8.16 | 8.15 | 10.18 | 7.2 | 9.19 | 11.19 | 9.15 | 10.14 | 10.17 | 9.11 | 200 |
| Potassium | 1.3 | 1.8 | 1.0 | 1.3 | 1.2 | 1.6 | 1.7 | 1.8 | 1.2 | 1.5 | - |
| Cadmium | 0.051 | 0.071 | 0.054 | 0.068 | 0.041 | 0.061 | **0.113** | 0.068 | 0.11 | 0.069 | 0.01 |
| THC | 1.8 | 1.9 | 1.3 | 1.9 | 1.7 | 1.0 | **1.1** | 1.8 | 1.1 | 1.8 | 10 |

**1** = Soil samples (0-15 cm); 2 = Soil samples (15-30 cm) ; I/L = Irrigation left ; MC = Main canal; KM 12 =12 km along the main canal; GIS = Pump station; JAS = Pump station; FME = Acceptable Standard of Federal Ministry of Environment of Federal Republic of Nigeria.

**Table 2.** Physico-chemical properties of surface water.

| S/N | Parameter (units in mg/L) | SW1 MC | SW1 | SW2 | SW3 | SW4 | SW5/MC 15KM | SW6 | SW7 | SW9 | FME limit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Temperature (°C) | 25.4 | 25.6 | 26.3 | 26.6 | 26.5 | 26.6 | 26.5 | 26.6 | 26.6 | <40 |
| 2 | pH | 6.0 | 5.4 | 5.3 | 5.4 | 5.4 | 5.2 | 5.5 | 5.2 | 5.4 | 6-9 |
| 3 | Dissolved oxygen | 3.2 | 3.1 | 2.9 | 3.4 | 3.6 | 2.8 | 3.5 | 3.4 | 2.6 | 7.5 |
| 4 | conductivity (µs/cm) | 75 | 54 | 93 | 54 | 54 | 54 | 55 | 56 | 96 | 1000 |
| 5 | Salinity (%) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 |
| 6 | Turbidity (Ntu) | 55 | 53 | 46 | 91 | 89 | 59 | 94 | 65 | 74 | 100 |
| 7 | Colour (Tcu) | 17 | 15 | 12 | 61 | 59 | 66 | 68 | 17 | 24 | 100 |
| 8 | Total dissolved solid | 38 | 27 | 46 | 27 | 27 | 27 | 27 | 28 | 47 | 1000 |
| 9 | Nitrate | 10.2 | 12.8 | 1.3 | 11.0 | 14.2 | 13.1 | 9.8 | 11.0 | 1.0 | 20 |
| 10 | Sulphate | 87.6 | 98.2 | 119.3 | 98.4 | 107.1 | 100.1 | 83.0 | 94.9 | 13.8 | 500 |
| 11 | Phosphate | 5.5 | 6.7 | 8.8 | 5.9 | 7.6 | 7.0 | 5.4 | 5.9 | 4.0 | 5 |
| 12 | Iron | 1.43 | 1.41 | 1.42 | 1.35 | 1.86 | 1.44 | 1.53 | 1.71 | 1.37 | 1.5 |
| 13 | Copper | 0.17 | 0.54 | 0.98 | 0.29 | 0.69 | 0.56 | 0.15 | 0.32 | 0.16 | <1 |
| 14 | Ammonium | 0.18 | 0.28 | 0.37 | 0.22 | 0.31 | 0.27 | 0.19 | 0.21 | 0.05 | <1 |
| 15 | Potasium | 12.3 | 16.4 | 20.3 | 13.5 | 17.9 | 16.1 | 12.8 | 13.5 | 2.1 | <1 |
| 16 | Total Hardness | 34.24 | 51.36 | 68.48 | 34.24 | 34.24 | 34.24 | 34.24 | 34.24 | 51.36 | 200 |
| 17 | Calcium | 17.12 | 34.24 | 34.24 | 17.12 | 17.12 | 17.12 | 17.12 | 17.12 | 34.24 | 150 |
| 18 | Magnesium | ND | 17.12 | 17.12 | 17.12 | ND | 17.12 | 17.12 | 17.12 | 17.12 | 50 |
| 19 | Carbonate | 40 | 27 | 40 | 60 | 68 | 56 | 32 | 26 | 33 | - |
| 20 | Bicarbonate | 95 | 54 | 95 | 80 | 74 | 83 | 68 | 54 | 70 | - |
| 21 | Sodium | 54.5 | 55.4 | 55.8 | 44.8 | 46.7 | 57.5 | 56.0 | 57.5 | 53.2 | 200 |
| 22 | Chloride | 9.47 | 13.98 | 19.1 | 10.78 | 15.5 | 14.06 | 9.86 | 10.91 | 0.08 | 250 |
| 23 | $BOD_5$ | 12.5 | 16.9 | 17.2 | 13.9 | 18.5 | 16.5 | 13.0 | 14.0 | 2.1 | 30 |
| 24 | COD | 501 | 676 | 868 | 558 | 740 | 660 | 524 | 561 | 81.8 | 80 |
| 25 | THC | 1.2 | 1.3 | 1.0 | 0.9 | 1.1 | 1.0 | 0.9 | 0.8 | 1.3 | 10 |

Sw1 Mc = Reservoir; Sw1= Main canal; sw2 = Jas; sw3 = 7 km from reservoir; sw4 = 12 km from reservoir; sw5 = 15 km from reservoir; sw6 = irrigation left; sw7 = FS 10-1 station.

**Table 3.** Physico-chemical properties of ground water.

| S/N | Parameters (units in mg/L) | GW1 | GW3BH | GW2 | FME limit |
|---|---|---|---|---|---|
| 1 | Temperature (°C) | 25.7 | 26.4 | 26.6 | <40 |
| 2 | pH | 5.6 | 5.8 | 5.7 | 6.5-8.5 |
| 3 | Conductivity (µs/cm) | 742 | 278 | 546 | 1000 |
| 4 | Dissolved oxygen | 0.9 | 1.1 | 0.8 | 7.5 |
| 5 | Salinity (%) | 0.3 | 0.2 | 0.2 | 0 |
| 6 | Turbidity (NTU) | 0.3 | 0.2 | 0.2 | 5 |
| 7 | Color (TCU) | 0.15 | 0.13 | 0.14 | 15 |
| 8 | Total dissolved solid | 371 | 139 | 272 | 1000 |
| 9 | Nitrate | 0.13 | 0.16 | 0.15 | 10 |
| 10 | Sulphate | 7.5 | 7.2 | 8.8 | 500 |
| 11 | Phosphate | 0.07 | 0.05 | 0.05 | 5 |
| 12 | Iron | 0.2 | 0.2 | 0.2 | 1.5 |
| 13 | Copper | 0.07 | 0.09 | 0.09 | 0.1 |
| 14 | Ammonium | 0.03 | 0.03 | 0.04 | - |
| 15 | Potasium | 1.2 | 1.4 | 1.3 | - |
| 16 | Total Hardness | 428 | 102.72 | 308.16 | 200 |
| 17 | Calcium | 308.18 | 85.6 | 256.8 | 150 |
| 18 | Magnesium | 119.84 | 17.12 | 51.36 | 50 |
| 19 | Carbonate | 21 | 21 | 19 | 200 |
| 20 | Bicarbonate | 45 | 44 | 43 | 200 |
| 21 | Sodium | 189.8 | 128.1 | 101.7 | - |
| 22 | Chloride | 0.04 | 0.04 | 0.04 | 250 |
| 23 | $BOD_5$ | 0.1 | 0.3 | 0.3 | 0 |
| 24 | COD | 4.6 | 5.3 | 5.3 | 7.5 |
| 25 | **THC** | 0.7 | 0.5 | 0.4 | 10 |

and total hydrocarbons were within the acceptable limit, however, as shown in Table 2 the iron concentration in Irrigation Left (SW6) and FS 10-1 (SW7) were beyond the permissible level which may be due to the fact that members of the community use the water from the canal to wash their motorcycles and bicycle, also some use to throw metallic object into the channel, it is therefore recommended that the channel should be clean and protected from been used by constructing a barricade to prevent members of the community from encroaching. Potassium and chemical oxygen demand concentrations are beyond the permissible limit in almost all the samples collected even with water sample collected at the reservoir which could be the resulting effect of fertilizers from the Bakolori Irrigation project which can be seen by the level of algae around the river banks as also reported by USAID (2010) . The elevated of level of potassium and phosphate in other points of collection may be because of the cumulative residual application of wrong dosage of agrochemicals and level of use of pesticide in farm land during crop production over the last 30 years which drained into the ditches. A water treatment plant is therefore needed at the Reservoir because of the high concentration of potassium and phosphate.

### Water quality for ground water

The ground water table has risen over the last 30 years, which occurs between 2 m and above in the project area. The degradation of surface and groundwater quality due to industrial and urban waste has been recognized for a long time (Mohammad et al., 2013), that is why farmers could use tube wells for areas formerly meant for sprinkler system. Groundwater samples were collected at a hand Dug well, deep bore hole and at Bakolori Mono pump and the physico-chemical properties were determined as shown in Table 3. The salinity, total hardness and biological oxygen demand concentration were all above the permissive level in the samples collected which is at par with the report of USAID (2010). Hence, water treatment plant should be connected to all the areas where water is harvested for consumption.

### Dam safety appraisal

Bakolori Irrigation Reservoir is over 30 years and underutilized. The dam is not being monitored and very little exist about the status of the dam. Records of dams' instrumentation stop shortly after the contractor left site and the instrument seems to be vandalized. Thus it was not possible to:

1. Determine the phreatic surface of seepage through dam embankments;
2. Assess any settlement of horizontal movement of dam structures;
3. Observe any unusual hydrostatic pressures particularly at the toes of the embankment;
4. Assess the functioning of the internal drainage system

Only the physical inspection and physical safety assessment were carried out, the concrete of the dam was founded on rock so there is low risk of internal erosion in the foundation; the upstream face of the dam is uniform and in good condition, there is no sign of settlement or cracking in the crest even though vegetation has taken root in places of the crest and the downstream shoulder it does not pose any threat to the embankment but could develop into substantial tree, the spillway appeared to be in excellent condition and also the downstream face is also protected from erosion.

## Conclusion

Excavated soil from any region in the project area should not be used as amendment for soils in the farm plots, rather the excavated soils may be used to fill the borrow pits in the project area. Water monitoring of the Sokoto and Bobo River within the project area after the drainage ditches have been de-silted should be monitored, status of chemicals and nutrients entering the river should be ascertained. Regular monitoring of the physical and chemical properties of the water should be done; its frequency is a function of the silt-build up. Members of the communities within the project area should be advised to stop taking their bath, washing clothes and swimming inside the water course (canal).

## Conflict of Interest

The authors have not declared any conflict of interest.

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academicJournals

Vol. 10(7), pp. 697-701, 12 February, 2015
DOI: 10.5897/AJAR2013. 8273
Article Number: 838F14950390
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

# Economic threshold level (ETL) of okra shoot and fruit borer, *Earias* spp. on okra

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Received 21 November, 2013; Accepted 10 October, 2014

**Shoot and fruit borer (SFB), *Earias* spp. is the second major pest on okra after cotton jassid under Punjab conditions. High incidence of this pest has been reported mainly in the pre- and post- rainy seasons. The farmers are using indiscriminate sprays of insecticide on this crop. Since crop is harvested on every alternate day, thus, insecticide residues on this crop are of great concern. Therefore to develop more safe and eco-friendly management strategies involving the application of insecticides at right time to reduce the use of insecticides on okra for the quality vegetable production; the present studies on "Economic threshold level (ETL) of shoot and fruit borer, *Earias* spp. on okra" were carried during the year 2009. Cumulative percent fruit infestation on the basis of fruit numbers and weight was found to be significantly lower in the first three ETLs (12.89-14.15 and 14.73-16.81%, respectively) than other ETLs (16.67-22.08 and 19.09-23.41%, respectively) standard check (20.14 and 22.67%, respectively) and control (23.13 and 24.22%, respectively). Marketable yield were significantly higher (95.49-96.17 q/ha) in the former three ETLs, that is, 20% shoot infestation (6 sprays), 2% fruit infestation (5 sprays) and 4% fruit infestation (5 sprays) in comparison to other ETLs (65.64-85.25 q/ha), standard check (67.73 q/ha) and control (64.19 q/ha). Significantly higher economic returns (Rs. 23059 - Rs. 23378/-) were also achieved from first three ETLs. The lower number of sprays, higher marketable yield and economic returns were obtained in the two ETLs, that is, 2 and 4% fruit infestation level. Keeping in view the development of resistance to the insecticides, it is desirable to start the spray at 4% fruit infestation which will provide sufficient protection against pest.**

**Key words:** Determination, economic threshold level (ETL), shoot and fruit borer, *Earias* spp., okra.

## INTRODUCTION

Okra, *Abelmoschus esculentus* (Linn.) Moench is an important summer vegetable crop cultivated throughout the tropical and warm temperate regions of the world. In Punjab, it was grown over an area of 1940 ha with a production of 14610 thousand tonnes (Anonymous 2010). Shoot and fruit borers (SFB), *Earias* spp. [Noctuidae: Lepidoptera] is the second major pest on okra after cotton jassid. Under Punjab conditions, *E. vittella* is a pest under high humidity and high temperature conditions. It has been reported to cause 61.32% damage to fruits (Anonymous 2008) and 50.58% loss of fruit yield (Brar et al., 1994). High incidence of this pest has been reported

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mainly in the pre- and post- rainy seasons (Kadam and Khaire, 1995). The farmers are using indiscriminate sprays of insecticide on this crop. Since, this crop is harvested on every alternate day, the insecticide residues on this crop are of great concern. Thus, there is, an urgent need to develop more safe and eco-friendly management strategies involving the application of insecticides at right time to reduce the use of insecticides on okra for the quality vegetable production under Punjab conditions. The present studies were proposed with the objectives to determine the economic threshold level (ETL) of okra shoot and fruit borer, *Earias* spp. on vegetable crop of okra. This will help the farmers in applying insecticides at right time for the effective control of pest and to reduce the excessive load of insecticides on okra crop. Similar solution for the effective control of okra shoot and fruit borer are suggested by other workers, that is Saha (1982) and Sreelatha and Divakar (1998) who reported 2.67-4.94 and 5.3% fruit infestation, respectively as ETL for this pest.

## MATERIALS AND METHODS

The present studies were carried out at the Vegetable Research Farm, Punjab Agricultural University, Ludhiana in 2009. Okra variety Punjab- 8 was sown on June 23, 2009. The trials were laid out in Randomized Block Design (RBD) and were replicated thrice. The plot size was kept 10m$^2$ with spacing of 60 cm × 30 cm. The sprays of recommended insecticide, that is, cypermethrin 25 EC at 200 ml per hectare (This is a recommendation of Punjab Agricultural university, Ludhiana for the control of Shoot and fruit borer of okra) were given in the above different treatments on the attainment of respective ETLs except for control treatment. The detail of sprays in different ETLs is given as: T1: Six sprays were given on 26/8, 3/09, 10/09, 18/09, 24/9 and 1/10 at 20% shoot infestation; T2: Five sprays were given on 14/09, 18/09, 22/09, 26/09 and 1/10 at 2 percent fruit infestation; T3: Five sprays were given on 14/09, 18/09, 22/09, 26/09 and 1/10 at 4% fruit infestation; T4: Three sprays were given on 18/09, 22/09 and 26/09 at 6%fruit infestation; T5: One spray was given on 18/09 at 8% fruit infestation; T6: No spray was given at 10% fruit infestation; T7: No spray was given at 15% fruit infestation and the standard check T8 (that is, spray was given on 12$^{th}$ August, 2009 when 50% of plants bear flowers and subsequently two sprays were given at 15 days interval) and control treatment T9. The following observations were recorded:

1. Shoot infestation in standing crop: The number of infested and total shoots was counted from all the plants in each plot of treatment $T_1$ at weekly intervals. Later on, percent shoot infestation was calculated.
2. Fruit infestation in standing crop: The number of infested and total fruits was counted from all the plants in each plot twice a week. Later on, percent fruit infestation was calculated.
3. Cumulative fruit infestation: At each picking, infested and total fruits were counted in each plot. Cumulative percent fruit infestation was calculated on the basis of cumulative totals of infested and total fruits of all the pickings in each plot.
4. Marketable fruit yield: At each pickings, weight of healthy fruits was recorded on plot basis and the yield (q/ha) was calculated from the cumulative total of healthy fruits of all the pickings in each plot.
5. Economics of control of *Earias* spp. for different ETLs was worked out.

The data recorded in present studies were subjected to statistical analysis by following RBD in factorial as per the method given by Cheema and Singh (1990).

## RESULTS AND DISCUSSION

### Percent fruit infestation by *Earias* spp. at each picking

The fruit infestation by *Earias* spp. in the first four pickings, that is, on 11$^{th}$, 13$^{th}$, 17$^{th}$ and 21$^{st}$ August, 2009 was nil in different economic threshold levels including standard check and control treatments (Table 1). The fruit infestation was first noticed in the fifth picking, that is, on 25$^{th}$ August ranging from 0.00-3.10% and increased till the last harvest of the crop that is, 6$^{th}$ October, 2009 ranging from 24.34-53.78% in different treatments. Differences in percent fruit infestation among different treatments were found to be significant from fifth to ninth picking, that is, on 25$^{th}$, 27$^{th}$ August, 3$^{rd}$, 9$^{th}$ and 14$^{th}$ September ranging from 0.00-3.10, 0.00-11.11, 3.67-20.01, 4.27-12.82 and 10.08-21.78%, respectively, however, the sprays were given only in the ETLs, that is, $T_1$- 20% shoot infestation on 26$^{th}$ August, 3$^{rd}$ and 10$^{th}$ September and in the treatment $T_8$-standard check on 12$^{th}$ and 27$^{th}$ August and 11$^{th}$ September. The reason for this may be the scattered and non-uniform distribution of the pest during the early stages of pest incidence in the field. Later on, in the tenth picking on 18$^{th}$ September, significantly low fruit infestation was observed in the ETL i.e. 20 % shoot infestation, 2 % fruit infestation and 4 % fruit infestation ranging from 11.94- 14.59 % as compared to other ETLs (17.51-22.90%), standard check i.e. three sprays at 15 days interval starting when 50 % plants bore flowers (21.62%) and the control treatment (23.16%). The same trend was observed in afterward pickings from eleventh to fourteenth on 22nd, 25th September, 1st and 6th October with fruit infestation range 16.92-18.85, 18.98- 21.80, 20.00- 21.71 and 24.34- 28.02 %, respectively in first three ETLs as against others ETLs(22.59-31.92, 25.06-32.89, 25.09-33.74 and 39.91-51.96%, respectively), standard check (29.02, 30.36, 32.02 and 52.72% respectively) and control treatment (31.82, 33.05, 34.91 and 53.78%, respectively).

### Cumulative percent fruit infestation

The cumulative percent fruit infestation on the basis of fruit numbers (Table 2) found to be significantly lower in the first three ETLs, that is, 20% shoot infestation, 2% fruit infestation and 4% fruit infestation (12.89-14.15%) than other ETLs (16.67-22.08%), standard check (20.14%) and control (23.13%). Similar trend for the cumulative fruit infestation on weight basis was observed. On weight basis, percent fruit infestation (Table 2) was found to be significantly low in the first three ETLs (14.73-16.81%) than other ETLs (19.09-23.41%), standard

**Table 1.** Percent fruit infestation by *Earias* spp. at each picking in different ETLs in okra.

| Treatments | Percent fruit infestation by *Earias* spp. at each picking* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | V | VI | VII | VIII | IX | X | XI | XII | XIII | XIV |
| | 25-Aug | 27-Aug | 3-Sep | 9-Sep | 14-Sep | 18-Sep | 22-Sep | 25-Sep | 1-Oct | 6-Oct |
| $T_1$ | 2.94 (9.79)$^{c}$ | 0.00 (0.00)$^{a}$ | 6.93 (15.02)$^{abc}$ | 6.65 (14.90)$^{abc}$ | 11.99 (20.14)$^{a}$ | 14.59 (22.42)$^{abc}$ | 17.91 (25.02)$^{ab}$ | 18.98 (25.79)$^{a}$ | 20.00 (26.53)$^{a}$ | 26.90 (31.14)$^{a}$ |
| $T_2$ | 1.08 (5.95)$^{b}$ | 0.00 (0.00)$^{a}$ | 8.59 (16.92)$^{bcd}$ | 7.90 (16.21)$^{bcd}$ | 10.08 (18.44)$^{a}$ | 11.94 (20.18)$^{a}$ | 16.92 (24.26)$^{a}$ | 20.85 (27.04)$^{ab}$ | 20.67 (26.98)$^{a}$ | 24.34 (29.55)$^{a}$ |
| $T_3$ | 0.00 (.00)$^{a}$ | 9.52 (17.95)$^{e}$ | 13.82 (21.66)$^{e}$ | 4.27 (11.76)$^{a}$ | 13.19 (21.27)$^{ab}$ | 13.15 (21.18)$^{ab}$ | 18.85 (25.60)$^{ab}$ | 21.80 (27.79)$^{ab}$ | 21.71 (27.71)$^{ab}$ | 28.02 (31.92)$^{a}$ |
| $T_4$ | 0.00 (.00)$^{a}$ | 2.38 (8.66)$^{c}$ | 3.67 (11.04)$^{a}$ | 11.27 (19.60)$^{de}$ | 12.70 (20.83)$^{ab}$ | 17.51 (24.69)$^{bcd}$ | 22.59 (28.35)$^{bc}$ | 25.06 (29.98)$^{bc}$ | 25.09 (30.02)$^{abc}$ | 39.91 (39.15)$^{ab}$ |
| $T_5$ | 3.03 (10.02)$^{c}$ | 0.00 (.00)$^{a}$ | 12.45 (20.63)$^{de}$ | 9.30 (17.69)$^{bcde}$ | 14.07 (21.94)$^{ab}$ | 19.01 (25.77)$^{cde}$ | 24.90 (29.89)$^{cd}$ | 32.10 (34.45)$^{d}$ | 28.08 (31.97)$^{abc}$ | 47.23 (43.37)$^{b}$ |
| $T_6$ | 0.00 (.00)$^{a}$ | 11.11 (19.44)$^{e}$ | 4.87 (12.59)$^{ab}$ | 9.92 (18.32)$^{cde}$ | 19.79 (26.36)$^{c}$ | 21.96 (27.93)$^{de}$ | 28.48 (32.23)$^{de}$ | 30.82 (33.69)$^{cd}$ | 32.86 (34.62)$^{c}$ | 50.41 (45.22)$^{b}$ |
| $T_7$ | 0.00 (.00)$^{a}$ | 0.00 (0.00)$^{a}$ | 10.79 (19.15)$^{cde}$ | 11.85 (20.06)$^{e}$ | 21.78 (27.77)$^{c}$ | 22.90 (28.54)$^{e}$ | 31.92 (34.37)$^{e}$ | 32.89 (34.96)$^{d}$ | 33.74 (35.41)$^{c}$ | 51.96 (46.11)$^{b}$ |
| $T_8$ (standard check) | 3.10 (10.13)$^{c}$ | 1.33 (6.60)$^{b}$ | 14.22 (22.05)$^{e}$ | 6.05 (14.03)$^{ab}$ | 17.05 (24.33)$^{bc}$ | 21.62 (27.68)$^{de}$ | 29.02 (32.56)$^{de}$ | 30.36 (33.38)$^{cd}$ | 32.02 (34.43)$^{bc}$ | 52.72 (46.90)$^{b}$ |
| $T_9$ (untreated control) | 0.00 (.00)$^{a}$ | 7.84 (16.25)$^{d}$ | 20.01 (26.46)$^{f}$ | 12.82 (20.92)$^{e}$ | 20.17 (26.66)$^{c}$ | 23.16 (28.73)$^{e}$ | 31.82 (34.29)e | 33.05 (35.06)d | 34.91 (36.18)$^{c}$ | 53.78 (47.17)$^{b}$ |
| **CD (p = 0.05 %)** | (0.95) | (1.50) | (4.37) | (3.50) | (3.67) | (3.52) | (3.67) | (3.87) | (6.86) | (10.26) |
| **CV (%)** | 13.72 | 11.32 | 13.74 | 11.85 | 9.20 | 8.06 | 7.15 | 7.14 | 12.57 | 14.81 |

Percent fruit infestation by *Earias* spp. was nil on August 11, 13, 17 and 25, 2009. *Figures given in parentheses are Arc Sine √ percentage transformed values. CD = Critacal difference, CV = coefficient of variance. $^{a,ab,abc,ad,\ b,\ bc}$, the comparisons of different treatments values based on critical difference (CD)

check (22.67%) and control (24.22%).

### Marketable fruit yield

The marketable fruit yield (Table 2) was also found significantly higher (95.49- 96.17 q/ha) in the former three ETLs, that is, 20% shoot infestation, 2% fruit infestation and 4% fruit infestation in comparison to other ETLs (65.64-85.25 q/ha), standard check (67.73 q/ha) and control (64.19 q/ha).

### Economics of control of Earias spp. on okra based on ETLs

Significantly higher economic returns were achieved from first three ETLs, that is, 20% shoot infestation, 2% fruit infestation and 4% fruit

**Table 2.** Cumulative per cent fruit infestation by *Earias* spp and economics of control in different ETLs on okra.

| Treatments | Cumulative percent fruit infestation* | | Marketable fruit yield (q/ha) | Cost of spray (Rs.) | Net income (Rs.) |
|---|---|---|---|---|---|
| | Number basis | Weight basis | | | |
| $T_1$ | 13.51(21.52)[a] | 14.73 (22.49)[a] | 96.17[a] | 1279 | 23378 |
| $T_2$ | 12.89(20.95)[a] | 15.82 (23.40)[a] | 95.86[a] | 1066 | 23352 |
| $T_3$ | 14.15 (22.04)[ab] | 16.81(24.17)[ab] | 95.49[a] | 1066 | 23059 |
| $T_4$ | 16.67(24.08)[abc] | 19.09(25.83)[abc] | 85.25[ab] | 639 | 15598 |
| $T_5$ | 19.23(25.93)[bcd] | 20.81(27.11)[abc] | 72.46[bc] | 213 | 6163 |
| $T_6$ | 21.83(27.79)[cd] | 22.98 (28.62)[bc] | 66.32[c] | 0 | 1642 |
| $T_7$ | 22.08(27.91)[cd] | 23.41(28.88)[c] | 65.64[c] | 0 | 1118 |
| $T_8$ (standard check) | 20.14 (26.57)[cd] | 22.67(28.19)[bc] | 67.73[c] | 639 | 2090 |
| $T_9$ ( untreated control) | 23.13(28.70)[d] | 24.22 (29.36)[c] | 64.19[c] | - | - |
| CD (p = 0.05 %) | (4.18) | (4.66) | (14.49) | - | - |
| CV (%) | 9.64 | 10.18 | 10.63 | - | - |

[a,ab,abc,ad, b, bc], the comparisons of different treatments values based on critacal difference (CD).Figures in parentheses are Arc Sine √percentage transformed values. Daily wages per person = Rs. 123.12/-. Average rate of okra = Rs. 771/quintal.

infestation (Rs. 23059-Rs. 23378/-) than other ETLs (Rs. 1118-Rs. 15598/-) and standard check (Rs. 2090/-) over the untreated control (Table 2).

The above data indicated that significantly lower cumulative fruit infestation by shoot and fruit borer, *Earias* spp. on number (12.89-14.15%) and weight basis (14.73-16.81%), respectively and significantly higher marketable yield (95.49-96.17q/ha) and economic returns (Rs. 23059- Rs. 23378/-) were recorded in first three ETLs (20% shoot infestation, 2% and 4% fruit infestation) against other ETLs, standard check and control. In case of standard check, three sprays were given at 15 days interval starting from when 50% plants bore flowers, did not provide complete protection to the crop till the last harvest. As pest infestation started on 25th August, 2009 and continued till the last harvest of crop in the first week of October. The pest pressure increased till last harvest of crop, while the last spray in the standard check treatment was given on 11th September and its effect was over after a week. Since, no spray was given afterwards, the fruit infestation level increased in this treatment late in the crop season.

The present results are in line with the findings of Saha (1982) who reported the ETLs for *Earias* spp. as 2.67 and 4.94%, respectively during the year 1980 and 1981. The present findings are also in line with the work of Sreelatha and Divakar (1998) who described the ETL of *Earias* spp. as 5.3 % fruit infestation. However, the ETL determined in the present study is not close to the ETL described by Sundararaj et al. (1989), that is, sprays at 10% fruit infestation level.

Although the higher returns were obtained from the first three ETLs, but the number of sprays given in first ETL, that is, 20 % shoot infestation were six, while number of sprays was less, that is, five in the later two ETLs, that is, 2 and 4 % fruit infestation. Since, the second and third ETL, that is, 2 and 4 % fruit infestation were obtained at same time, thus, there was no difference in these two treatments. The sprays at 2% fruit infestation level may increase the selection pressure on the pest and ultimately enhance the development of resistance to the insecticide in the pest. Therefore, it is desirable to start spray at 4% fruit infestation which will provide sufficient protection against the pest and reduce the unnecessary insecticide load on the crop.

## Conflict of Interest

The authors have not declared any conflict of interest.

## ACKNOWLEDGEMENTS

Authors are highly thankful to the Dr. DS Cheema, Head, Department of Vegetable Science, Punjab Agricultural University, Ludhiana for providing necessary facilities and the members of Student's Advisory Committee: Dr. Balwinder Singh, Sr. Residue Analyst, Department of Entomology, Dr SS Kang, Prof. of Plant Pathology, Department of Plant Pathology and Dr. SS Bal, Director of Seeds for providing their able guidance and valuable comments.

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Vol. 10(7), pp. 702-709, 12 February, 2015
DOI: 10.5897/AJAR2014. 8862
Article Number: F26793950392
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Towards understanding the diversity of banana bunchy top virus in the Great Lakes region of Africa

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Received 24 May, 2014; Accepted 10 February, 2015

**The genetic variability of banana bunchy top virus (BBTV) isolates from the Great Lakes region of Africa (GLRA) spanning Burundi, the Democratic Republic of the Congo and Rwanda was assessed to better understand BBTV diversity and its epidemiology for improved disease management. DNA-R and DNA-S fragments of the virus genome were amplified and sequenced in this study. These two BBTV fragments were previously used to classify isolates into the South Pacific and the Asian groups. Phylogenetic analyses based on nucleotide sequences involving GLRA isolates and those obtained from the GenBank database were carried out. Sequence similarity for both DNA-R and DNA-S fragments ranged between 99.1 to 100.0% among the GLRA isolates, 96.2 to 100.0% and 89.7 to 94.3% between the GLRA isolates and those previously clustering in the South Pacific and the Asian groups, respectively. These results showed that GLRA isolates belong to the South Pacific group and are phylogenetically close to the reference Indian isolate. The similar banana cultivars and BBTV isolates across the GLRA implied that the disease may have mainly spread through exchange of planting material (suckers) between farmers. Thus, farmers' awareness and quarantine measures should be implemented to reduce BBTV spread in the GLRA.**

**Key words:** Banana bunchy top disease (BBTD), *Musa* spp., *Pentalonia nigronervosa,* virus genome.

## INTRODUCTION

*Musa* spp. (banana and plantain) is a staple food crop for approximately 400 million people worldwide and nourishes over 70 million people in sub-Saharan Africa (AATF, 2003). This crop is ranked the first in terms of contribution to the total annual agricultural production in Burundi and Rwanda while it is the second after cassava in the Democratic Republic of the Congo (DR Congo) (FAOSTAT, 2009). The perennial nature of banana, compared with other staples, allows households to access food all-year round, providing significant amounts of micronutrients (Kumar et al., 2011). Among banana cultivars grown in Africa, plantain types (AAB genome)

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are mainly found in the humid lowlands of West and Central Africa, while the highland cooking and beer banana (AAA-EA) which contribute to approximately 30% of world banana production are common in the Eastern African highlands (Tenkouano et al., 2003). Eastern Africa, including the Great Lakes zone, is considered as a secondary centre of diversity for the highland banana (Karamura et al., 1998; Tenkouano et al., 2003) where smallholder farmers grow a mixture of 5 to 10 different cultivars around their homesteads (AATF, 2003). Banana plantations are subjected to various natural calamities, in particular viral diseases, limiting their production. Among the viral infections, banana bunchy top disease (BBTD) is reported as the most destructive disease (Dale, 1987; Islam et al., 2010; Stainton et al., 2012).

BBTD was first reported from the Fiji Islands in 1889, but its causal agent was only identified 100 years later in 1990s (Magee, 1927; Wardlaw, 1961; Kumar et al., 2011), and was given the name, banana bunchy top virus (BBTV) (Karan et al., 1994). Currently, BBTV has spread to 33 countries worldwide (excluding the Americas) including 13 African countries (IITA, 2010).

BBTV spreads from one location to another by exchange of infected planting material and from plant to plant through the banana aphid, *Pentalonia nigronervosa* Coquerel (Hemiptera, Aphididae), but is not transmitted mechanically (Thomas and Dietzgen, 1991; Foottit et al., 2010). The banana aphid transmits the virus with high host specificity to *Musa* spp. in a circulative and persistent manner (Hafner et al., 1995; Hogenhout et al., 2008; Foottit et al., 2010). In the plant, replication of these circulative viruses is frequently restricted to the phloem providing a route for uptake and inoculation of viruses between plants via stylet-feeding aphids (Hogenhout et al., 2008). The virus is also transmitted over long distances through the movement of BBTV-infected planting materials (Kumar and Hanna, 2008; Vishnoi et al., 2009; Kumar et al., 2011).

BBTD is easily recognizable from other banana diseases by its characteristic symptoms consisting of dark green streaks on leaves and petioles, marginal leaf chlorosis, dwarfing of the plant and leaves that stand more erect and bunched at the top of the pseudostem, forming a rosette with a ‘bunchy top’ appearance (Magee, 1927; Su et al., 2003).

The BBTV is a member of family *Nanoviridae,* genus *Babuvirus* belonging to a group of circular single-stranded DNA (cssDNA) viruses (Allen, 1987; Amin et al., 2008; Karan, 1995). It is an isometric virus with a genome consisting of at least 6 fragments (Harding et al., 1993; Horser et al., 2001; Hu et al., 2007) and two components were considered in this study. The DNA-R encodes the ‘master’ Rep (M-Rep) that directs self replication in addition to replication of other BBTV genome fragments (Harding et al., 1993; Karan et al., 1994; Theresa, 2008). On the other hand, the coat protein (CP) is encoded by DNA-S for the integral BBTV fragment (Horser et al., 2001). Based on sequence analysis of DNA-R and DNA-S (CP) fragments, respectively, Karan et al. (1994), Wanitchakorn et al. (2000) and Kumar et al. (2011) demonstrated that BBTV isolates can be clustered into two distinct groups. The ‘South Pacific’ group comprising isolates from Australia, the South pacific region, South Asia (that is, India, Pakistan) and Africa; while the ‘Asian’ group comprises isolates from China, Indonesia, Japan, the Philippines, Taiwan and Vietnam (Horser et al., 2001). Although BBTD has long been recognised (Magee, 1927), molecular characterisation of BBTV began in the early 1990s (Harding et al., 1993). In Africa, a handful of BBTV isolates from sub-Saharan Africa (SSA) have been characterized (Wanitchakorn et al., 2000; Kumar et al., 2011) which includes only a single isolate originating from Burundi (accession AF148943). To date, significant molecular characterization using a substantial number of samples from the African Great Lakes region is lacking. To better understand BBTV diversity and its epidemiology for accurate BBTD management, knowledge of the molecular nature of BBTV in Africa is required. In this study, the DNA-R fragment and the coat protein (CP) (Wanitchakorn et al., 2000; Horser et al., 2001; Furuya et al., 2005; Kumar et al., 2011) were used to characterize BBTV isolates from the African Great Lakes region. BBTV isolates from the GLRA were compared with isolates already available in existing GenBank databases to assess their relationship with the Asian and South Pacific groups. In addition, the likely sampling site at different altitudes and influence of banana cultivar on sequence mutations within the GLRA were considered.

## MATERIALS AND METHODS

### Sampling

Banana leaf samples were collected in regions affected by BBTD in three countries namely Burundi, DR Congo and Rwanda from April to May 2010. Duplicate pieces of banana leaves of approximately 4 $cm^2$ each were taken from the youngest leaf of a banana plant displaying advanced BBTD symptoms. Leaf pieces were placed in individual Petri dishes lined with silica gel for the duration of the transport and transferred to the laboratory, where they were extracted and stored at -20°C pending use (Chase and Hills, 1991). In all, 37 samples were collected from five Provinces of Burundi (Bubanza, Bujumbura Rural, Bururi, Cibitoke and Makamba), 22 from three districts in the Eastern South Kivu DR Congo (Kabare, Nyangezi and Kamanyola) and 20 from the Rusizi district of the Western Province of Rwanda, giving a total of 79 samples. These samples were collected from diverse local banana genotypes namely AAA-EA, ABB, AAB and AABB types cultivated at different altitudes across the three countries. Diagnostic tests confirming the viral status of samples were performed using previously described PCR analysis (Harding et al., 1993; Thomson and Dietzgen, 1995).

### PCR analyses and sequencing based on DNA-R and DNA-S virus genome

Leaf pieces were placed in mesh plastic bags (Agdia Biofords,

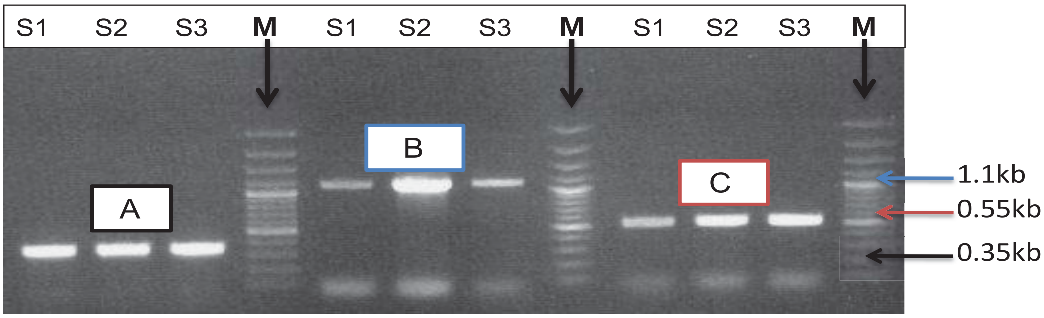


**Figure 1.** Molecular detection profile of banana bunchy top virus putative replicate gene (A=349 bp), DNA-R (B=1111bp) and coat protein (C=550 bp) components. Lane M: 100-bp ladder (Fermentas, France). S1, S2, S3 are examples of amplified samples from the African Great Lakes region.

France) and 2 ml of extraction buffer at 4°C was added (Busogoro et al., 2009). The crude extract was obtained for each sample by thoroughly crushing banana leaves before being dispensed in three 200 µl aliquots and stored at -20°C pending PCR analyses. PCR amplifications were carried out using diluted extracts (1:100 in distilled water). The PCR amplification was performed using specific primer pairs previously described for BBTV CP and DNA-R fragments (Harding et al., 1993; Thomson and Dietzgen, 1995; Amin et al., 2008). All 79 samples were first subjected to the PCR amplification of a 349 bp fragment of the putative BBTV replicase gene using primer pairs BBT1 forward (5'-CTCGTCATGTGCAAGGTTATGTCG-3') and BBT2 reverse (5'-GAAGTTCTCCAGCTATTCATCGCC-3') for detection of the virus in different samples (Harding et al., 1993; Thomson and Dietzgen, 1995). The selected representative positives samples were then amplified using primer pairs, MREPF forward (5'-GAATTCAAGAATGGAATAATTC-3') and MREPR reverse (5'-GAATTCCTCTAATAACCC-3') described by Amin et al. (2008) targeting amplification of DNA-R fragment, whereas primer pairs CPXI.PRI forward (5'-GCTAGGTATCCGAAGAAATCC-3') coupled with BBTV3C.EXP reverse (5'-ATAAAGCTTTCAAACATGATATGT-3') described by Wanitchakorn et al. (2000) were used to amplify the BBTV DNA-S coat protein fragment.

The PCR reactions were set up in a final volume of 50 µl comprising 5 µl of crude extract (diluted 1:100 in distilled water), 5 µl of 10x PCR buffer (Roche), 6 µl of $MgCl_2$ (25mM), 1.2 µl (200 µM/each) of dNTPs mix, 1 µl of each primer (0.5 µM), 0.25 µl (1.25 u/50 µl) of *Taq* DNA polymerase obtained from Fermentas-France and sterile distilled water (30.55 µl) was added to make the final volume (Amin et al., 2008; Burns et al., 1995). The PCR procedure was performed using MyCycler from Bio-Rad, Belgium. The thermo-cycling scheme consisted of denaturation at 94°C for 4 min; 40 cycles of 30 s to 1 min at 94°C, 1 min at 52°C and 2 min at 72°C followed by a final elongation step at 72°C for 10 min. The amplified products were visualized by electrophoresis in a 1% (w/v) agarose gel using ethidium bromide staining along with 100 bp ladder from Fermentas, France. Gels were then photographed on a digital gel documentation system. PCR products were quantified in ng/µl using NanoDrop ND-1000 spectrophotometer machinery with a limit of 1.80 values at A260/280 absorbance ratio. Amplified specific products to each of the DNA-R and CP fragments were then shipped for subsequent sequencing, using the same primer pairs, at Macrogen in South Korea.

#### Phylogenetic analyses (sequence alignment and phylogenetic tree) of BBTV nucleotide sequences

The nucleotide sequences of BBTV DNA-R and CP fragments of the GLRA isolates were compared in a pairwise matrix with existing BBTV and *Abaca bunchy top viruses (ABTV)* sequences obtained from the GenBank database using the Basic Local Alignment Search Tool (BLAST) available on the National Centre for Biotechnology Information (NCBI) (Theresa, 2008; Vishnoi et al., 2009). Multiple alignments for sequence comparison were performed using CLUSTALO (Thomson and Dietzgen, 1995; Amin et al., 2008). The genetic diversity of BBTV isolates was determined between GLRA isolates and those representing reference isolates from the previously described Asian and South Pacific groups including a previously sequenced Burundian isolate (AF148943) and other isolates from sub-Saharan Africa (Kumar et al., 2011). The consensus trees were generated using neighbour-joining algorithms with 100 bootstrap replications with Sea View Version 4.2.9 (Gouy et al., 2010).

## RESULTS

### PCR detection and sequencing of BBTV

The BBTV was confirmed in all 79 samples collected from symptomatic banana plants using a primer pair targeting the putative replicase gene (349 bp) of the BBTV genome. Among these positive samples, BBTV DNA-R and CP fragments of 27 representative samples covering the different localities and banana varieties were amplified using corresponding primer pairs of each fragment. Among those samples, 14 same isolates were successfully amplified for DNA-R and CP in addition to 8 and 5 different isolates for DNA-R and CP, making a total of 22 and 19 isolates, respectively. The PCR products of DNA-R (1111bp) and CP (550bp) fragments (Figure 1) were sequenced and used in comparisons.

### Sequence analysis of BBTV based on coat protein fragment

The phylogenetic analysis was carried out using the sequences of a 475 bp product representing the BBTV-CP fragment. The sequence comparisons showed a nucleotide sequence identity between the BBTV isolates from the GLRA (sequenced in this study) greater than

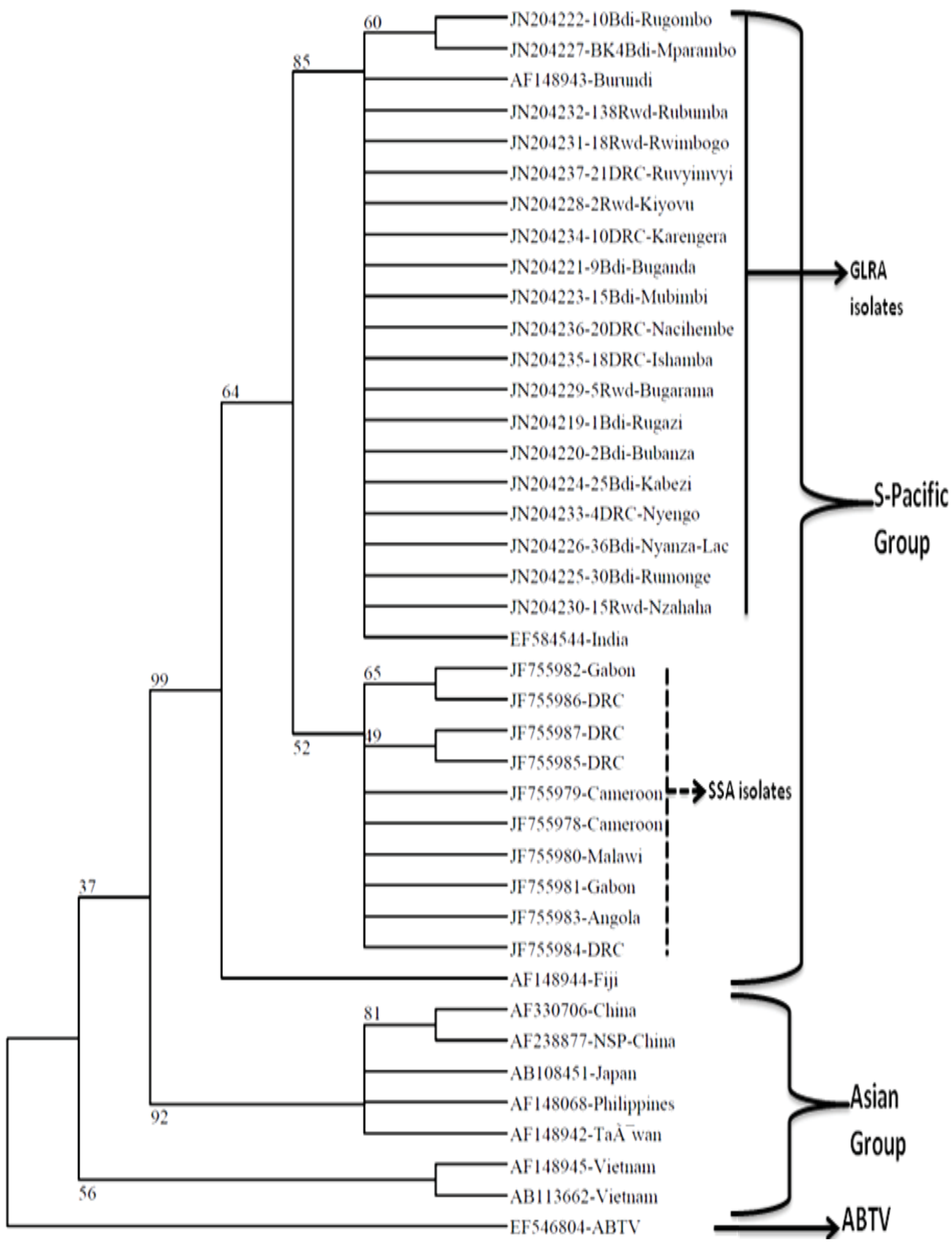


**Figure 2.** Neighbour-joining tree showing relationships based on BBTV CP nucleotide sequences of 19 isolates collected in the African Great Lakes Region (GLRA) compared with representative BBTV and ABTV isolates both obtained from the GenBank database.

99%. The GLRA isolates showed nucleotide sequence identity ranging from 97.2 to 99.7% with the South Pacific group which include isolates from sub-Saharan Africa (SSA), whilst they share only between 89.8 and 94.3% identity with CP nucleotide sequences of Asian isolates. On the other hand, pairwise comparisons between CP nucleotide sequences from the Asian and South Pacific groups showed higher sequence variability among isolates of the Asian group (99.3 to 92.0%) than among isolates from the South Pacific (100.0 to 95.2%). Phylogenetic analysis based on the BBTV CP nucleotide sequences confirmed the clustering of BBTV isolates into two major groups, the Asian and the South Pacific groups. The South Pacific group consists of all GLRA isolates including Burundian isolate (AF148943) that was deposited earlier in GenBank and Indian isolate (EF584544) followed by isolates from sub-Saharan Africa and Fiji (Figure 2). Within the South Pacific group, three sister subgroups with high bootstrap support (99%) were distinguished. The first subgroup includes all GLRA isolates (sequenced in this study), the Burundian isolate (AF148943) previously reported and the Indian isolate (EF584544). The second subgroup is represented by all sub-Saharan isolates, while a single isolate from Fiji (AF148944) was classified in the third subgroup. The Asian group was divided into two main subgroups, the subgroup which includes isolates from China, Japan, Philippines and Taiwan and the subgroup of Vietnam's isolates with bootstrap support of 92 and 56%, respectively (Figure 2).

### Sequence analysis of BBTV based on DNA-R genome fragment

Sequence analysis was carried out using a 238 bp DNA fragment for each of the 22 isolates, corresponding to the core region of the BBTV DNA-R. The core region was considered for the purpose of sequences comparisons using the same size of the majority of reported BBTV sub-Saharan Africa isolates available in GenBank database. Nucleotide sequence comparisons showed greater than 99% identity among GLRA isolates. BBTV GLRA isolates showed high levels of nucleotide sequence similarity with the South Pacific group (96.2 to 100.0%) compared with the Asian group isolates (89.7 to 93.4%). In addition, the nucleotide sequence variability was rather high within the Asian group (99.3 to 89.3 %) compared with those of the South Pacific group including the GLRA isolates (100.0 to 95.8%).

Phylogenetic analysis based on Rep sequences using the neighbour-joining method has also confirmed the previous reports of the clustering of BBTV isolates into the Asian and the South Pacific groups with high bootstrap support (100%). Four subgroups were distinguished among South Pacific isolates, the first includes all GLRA and SSA isolates followed by the Indian isolate (AF 416470-In); the second subgroup includes isolates from Australia, Fiji, Tonga, Hawaiï and Pakistan, while Egypt is in its own subgroup. The GLRA and other SSA isolates show the closest relationship with a Maharashtra isolate from India.

Among the GLRA isolates, the 2 isolates collected in DR Congo (JN204218-18DRC and JN204217-13DRC) at different altitudes and from different banana cultivars ('Malaya' and 'Yangambi Km5') were grouped together, whereas four isolates from the south of Burundi (JN204206-36Bdi, JN204204-33Bdi, JN204205-35Bdi and JN204203-30Bdi), collected in similar locations but from different banana cultivars ('Yangambi Km5', 'Igisahira', 'Indarama' and 'Kayinja'), formed another subgroup. Interestingly, among SSA isolates, the Cameroun isolate (JF755989-TV13.1) grouped together with the GLRA isolates, while 9 other isolates from SSA belonged to a different subgroup (Figure 3).

## DISCUSSION

This study contributed to better knowledge of the GLRA BBTV genome in comparison with other isolates from South Pacific and Asian zones based on two BBTV genome fragments (DNA-R and CP). The BBTV-CP GLRA sequences compared with those of the South Pacific and the Asian groups showed nucleotide differences ranging from 0.7 to 2.8 and 5.7 to 10.2%, respectively. This corroborates previous estimations of 3% variability among the South Pacific group isolates and around 6% across the Asian group isolates (Wanitchakorn et al., 2000). On the other hand, using BBTV DNA-R fragment (Rep) of GLRA isolates, a range of 0.9 to 3.8% and 6.6 to 10.3% of nucleotide differences were comparable to the previous averages of 3.8% among South Pacific group isolates and approximately 10% between the two groups (Karan et al., 1994). Additionally, the phylogenetic analysis using these two genome fragments strongly confirmed that all GLRA isolates belong to the South Pacific group (Figures 2 and 3).

Among the South Pacific isolates, based on the CP nucleotide sequences, the Indian isolate (EF584544) showed a closer relationship with the GLRA isolates than other SSA isolates. Using the core region of the DNA-R fragment, all BBTV isolates from sub-Saharan Africa grouped together followed by the Indian isolate. Additionally, the interrelationships among the SSA isolates showed that Cameroon isolate (JF755989) fell within the group of GLRA isolates. Karan (1995) had suggested that BBTV infections should have two major sources, one in Asia and another in the South Pacific, while Stainton et al. (2012) based on the evidence of re-assortment and recombination events within and between the Asian and the South Pacific BBTV subgroups support the hypothesis of the same geographical origin of both subgroups. Irrespective of the means of the first BBTV introduction, the GLRA isolates fall within the South Pacific group and may spread through either the traditional farmers' practices of intra-and inter-regional exchange of suckers for planting material or introduction of infected plants from research stations (that is, as observed in Rwanda during the survey, banana field of ISAR research station at Bugarama, Rusizi valley, have been reported to have contributed to the spread of BBTV in surrounding areas). Aphids may have extended the spread between plantations at a local level (Kumar et al., 2011). The two gene sequence-based phylogenies (Figures 2 and 3) suggest that the virus isolates from the GLRA could have originated from India rather than from other countries of the South Pacific through exchange of non indexed virus-free banana plantlets before development of diagnostic molecular tools.

In the Great lakes region, previous survey work (Sebasigari and Stover, 1988) suggested in 1987 that BBTD might have been present since the early 1970s in

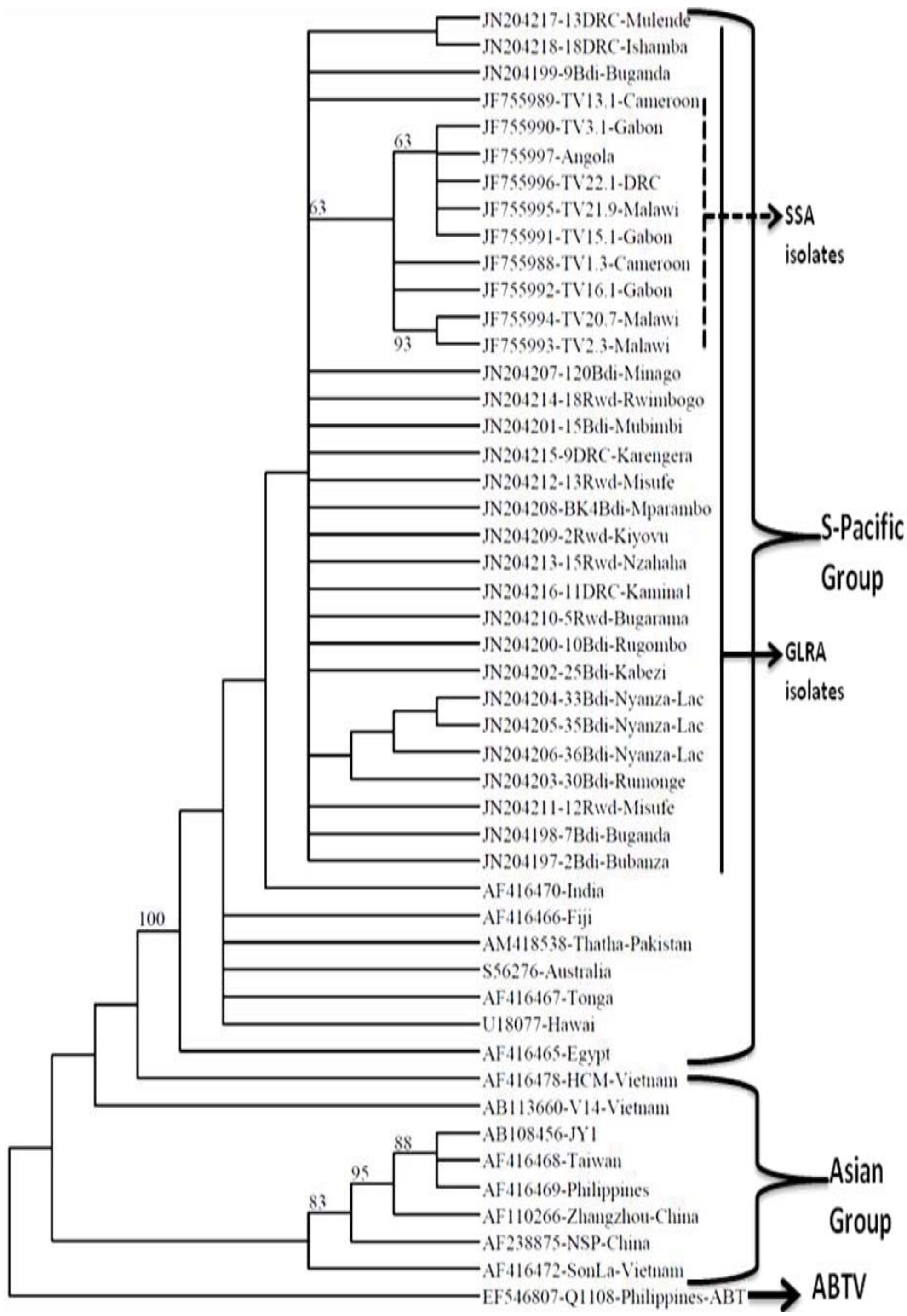


**Figure 3.** Neighbour-joining tree illustrating the BBTV DNA-R sequence relationships among 22 isolates from the Great Lakes Region of Africa (GLRA) compared with 26 representative isolates from GenBank database.

the Rusizi valley (encompassing parts of Burundi and Rwanda) while the DNA-R sequence variation was around 0.9% among GLRA isolates. In other countries within the south Pacific group such as Pakistan, the DNA-R sequence variations of 0.45% were reported 20 years after disease identification compared with 2% reported over 80 years in Australia (Karan et al., 1994).

The BBTV isolates across the three countries of the GLRA were grouped together. This suggests similarity in origin of GLRA isolates which were most likely distributed through exchange of planting material. It is likely that the virus was introduced in the Rusizi valley and its surrounding regions of Burundi, Eastern South-Kivu DR Congo and Rwanda by the exchange of 'Yangambi Km5'-(AAA genome) banana variety commonly grown in those regions. This is a cultivar that originated from INEAC Yangambi Agricultural Research station in the central DR Congo where BBTV was reported as early as the 1950s (Wardlaw, 1961; Kavino et al., 2007).

The BBTV isolates from the same region, but of different altitudes and banana cultivars, were grouped together. This implies the likely virus mutation according to the introduction period regardless the different types of banana cultivars or altitudes, corroborating previous reports which stated that sequence variation of the virus is strongly dependent on the period of time it has spent in a region (Tenkouano et al., 2003, Amin et al., 2008).

Overall, the use of tolerant cultivars should be associated with collective eradication of BBTV-infected mats to reduce virus inocula for long term BBTV management. In fact, the lack of farmers' awareness on transmission and management practices could be the main factor explaining the continuous spread of BBTD in the GLRA. Therefore, there is a need of stricter regional policy in an attempt to manage BBTD and prevent further spread of the virus in areas not yet affected by the disease. This involves raising farmers' awareness and implementation of quarantine measures. Further research on the virus using all six BBTV fragments should study the sequence variation and provide a complete view of the evolutionary processes based on BBTV likely recombination and re-assortment within the African Great Lakes region.

## Conflict of Interest

The authors have not declared any conflict of interest.

## ACKNOWLEDGEMENT

The authors thank Université de Liège-Gembloux Agro-Bio Tech (Belgium), Phytopathology unit for laboratory facilities. This research was supported by the Directorate General for Development (DGD-Belgium) funded project "CIALCA" (Consortium for Improving Agriculture-based Livelihoods in Central Africa).

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Vol. 10(7), pp. 710-719, 12 February, 2015
DOI: 10.5897/AJAR2013. 8120
Article Number: F02C01C50398
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Extrusion cooking on pasting properties and relative viscosity of selected starch crops

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Received 24 October, 2013; Accepted 17 December, 2014

**Rheological properties of food are very important indicators of the quality and texture of food products. In this study, the relative viscosity and pasting characteristics (cold and hot paste viscosity) of extrudates from a locally developed extruder (L/D 12:1, CR 4.4:1, 4 KW) were determined. The extrudates were processed from the flour and starch of cassava and maize and wheat flour. Stepwise regression and other follow up tests were employed to a factorial experiment in completely randomized design. Relative viscosity increased positively with duration of operation for cassava products and negatively for cereal products. For Hot Paste Viscosities (HPV) and Cold Paste Viscosities (CPV) however, both products decreased negatively with extrusion. The most stable of the products is Cassava Starch at 40% moisture content. Also, retrogradation decreased with increasing extrusion time and moisture content. The equations relating the various dependent and independent variables were established to predict the quality of the products. Quadratic coefficients fitted the extrusion data very well than linear models.**

**Key words:** Extrusion, hot and cold paste viscosities, relative viscosity, food stability, cassava, maize, wheat.

## INTRODUCTION

In Nigeria and West Africa, starches from cereals, roots and tubers are used as a staple food in the diet of the people. Nigeria production of cassava (*Manihot esculenta*, Crantz), a starch-rich root tuber crops is the largest in the world, producing more than 70 million tonnes of cassava annually (Yisa, 2008; UNCTAD, 2004). However, a high percentage of the crops are lost because of inadequate processing. There is need for alternative processing options for cassava to add to its value and for its sustainability. One of the means to arrest post-harvest losses is by expansion of the processing technology. Food extrusion, a process in which food ingredients are forced to flow, under one or several conditions of mixing, heating and shear, through a die that forms and/or puff-dries the ingredients, is a versatile process that helps in the expansion of the processing technology of crops. Efficient and increased processing will be enhanced by developing an indigenous extruder (Ademosun, 1997). Cassava as a starchy crop has high potential for production of extruded foods. Meanwhile it is obvious that cassava is not popular for production of extruded foods. Maize and wheat are however popular

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**Table 1.** Proximate compositions of samples.

| Variable | Mc | Protein | Fat | Ash | Fibre | Carbohydrate |
|---|---|---|---|---|---|---|
| cs | 1.47 | 0.31 | 1.50 | 0.20 | 0.12 | 96.40 |
| cf | 1.90 | 7.36 | 1.4 | 1.62 | 0.24 | 87.48 |
| ms | 2.45 | 0.86 | 2.32 | 0.40 | 0.15 | 93.82 |
| mf | 1.30 | 3.95 | 2.43 | 0.80 | 0.36 | 91.16 |
| wf | 9.65 | 13.20 | 1.50 | 0.45 | 2.17 | 3.10 |

cs, Cassava starch; cf, cassava flour; mf, maize flour; ms, maize starch; wf, wheat flour.

for production of extruded foods.

Viscosity is one of the factors that determine acceptability of fabricated foods and to know or monitor the effect of any treatment on the starch. Also, 'the knowledge of the rheological properties of melted dough is very important in food extrusion systems because they affect extrudate expansion, texture, appearance and hydration properties as well as the thermal and mechanical energy input etc' (Lo et al., 1998). Functional and pasting properties of flour and starch products are important for their use in the food industry. For example, the characteristics of products formulated with starch, such as food thickeners and other flour or starch based products, are greatly influenced by functional and pasting properties (Niba et al., 2001). According to Osundahunsi (2005), pasting characteristics is necessary to determine the nature of food if it to be in paste form. The ability of a starch-containing food to form a paste or a gel is one of the principal factors that determine the texture and the quality of that food product. Functional properties of starch such as pasting viscosities influence the textural and gross structure of the food products and they provide information that could be used to determine specific end use applications (Henshaw and Adebowale, 2004).

Cold viscosity, the viscosity of the paste when cooled to the required temperature, is an important property if the extruded starch will be used as an ingredient in the foods that require cold thickening capacity, like instant soups, creams or sauces while hot paste viscosity is the viscosity of the paste at the start of cooling after heating. The aim of this study is to characterize the relative viscosity and hot and cold paste viscosities of the flour and starch of cassava and maize and wheat flour from a locally developed extruder.

## MATERIALS AND METHODS

### Sample preparation

Samples of flour and starch of cassava were sourced and prepared from the same varieties grown under the same cultivation practices to give room for basis of comparison of results. Cassava tubers (*M. esculenta* Crantz) TMS 30572, were sourced from experimental plots at the Federal College of Agriculture, Akure and processed into flour and starch respectively according to International Starch Institute Standards (2005). The materials were passed through a 300 um sieve separately and the proximate analysis and moisture contents (dry basis) of samples were determined as described by AOAC (1995) approved method (Table 1). White maize, EV8363-SR QPM (breeder seed) was sourced from the International Institute of Tropical Agriculture (IITA), Ibadan and processed into flour and starch respectively as described by Akanbi et al. (2003). Hard durum wheat flour (Triticum aestirum) was purchased from Akure main market. Table 1 shows the proximate compositions of samples.

### Extrusion

The extruder used in this study is the dry type. It is made up of three main units namely the feeding unit, the compression and melting unit and the die unit all fabricated using locally available materials. The feeding unit and the compression/melting unit are operated by one electric motor through a gear reducer and belt and pulley transmission system. As a test rig, allowance was given for varying the screw configuration, feed rate, screw speed, die configuration and nozzle. Speed variation was done by varying the pulley ratios. All parts through which the feed material will pass were made of stainless steel to prevent food contamination and to withstand frictional wear. Figure 1 shows the isometric drawing of the extruder. As showed in Figure 2, the screw is of single flight, increasing diameter and tapering/decreasing pitch with a compression ratio of 4.5:1 L/D Ratio of 12:1. The diameter of the final portion of the screw is reduced to a cone. This aid in pressure built up, easy conveyance of materials through the die and in reducing wear rate. The length to diameter ratio is 12:1. An electric motor drives the screw through a gear reducer, and the backward thrust of the screw is absorbed by a thrust bearing. The barrel and the screw/die configuration are typical of alimentary food production equipment. The extrudates were extruded as ribbons and later cut manually.

### Experimental procedure

Samples were fed into the extruder at a feed rate 10 Kg/h at room temperature. The extruder was operated for 30 min for each set of condition. Steady state extrusion conditions is assumed to have been reached where there is no visible drifts in products temperature and torques required to turn the screw rate. Temperature, both of the barrel and product were varied by continuous running of the machine, thereby building up the temperature. A major reason why heat was generated through viscous dissipation and not by addition through the barrel walls is that heat generated by drive unit (through viscous dissipation) is more dominant and cost efficient (Liang et al., 2002). Since barrel temperature varies with duration of operation, duration of operation was observed as the independent variable. Temperature was controlled by dipping the barrel and screw in a bath of cold water at

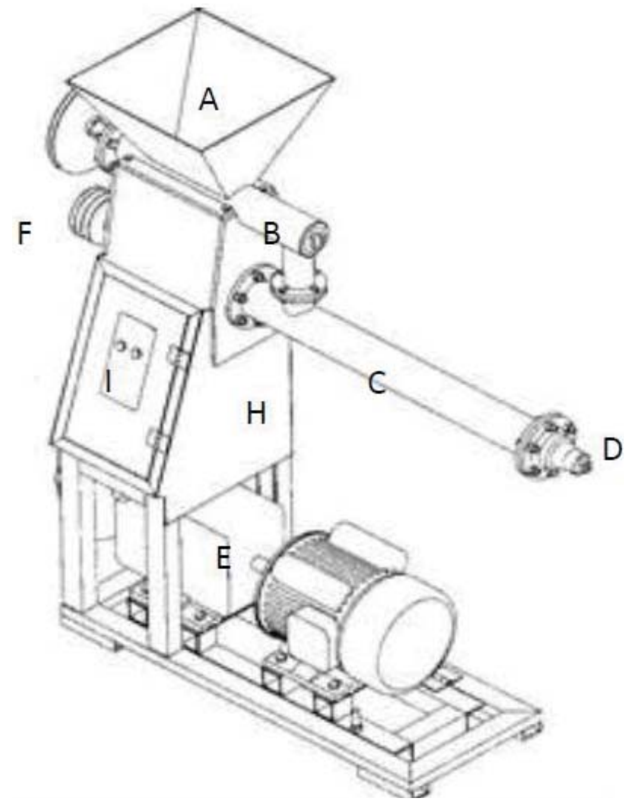


**Figure 1.** Isometric view of the extruder. **A**- Hopper, **B**- Feeding Conveyor, **C**- Extruder worm, **D**- Die Unit, **E**- Power train, **F**- Conveyor pulley, **G**- Extruder pulley, **H**- Extruder Housing, **I**- Control.

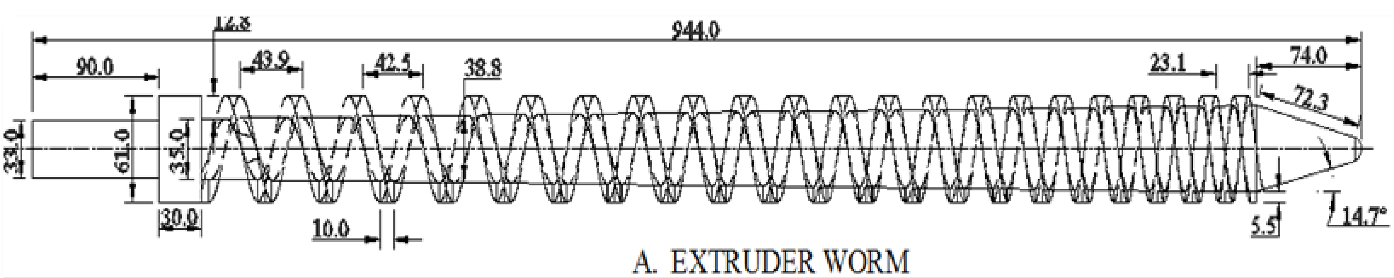


**Figure 2.** The screw's configuration.

each run of sample.

### Statistical analysis

This experiment was conducted using a factorial design comprising of five levels of product classification, three employed to fit the experimental data to second-order levels of initial moisture content, three levels of screw speed and five levels of duration of operation of machine. The four independent variable levels were preselected based on the results of preliminary tests. Each treatment was replicated thrice. One way ANOVA, least significant follow up tests, and stepwise multiple regression analysis were carried out using Statistical Package for Social Scientists (SPSS 13.0) software. Variables were analyzed with and without their interaction to see if there will be any improvement in the model fit. Microsoft Excel © 2007 was used for plotting graphs. Regression analyses were employed to fit the experimental data to second-order polynomials. Also, response surface methodology was applied to the extrusion data using a second order polynomial as fitted to the data to obtain regression equations showing the importance of each independent variable and their interactions on the response variables considered using (SAS) software v.9.R1 (2003). The generalized regression model fitted to the experimental data is given as follows:

$$Y = Bo + b1PC + b2SC + b3MC + b4DT + b11PC^2 + b21SC.PC + b32\ MC.SC + b31MC.PC + b33MC^2 + b4\ 1(DT*PC) + b42DT.SC + b43DT.MC + b44\ (DT^2) + \varepsilon$$

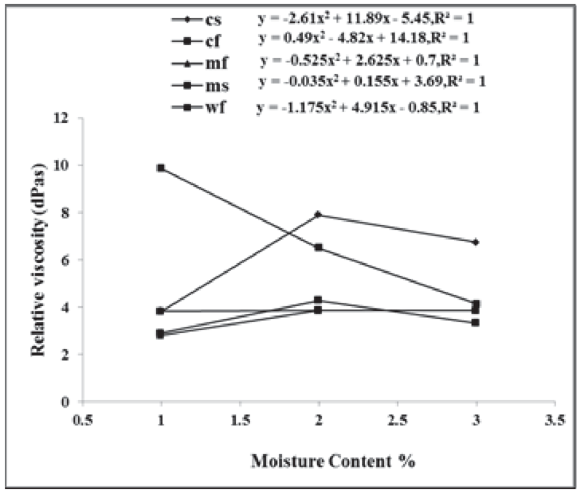


**Figure 3.** Variation of relative viscosity with duration of operation at screw speed 100 rpm and initial moisture content 30%.

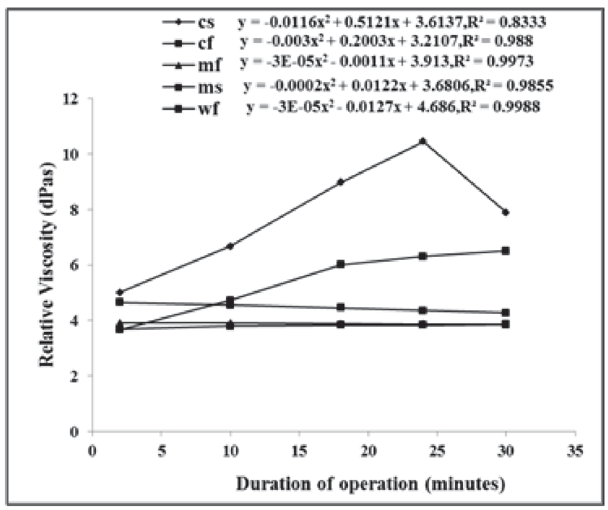


**Figure 4.** Variation of relative viscosity with initial moisture content at 30 min extrusion time and 100 rpm screw speed.

**Data collection**

The extruded samples were dried according to Iwe et al. (1999), coarsely ground in a high speed laboratory blender (Waring Commercial Heavy Duty Blender, New Hartford, Conn. U.S.A.), milled in a domestic blender (Martex, Dawan) and passed through a 300 um sieve. The viscosity of the melts was determined with Capillary Viscometer Method, AOAC (1995) using Equation 1.

$$\frac{\text{Flow rate of sample solution at 20 oC} \times \text{specific gravity of sample solution} \times 1.002 \text{ ( specific gravity of water)}}{\text{flow rate of water}} \quad (1)$$

Pasting properties (hot and cold paste viscosity) were determined as described by Wang et al. (2011) but with a few modification e.g. the instrument used to measure the pasting viscosity of the extrudates is the Rion viscotester (VT – O4E – Japan) (Mouquet, 1998; Owolarafe et al., 2008). Also, the samples were heated to 90°C and the HPV determined. This was because all the materials under study had a gelatinization temperature much less than 90°C. The test fluid was then cooled at a constant rate to 30°C. This value represents the CPV at which temperature the product is normally eaten or the room temperature.

## RESULTS AND DISCUSSION

### The effect of extrusion conditions on relative viscosity

The effect of duration of operation and moisture contents on relative viscosity at different extrusion conditions are shown in Figures 3 and 4. Relative viscosity increased positively as the duration increased for cassava starch and flour whereas it decrease with increase in duration of

**Table 2.** The stepwise regression data analysis of relative viscosity.

| Models | Coefficients | | T-test | Prob | Adjusted $R^2$ | F value | Prob | VIF |
|---|---|---|---|---|---|---|---|---|
| 1 | $B_0$ | -577 | -0.287 | -0.775 | 0.068 | 6.396 | 0.014 | 1.000 |
| | Sc | 0.057 | 2.529 | 0.014 | | | | |
| 2 | $B_0$ | -13.493 | -2.578 | 0.012 | 0.139 | 6.986 | 0.002 | 6.224 |
| | Sc | 0.188 | 3.487 | 0.001 | | | | 6.224 |
| | Pc | 0.246 | 2.655 | 0.010 | | | | |
| 3 | $B_0$ | -14.095 | -2.751 | 0.008 | 0.178 | 6.341 | 0.001 | 6.224 |
| | Sc | 0.188 | 3.568 | 0.001 | | | | 6.224 |
| | Pc | 0.246 | 2.716 | 0.008 | | | | |
| | Dt | 0.036 | 2.096 | 0.040 | | | | 1.000 |
| 4 | $B_0$ | -14.645 | -2.939 | 0.004 | | | | 6.239 |
| | Sc | 0.194 | 3.783 | 0.000 | | | | |
| | Pc | 0.251 | 2.857 | 0.006 | 0.224 | 6.355 | 0.000 | 6.228 |
| | Dt | 0.123 | 2.966 | 0.004 | | | | 6.201 |
| | dm | -0.003 | -2.292 | 0.025 | | | | 6.206 |

B0, constant term; Sc, starch content; Pc, protein content; Dt, duration of operation; dm, interaction of Dt and Moisture content.

operation for cereal products. The maximum relative viscosity of 10.45 (0.001 Pas) was attained at 30% moisture content by cassava starch. The relative viscosity at 30% moisture content was higher than 25 and 40% for the entire products expect cassava flour.

This shows a difference between the behaviour of the viscosity of cassava flour and its starch. This may be because at 25% mc, there was no transition of the starch from the original floury nature to a melted state typical of most extrusion because of blockage of the screw. This problem of getting stocked at lower moisture levels can be overcome by improving the torque. Also, the maximum value for the viscosity occurs where the cellulose is least, that is, starch. For higher concentration as contained in flour, it decreased. This may be due to the fact that cellulose, being a major component of flour does not develop viscosity (Arambula et al., 2002).

Viscosity decreases with duration of operation, product temperature and moisture content for cereal products. This can be due to the fact that within normal operating ranges starches and protein rich material are shear thinning (Lin et al., 2009; Moscicki and van Zuilichem, 2011). This justifies the use of a power low constitutive equation for the shear dependency of viscosity. However, the result of relative viscosity for cassava products generally showed a deviation from above concept. Only at extreme temperature does the equation applied to cassava product and by this time, from observation, the cassava is already becoming dextrinized. Also, it has been reported (Lo et al., 1998) that as the temperature of the dough rises above the gelatinization range the starch granules undergo swelling. The force may have been great enough to break these fragile granules into smaller fragments thereby causing a reduction in viscosity. For cassava products, the rise in viscosity with temperature before a decline may be due to the fact that it requires greater force to break the strong bonds that exists between the starch molecules than those of cereals because of their higher amyl pectin contents (Huang et al., 2008; Moorthy, 2004).

Also, the gelatinization temperature for cassava is lower than that of maize and wheat. (Ihekoronye and Ngoddy, 1985; Van Zuilichem and Stolp, 1987). The stepwise regression data analysis of relative viscosity is shown in Table 2. The low $R^2$ for relative viscosity is an indication that the relationship is not best described by a linear model. The polynomial models as shown on the graph have better representation of the relationships. The interaction terms did not improve the model $R^2$. As food, the extrudates with low relative viscosity can easily be eaten by infants while those with high viscosity can only be eaten easily by adults because they tend to be hard and cohesive in texture than samples with low viscosities.

## Effect of extrusion variables on pasting properties

### *Hot paste viscosity*

The effect of extrusion variables (initial moisture content, duration of operation and screw speed) on hot paste viscosity are shown in Figures 5 and 6. Hot paste

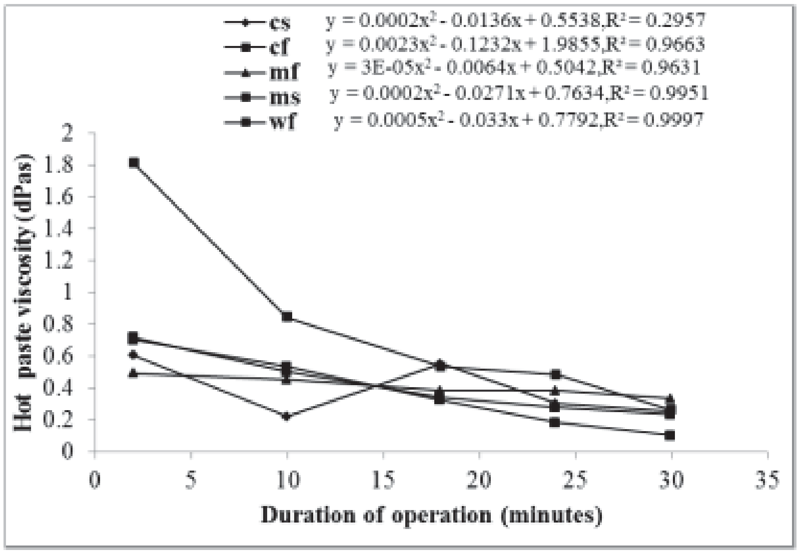


**Figure 5.** Variation of hot paste viscosity with initial moisture content at 30 in extrusion time and 100 rpm screw speed.

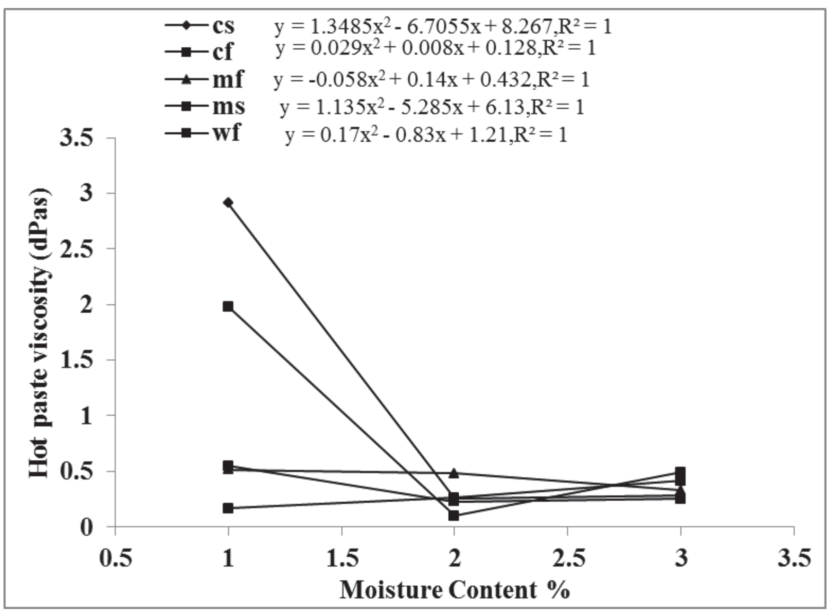


**Figure 6.** Variation of hot paste viscosity with duration of operation at screw speed 100 rpm and initial moisture content 30%.

viscosity (HPV) varies inversely with duration of operation that is, HPV decreases with increase in duration of operation and decreased with increase in moisture content from 25 to 30% and increased at 40%. Maximum (HPV) of 9.1 dPas was attained at 25% (not shown on graph). The stepwise regression data analysis of HPV is shown in Table 3. The $R^2$ showed that the relationship is not best described by a linear model. However, the polynomial equation generated by the response surface regression (Appendix Table 1) gave a better fit.

### *Cold paste viscosity*

The effect of extrusion variables (initial moisture content, duration of operation and screw speed) on cold paste viscosity is shown in Figures 7 and 8. Cold paste viscosity (CPV) varied inversely with duration of operation and decrease with increase in moisture content from 25 to 30% and an increase at 40%. Maximum CPV of 12.98 dPas was attained at 25% moisture content. A CPV of 16.47 dPas was attained at 0 duration of operation (that

**Table 3.** Stepwise regression analysis for hot paste viscosity

| Models | Coefficients | | T-test | Prob. | Adjusted $R^2$ | F value | Prob. | VIF |
|---|---|---|---|---|---|---|---|---|
| 1 | $B_0$ | 0.664 | 8.777 | 0.000 | 0.605 | 16.347 | 0.003 | 1.000 |
| | Dt | -0.016 | -4.043 | 0.003 | | | | |
| 2 | $B_0$ | 1.216 | 6.099 | 0.000 | 0.782 | 18.962 | 0.001 | 1.058 |
| | Dt | -0.014 | -4.614 | 0.002 | | | | |
| | Mc | -0.017 | -2.882 | 0.020 | | | | 1.058 |
| 3 | $B_0$ | 1.800 | 15.154 | 0.000 | 0.966 | 94.511 | 0.000 | 35.319 |
| | Dt | 0.061 | -8.513 | 0.000 | | | | |
| | Mc | -0.035 | -9.733 | 0.000 | | | | 2.491 |
| | dm | 0.001 | 6.604 | 0.000 | | | | 39.982 |

$B_0$, constant term; Dt, duration of operation; Mc, moisture content; dm, interaction of Dt and Mc.

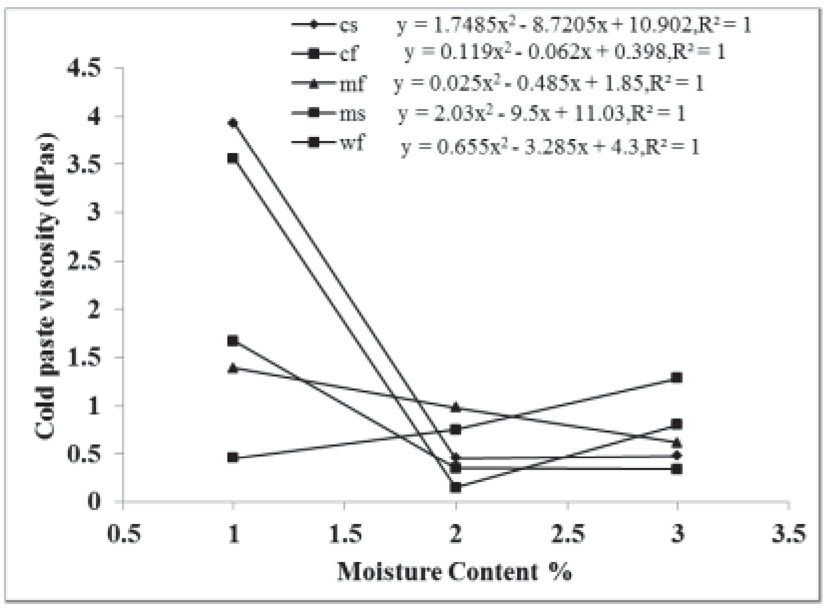


**Figure 7.** Variation of cold paste viscosity with initial moisture content at 30 min extrusion time and 100 rpm screw speed.

is, when the cassava starch was not run through the extruder). However, a minimum CPV of 0.477 dPas was attained at 25% and 30 min duration of operation. The stepwise regression data analysis of CPV is shown in Table 4. The Duration of sampling has the highest contribution 52.8% to $R^2$ of CPV. The variable, moisture content accounted for 18.8% and screw speed only 2.7% of the total variation in $R^2$.

### *Stability of the products*

Table 5 shows the stability of the extrudates obtained from the differences obtained between the HPV and CPV of each sample. From the analysis, MS at 25% m.c is the least stable, having the highest difference between its CPV and HPV values. This is followed by Wf at 25% mc. Also, the most stable of the products. Also, the most stable of the products is MS at 30% mc, followed by Wf, and then CS. If the HPV and CPV are far apart indicating lower stability then its tendency for retrogadation is very high. Table 5 shows there is generally an improvement in the stability of the extruded products when compared to the raw samples. Also, the stability of cassava products were improved better than cereal products. According to Chang et al. (1998), starch with low moisture content extruded at a high temperature results in an extrudate characterized by a low degree of retrogradation, while

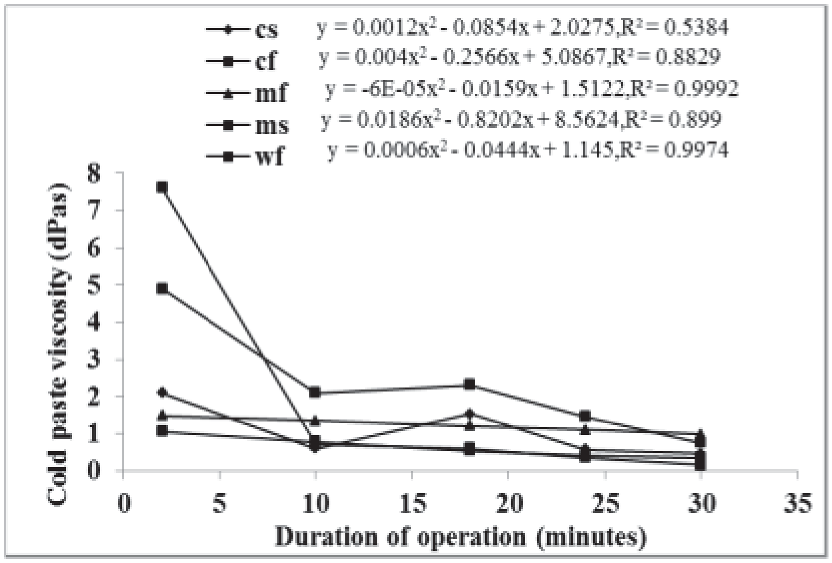


**Figure 8.** Variation of cold paste viscosity with duration of operation at screw speed 100 rpm and initial moisture content 30%.

**Table 4.** Stepwise regression analysis for cold paste viscosity

| Models | Coefficients | | T-test | Prob | Adjusted $R^2$ | F value | Prob. | VIF |
|---|---|---|---|---|---|---|---|---|
| 1 | $B_0$ | 1.621 | 8.317 | 0.000 | 0.674 | 21.640 | 0.001 | 1.000 |
| | Dt | -0.049 | -4.652 | 0.001 | | | | |

B0, constant term; Dt, duration of operation.

**Table 5.** Differences in pasting characteristics of extrudates at the various moisture contents.

| Variables | Differences in pasting characteristics | | | |
|---|---|---|---|---|
| | 25% mc | 30%mc | 40%mc | Raw samples |
| **cs** | 1.02 | 0.205 | 0.19 | 7.5 |
| **cf** | 0.29 | 0.49 | 0.87 | 10.09 |
| **mf** | 0.88 | 0.5 | 0.29 | 5.66 |
| **ms** | 1.58 | 0.05 | 0.31 | 0.38 |
| **wf** | 1.12 | 0.12 | 0.11 | 1.54 |

cs-cassava starch, cf-cassava flour, mf-maize flour, ms-maize starch, wf-wheat flour.

starch with a moderate to high moisture content (190 to 260 g $kg^{-1}$) extruded at a moderate temperature (125-190°C) produces an extrudate with a high degree of retrogradation. However, in this work, retrogradation decreased with increasing extrusion time and moisture content.

## Conclusion

The relative viscosity and pasting behaviour of extrudates from a locally developed single screw extruder at different conditions have been well studied. Relative viscosity increased with increase in duration of operation for cassava products whereas it decreases with increase in duration of operation for cereal products. HPV decreases with increase in duration of operation and decrease with increase in moisture content from 25 to 30% and an increase at 40%. Cold paste viscosity decreased when moisture decreased and temperature increased. Retrogradation decreased with increasing extrusion time and moisture content. The study provided database on extrusion of selected foodstuffs beneficial to the food industry. The equations relating the various dependent and independent variables were established to predict this quality attributes of the products. Both quadratic coefficients and linear models fitted the extrusion data very well expect for relative velocity quadratic where quadratic coefficient proved better.

## Conflict of Interest

The authors have not declared any conflict of interest.

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## APPENDIX

**Appendix Table 1.** Models generated by response surface analysis for RV, HPV, CPV.

| R. Var | Coefficients | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | b0 | b1 | b2 | b3 | b4 | b1*b1 | b1*b2 | b3*b2 | b3*b1 | b3** | b4*b2 | b4*b1 | b4*b3 | b4** | $R^2$ |
| RV | -91.909 | 3.480$^{NS}$ | 0.895* | 2.264* | -0.937$^{NS}$ | 0.0032$^{NS}$ | -0.0236$^{NS}$ | -0.042$^{NS}$ | -0.019* | -0.004$^{NS}$ | 0.0202$^{NS}$ | 0.0136* | -0.007* | -0.003$^{NS}$ | 0.634 |
| CPV | 140.008 | -14.353* | -1.028$^{NS}$ | -4.087* | -0.05$^{NS}$ | 0.264$^{NS}$ | 0.105$^{NS}$ | 0.075** | 0.026$^{NS}$ | 0.017* | 0.0014$^{NS}$ | -0.006$^{NS}$ | 0.0075$^{NS}$ | 0.005$^{NS}$ | 0.713 |
| HPV | 42.133$^{NS}$ | -6.463$^{NS}$ | -0.172$^{NS}$ | -1.688$^{NS}$ | -0.024$^{NS}$ | 0.154$^{NS}$ | 0.046$^{NS}$ | 0.027$^{NS}$ | 0.007$^{NS}$ | 0.012* | 0.002$^{NS}$ | -0.003$^{NS}$ | 0.005$^{NS}$ | 0.002$^{NS}$ | 0.611 |

Significant at *p<0.05; **p<0.01, NS-Non significant at p=0.05. Coef, Coefficients: Bo, (constant term) b1, b2, b3, b4, b5 linear effect of protein content, starch content, moisture content, screw speed and duration of operation respectively. R.Var, Response variable.

academicJournals

Vol. 10(7), pp. 720-726, 12 February, 2015
DOI: 10.5897/AJAR2014. 9372
Article Number: C367EA050402
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

# Effect of recharge, irrigation and soil nature on the variation of nitrate in the groundwater of Wadi Nil (Jijel – North-East Algeria)

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Received 26 November, 2014; Accepted 22 January, 2015

**This paper presents the effect of recharge, irrigation and soil nature on the variation of nitrate in the groundwater of Wadi Nil (Jijel – North-East Algeria) where the intensive use of fertilizers and the recycling of irrigation water have resulted in an alarming increase in nitrate concentrations. In this plain, the groundwater is increasingly polluted by excessive use of fertilizers in agriculture. Indeed, in several areas cultured with irrigated vegetable crops, water contains nitrate levels which exceed the allowed standards for human consumption. The present study consists of a spatio-temporal monitoring of nitrate in groundwater in relation to the dilution caused by charging during the rainy season, on the one hand, and to the leaching caused by irrigation water during the dry season, on the other hand. The results obtained show an increase in the contamination of groundwater by nitrates and their seasonal variations under the effects of recharge, irrigation and soil nature.**

**Key words:** Agricultural pollution, nitrates, recharge, irrigation, groundwater, soil nature.

## INTRODUCTION

The agricultural pollution is a major cause of the deterioration of groundwater quality (Lasserre et al., 1999). The development of agricultural land and the requirements of good production require an input of fertilizers which often leads to groundwater pollution by nitrates due to their high solubility and their weak affinity for ionic exchanges (Addy et al., 1999; Engel et al., 1996).

Many studies proved that, husbandries are the probable cause of the excessive nitrate levels in the groundwater (El Tabach, 2005). Concentrations raised out of nitrates in drinking water are related to health issues such as the methemoglobinemy for children and the cancer of the stomach for adults (Maticic, 1999; Bohlke, 2002). There exist values of limiting acceptable nitrate concentration in drinking water. WHO to define an

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obligatory limiting value fixed at 50 mg/l (Hallberg and Keeney, 1993).

Natural reactions of atmospheric forms of nitrogen with rainwater result in the formation of nitrate ($NO_3$) and ammonium ($NH_4$) ions. Nitrate is a common compound, naturally generated from the nitrogen cycle. However, anthropogenic sources have greatly increased the $NO_3$ concentration, particularly in groundwater (Chand et al., 2011; Vomocil, 1987). The largest anthropogenic sources are septic tanks, nitrogen-rich fertilizers applied to turf grass, and agricultural processes. Nitrogen fertilizers are extensively applied in agriculture to increase crop production, but excess nitrogen supplies can cause air, soil, and water pollution. Arguably, one of the most widespread and dam aging impacts of agricultural over-application of nitrogen fertilizers is the degradation of groundwater quality and contamination of drinking water supplies, which can pose immediate risks to human health (Rail, 1999). There exist values of limiting acceptable nitrate concentration in drinking water.

Thus, in the plain of the Wadi Nil, where the increase in the contents of nitrates of the groundwater, found in certain zones is related to surpluses of manures brought to the cultures. The evolution of nitrate contents in the agricultural zones display the existence of several parameters (the geologic nature of top to aquifer, the effect of the evaporation, the nature of irrigation waters, the rain and the redox conditions (Elmobarak and Mahgoub, 2014)) which could influence the concentration variation.

To address this question, a monthly sampling of groundwater for chemical analysis was carried out during the year 2012 in five wells distributed in terms of the use of land, the use of fertilizer and the frequency of irrigation.

### Presentation of the study area

The studied area is located in the north-east of Algeria. The alluvial aquifer of this area forms part of the coastal plains region of Jijel (Figure 1); it covers an area of 83 $km^2$ and opens to the north of the Mediterranean Sea. It corresponds to the lower Nil valley and its tributaries which contribute to the groundwater recharge (Boufekane and Saighi, 2010).

The maritime location of this plain gives it a mild and damp climate. Between the winter and summer, the monthly median values of temperatures vary from 11 with 25°C (the average air temperature is 17°C/year), the relative humidity is from 70 to 75% and the evaporation is from 41 to 80 mm. The rainfall is relatively high, reaching 900 mm/year (Boufekane and Saighi, 2013).

The geological substratum of the area consists of gneiss and the schist. However, the parts of swallow, sedimentary formations mainly marly Oligocene age, Miocene and Pliocene cover these metamorphic facies. Finally, the depressions and valleys are filled with quaternary alluvial deposits which are interstation terraces aquifers (Boufekane and Saighi, 2013).

The groundwater recharge is mainly directed by infiltration of rainfall and the low water situation by the various rivers which cross the plain. The aquifer forms part of the socio-economic development of the region by the exploitation of the domestic wells and boreholes (36 million $m^3$/year).

## MATERIALS AND METHODS

The study is based on a monthly piezometric monitoring of groundwater and on nitrates analyses carried out on samples of groundwater taken monthly in five water points for year 2012. The chemical analyses were performed by the colorimetric method. The technical characteristics of the photometric device are: UV visible - precision 0.10 mg/l; Interval of measurement 00-30 mg/l; wavelength 555 Nm and the color yellow amber.

The characteristics of the water points selected for the study (Figure 2) are as follows:

i. Point No 1 (borehole ON18) corresponds to a drilling situated in a field of drinking water abstraction. Neither fertilized nor irrigated, its zone of influence coincides with a perimeter of protection of groundwater.
ii. Point No 2 (borehole ON23) corresponds to a drilling located in an agricultural zone little or no fertilized, irrigated from aquifer little loaded with nitrates.
iii. Point No 3 (well P7) corresponds to a drilling situated in a zone of vegetable gardening and greenhouse regularly fertilized; this zone is irrigated from the aquifer. The roof of the aquifer is permeable.
iv. Point No 4 (borehole ON5) corresponds to a drilling located in an agricultural zone fertilized and irrigated only for the summer period.
v. Point No 5 (well P70) corresponds to a drilling situated in a zone of vegetable gardening and greenhouse regularly fertilized; this zone is irrigated from the aquifer. The roof of the aquifer is impermeable (argillaceous).

## RESULTS AND DISCUSSION

### Recharge and irrigation effect on the variations of the nitrates in groundwater

The graph (Figure 3) shows that the rainy season takes place in winter between November and March. It is therefore natural that, on the piezometric level, the groundwater is in situation of "high water" between December and May with a maximum in March – April.

In terms of nitrate, water collected in Points 1 and 2, located in zones not fertilized, sometimes with perimeters of protection is characterized by low values (less than 23 mg/l), while those collected in Points 3 and 4, which form part of zones of vegetable gardening, fertilized and regularly irrigated, their nitrate concentrations are higher (57 to 125 mg/L). Aside from Point 2 which is in an area irrigated with waters little loaded with nitrate (1-6 mg/L).

Figure 3 shows that the concentration of nitrates in the aquifer changes inversely with the piezometric level.

Indeed, they pass from low values when the groundwater is in situation of "high water" to high values in situation of



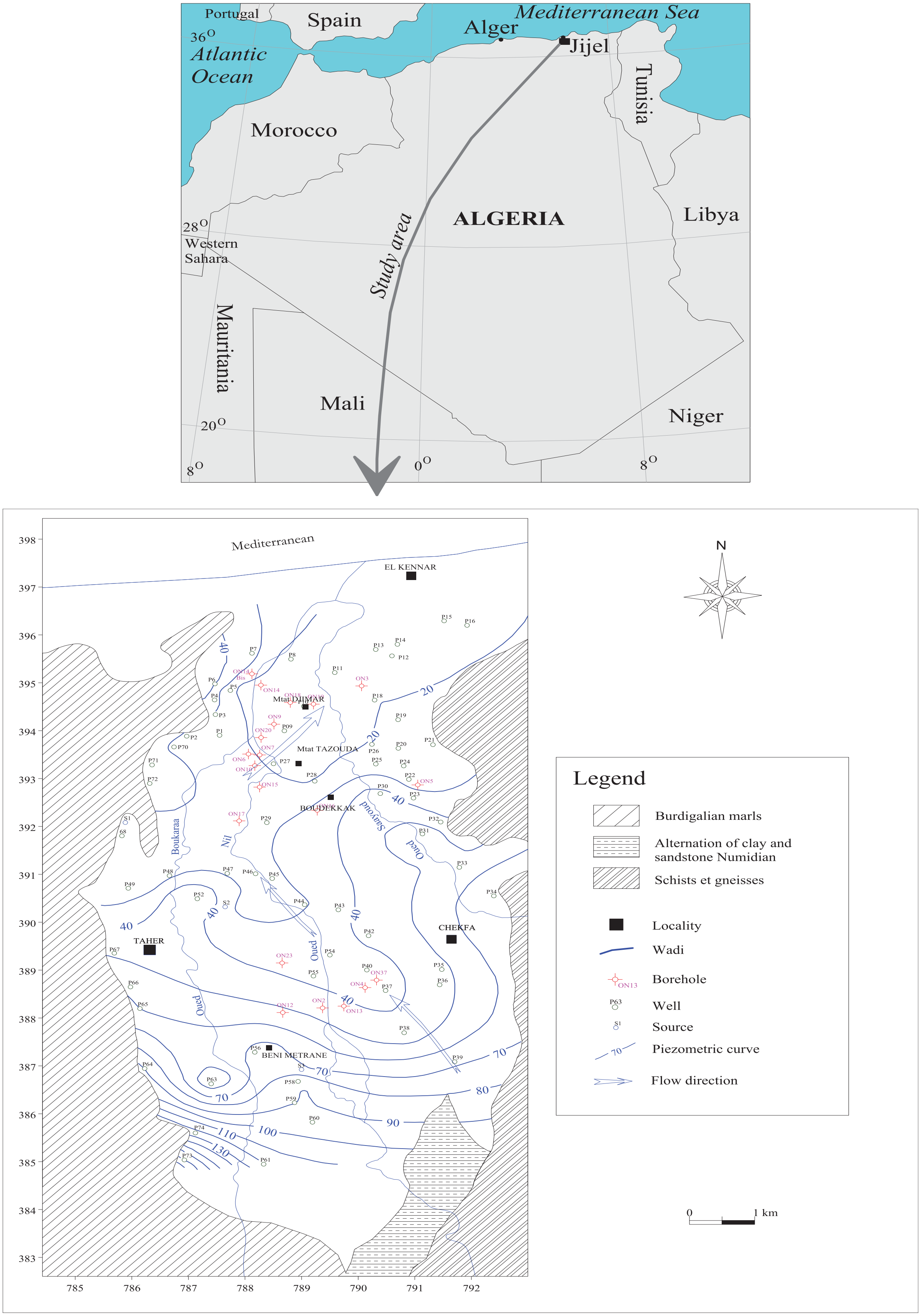

Figure 1. Piezometric map in the plain of Wadi Nil (May 2012).



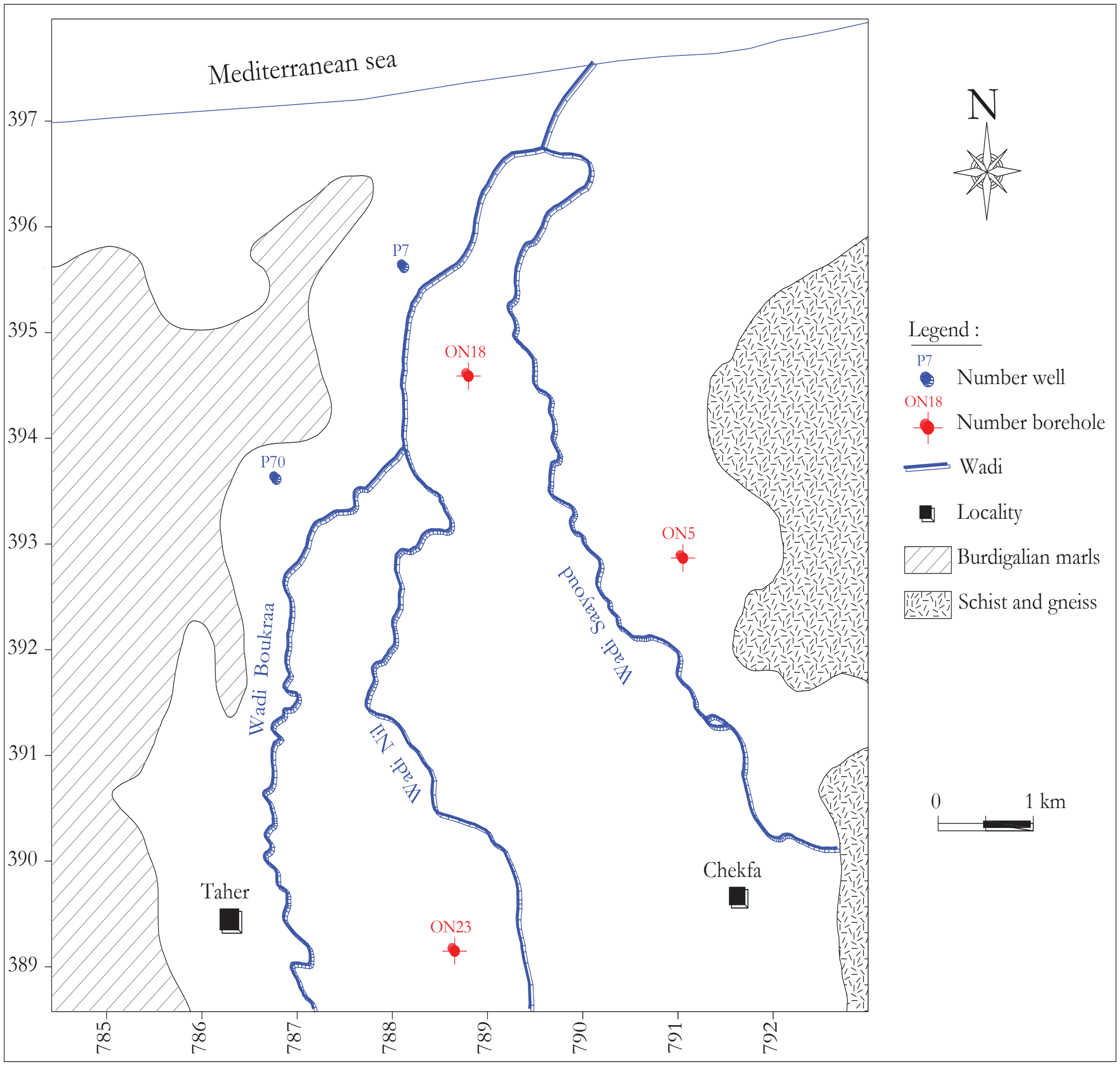


**Figure 2.** Locations of groundwater monitoring wells.

"low water". This translates the dilution effect caused by recharge during the rainy season. This dilution effect is nevertheless insufficient to bring the nitrate contents to acceptable values, especially in areas where the fertilizer contributions are important as in Point No 3.

More explicitly, each water point has its specificity as follows:

i. The water point No 1 (borehole ON18) which is a drilling located in a field of drinking water abstraction, reflects a natural state without fertilization and irrigation. The nitrate levels in the groundwater (less 23 mg/l) are still below the threshold limit for human consumption in spite of light increase in summer (Figure 3A).

ii. The water point No 2 (borehole ON23) illustrates the characteristic of a zone not fertilized but irrigated with water little loaded with nitrates (1-6 mg/l). In this case, the low nitrate levels which characterize the groundwater are stable all the year (Figure 3B), oscillating around a value of 4 mg/l. They undergo an effect of dilution regularly either by the winter rain or by water of irrigation little mineralized in summer.

iii. The water point No 3 (well P7) corresponds to a zone of intense agricultural practices and greenhouse farming, with permanent contributions of fertilizer and frequent irrigation carried out starting from the well No 3. The leaching of nitrates and their transfer to the groundwater remains all the year with an effect accentuated in summer (Figure 3C). The nitrate levels are constantly with the top of the acceptable threshold: about 80 mg/l in winter in spite of the effect of dilution generated by the rain and nitrate levels higher than 120 mg/l were found in summer due to leaching and transfer of nitrate to groundwater by irrigation water.

iv. The fourth point (borehole ON5) represents an agricultural zone irrigated and fertilized only in summer



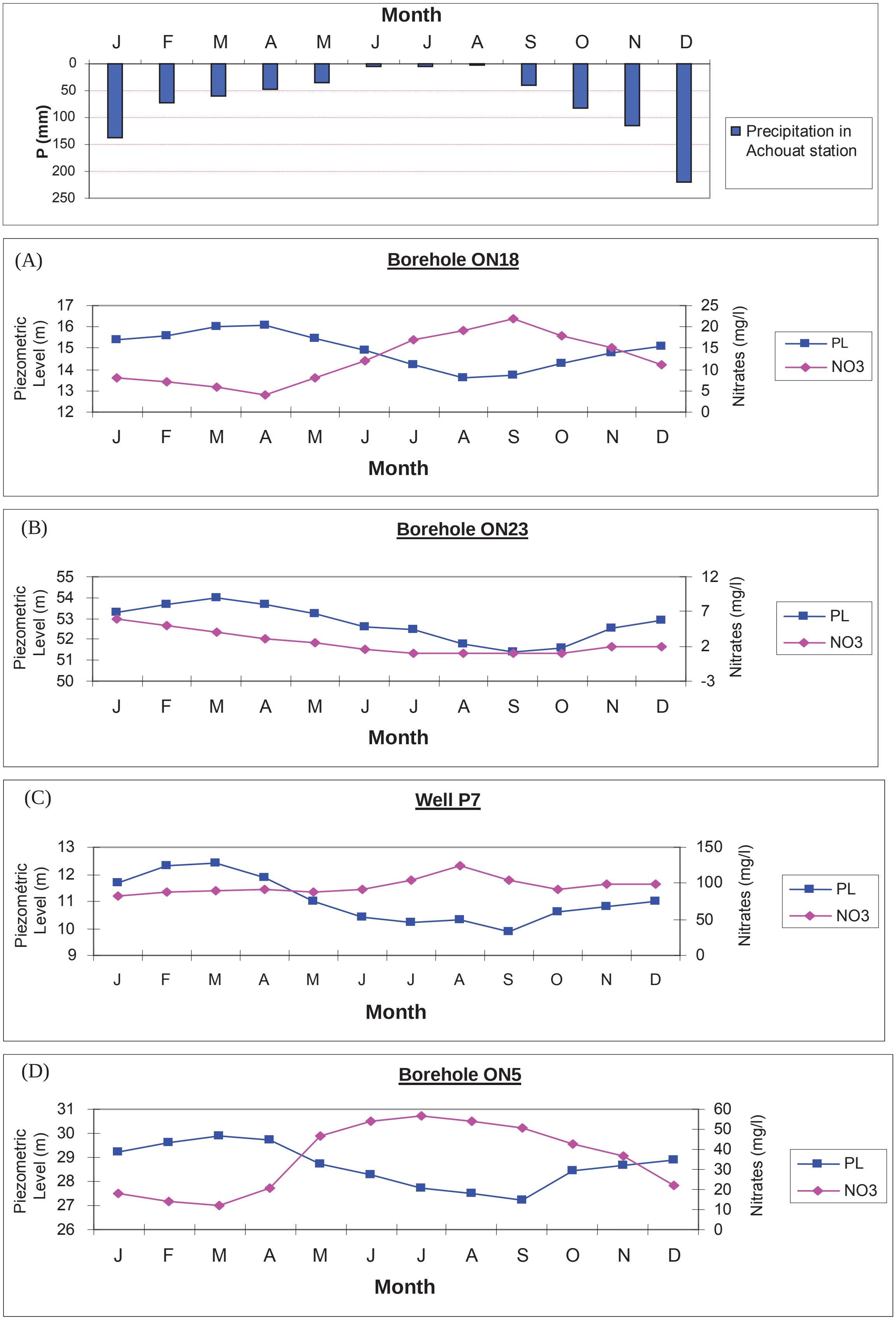

Figure 3. Evolution of nitrate in groundwater with piezometric fluctuations in 2012.



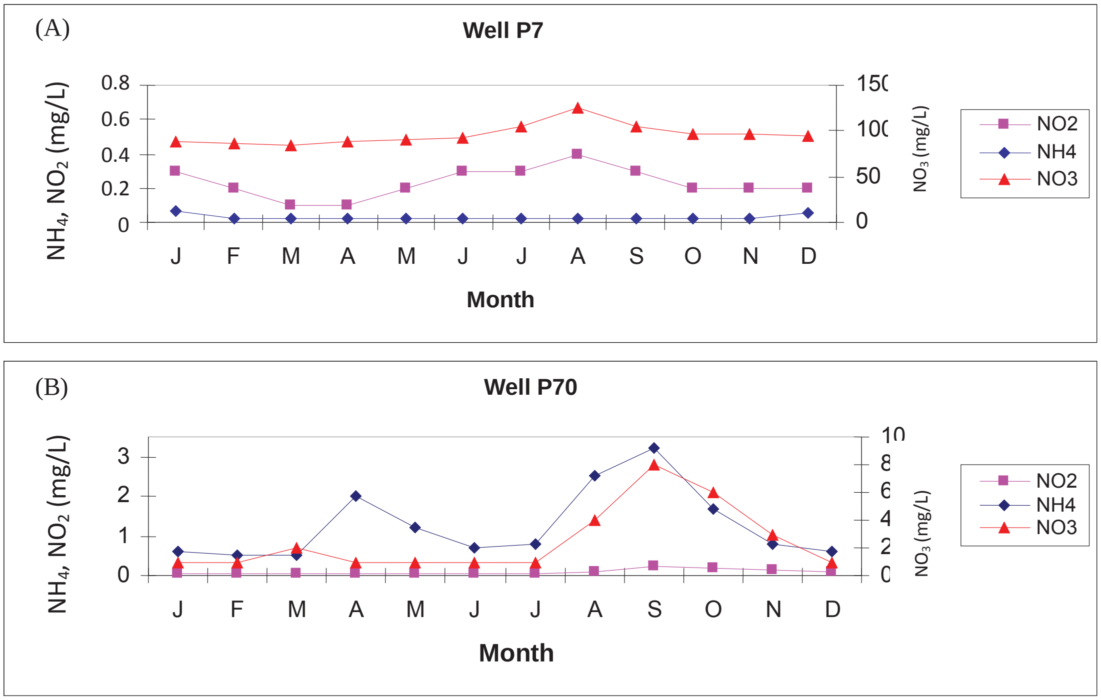


**Figure 4.** Evolution of the nitrate according to the soil nature.

season. In spite of an intermittency of the fertilizer contributions, the diagram of evolution of the nitrate levels (Figure 3D) is similar to the preceding case but with lower values (maximum 57 mg/L). The dilution effect caused by the winter recharge is however more efficient to lower the nitrate concentrations with 12 mg/L.

In addition, the low nitrate levels recorded on the level of the perimeters protected (as at the water No 1 point), testify to the feature not generalized of the nitric contamination. Drainage waters which join the rivers are still healthy. The main source of nitrate excess in groundwater is of agricultural origin. It is specific, since is highlighted only at plots excessively fertilized and irrigated.

Finally, it should be noted that in addition to its low efficiency, the technique of surface irrigation, not in agreement with the economy of water is largely responsible for the training of nitrate to groundwater. It also helps to maintain the level of water (close enough to the surface), favoring capillary evaporation in summer, increase in hydro-chemical contents and that of nitrates. This is also what is found in 3 out of 4 water points studied.

## Soil effect on the variations of the nitrates in groundwater

To study the soil effect on the variations of the nitrates in groundwater, we considered two representative water points: one located in a zone where the roof of the aquifer is permeable (well P7) and the other in the case of an argillaceous roof (P70 well) (Figure 4).

In the well P7, with a permeable roof, the annual evolution of the chemical forms of nitrogen show a weak increase in the nitrates tenors during high water levels (December at March), (Figure 4A). For the period of high water levels; nitrites appear with weak concentrations (0 to 0.41 mg/L) and evolve inversely with the redox potential, due to the effect of the rains which bring back the water more oxygenated towards the aquifer. On the other hand, for the period of low water levels, the reduction in the redox potential under the effect of the bacterial activity will produce an increase in the nitrites. Ammonium often presents rather weak concentrations (0 to 0.071 mg/L), which indicates that the reduction of nitrates stops in the nitrite forms.

In the well P70 with an impermeable roof, the nitrate concentrations remain weak (1 to 8 mg/L), (Figure 4B). The existence of clayey intercalations in the ventilated zone slows down the transit of nitrates towards the aquifer. A peak with 8 mg/L is observed in September during the irrigation period. The ammonium form presents the same evolution and remains with weak concentrations. In period of low water levels, the values of ammonium reach 0.23 mg/L. The nitrites exist in very weak concentrations, considering their transitory character between the forms of nitrate and ammonium (Debieche et al., 2001).

The interpretation of the evolution forms the nitrogen



according to the hydrodynamics of groundwater leads to the following conclusions:

i. The contamination of groundwater of Wadi Nil is linked to inputs of nitrogen fertilizers in excess to the needs for plants,
ii. The water of irrigation and rain play a major role in the transport of nitrate ions from soil to groundwater,
iii. The clayey intercalations which can exist in the roof of the superficial layer protect the aquifer against the filtrations of the flows of nitrogen pollutants to groundwater and favor reducing conditions, allowing nitrate appear in the form of ammonium.

## Conclusion

The nitrate pollution of groundwater in the valley of the Wadi Nil is of agricultural origin. The excessive use of fertilizers in the perimeters of vegetable gardening associated with important amounts of irrigation involves in-depth nitrogen excess and constitutes the principal factor in the deterioration of groundwater quality. At certain points of water, nitrate pollution exceeds 50 mg/l. Fortunately, it is confined to those areas where the groundwater is covered with excessively fertilized and irrigated cultures. The low nitrate levels recorded in protected areas and in water Wadi support this conclusion. This finding, although not very alarming, calls however on the fact that the groundwater remains under the threat of a generalized nitrate pollution, if the supply of fertilizers to cultures is not regulated and strictly controlled. It is therefore, without delay, to adopt an action plan aimed at raising awareness among farmers about the dangers of nitrate pollution of groundwater. Well adapted farming practices and rational fertilization have to be implemented to meet the requirements of good returns within the state of the environment.

## Conflict of Interest

The author(s) have not declared any conflict of interests.

## ACKNOWLEDGEMENT

The authors are grateful to the authorities of Jijel for providing data and permission to pursue and publish the present work.

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Vol. 10(7), pp. 727-730, 12 February, 2015
DOI: 10.5897/AJAR2014. 8557
Article Number: B45528250403
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Review*

# Growth, yield and quality responses to plant spacing in Irish potato: A review

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Received 27 January, 2014; Accepted 22 January, 2015

**A review of literature was conducted on how growth, yield and quality respond to plant spacing in Irish potato. A number of parameters were considered: stem length, stem number, tuber numbers, tuber size categories, total yield, marketable yield, dry matter content and specific gravity. Some contradictions were exposed showing the need for further researches concerning how spacing interacts with the environment and other production practices including varietal choices. This information will help producers to optimise productivity.**

**Key words:** Plant spacing, potato growth, potato yield, potato quality.

## INTRODUCTION

How closely potato plants are spaced in a field affects markedly the growth, yield and quality of the crop. Plant population studies in potato production were among the earliest and most common field experiments (Caliskan et al., 2009; Foti, 1999) and continue to be of immense importance. The most recent in this area include the work by Masarirambi et al. (2012) and Getachew et al. (2013). Some works have focused on optimizing crop production and profitability (Rex et al., 1987; Wurr et al., 1993). Since new cultivars are continually being released, these studies will continue to be essential (Barry et al., 1990; Wurr et al., 1993). Such new cultivars will differ in how their growth, yield and quality will be influenced by how far apart the individual plants will be spaced in a field. In any unique growing locality, the optimum plant population levels must be well established (Kabir et al., 2004; Rykbost and Maxwell, 1993). Masarirambi et al. (2012) asserted that there was still much to learn about even the simple interrelationships of haulm and tuber growth and the interferences between branches. If these inter-relationships are well understood, the crop would be managed well, so as to provide a wide range of responses. Such responses could include radiation interception, the influence of climate variation on maturity and earlier tuber formation, and the number and sizes of tubers at maturity (Masarirambi et al., 2012).

## EFFECT OF PLANT SPACING ON GROWTH

Some studies, for example those by Fonseka et al. (1996), Ifenkwe and Allen (1978), in which the relation between plant spacing and growth were examined, the results showed an increase in plant spacing to be

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accompanied by an increased stem length. The increased branching at the wider spacing did not compensate for fewer plants/m$^2$. They attributed increased branching at wider spacing to the availability of more space at lower plant densities. More space meant that plants were able to exploit the available nutrients in the soil and the photosynthetic active radiation for growth than plants at close spacing. In other words, the growth rate was increased. Vander Zaag et al. (1990) studied the response to plant population under two different sites; one temperate and the other tropical. At the temperate site, closer spacing increased plant height. At the tropical site, closer spacing decreased plant height when canopy cover did not reach 100%.

Other studies have examined the effect of planting population on stem number. Bussan et al. (2007) showed that stem density (number of stems emerging from all planted tubers) increased linearly with increasing plant density (number of seed tubers planted per unity area), but the response differed across years. They highlighted that the linear response indicated that the stems per plant were not influenced by plant density. This was confirmed by other workers (O'Brien and Allen, 1992; Knowles et al., 1985; Love and Thompson-Johns, 1999; Rex, 1990; De la Morena et al., 1994; De la Morena et al., 1994; Khalafalla, 2001; Rex, 1991). Stems per plant were not influenced by plant density but by physiological factors resulting from the management of the seed. Masarirambi et al. (2012), however, found population density to have a highly significant influence on the subsequent development of secondary stems. Stem numbers were reduced at high plant density level and increased significantly at lower densities. This is likely due to intense competition for light, water and nutrients at high densities. Wurr et al. (1993) attributed the reduction in stem number and development at the high-density spacing levels to the limited space for root and tuber expansion.

Masarirambi et al. (2012) found out that plant population density (E) had an impact on above ground biomass production, specifically leaf area production, with plants grown at a spacing of 90 by 45 cm exhibiting highest haulm growth. The least values of leaf area production were recorded at 90 by 15 cm. Masarirambi et al. (2012) also found a lower leaf area at highest crop density (90 × 15 cm) than at 90 × 30 cm. Ifenkwe and Allen (1978) found that increasing planting density reduced number of axillary branches and their leaves per plant, dry weight of leaf, stem, underground parts and tubers per plant, but increased stem length. Almekinders (1993) showed that increasing plant density resulted in cessation of shoot growth at an earlier stage and concentrated inflorescence and flower production at primary positions of early-flowering shoots. He worked on spacing but using different cultivars. With cultivars Renacimiento and Yungay, a higher plant density increased the percentage of flowers produced in the first three weeks of the flowering period but with cultivar Atzimba, the effect of plant density on the distribution of flower production was off-set by a slower stem development.

## EFFECT OF PLANT SPACING ON TUBER NUMBERS

High numbers of tubers at high plant densities have been reported by O'Brien and Allen (1992), Iritani et al. (1983), Hammes (1985), Wurr et al. (1993), Allen and Wurr (1992), Karafyllidis et al. (1996), Wiersema (1986). The high number of tubers at high densities may be accounted for by the fact that at low density plantings, fewer sinks are produced per unit area and increase as the planting density increased. This is in contrast with Masarirambi et al. (2012), Strange and Blackmore (1990), Vander Zaag et al. (1990) and Güllüoglu and Arioglu (2009) who found out that the availability of space had an effect on number of tubers formed. The greater the space, the higher the number of tubers formed (Güllüoglu and Arioglu, 2009).

## EFFECT OF PLANT SPACING ON YIELD

Reduced plant population was reported to increase yield (Arsenault and Malone, 1999; Vander Zaag et al., 1990; Mauromicale et al., 2003). Work by Güllüoglu and Arioglu (2009) revealed that major yield components; mean tuber weight and tuber yield per plant, significantly decreased as planting distance got closer due to increasing inter-plant competition. Rykbost and Maxwell (1993) showed that only one out of seven varieties showed reduced total yield at low populations.

Contrastingly, reports of increased yield at high plant population are available (Güllüoglu and Arioglu, 2009; Nelson, 1967; Wurr et al., 1993; O'Brien and Allen, 1992; Rex, 1991; Strange and Blackmore, 1990; Love and Thompson-Johns, 1999; Iritani et al., 1983; De la Morena et al., 1994; Bleasdale, 1965; Allen and Wurr, 1992). Khalafalla (2001) attributed this to increased number of plants/unit area and more tubers/plant. Similar results were reported by Nelson (1967) in North Dakota. He found that increased plant populations reduced average tuber weight but increased yields due to more tubers being harvested. Similarly, Giovanni and Signorelli (2003) reported yield increases. In a study by Masarirambi et al. (2012), yield was not affected by population density although they did not examine the tuber size distribution which would have shown an increase in smaller tubers with increased plant population.

## TUBER SIZE

Plant spacing has been manipulated in the production of seed sizes that can satisfy the targeted market. Farmers that produce tubers for seed tend to produce smaller tubers because that is what the market demands whereas for processing markets bigger tubers are required. A number of researches have been carried out to investigate the effect of plant spacing on tuber size category. In studies done by Getachew et al. (2013), tuber bulking of individuals at close spacing was reduced resulting in small tubers. Khalafalla (2001), Love and Thompson-Johns (1999), Nelson (1967) and Cortbaoui and Center (1988) also showed that closer spacing resulted in smaller tubers. In a similar studies but using different varieties, Rieman et al. (1953) showed that the cultivar Russet Burbank had a tendency to produce many tubers of small size implying a genetic influence on tuber size.

However, work by Güllüoglu and Arioglu (2009), Love and Thompson-Johns (1999), and Getachew et al. (2013) found that a larger proportion of large sized tubers occurred when a wider spacing was used. Getachew et al. (2013) attributed this to the presence of fewer sinks that were available per unit area. That in turn resulted in less competition between the individuals. Other researchers also supported the same findings (Yenagi et al., 2010; Essah, 2004).

## MARKETABLE YIELD

In terms of the marketable yield, the results from researches carried out by a number of researchers are also contrasting. Khalafalla (2001) carried out his studies on 2 different sites namely Shehainab and Shambat. He found marketable yield to increase as the spacing was reduced except when the research was carried out again in another year. At Shambat marketable yield significantly ($P<0.05$) increased with close spacing and out-yielded wider (35 cm) spacing by 26%. Love and Thompson-Johns (1999) used different varieties and when tested on different plant spacing that were used, responded differently with regard to marketable yield. Variety Ranger Russet produced higher marketable yield at narrowest spacing than Russet Burbank whilst variety Frontier Russet was intermediate. Entz and LaCroix (1984) in their research where they studied the effect of row spacing and seed type on yield and quality found that those plants grown from large seed pieces produced higher marketable yield at the widest spacing. Lynch and Rowberry (1977) also found marketable yield to respond negatively to an increased plant density.

## EFFECT ON SPECIFIC GRAVITY

Numerous studies showed that increasing plant spacing resulted in an increase in specific gravity (Vander et al., 1990; Burton, 1948; Zebarth et al., 2006). Getachew et al. (2013) attributed this to the resultant less intra-plant competition associated with reduced plant population. Fonseka et al. (1996) also observed a fall in specific gravity as the plant spacing was increased from 30 to 35 cm drawing the same conclusion as Getachew et al. (2013). White and Sanderson (1983) also showed that wider spacing (38 and 56 cm) increased specific gravity. Rykbost and Maxwell (1993) however, found plant population not to have an effect on the specific gravity of all the varieties they studied.

## DRY MATTER CONTENT

Getachew et al. (2013) found high plant population to be associated with low dry matter content. It then rose to a peak at 30 but then fell with a further increase in plant spacing. He thought that at low plant spacing, there was a high competition for light and other important resources. This then led to a few resources being channeled to each sink. Low dry matter content at the widest plant spacing was due to the high photosynthetic rate thus a relatively high vegetative growth at the expense of the tubers. Dry matter partitioning to the tubers was less. Many other studies showed increased dry matter with decreasing plant population (Tafi et al., 2010; Burton, 1948; Vander Zaag et al., 1990; Tamiru, 2004).

## CONCLUSION

Varietal and environment seemed to lead to the contradictions reported among various workers. Clearly, there is need for continued research particularly with the advent of climate change. For instance, work done under temperate contradicts that done under tropical conditions. In some instances, results varied from year to year indicating complex relationships with climate elements. Ultimately, yield is affected in a complex way by plant spacing and this is made even more complex when different varieties are evaluated. Rykbost and Maxwell (1993) showed that only one out of seven varieties showed reduced total yield at low populations while other showed consistent increased yield at high populations.

## Conflict of Interest

The author(s) have not declared any conflict of interests.

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