African Journal of Agricultural Research

Volume 9 Number 27 3 July 2014

ISSN 1991-637X

Academic Journals

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Vol. 9(27), pp. 2095-2103, 3 July, 2014
DOI: 10.5897/AJAR2014.8464
Article Number: 02D7FA345957
ISSN 1991-637X
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African Journal of Agricultural Research

Full Length Research Paper

Summer sesame response to moisture and thermal regimes

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Received 2 January, 2014; Accepted 16 June, 2014

A field experiment was conducted at Instructional Farm of Soil and Water Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh during summer season (February - May) 2012 to study the sesame response to moisture and thermal regimes with three factorial strip plot design; three factors are thermal regimes (date of sowing), moisture regimes (Irrigation interval) and use of mulch. The crop was exposed to different thermal regimes at four different dates of sowing that is, 1st February, 14th February, 1st March and 14th March with different moisture regimes by varying the irrigation interval (3, 4 and 5 days irrigation interval). Results revealed that the seasonal depth of irrigation moreover decreased with delay in sowing from 1st February and the growing days requirement decreased with delaying sowing after 1st February with irrigation water depth 380, 402, 356 and 355 mm, while growing degree days as 109, 94, 83 and 74 days. The more number of growing days were required to mature the crop with less total thermal heat units as 2152, 1946, 1803 and 1722 degree - days, respectively. The sesame yield is significantly influenced by the thermal regimes. The highest and lowest sesame grain yield of 1131.59 and 555.20 kg/ha was observed for the thermal windows of 16th and 1st February, respectively. The grain yield increased rapidly by delaying the sowing from 1st to 21st February then it decreased slowly and continously. The vegetative stage was found the most sensitive stage to thermal regimes followed by establishment stage, flowering stage, ripening stage and reproductive stage. The highest grain yield of 991.27 kg/ha was found under drip irrigation at 3-days interval which was higher by the tune of 10.33, 17.32 and 20.86% as compared to that of under 4, 5 days under drip and 7-days under surface irrigation, respectively.

Key words: Sesame, thermal regimes, moisture regimes, drip irrigation in sesame, mulching in sesame.

INTRODUCTION

India occupies 329 M-ha geographical area, which is 2.4% of the world's land area; it supports over 15% of the world's population. The population of India on 31 March, 2011 was 1,210,193,422 persons. Thus, India supports (www.indianetzone.com). Drip irrigation is one of the best and latest methods for efficient utilization of irrigation

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water. It is an efficient method of application of water, in which the water is applied at low rate over longer period of time at frequent intervals with low-pressure delivery system, in order to avoid water stress to the plant. Drip irrigation provides high water use efficiency, higher crop yield, less labor requirement and relatively low operating cost, less weed growth, less insect and pest attacks, shorter growing season and earlier harvest of the crop. The soil moisture in the upper root zone is evacuated mainly due to soil evaporation and the water stored in the lower portion can be utilized efficiently by plants. To conserve water for a longer period and to reduce evaporation mulching is used. Mulching is the application of any plant residues or other materials to cover the top soil surface (Yadav, 2010).

Temperature is an important weather parameter that affects plant growth, development and yield. Temperature and radiation influence the rate of photosynthesis. However, plants also have an obligatory development in time, which must be met if the photosynthetic assimilates are to be converted into economically useful yields of satisfactory quantity and quality temperature and day-length in case of photosensitive crops influences the developmental sequence of crop growth in relation to crop phonology. Evolutionary changes that have occurred in the biochemical and physical characteristics of photosynthesis have resulted in a large variation between crops in both their optimum temperature requirements and the responses of photosynthesis to changes in temperature, radiation, and composition of the atmosphere. The objectives of this study were to: a) To assess the effect of thermal regimes during different growth stages of sesame crop on yield. b) To assess the effect of irrigation interval on crop yield.

MATERIALS AND METHODS

A field experiment was conducted at Instructional Farm of Soil and Water Engineering, CAET, JAU, Junagadh during summer season (February - May) 2012 to study the sesame response to moisture and thermal regimes with three factorial strip plot design. The experiment comprising of 24 treatment combinations were laid out in strip plot design with four replications. The treatment combination of four levels of thermal regime (four dates of sowing 1st February, 16th February, 1st March and 16th March, 2012) and three levels of irrigation interval viz. 3, 4, 5 days with drip irrigation and 7 days with surface irrigation without mulch as common to all treatments. Three factorial strip plots were used for the analysis of the data (Panse and Sukhatme, 1985).

First factor

Thermal window three levels
i) W_1 : 1st February
ii) W_2: 16th February
iii) W_3: 1st March
iv) W_4: 16th March

Second factor

Irrigation interval four levels
(i) I_1: 3 days by drip irrigation with mulch and without mulch (14 lph × 0.8 × 2.1 m)
(ii) I_2: 4 days by drip irrigation with mulch and without mulch (14 lph × 0.8 × 2.1 m)
(iii) I_3: 5 days by drip irrigation with mulch and without mulch (14 lph × 0.8 × 2.1 m)
(iv) I_4: Farmers practices (7 days by surface irrigation without mulch as control)

Third factor

Mulch level
i) With mulch
ii) Without mulch

There was season of no rainfall so elimination of rainfall depth and considered only the water required for the plant physiological growth and losses of water occurred by evaporatranspiration. During the course of study, there is no rain so the data regarding rain is meaningless to calculate The irrigation depth and time of application was decided based on the wetting the strip of 2.1 m. Irrigation was measured with water meter of 16 mm installed in the lateral of each treatment and calculated by the irrigation was applied at 3, 4 and 5 day interval under drip irrigation and at 7 days interval under surface irrigation as per treatments. Under drip system, the irrigation was continued till the wetted strips of 2.1 m (that is, 9 rows of sesame crop) was obtained. The time was noted to get 2.1 m wide wetted strip to cover 9 rows of the sesame crop. The dripper flow rate was measured and total flow volume of water was calculated. It was also verified with the 16 mm water meter fitted on lateral. The depth of irrigation applications was calculated using the following equation:

$$ID = V/A = q \times n \times t / A$$

Where, ID = depth of irrigation water application (mm); V = volume of water application in a treatment plot; q = dripper flow rate (lph); n = no of drippers in a treatment plot (nos.); A = area of the treatment plot (sq.m); t = time of irrigation application in respective treatment plot (hour).

Thermal heat unit calculated by daily maximum and minimum temperature were collected from the observatory and utilized for calculating the available heat units. The base temperature was taken as 15.56°C (Wanjura et al., 2002). The following expression was used to calculate the heat units:

$$HU = [T_{max} + T_{min}] / 2 - T_b$$

Where, HU is the heat units, degree-days/day; Tmax is the maximum temperature of the day, °C; and T_{min} is the minimum temperature of the day, °C and Tb is base temperature for sesame crop taken as 8°C (Ramankutty, 2002).

RESULTS AND DISCUSSION

Irrigation water applications

The seasonal depth of irrigation varied from 225 to 432 mm keeping irrigation interval of 5 days under thermal

Table 1. Seasonal depth of irrigation under different treatments.

Thermal window	Seasonal irrigation depth for Irrigation interval (days)						
	3		4		5		7
	M (mm)	NM (mm)	M (mm)	NM (mm)	M (mm)	NM (mm)	NM (mm)
01-Feb	405	405	396	396	346	346	488.8
16-Feb	432	432	330	330	303	303	454.8
01-Mar	376	376	309	309	280	280	390.4
16-Mar	300	300	237	237	225	225	320

M = Wheat straw mulch at 5 t/ha; NM = no mulch application.

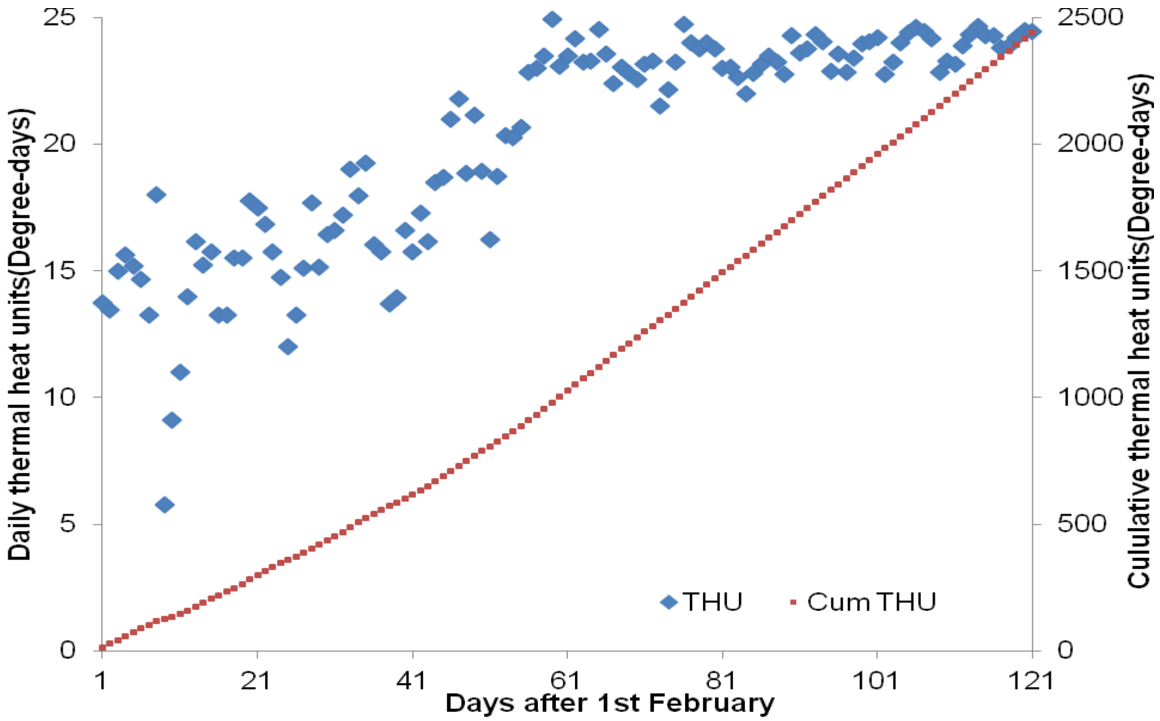


Figure 1. Daily and cumulative thermal heat units availability from 1st February.

window 16th March and 3 days irrigation interval under thermal windows of 16th February. The seasonal depth of irrigation applied under surface irrigation (7 days irrigation interval) varied from 488.8 to 320 mm under thermal windows of 16th March and 1st February. With delayed in sowing from 1st February the irrigation requirement of crop was found decreased, the reason behind that is decrease in number of growing days required for crop. As the heat unit availability increased the days required for maturity decreased with delay in sowing (Table 1 and Figure 1).

The highest growing days and inputs of seasonal thermal heat unit were found as 109 days and 2152 degree days, respectively for the thermal window - W1. The lowest growing days and inputs of seasonal thermal heat unit were found as 74 days and 1722 degree days for the thermal window - W1. As the seasonal thermal heat unit increased the growing days decreased the reason behind that is early maturity of the plant in higher thermal heat unit availability (Table 2 and Figure 2).

The estimated crop water requirements increased with delayed sowing from 1st to 16th February and then decreased. The reason behind increase in crop water requirement (that is, from 380 to 402 mm) up to thermal window of 16th February was due to increase in mean daily temperature and after 16th February decrease in crop water requirement was because of deceased in growing days requirements to mature the crop.

Table 2. Growing days, thermal heat unit inputs and average grain yield of sesame for different thermal windows.

Thermal window	Growing days	Seasonal thermal heat unit (degree-days)	Estimated water requirements as per climatic approach (mm)
01-February	109	2152	380
16- February	94	1946	402
01-March	83	1803	356
16- March	74	1722	355

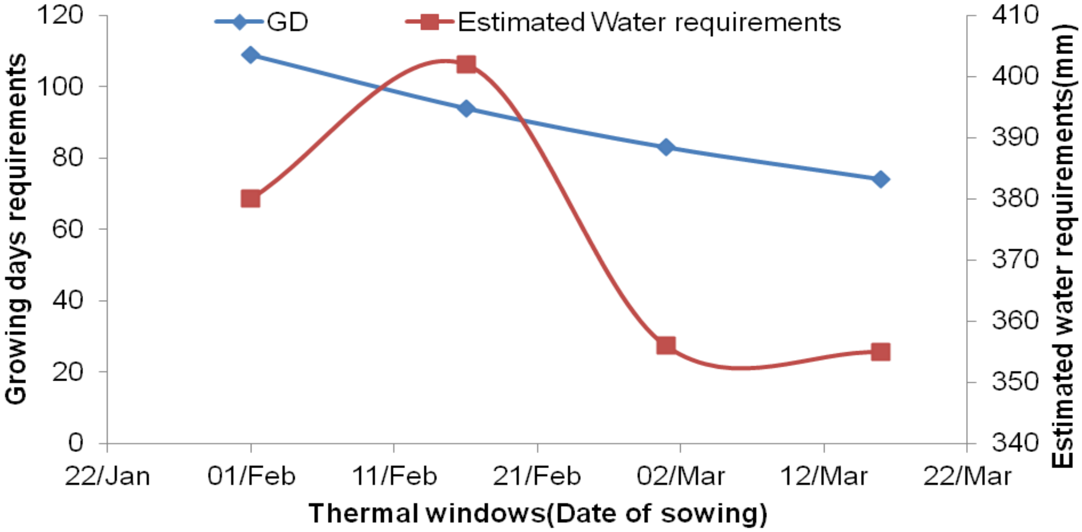


Figure 2. Effects of thermal windows on growing days and water requirements.

Effects of thermal regime on crop yield

The effects of seasonal thermal heat unit's availabilities on the sesame grain yield and thermal heat use efficiency is presented in Figure 3 and the grain yield obtained under different thermal window presented in Table 3. It was found that the highest and lowest sesame grain yield of 1131.59 and 555.20 kg/ha was observed for the thermal windows of 16th and 1st February, respectively. The thermal windows after 16th February resulted in decrease in crop yield. The pod yield 828.10 kg/ha was found under thermal windows of 16th March as the crop matured rapidly due to higher rate of thermal heat unit available per day. The highest grain yield under thermal windows of 16th February shows that the crop production can be optimum if the daily thermal heat units' availability is around 15, 18, 23 and 24 degree-days/day during the establishment, vegetative, flowering-reproductive and ripening stages, respectively. The crop yield decreased for the thermal windows later than 16th February. The pod yield of 828.10 kg/ha was found under thermal windows of 16th March as the crop matured rapidly due to higher rate of thermal heat unit availability per day. The highest grain yield under thermal windows of 16th February shows that the crop production can be optimum if the daily thermal heat units availability are around 15, 18, 23 and 24 degree-days/day during the establishment, vegetative, flowering-reproductive and ripening stages respectively. Sesame is generally a warm region plant and the temperatures recorded during this study were suitable for sesame growth and development. As per Cattan and Schilling (1991), temperature range of 25 to 27°C encourages rapid germination, initial growth and flower formation, whilst temperature below 18°C inhibit germination and growth (Ramankutty, 2001).

Crop yield response to thermal heat unit availability during growth stages

The crop yield response to thermal heat unit availability during growth stages are presented separately in Figures 4 and 5 for different irrigation interval with and without mulch.

It could be seen that the quadratic relationship could be

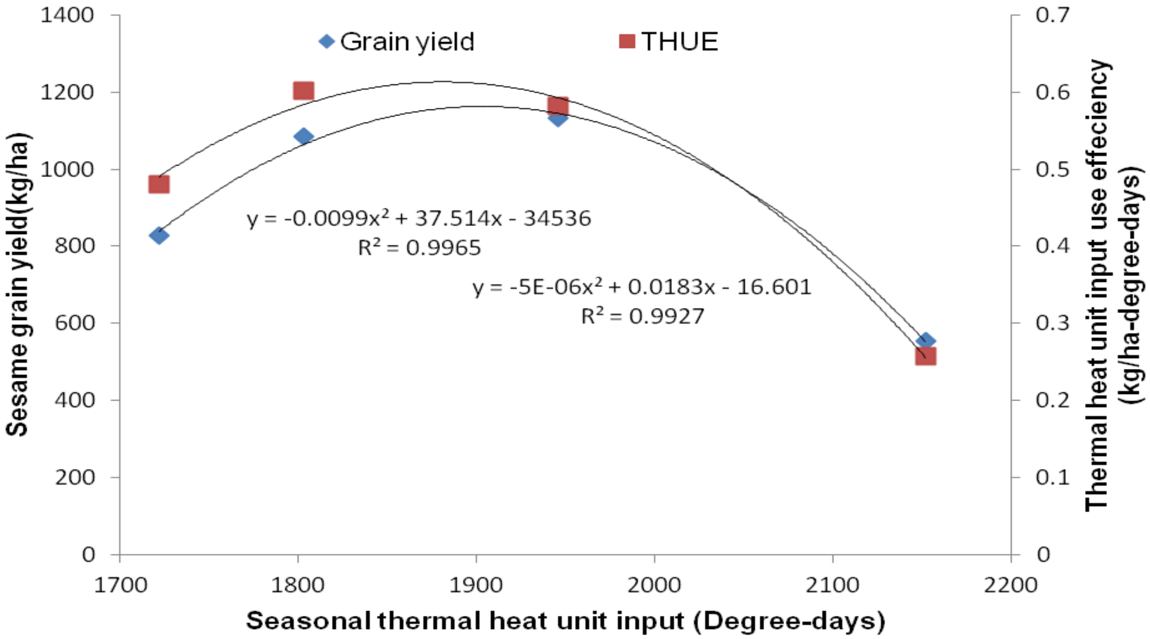


Figure 3. Effects of seasonal thermal heat units on sesame grain yield and thermal heat use efficiency.

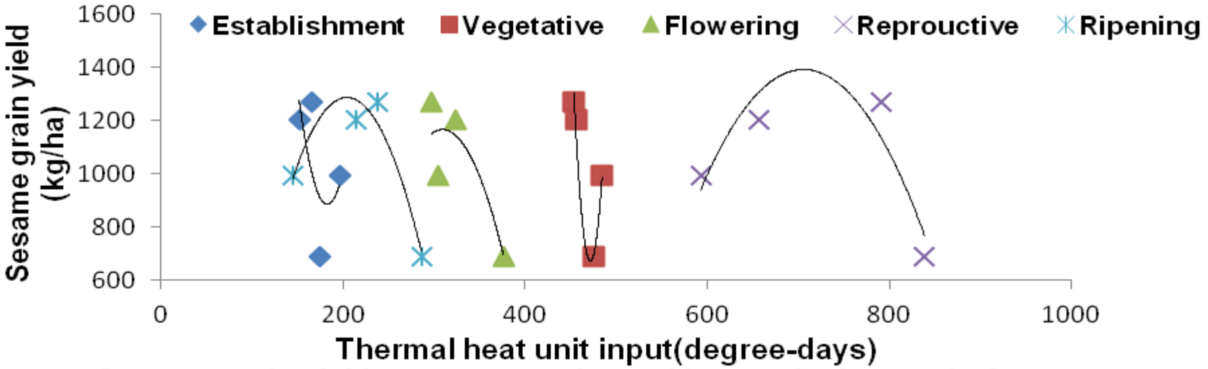
Table 3. Effect of thermal window on grain yield of sesame.

Treatment	Grain yield (kg/ha)
Thermal window	
W_1 = 1st February	555.20
W_2 = 16th February	1131.59
W_3 = 1st March	1084.72
W_4 =16th March	828.09
SEm±	33.36
CD (0.05)	106.75
CV (%)	18.16

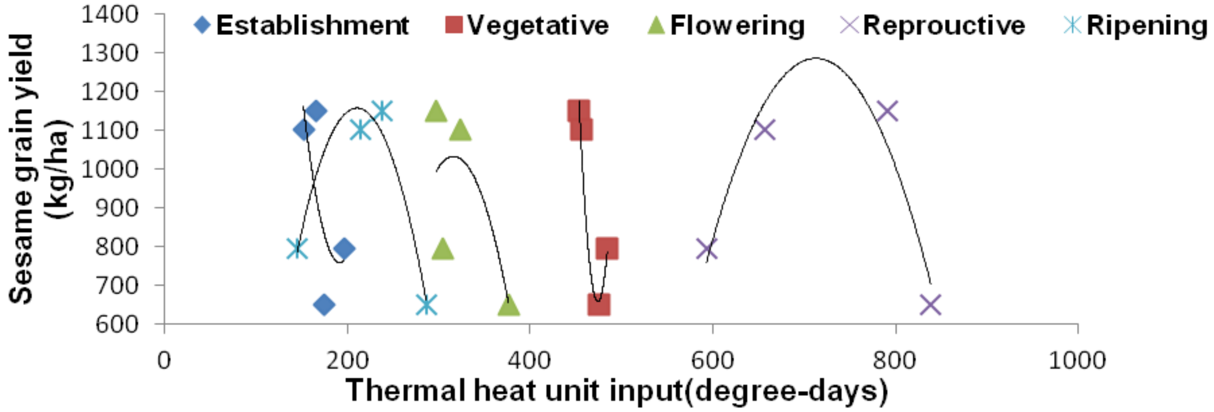
found between grain yield and thermal heat unit for all the stages. The yield decreased with increase in thermal heat unit availability up to certain level for establishment and vegetative stages. This indicated that these two stages require the lower thermal heat units. The reason behind the yield increase after reaching the minimum yield level could not be identified. It was found that the increase in thermal heat unit was due to increase in growing days requirement because of lower rate of thermal heat unit availability per day, which had slow down the physiological growth. The vegetative stage was found most sensitive followed by establishment stage, flowering stage, ripening stage and reproductive stage. The growth stages of sesame affected by the thermal heat availability and this result was contradictory with the result obtained by Tadashi et al. (2008) and Michiyama et al. (2005) for the flowering stage of sesame stating that low temperature during the flowering period decreased the rate of increase in the flowering-node number, although it prolonged the flowering period. Increased degree days over normal will shorten the vegetative and reproductive stages reported by Langham (2007).

Crop response to seasonal depth of irrigation

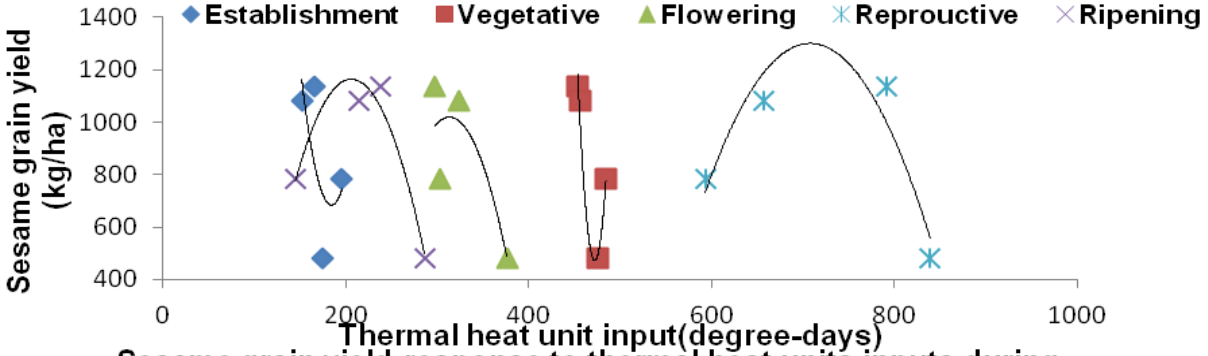
Crop yield response to seasonal depth of irrigation under different thermal window with mulch and no mulch is represented in the Figure 6. The linear relationship was found between grain yield and seasonal depth of irrigation for all the thermal windows. The yield decreased by reducing seasonal depth of irrigation and water applied



Sesame grain yield response to thermal heat units inputs during different growth stages for 3 day irrigation interval under mulch



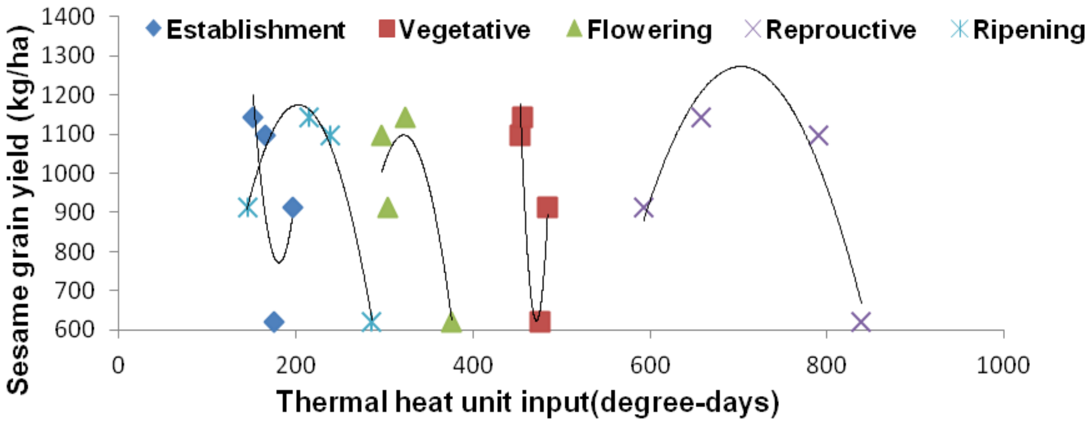
Sesame grain yield response to thermal heat units inputs during different growth stages for 4 day irrigation interval under mulch



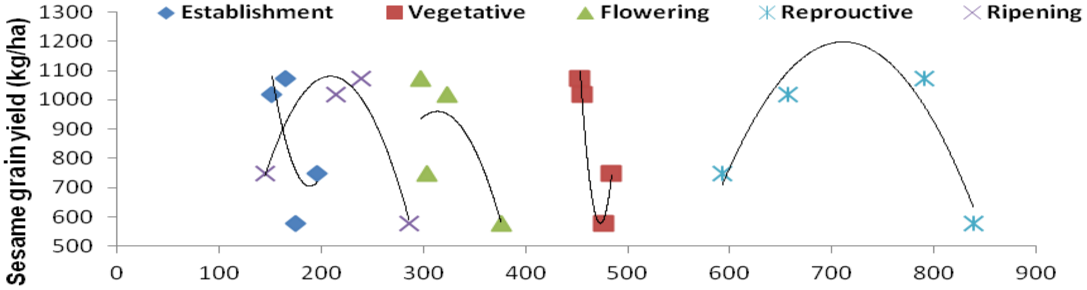
Sesame grain yield response to thermal heat units inputs during different growth stages for 5 day irrigation interval under mulch

Figure 4. Sesame grain yield response to thermal heat units' inputs during different growth stages for 3, 4 and 5 days irrigation interval with mulch.

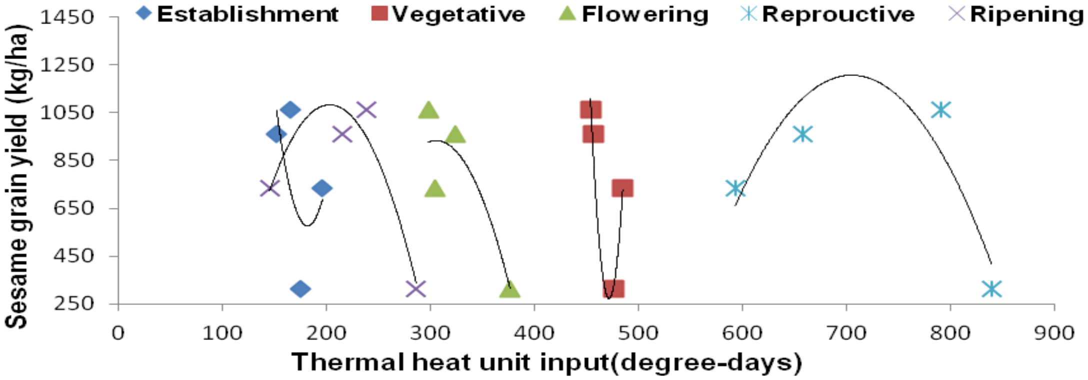
was lower than the optimal water requirements and yet there is a scope to enhance yield by increasing water application. The similar results obtained by Ucan (2007) who reported that the amount of irrigation water applied significantly affected the seed yield of sesame. Significantly higher grain yield was recorded in the treatments with higher water quantities treatments. The results obtained shows close agreement with the results of Foroud et al.



Sesame grain yield response to thermal heat units inputs during different growth stages for 3 day irrigation interval under no mulch



Sesame grain yield response to thermal heat units inputs during different growth stages for 4 day irrigation interval under no mulch



Sesame grain yield response to thermal heat units inputs during different growth stages for 5 day irrigation interval under no mulch

Figure 5. Sesame grain yield response to thermal heat unit's inputs during different growth stages for 3, 4 and 5 days irrigation interval under no mulch.

(1993) and Balasubramaniyan et al. (1996), who found that increase in yield was directly related to increased number of irrigations (Table 4).

Conclusions

Based on the data observations, analysis and its

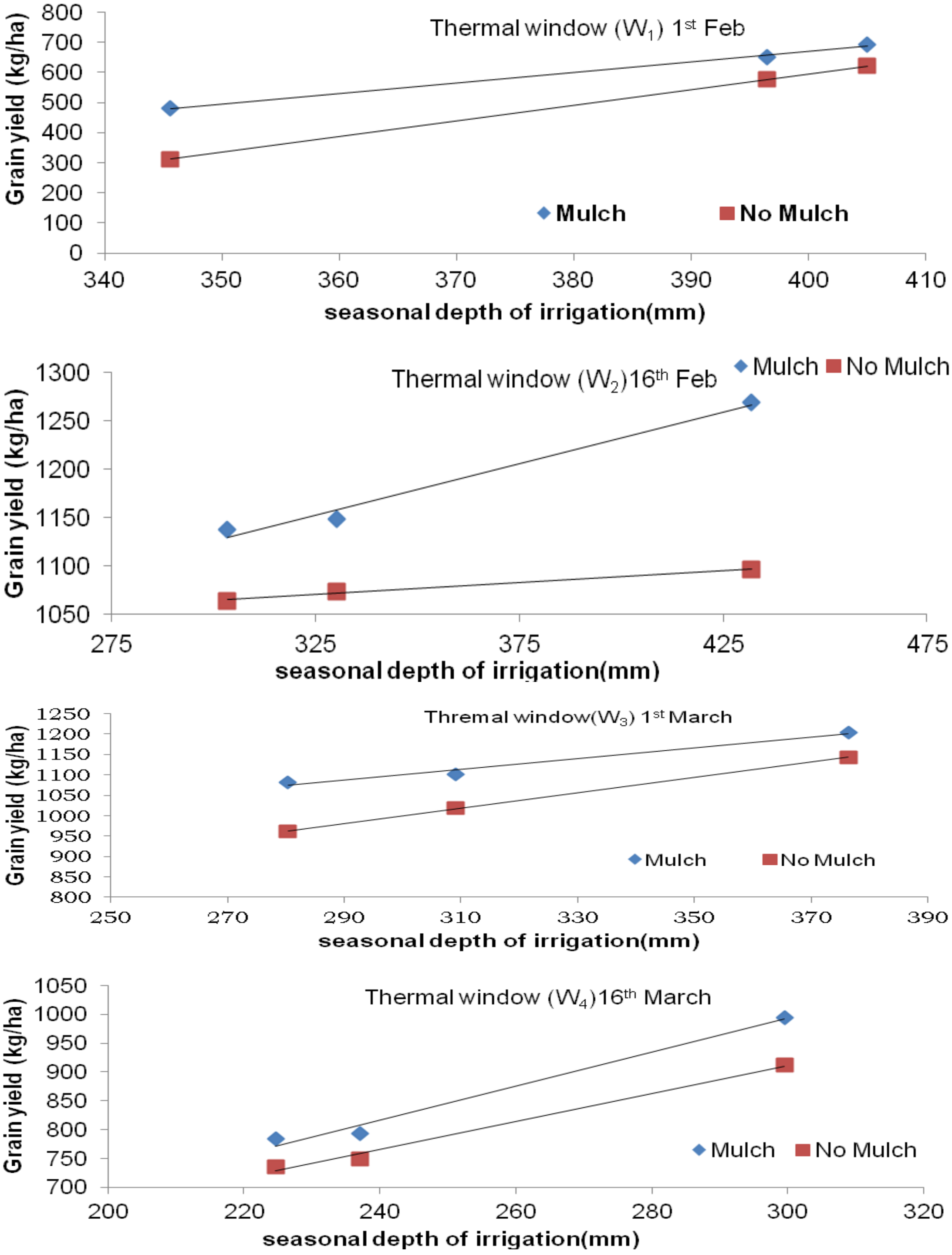


Figure 6. Sesame grain yield response to thermal heat units inputs during different growth stages for 3, 4 and 5 days irrigation interval with mulch.

interpretations, the following conclusions could be drawn from the present investigation:

1) The daily thermal heat units' availability was lower than 20 degree-days up to 45 days that is, 15th March, 2012. During

Table 4. Effect of Irrigation Interval on grain yield of sesame.

Irrigation interval	Grain yield (kg/ha)
I_1 = 3 days	991.27
I_2 = 4 days	888.86
I_3 = 5 days	819.56
Control = surface at 7 days	784.46
SEm. ±	31.92
CD (0.05)	110.47
CV (%)	20.06

45 to 75 days after 1st February, it varied from 20 to 23, while it was around 24 after that.

2) The highest daily thermal heat unit availability was 24.95 at 59th day after 1st February. The cumulative thermal heat unit of 2440 degree-days was observed after 121 days after 1st February.

3) The highest growing days requirements was observed as 109 days for 1st February (W1) with highest seasonal thermal heat unit for 109 days of 2152 degree-days while the lowest growing days requirements was observed as 76 days for the sesame sown at 16th March (W4) with lowest thermal heat units of 1722 degree-days.

4) If daily thermal heat unit availability is lower, the more number of growing days are required to mature the crop with less total thermal heat unit requirements.

5) The highest and lowest sesame grain yield of 1131.59 kg/ha and 555.20 kg/ha was observed for the thermal windows of 16th and 1st February, respectively it shows that the crop production can be optimum if the daily thermal heat units availability are around 15, 18, 23 and 24 degree-days/day during the establishment, vegetative, pod development and pod maturity stages respectively.

6) The grain yield observed under different irrigation interval with statistical analysis result shows the irrigation interval (I) had significant effect on grain yield of sesame. The highest grain yield of 991.27 kg/ha was found under irrigation by drip at 3-days interval which was higher by the tune of 10.33, 17.32 and 20.86% as compared to that of under 4, 5 days under drip and 7-days under surface irrigation respectively.

Conflict of Interests

The authors have not declared any conflict of interests.

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Vol. 9(27), pp. 2104-2110, 3 July, 2014
DOI: 10.5897/AJAR09.710
Article Number: F2C06AA45971
ISSN 1991-637X

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Received29,November, 2009; Accepted 21 November, 2013

This study estimates a food insecurity index and examines the factors that influence food insecurity among small farmers in Nigeria. Data for the study were collected from 400 farming households in Osun area of the southwestern Nigeria. Descriptive statistics, a cost of calorie function (COC) and a Tobit regression model were used to analyze the data. A regression model made up of 15 regressors was specified. Eleven of the specified variables were found to have significant influence on food insecurity. A decomposition of the total elasticity change in the dependent variables shows that three of the variables are elastic. The results showed that food insecurity among farming households in south western Nigeria was influenced by agricultural production inputs, remittances received from external members of household, improved asset base and production capacity of the households.

Key words: Food insecurity, determinants, cost of calorie function (COC) function, Tobit, small farmers, Nigeria.

INTRODUCTION

Inadequate food supply is one of the most critical problems facing Nigeria. The agricultural sector has not been able to meet the demand for food. This is due to the fact that the Nigerian agriculture is still predominantly small scale, rudimentary and largely unmechanised characterized by subsistent to semi-commercialized production systems. Farmers' average holding is two hectares of land on scattered plots (Falusi and Olayide, 1980; CBN/NISER, 1992; Yusuf and Falusi, 2000; Adejobi, 2004; Amaza et al., 2008). Farmers operate at a low level of production with highly labour intensive technology. Hired labour costs constitutes over 60% of total cash costs of production with family labour representing over 75% of the supply of farm labour. The sector is further characterized by low fixed capital investment with practitioners having a low level of literacy (Anthonio, 1967; Olayemi, 1980; Amaza et al., 2008). Little is known about the food situation of these farmers who are expected to bring the country out of her state of food insecurity to that of food security. Amaza et al. (2008) in a study to identify and analyze the food security measures of rural households in Borno State of Nigeria revealed that the major determinants of food insecurity in the study area are household size, gender, educational level, farm size and type of household farm enterprise. Nyangwesoi et al. (2007) in a study of household food security in Vihiga district of Kenya established that household income, number of adults, ethnicity, savings behaviour and nutrition awareness significantly influence household food security.

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Similarly, Kohai et al. (2005) found that the significant determinants of food security in the Mwingi district of Kenya were participation of households in the food for work program, marital status of the household head and their educational level. Further more in a study of food security in the Lake Chad Area of Borno State, Nigeria, Goni (2005) reported that factors influencing household food security, included household size, stock of home produced food and number of income earners in the household. Olayemi (1998) in a study of food security in Nigeria categorized factors affecting food security at the household level into supply-side factors, demand-side factors and stability of access to food, which include: household food and non-food production variability; household economic asset; household income variability; quality of human capital within the households; degree of producer and consumer price variability and household food storage and inventory practices. Food security is a prerequisite to good health while a combination of the two is necessary for labour productivity bearing in mind that the majority of the farmers operate a highly labour intensive production technology. The World Health Organization (WHO) recommends a calorie intake of 2250 Kcal per adult per day for healthy living in the rural area. A farmer who consumes less than this is categorized as food insecure.

The issue of food insecurity is of great importance to Africa. In Nigeria it remains a fundamental challenge due to the fact that average calorie and protein intake is only at the threshold of adequacy. Estimates show that at least 41% of the population were food-insecure; with 16% being severely undernourished in year 1996 and that 58% of the sampled households were food insecure by headcount (H) in year 2008 (Olayemi, 1996; Amaza et al., 2008). The daily per capital calorie supply as a proportion of requirement was 90% in 1988-1990 and 85% in 1992-1996 (FOS, 1999). National food expenditure data show that almost two thirds of total expenditure in 1980 was on food while the diet comprised of 64% cereals and roots and tubers. This food share rose by about 10% points by 1985, but dropped during the period 1985-1992. In the subsequent four year period, 1992-1996, a further drop of 5% points took place. The figures were 63.4, 74.1, 72.8 and 63.6% for 1980, 1985, 1992 and 1996 respectively. The average household in the rural areas earned ₦5590.00 (FAO, 2000). At the world food summit in 1996, Nigeria along with 184 other countries made a commitment to reduce the number of chronically undernourished people by half by the year 2015 (FAO, 2002). Therefore, in order to formulate effective policies for reaching this goal, a thorough understanding of the causes of food insecurity is needed. Also, the process of identifying the food insecure as target groups and achieving a better understanding of the determinants of food insecurity as policy instruments for development planners is crucial for designing effective food security programmes. This study estimates a food insecurity index and examines factors that influence food insecurity among farming households in South Western Nigeria.

CONCEPTUAL FRAMEWORK

The definition of food insecurity adopted in this paper is: A state of food insecurity exists when members of a household have an inadequate diet for part or all of the year or face the possibility of an inadequate diet in the future. In this concept, food insecurity is defined in terms of the household and it relates to both the current and future adequacy of the household diet. Following Truman and Daphine (1990) the concept of food insecurity can be expressed mathematically as:

$$FS = CS + F(R, I, HT) \qquad (1)$$

Where: FS =Future State of Household Food Insecurity, CS = Current State of Household Food Insecurity, I = Food Insecurity Insurance, R=Food Insecurity Risks, HT = Household Type.

Equation (1) expresses the determination of the future state of food insecurity as an assessment of the current state of food insecurity and the likelihood of deviation from this state. This deviation is a function of food insecurity risks, food insecurity insurances and household types.

Current state of household food insecurity (CS)

This refers to the adequacy of the household’s present food consumption. The assessment is based on both the quality and the quantity of the household’s diet and should indicate if the household is in a state of food security or a state of insecurity. States of food insecurity may be defined in terms of types of food insecurity (e.g. temporary, cyclical, and chronic), levels of food insecurity (e.g. dietary intake as a percentage of an acceptable standard) or a combination of both (Truman and Daphne, 1990).

Food insecurity risks (R)

These refer to events that increase food insecurity and lessen household food consumption. This can be measured in terms of damage caused by these events and by the likelihood that these events will occur. Examples of such risks include: Food shortages prior to harvest, temporary marketing problems, wastages due to inadequate storage facilities, seasonal or unforeseen unemployment, exceptional increases in prices, civil strife, chronic poverty etc. (Truman and Daphine, 1990).

Food insecurity insurances (I)

These refer to actions, which decrease the likelihood that risky events happen, or their resulting damage. These may be actions taken by households, communities, or nation. Examples of such insurances include: Increasing employment opportunities, land reform, use of improved agricultural production techniques, local charity, supplementary feeding programs, and emergency food aid. As these examples indicate, many food insecurity insurances are provided through government policy interventions and programs.

Household type (HT)

This reflect the means and methods by which household acquire food for consumption. A household can be defined as a group of individuals who contributed to and shared a common economic resource base and relied on the income from that base for the greater part of their food acquisition and utilization (Alumira, 2002). Household type can be market-food-oriented or non-market-food-oriented. Market-food-oriented households are those that acquire the bulk of their food through the exchange of resources such as cash, services or goods. A non-market-oriented household acquires the bulk of its food supplies through home food production. Household type can also be defined by sources of income, percentage of market dependence, resource base, location such as rural or urban etc.

Data

This study was carried out under the rural livelihood study of the food and marketing policy unit of the International Institute of tropical Agriculture, Nigeria. Data for the study were collected through a survey of 400 farming households in Osun area of the southwestern Nigeria. The study area constitutes an important agricultural zone of the country. The predominant occupation over all the villages is farming. Close to 61% of the population regard farming as the main occupation. Farming activities take place round the year. They also engaged in trading, hunting, tailoring, teaching, civil service, food processing, artisan etc. Farmers in the study area are predominantly smallholders. Common to them is a small unit of production, which may not encourage modern agricultural technologies. About 65% of the farming households have less than 1 ha of farmland under cultivation while 29% cultivated between 1 and 2 ha. Those that cultivated more than 2 ha of land constitute 6%. The average farm size among the sampled farming households is 0.9 ha with 0.5 ha land holding being the most common. Data collection was accomplished with the aid of pre-tested structured questionnaires. Information sought included:

Socio-economic/Demographic data

The various socio-economic/demographic data are age, gender of household head, marital status, educational level of household head, household type (monogamous or polygamous) and household size. Others are occupational status of household head, total household income, non-farm income, types of production enterprises, possession of assets, loan/credit facilities, membership of cooperative societies, gender ratio, dependency ratio and source-of-income ratio.

Agricultural production data

Years of farming experience, total farm size, number of farm sites operated, types of crops grown/combination, farming systems, farm labour, access to farming input, labour utilization, quantity marketed, quantity consumed, quantity produced, land acquisition and on-farm expenses.

Household demand data

Total expenditure, food expenditure, non-food expenditure, quantity of food purchased and quantity consumed. Data collection also comprised of a set of core-module questions which works systematically together to provide a measurement tool for identifying, with considerable sensitivity, the level of severity of food insecurity/hunger experienced in a household. The questions covered three major areas relating directly or indirectly to food insecurity that is,

(i) Household food expenditures (actual, usual and least amount needed)
(ii) Coping behaviors to augment food supply from emergency sources (e.g. borrowing)
(iii) Direct indicators of food insecurity and hunger

METHODS OF ESTIMATION

The approach taken in this study for the determination of food insecurity followed the identification procedures. Identification is the process of defining a minimum level of nutrition necessary to maintain healthy living. This is referred to as the “Food insecurity Line (Z)” for the society under study, below which people are classified as food insecure subsisting on inadequate nutrition. Calorie adequacy was estimated by dividing estimated calorie supply for the households by the family size adjusted for adult equivalence using the consumption factors for age-sex categories (Runge-Metzger and Diehl, 1993). Table 1 presents the nutrition (Calorie) based equivalent scale as calculated from world health organization data (Stefan and Pramila, 1998):

Cost-of-calorie (COC) function

In order to measure the extent of food insecurity among the

Table 1. Nutrition (calorie) based equivalent scales.

Years of age	Men	Women
0-1	0.33	0.33
1-2	0.46	0.46
2-3	0.54	0.54
3-5	0.62	0.62
5-7	0.74	0.70
7-10	0.84	0.72
10-12	0.88	0.78
12-14	0.96	0.84
14-16	1.06	0.86
16-18	1.14	0.86
18-30	1.04	0.80
30-60	1.00	0.82
60 above	0.84	0.74

Source: Calculated from world health organization data (Stefan and Pramila, 1998).

households, an index of food insecurity was constructed. The COC method proposed by Greer and Thorbecke (1986) was used in the study for its simplicity and ease of computation. In this procedure COC function of the following forms was estimated.

$$\ln x = a + bC \qquad (2)$$

Where: x=food expenditure (=N=), C=calorie consumption (kcal) The calorie contents of the recommended daily nutrients level (L) were used to derive the food insecurity line Z:

$$Z= e^{(a+bL)} \qquad (3)$$

Where Z gives the cost of buying the minimum calorie intake (L) and L=Recommended daily energy levels (2250 kcal).

Food insecure households are defined as those with less than minimum intake of 2250 kilocalories, recommended by the FAO/WHO (1973). The nutrient composition of commonly eaten foods in Nigeria (Oguntona and Akinyele, 1995, Table 2) was used to estimate the calorie intake of households.

Tobit regression model

The relationship between rural food insecurity and various Socio-economic/demographic and farm specific variables has been examined. The Tobit model was employed to identify the factors influencing food insecurity and the intensity of food insecurity in the study area. It measures the parameters of the conditional probability of being food insecure. It also shows the effects of marginal changes in the explanatory variables on the food insecurity status of the households (Tobin, 1958; and McDonald and Moffit, 1980). Following McDonald and Moffit (1980) and Omonona (2001) the model can be expressed as:

$$F_{insi} = \beta Q_i + e_i \qquad (4)$$

Where, $F_{insi} = 0$ for $x_i \geq Z$, and $F_{insi} = (Z - x_i)/Z$ for $X_I < Z$, Q_i = Vector of explanatory variables, β= Vector of respective parameters, e_i = Independent distributed error term, F_{insi}= Food insecurity index of household i (0-1), Z = Food insecurity line, x_i food expenditure (₦) of household i.

The variables, which are the Socio-economic, demographic, agricultural production and household food demand variables, are captured as: Household size, Gender of household head (1, if male and 0, if female), Age of household head (years), Food allocation (as a % of total expenditure), Value of crop output (₦), Total expenditure (₦), Household net worth (₦), Child dependency ratio (ratio of ages 0-14 to household size), Diversification extent (measured by Herfindah Index, Omonona, 2001; Adejobi, 2004), Remittances received (₦), Inputs usage (₦) (naira value of seeds used in production), Educational level of household head (number of years of formal Education), Membership of cooperative (1, 0), Farm size (hectare) and Fertilizer usage (₦) (naira value of fertilizer used in production) respectively. Naira (₦) is local currency in Nigeria. One USD = (₦) 150 in 2009. The regression parameters and diagnostic statistics were estimated using the maximum likelihood estimation (MLE) technique of Limdep 7.0.

RESULTS AND DISCUSSION

Here presents the results of the determinants of food insecurity among the rural households in the study area. Based on the recommended daily energy level (L) of 2250 Kcal, the food insecurity line (Z) for the households was estimated at ₦ 69.14 per day (₦ 2143.47 per month) per adult equivalent. Table 3 presents the summary statistics of food insecurity measurement in the study area.

Determinants of food insecurity in the study area

In estimating the determinants of food insecurity among the households, a regression model was specified. Eleven of the specified regressors were found to have significant influence on food insecurity and its intensity (Table 4). The result shows that sigma is 0.199387 with a p-value that is less than 0.01 hence sigma is statistically significant. The p-value signifies that the model displays a

Table 2. Nutrients composition of commonly eaten foods in Nigeria (Raw, processed and prepared).

Food item	Kcal/kg
Gari	3840
Cowpea	5920
Rice	1230
Soybean	4050
Melons (shelled)	5670
Groundnut	5950
Bread	2330
Sugar	3750
Orange	440
Mango	590
Powdered milk	4900
Agric egg	1400
Fish	2230
Meat	2370
Maize	4120
Okra	4550
Pepper	3930
Tomatoes	880
Plantain	770
Yam	3810
Cocoyam	3830
Cassava flour	3870

Source: Oguntona .E. B and Akinyele .I. O (1995).

Table 3. Summary statistics of food insecurity measurement.

Variables	Value
Cost –of – calorie equation	$\ln x = a + bC$
Constant	4.08
Slope coefficient	0.0006942
Adj R^2	0.04691
Recommended daily calorie intake (L)	2250 kcal
Food poverty line (Z): cost of recommended	₦ 69.14 per day
Calorie intake per adult equivalent	₦ 2143.47 per month

Naira (₦) is local currency in Nigeria. One USD = (₦) 150 in 2009.

good fit. Variables with significant coefficients include household size, household net worth, input usage, diversification extent, remittances received, total expenditure (proxy to income), food allocation as a percentage of total expenditure, value of crop output, fertilizer usage and child dependency ratio. It should be noted that a positive sign on a parameter indicates that higher values of the variable tend to increase the likelihood of food insecurity. Similarly, a negative value of coefficient implies that higher value of the variables would decrease the probability of food insecurity.

Total expenditure was used as proxy to income. The negative and significant effect of the household income conforms to a priori expectation. This is because income levels determine the quantities of food that is consumed, the composition of the diet and access to social services, which have some link with the nutritional conditions of individuals. An increase in the level of household income increases the capacity of farming households to consume more, especially of foods that are not produced by the household. An increase in remittance received will have an effect that is similar to that of household income. Stable income increases the capacity of households to consume more. The regression coefficient of

Table 4. Factors influencing food insecurity and intensity of food insecurity in the study area.

Variable	Coefficient	Standard error	t-value	Elasticity of		
				Probability of food insecurity	Intensity of food insecurity	Total Elasticity
Constant	0.831243	8.48E-02	9.797***			
Gender of household head	-3.61E-02	6.17E-02	-0.585	-0.1899	-0.31058	-0.50049
Age of household head (yrs)	9.15E-04	5.69E-04	1.609*	0.235716	0.385509	0.621224
Educational level of household head (yrs)	-2.08E-04	2.01E-04	-1.035	-0.00813	-0.0133	-0.02143
Household size	2.00E-02	2.93E-03	6.814***	0.820636	1.342135	2.16277
Child dependency ratio	-0.15733	5.80E-02	-2.714***	-0.24562	-0.40171	-0.64733
Household net worth (₦)	-1.42E-06	4.28E-07	-3.326***	-0.22219	-0.36339	-0.58558
Farm size (hectare)	-1.76E-05	3.12E-05	-0.565	-0.00274	-0.00448	-0.00721
Input usage (₦)	-3.76E-05	1.21E-05	-3.099***	-0.1079	-0.17647	-0.28438
Diversification extent	2.37E-04	6.51E-05	3.646***	-0.0875	-0.14311	-0.23061
Remittance received (₦)	-6.14E-07	1.87E-07	-3.281***	-0.17254	-0.28218	-0.45472
Membership of cooperatives	-1.65E-02	2.42E-02	-0.682	-0.03104	-0.05077	-0.08181
Total expenditure (₦)	-3.66E-05	3.28E-06	-11.161***	-1.33466	-2.18281	-3.51748
Food allocation (%)	-1.09E-02	7.48E-04	-14.622***	-1.99878	-3.26896	-5.26774
Crop output (₦)	-7.38E-07	2.93E-07	-2.52***	-0.14174	-0.23181	-0.37355
Fertilizer (₦)	-1.32E-05	5.18E-06	-2.547***	-0.0974	-0.15929	-0.25669

Asterisks indicate significant at *** 1%, ** 5%, *10%, Dependent variable, Food Insecurity Index (0 to I). Sigma = .199387, P < 0.01, Log likelihood function, -29.74397, Source: Computed from field data.

household's net worth shows that ownership of some assets by farming households also significantly reduces food insecurity. The effect of the net worth of the households is evident in the fact that low level of initial wealth is detrimental to food production and agricultural development leading to inescapable burden or cycle of poverty. Initial wealth can be examined from the perspective of providing finance for maintaining and sustaining the production process such as hiring labour, purchasing fertilizer, storage and processing particularly where production is largely seasonal. Also in times of emergency, assets meet needs and in addition can be good collateral for loan. Better quality of farm inputs used in production (e.g. improved seeds etc.), led to higher output thus, a reduction in food insecurity. Furthermore, food allocation constitutes higher percentage of total expenditure among food insecure households. The more the quantity of fertilizers used in crop production, the more the output thus, a reduction in food insecurity. Higher value of Child dependency ratio reduces food insecurity in the study area. This is due to the fact that child labour constitutes a major source of labour thus income to the households in the study area. Other variables that reduce food insecurity in the study area include educational level, farm size, and membership of cooperative societies. Though they are insignificant, the finding implied that increases in the values of these factors decrease the likelihood of food insecurity. The hypothesis, that collectively the variables considered will have significant influence on food insecurity status of households was accepted at 1% significant level.

Elasticity of the determinants of food insecurity

A decomposition of the total elasticity change in the dependent variable shows that three out of the variables are elastic (Table 4). These are household size, total expenditure and food allocation.10% change in household size leads to about 21.6% total elasticity change in the dependent variable. This is decomposed into about 8.2% in the probability of food insecurity and 13.4% in the intensity of food insecurity. Similarly a 10% change in total expenditure leads to about 35.2% change in total elasticity. This is also decomposed into about 13.4% in the probability of reduction in food insecurity and 21.8% in the intensity of the reduction. Furthermore, 10% change in food allocation leads to about 52.7% change in total elasticity. This is similarly decomposed into about 20.0% in probability of reduction in food insecurity and 32.7% in the intensity of reduction. The effect of the household size variable is more on the intensity of food insecurity while that of total expenditure and food allocation is more on the intensity of reduction. All other variables are inelastic with 10% change in the variables leading to less than 10% change in the dependent variable.

Conclusion

The results showed that food insecurity among farming households in south western Nigeria was influenced by agricultural production inputs, remittances received from external members of household, improved asset base and production capacity of the households. The findings presented in this study have implications for government policy towards food security. Interventions should include a component of which the objective is to increase the minimum level of subsistence production. Measures must be taken to improve the access of households to more complementary inputs so that the amount of food produced by the households could increase to a level above food insecurity.

Conflict of Interests

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

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Vol. 9(27), pp. 2111-2118, 3 July, 2014
DOI: 10.5897/AJAR09.758
Article Number:60205BD45972
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Improved efficiency of microspore culture of *Brassica campestris* ssp. *pekinensis* (Chinese cabbage)

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Received 13 December 2009; Accepted 12 June, 2014

We selected two cultivars of *Brassica campestris* ssp. *pekinensis* (Chinese cabbage), 'Futian 50' and 'Changkuai,' to investigate the factors that influence microspore embryogenesis and plantlet regeneration. We have also discussed some protocols for the induction culture of microspore-derived embryos and for rooting and transplantation of microspore-derived plantlets. We obtained the following findings in our study. Although NAA promotes the development of embryo and reduces the percentage of abnormal embryos, it inhibits the formation of microspore-derived embryos. 2,4-D also inhibits the formation of microspore-derived embryos. Low concentrations of cytokinins facilitate embryogenesis, while high concentrations inhibit embryogenesis; BA has a stronger influence than zeatin (Z) on embryo induction. The combined effects of auxin and cytokinin are synergistic. Organic compounds increase the rate of formation of microspore-derived embryos. However, activated charcoal (AC) inhibits embryo development. The better the development of the embryos, the higher is the plantlet regeneration rate. The plant regeneration rate increased significantly on the MS culture medium supplemented with 200 mg·L^{-1} AC. The MS medium s suitable for the subculture of the regenerated plantlets. MS medium containing 0.1 mg·L^{-1} NAA is the optimal medium for rooting of microspore-derived plantlets.

Key words: Chinese cabbage, microspore culture, embryogenesis, plant regeneration.

INTRODUCTION

Doubled haploids (DHs) are now being commonly used in plant breeding as an important means of accelerating the development of new cultivars (Yao et al., 2008) or as one of the favored mapping populations for constructing linkage maps to identify quantitative trait loci (Pilet et al., 2001; Zhao et al., 2005; Yang et al., 2008). In recent years, isolated microspore culture has attracted a lot of interest because of its great potential for DH production. A microspore-derived embryo is also a suitable system for gene mapping (Graner, 1996; Zhang et al. 2005; Geng et al., 2007; Yu et al., 2008), genetic transformation (Stŏger et al., 1995) and selection of dominant and recessive traits (Polsoni et al., 1988; Swanson, 1989; Liu et al., 2003; Wang et al., 2008; Zou et al., 2009). Since Lichter (1982) first reported the embryogenesis in microspore cultures of *Brassica napus*, embryogenesis has been induced in microspore cultures of different *Brassica* species (Babbar et al., 2004). Since the first report on

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successful regeneration of haploid plants from isolated microspores of *Brassica campestris* ssp. *pekinensis* (Chinese cabbage) (Sato et al., 1989), the technique of isolated microspore culture has been considerably improved and embryogenesis can be induced effectively (Cao et al., 1992; Li et al., 1993; Liu et al., 1997; Shen et al., 1999; Zhao et al., 2008; Fang et al., 2009). However, the effective use of the technique in terms of breeding progress is impeded by limitations such as low embryo yield and poor plant regeneration from microspore-derived embryos.

Plant hormones play an important role in embryogenesis and organogenesis. However, only few studies have shown the role of phytohormones in the induction of microspore and embryonic development in Chinese cabbage. Moreover, no study has compared the effects of different types of auxins and cytokinins on microspore embryogenesis. Therefore, our study was designed to investigate the effects of different types of auxins and cytokinins on the microspore embryogenesis in Chinese cabbage. In addition, we determined the concentration of the hormone that was the most suitable for enhancing the rates of induction and germination of microspore embryos and which would thereby improve the efficiency of microspore culture. Therefore, we systematically studied the optimal conditions required for the induction of embryogenesis and germination of microspore-derived embryos, growth of these embryos, and the rooting and transplantation of the regenerated plantlets. Our findings may lead to considerable improvement in the efficiency of the microspore culture and increase its application in the breeding program of Chinese cabbage.

MATERIALS AND METHODS

Plant material for culture

B. campestris ssp. *pekinensis* 'Futian 50' and *B. campestris* ssp. *pekinensis* 'Changkuai' were used as the experimental materials. The seeds were vernalized at 4°C for 26 days and planted in 10 cm pots. At the 6-leaf stage, the young plants were transferred to a 3 L flower pot. The plants were cultivated in a greenhouse under controlled conditions (25°C/18°C, 16 h photoperiod). Fluorescent lamps were used as the light source, and the light intensity was approximately 300 $\mu E \cdot m^{-2} \cdot s^{-1}$. The plants were supplied with nitrogen-phosphorus-potassium (NPK) compound fertilizer every 2~3 days. The plants flowered by the end of May, and the flower buds were harvested for microspore culture.

Microspore culture

The procedures for microspore isolation and culture were based on the methods established by Sato et al. (1989) ith some modifications. When most of microspores reached the uninucleate stage (determined on the basis of bud size; usually 2.5~3.5 mm in length), 30 flower buds were harvested. The buds were washed under running water for 30 min, then surface-sterilized in 70% ethanol for 30 s, and then in 0.1% $HgCl_2$ for 8 min; this procedure was followed by 3 rinses for 3 min in sterile distilled water. The flower buds were dried and held with a glass rod in B5 medium (Gamborg et al., 1968) supplemented with 13% (w/v) sucrose (B5-13); subsequently, the microspores were squeezed out. The fluid containing the microspores was filtered through a 50 µm-mesh nylon screen. Then, the filtrates were collected in a 10 ml centrifuge tube and centrifuged at 1000 rpm for 3 min. After discarding the supernatant, the pellets were resuspended in 5 ml of B5-13 and centrifuged at 500 rpm for 3 min; this procedure was repeated twice. The supernatant was discarded, and a pure preparation of microspores was obtained.

This preparation was suspended in the Nitsch and Nitsch (NLN) medium (Lichter, 1982) supplemented with 13% (w/v) sucrose (NLN-13) and cultured in 6 cm petri dishes. Each dish contained 4 ml suspension of microspores at a concentration of $1 \sim 2 \times 10^5$ microspores/ml. The petri dishes were sealed with double layers of parafilm, and the microspores were cultured in the dark at 33°C for 1 day and later cultured at 25°C in the dark.

Experiment 1: Effects of auxin and cytokinin on the rate of embryo formation

To investigate the effects of auxin and cytokinin on microspore embryogenesis, we cultured the microspores in the NLN-13 culture media with different concentrations of BA, Z, NAA, 2, 4-D (Sigma, USA). The NLN-13 culture medium is control group. After 3 weeks of microspore culture, the yields of the various developmental stages of the embryo were examined.

Experiment 2: Effect of organic compounds on microspore embryogenesis

To investigate the effect of organic compounds on microspore embryogenesis, we cultured the microspores of *B. campestris* ssp. *perkensis* 'Futian 50' in NLN-13 without glutathione, serine, and glutamine. The NLN-13 culture medium is control group. After 3 weeks of culture, the embryo yields were determined.

Experiment 3: Effect of activated charcoal on microspore embryogenesis and plantlet regeneration

To investigate the effect of AC on microspore embryogenesis, we cultured the microspores in NLN-13 supplemented with 100 or 200 $mg \cdot L^{-1}$ AC. The NLN-13 culture medium is control group. After 3 weeks of culture, the embryo yields were determined. Four weeks after the microspores were cultured in the induction medium, the cotyledonous embryos that emerged from the microspores were transferred onto solid MS medium (supplemented with AC 100, 200, or 400 $mg \cdot L^{-1}$) and incubated at 25°C with a 16 h photoperiod regime and a light intensity of 200 $\mu E \cdot m^{-2} \cdot s^{-1}$. After 3 weeks, the regenerated plantlets were counted.

Experiment 4: Subculture and transplantation of the regenerated plantlet

The large leaves and roots of the plantlets were excised, the 2~3-cm-long microspore-derived plantlets were transferred to the MS subculture medium and cultured at 25°C under a 16 h photoperiod regime and a light intensity of 200 $\mu E \cdot m^{-2} \cdot s^{-1}$. The 2~3-mm-long seedlings were transferred to MS or MS + 0.1 $mg \cdot L^{-1}$ NAA for rooting. After 3 weeks of culturing in these media, the rooting rate was determined. We selected 3 cm-tall microspore-derived plantlets with well-developed roots for transfer to the soil. The culture bottle was opened 1~2 days before the plantlets were transferred. After washing the agar deposits on the roots, we transferred the

Table 1. Effect of auxins on the rate of formation of microspore-derived embryos.

NAA content (mgL^{-1})	2,4-D content (mgL^{-1})	No. of embryos /30 buds	
		Futian50	Changkuai
0 (CK)	0	136	61
0.1	0	107	43
0.2	0	112	43
0.5	0	98	40
1.0	0	81	25
0	0.2	0	0
0	0.5	0	0

Table 2. Effect of cytokinins on the rate of formation of microspore-derived embryos.

BA concentration (mg·L^{-1})	Z concentration (mg·L^{-1})	No. of embryos/30 buds	
		Futian 50	Changkuai
0 (CK)	0	136	61
0.05	0	137	67
0.1	0	162	73
0.2	0	151	90
0.4	0	183	112
0.6	0	118	93
0	0.05	136	73
0	0.1	155	81
0	0.2	160	96
0	0.4	118	75
0	0.6	98	71

regenerated plantlets to a loam-vermiculite mixture (loam:vermiculite = 1:1 mixture sterilized by high temperature treatment) and were maintained in a culture room (25°C/18°C, natural light). For the first week, the plantlets were covered with plastic sheets. Three weeks after the transfer, the survival rate of the plantlets was calculated. The above procedure was repeated at least 3 times with 3~5 replicates per treatment.

RESULTS

Effect of auxin on the rate of formation of microspore-derived embryos

Addition of NAA to the media reduced the yield of embryos (Table 1). When ‘Futian 50’ microspores were cultured in MS medium with NAA concentrations ranging from 0.1 to 1.0 mg·L^{-1}, the average percentage of microspore-derived embryos was 26.84%, which was lower than that of microspore-derived embryos in the control medium.

Similarly, when ‘Changkuai’ microspores were cultured in MS medium with 0.2 and 0.5 mg·L^{-1} of NAA, the percentage of embryos was low, at 29.51 and 34.43%, respectively.

In contrast, when the microspores were cultured on MS medium containing either only 2,4-D (0.2 or 0.5 mg·L^{-1}) or 2,4-D in combination with BA and Z, few cell clusters developed and no embryos developed. These results indicated that 2,4-D strongly inhibited the formation of microspore-derived embryos.

Effect of cytokinin on the rate of formation of microspore-derived embryos

When the concentrations of BA and Z in the medium were increased, the rate of formation of microspore embryogenesis increased at first and then decreased later (Table 2). This finding suggested that lower concentrations of BA and Z promoted embryogenesis, while higher concentrations of BA and Z inhibited embryogenesis (effective concentrations: BA, 0.4 mg·L^{-1}; Z, 0.2 mg·L^{-1}). Although both BA and Z had the same mechanism of embryo induction, the magnitude of their effect was different. In this experiment, the effect of BA was stronger than that of Z, regardless of whether the effect was the promotion or the inhibition of microspore embryogenesis.

Table 3. Combined effect of the auxins and cytokinins on the rate of formation of microspore-derived embryos of *Brassica campestris* ssp. *pekinensis* 'Futian 50'.

Hormone concentration (mg·L^{-1})			No. of embryos/30 buds
BA	Z	NAA	
0 (CK)	0	0	136
0.05	0	0.2	118
0.2	0	0.2	133
0	0.05	0.2	89
0	0.2	0.2	129

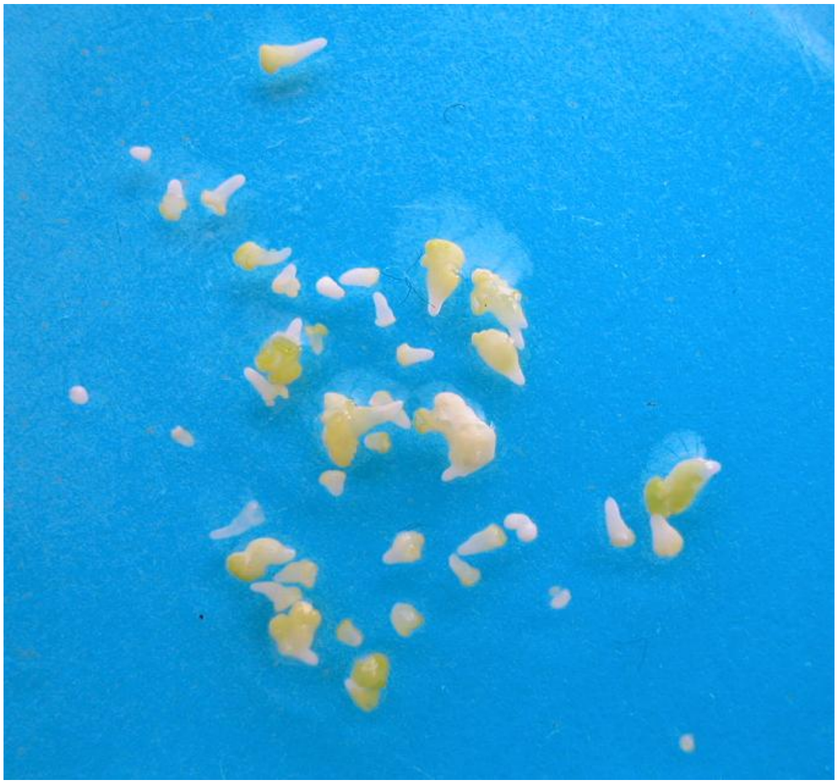

Figure 1. Embryos developed from microspores after 3 weeks in culture.

Combined effects of auxin and cytokinin

A set of experiments was performed to evaluate the combined effects of auxin and cytokinin (Table 3). The rate of induction of microspore-derived embryos in the induction medium containing BA or Z together with 0.2 mg·L^{-1} NAA was lower than that of embryos in media supplemented with the same concentration of only BA or only Z. These were also lower than that in the control MS medium but were higher than that in the medium containing only 0.2 mg·L^{-1} NAA. These results indicated that the combined effect of NAA and BA or Z was synergistic.

Effect of phytohormones on the development of microspore-derived embryos

Four weeks after the microspores were cultured in the induction media, various developmental stages of the embryos existed simultaneously (Figure 1), and these stages were cotyledonary embryo, torpedo embryo, heart embryo, globular embryo, abnormal embryo, and germinated embryo. Although NAA inhibited the formation of microspore-derived embryos, it promoted the development of the embryos. After 4 weeks of microspore culture in the medium with NAA, the percentage of cotyledonary and germinated microspore-derived embryos

Table 4. Effect of developmental stages of embryos on the plantlet regeneration rate.

Developmental stages of embryos	Number of embryo	Number of regenerated plantlet	Rate of regenerated plantlet (%)
Cotylednary embryo	360	199	55.28^{a}
Torpedo embryo	165	7	4.2^{b}
Heart and globular embryo	300	0	0^{c}

The differences of the values followed by different letters in the column are significant at $p \leq 0.05$.

increased on an average from 84.42 to 88.75%. Concurrently, the percentage of abnormal embryos dropped from 7.35 to 4.94%. We observed that higher the concentration of NAA, the more obvious was the effect. The most favorable effects of NAA were observed at a concentration of 1.0 mg·L^{-1}: the percentage of cotyledonary and germinated embryos was 90.86%, but the percentage of abnormal embryos was only 3.70%.

When cytokinin was added to the medium, the percentage of cotyledonary and germinated embryos decreased while the percentages of heart and globular embryos increased. The percentage of abnormal embryos greatly increased, especially when the induction medium contained higher concentrations (0.4~0.6 mg·L^{-1}) of Z or BA. The yield of abnormal embryos could be up to 19.39 and 26.27% when the media contained 0.6 mg·L^{-1} Z and BA, respectively. The above results suggested that the cytokinin exerted adverse effects on the development of microspore-derived embryos and inhibited embryo development to a certain extent. High concentrations of cytokinin could promote abnormal development of microspore-derived embryos.

Effect of organic compounds on the rate of formation of microspore-derived embryos

In this experiment, only the microspores of ‘Futian 50’ were used. We separated and purified the microspores and then cultured them in NLN-13 without glutathione, serine, and glutamine to determine the effect of the organic compounds on the rate of formation of microspore-derived embryos. Our results showed that the rate of embryo induction was 80%, which was lower than that observed in the control. This indicated that glutathione, serine, and glutamine were essential for microspore embryogenesis in Chinese cabbage.

Effect of the developmental stage of embryo on the plantlet regeneration rate

The embryo development was asynchronous. After 3 weeks of culture, in addition to cotyledonary embryos and torpedo embryos, small globular embryos and heart embryos were observed. The rate of embryo development decreased after 4 weeks of culture, regardless of the embryo size, probably because of the nutrient depletion in the medium. The cotyledonary, torpedo, heart, and globular embryos were inoculated separately in the MS regeneration medium, and after 3 weeks, the plantlet regeneration rate was analyzed, as shown in Table 4. Some microspore-derived embryos germinated normally in the regeneration media. They continued to grow into normal plantlets (Figure 2). Table 5 shows that the plantlet regeneration rate was closely associated with the developmental stage of embryos. The rate of regeneration from mature cotyledonary embryos was 55.28%, which was higher than the percentage of incomplete embryos. Culturing of early embryos in the regeneration media was difficult. The heart and globular embryos could not regenerate into plantlets.

Effect of AC on microspore embryogenesis and plantlet regeneration

The microspores were cultured in NLN-13 supplemented with 100 or 200 mg·L^{-1} AC. Our results indicated that AC did not promote embryogenesis (data not shown). The effect of AC on plantlet regeneration is shown in Table 5. The regeneration rate was higher in the regeneration medium supplemented with AC than it was in the control medium. A maximum regeneration rate of 44.5% green plants was observed on the medium supplemented with 200 mg·L^{-1} AC. Our results showed that AC promotes plant regeneration.

Subculture and transplantation of microspore-derived plantlets

The initially obtained microspore-derived plantlets were weak. The slender seedlings grew much stronger after 2~3 subcultures. The leaves of plantlets become larger as their color changed from yellow to green; concurrently, their petioles became thick. MS + 3% sucrose + 0.8% agar” was the optimal medium for subculture. The seedlings were transplanted to the rooting media. The rooting rate was 100% in MS + 0.1 mg·L^{-1} NAA medium and 70% in only MS medium. After 20 days of culture in the rooting medium, 10~15 adventitious roots developed.

Figure 2. Normal germination from a microspore embryo.

Table 5. Effect of activated charcoal on plantlet regeneration rate.

AC concentration ($mg{\cdot}L^{-1}$)	No. of embryos	No. of regenerated lantlets	Regeneration rate of the plantlets (%)
0 (CK)	180	36	20.0^a
100	135	34	25.2^a
200	180	80	44.5^b
400	150	36	24.0^a

The differences of the values followed by different letters in the column are significant at $p \leq 0.05$.

The type of rooting media affected the quality of the plantlets. Plants grown in media without NAA had a larger number of roots than those grown in media with NAA. The root growth rate was different in different media. The roots were delicate when plantlets were grown in media without NAA, while the root system was strong when plantlets were grown in media containing 0.1 $mg{\cdot}L^{-1}$ NAA. The root growth rate and the number of plantlet leaves were not different in the media with or without NAA.

Although a strong root system was observed in the medium supplemented with NAA, the number of roots was relatively low, while the survival rate of the plantlet was high during transplantation. The average survival rate of the plants rooting on MS + 0.1 $mg{\cdot}L^{-1}$ NAA was 90%. A weak root system was observed in the seedlings grown in the medium without NAA, and the survival rate during transplantation was 73.33%, which was lower than that of the plantlets growing on medium with 0.1 $mg{\cdot}L^{-1}$ NAA. The average survival rate of plantlets was 73.33% (Figure 3).

DISCUSSION

The addition of auxins and/or cytokinins to the induction media has been shown to influence microspore

Figure 3. A regenerated plant that was transferred to the pot.

embryogenesis in *Brassica* species (Lichter, 1981; Charne and Beversdorf, 1988; Li, 2004). There are a few studies on the effect of phytohormones on the formation of microspore-derived embryos in Chinese cabbage, and their results have been quite inconsistent. According to Sato et al. (1989), the effect of 0.5 mg·L^{-1} NAA + 0.05 mg·L^{-1} BA (basal medium, NLN) on induction of embryo formation was the same as that of the medium without plant growth regulators. Many researchers have also used the culture media without plant growth regulators. However, Xu et al. (2001) and Zhang et al. (2009) reported BA at a concentration of 0.2 mg·L^{-1} promoted embryo development. The results of our study were not completely consistent with the above mentioned reports. Our results showed that auxins inhibited microspore embryogenesis, and lower concentrations of BA or Z promoted embryogenesis, while high concentrations inhibited embryogenesis.

Our study is the first that describes the effect of phytohormones on the development of microspore-derived embryos in Chinese cabbage. The mechanism of how phytohormones regulate the development of microspore-derived embryos is unknown and will be studied in future. Shen et al. (1999) reported that addition of 0.05~0.10 mg·ml^{-1} AC increased the embryo yield of Chinese cabbage more than 2 times. Jiang et al. (2008) reported that addition of 0.50 mg·ml^{-1} AC increased the embryo yield by 4.8 or 16.1 times in the microspore cultures of the Y536 and Y535 of Chinese cabbage. However, in our study, the addition of AC did not increase the induction frequency of microspore-derived embryos.

The success of haploid technology ensures the successful conversion of microspore-derived embryos into plants. Direct germination of microspore-derived embryos resulted in a plumular shoot and a root that was expected in microspore cultures. Generally, the rate of direct germination of embryos in microspore cultures in *Brassica* species has been significantly low. A few reports have described the difficulties in the germination of microspore-derived embryos in the microspore culture of Chinese cabbage (Liu et al., 1997; shen et al., 1999; Jiang et al., 2008). Our results indicate that AC was helpful for obtaining high rate of direct plantlet regeneration.

The formation of abnormal embryos reduced the regeneration rate of microspore-derived plantlets. Although this is a common occurrence in microspore culture, the mechanism of abnormal embryo formation has not been discussed much. On the basis of the results of this experiment, we assume that cytokinins influence the development of microspore-derived embryos. High concentrations of cytokinin can result in the abnormal development of microspore-derived embryos of Chinese cabbage.

Conflict of Interests

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

ACKNOWLEDGEMENTS

We thank Mr. Wang Yuguang, Ms. Xuan Zhengying and Ms. Song Baoxiang for their excellent technical assistance. This work was supported by Liaoning Natural Science Foundation 20022041.

Abbreviations: DH, doubled haploid; **NAA,** naphthalene acetic acid; **2,4-D,** 2,4-dichlorophenoxyacetic acid; **BA,** 6-benzylaminopurine; **Z,** zeatin; **AC,** activated charcoal; **MS,** Murashige and Skoog Stock Medium.

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Vol. 9(27), pp. 2119-2123, 3 July, 2014
DOI: 10.5897/AJAR10.488
Article Number: 5D264EE45983
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Assessment of soil properties and crop yield under agroforestry in the traditional farming system

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Received 24 June, 2010; Accepted 12 June, 2014

The rate at which soil ecosystem is being degraded in crop production systems in the tropics is alarming. This study therefore attempts to assess the physico-chemical properties of soil and crop yield under agroforestry in the traditional farming systems. This was a researcher-designed, farmer-managed participatory experiment. Two farming systems (cashew/maize intercropping and sole maize cropping) were used. The two farm locations were in Wasangari village, near Saki. From 5 ha cashew plantation established in 1998 using a plant spacing of 9.0 × 9.0 m^2 by the collaborating farmer, two plots of 20 × 20 m^2 were mapped out for maize, intercropped at a plant spacing of 90 x 40 cm^2 in 2002. Also, to a fallowed land since 1998 adjacent to cashew plantation but cultivated to sole maize in 2002 using the same plant spacing, two plots of 20 × 20 m^2 were mapped out. The maize seedlings in the 4 plots were thinned to 2 stands per hole 2 weeks after planting (WAP) to give a plant population of 55,555 plants/ha. The two collaborating farmers weeded their farms 2 times (2 and 5 WAP) using hoe. The experiment was conducted over two planting seasons. Values of the soil nutrients (0 to 15 cm) evaluated before maize introduction in cashew/maize plots were significantly ($p< 0.005$) higher than those from sole maize plots. Also, the mean yields of maize in the intercropped plots (1.34, 1.02 t ha^{-1}) were significantly ($p < 0.05$) higher than mean yields in sole maize fallowed plots (1.05, 0.81 t ha^{-1}) in the early and late season studies respectively. The study demonstrated that intercropping maize with cashew, in the early stage serves as additional source of income to traditional farmers in the tropics.

Key words: Agroforestry, traditional farming system, cashew, soil nutrient depletion, litter falls,cashew/maize intercrop.

INTRODUCTION

Soil is a dynamic ecosystem for crop production and a living medium that houses the life-sustaining nutrients for crop growth formed from the consolidated rock (Tel and Hagarty, 1984). Soils are also homes to many diverse populations of species including earthworms, insects and micro-organisms (Olayinka, 2009). Soils of the humid tropics are sandy and fragile in nature (Agboola, 1982). Agboola and Omueti (1982) further summarized natural problems peculiar to tropical soils to include: low organic matter, low activity clay and high soil acidity level. The moment the native vegetation is cleared for crop production, the soil potential is exposed to all manner of external influence (Salami et al., 2002). The current increase in population in the humid and sub-humid

*Corresponding author. E-mail: adewoledele2005@yahoo.co.uk tropics has led to various increases in human activities which have brought about destabilization of the ecological equilibrium of forest ecosystem (Stewart, 1984). In Africa, and especially in Nigeria, nature has created a delicate balance between the soil, plant cover and micro-climatic conditions (Igboanugo, 1997). Rainfall pattern in Africa is torrential which encourages leaching of soil nutrients beyond the root-zones of plants into the ground water. Crop cultivation, generally, depletes soil nutrients (Mbagwu, 2008). Addition of soil amendments in the form of fertilizer, if properly used increases not only the yield of crops but also discourages soil nutrients' imbalance (Adewole and Adeoye, 2008). Blanket fertilizer application to crops is detrimental to crops' qualities and human health (Adeoye, 1993). Also, addition of one nutrient element may lead to the inhibition or stimulation of the absorption of other nutrient elements by plants (Adewole and Adeoye, 2008). An increase in P uptake with addition of N fertilizer to hybrid maize was observed by Barber and Mackey (1986). Most of the available forms of N, P and S in Nigerian soils are in the organic forms (Agboola, 1982). Any farming system that enhances the soil organic matter will also increase the values of N, P and S. This study therefore attempts to assess the impact of two farming systems (intercropping and sole cropping) on the physico-chemical characteristics of soil over a period of two planting seasons. This was done using two derived savanna sites located in the same climatic zone.

MATERIALS AND METHODS

Site and experimental design

The study area is located in Wasangari and lies within latitude 8° 45´ and 9° 05´N longitude 3° 05´ and 3° 50´E in Saki West Local Government Area of Oyo State, Nigeria. Ayanwale (1990) reported the abundance of gneiss due to metamorphic process of igneous rock in soils of the study area. Adewole (1995) described the study area as dry sub-humid tropical with derived savanna vegetation. From the 2 farms selected, one was cultivated to sole maize and the other farm was cultivated to cashew/maize intercrop. The 5 ha sole maize plot cultivated in March and July 2002 had been under fallow since 1998. Also, cashew plantation that was established in 1998 on another 5 ha farm plot adjacent to the maize plot was also intercropped with maize in March and July 2002. The two test crops; Brazilian variety of cashew and SUWAN-I-Y maize seeds were planted.

In cashew plantation, a plant spacing of 9.0 × 9.0 m with one stand per hole to give a plant population of 123 plants/ha was used. Core soil samples taken to the depths of 0-15 cm and 15-30 cm using systematic random technique from each quadrant of 2 × 2 m in four of the 20 × 20 m mapped-out plots (two plots from each farm) were thoroughly mixed for homogeneity. A total of five composite soil samples were obtained from each of the four farm plots per soil depth and per cropping season just before the planting of maize seeds. Also, 90 × 40 cm plant spacing at the seed rate of 3 seeds per hole was used for maize (in the sole cropping and intercropping plots with cashew). The maize seedlings were thinned to 2 stands per hole at 2 weeks after planting (WAP) to give a plant population of 55,555 plants/ha. The experimental plots were weeded 2 times (2 and 5 WAP) using hand hoe. No fertilizer treatment was imposed. The experiment was conducted over 2 planting seasons; the early and late seasons of 2002.

Laboratory analysis

Laboratory analyses of the soil samples were carried out using standard methods. The particle size analysis was determined using hydrometer method in 5% calgon as the dispersing agent (Bouyoucos, 1951). Soil pH was determined potentiometrically in 1 M KCl solution at a ratio of 1: 1 (soil to KCl) (Mclean, 1982). Soil organic carbon was determined using Walkey-Black method (Nelson and Sommers, 1982). Total nitrogen of the soil was determined by the macro-Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus in the soil was determined using Bray P1 method (Olsen and Sommers, 1982). Exchangeable cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were determined using 1 M NH_4OAc (Ammonium acetate) buffered at pH 7.0 as extractant (Thomas, 1982). The K^+ and Na^+ concentrations in soil extracts were read on Gallenkamp Flame photometer while Ca^{2+} and Mg^{2+} concentrations in soil extracts were read using Perkin-Elmer Model 403 atomic absorption spectrophotometer.

The exchangeable acidity (H^+ and Al^{3+}) in the soil was extracted with 1 M KCl (Thomas, 1982). Solution of the extract was titrated with 0.05 M NaOH to a permanent pink endpoint using phenolphthalein as indicator. The amount of NaOH used was equivalent to the total amount of exchangeable acidity in the aliquot taken (Odu et al., 1986). The total sum of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) gave the cation exchangeable capacity. The extractible micronutrients (Fe, Mn and Zn) were extracted with 0.1 M HCl (Juo, 1982) and their concentrations in soil extracts were read on AAS (Perkin-Elmer Model 403).

Statistical analysis

Soil data and crop yield obtained were analyzed using descriptive statistics and the treatment means were separated using new Duncan Multiple Range Test.

RESULTS AND DISCUSSION

Table 1 shows the results of laboratory analysis of the sampled soils to the depth 0 -15 cm from cashew/maize intercropped and sole maize plots before maize was planted in the early season of 2002. The mean of soil pH in 1:1 soil – 1M KCl ratio ranged from 6.3 to 6.8 indicating slight acidic soil conditions. The soil texture was sandy loam. The soil organic carbon (OC) mean values were (range, g kg^{-1}) 13.05-30.05 with cashew/maize 2 plot having significantly ($p < 0.005$) highest value. The total nitrogen (TN) mean values were (range, g kg^{-1}) 1.19 - 4.21 with the same plot, cashew/maize 2 having significantly ($p < 0.005$) highest value. The available P mean values were (range, mg kg^{-1}) 18.15-45.17 with cashew/maize 2 plot having significantly ($p < 0.005$) highest value. The observed highest values of OC and TN were however considered moderate while available P was considered high by Singh (2002) for maize cultivation in Nigeria.

The cation exchangeable capacity (CEC) mean values were (range, cmol kg^{-1}) 11.80-19.77 with cashew/maize 2 plot

Table 1. Physico-chemical properties of soil (0 – 15 cm) in the early cropping season.

Plot	pH in 1 M KCl	Sand gkg $^{-1}$	Clay gkg $^{-1}$	Silt gkg $^{-1}$	P mg kg $^{-1}$	OC gkg $^{-1}$	N gkg $^{-1}$	Ca cmol kg $^{-1}$	Mg cmol kg $^{-1}$	Na cmol kg $^{-1}$	K cmol kg $^{-1}$	Exchangeable acidity cmol kg $^{-1}$	CEC cmol kg $^{-1}$	Fe cmol kg $^{-1}$	Mn mg kg $^{-1}$	Zn mg kg $^{-1}$
Cashew/maize 1	6.40^{bc}	750^{c}	65^{c}	185^{b}	35.51^{b}	21.75^{b}	3.15^{b}	8.70^{b}	8.10^{a}	1.50^{b}	1.20^{b}	0.18^{b}	19.68^{b}	85.09^{d}	45.95^{d}	10.22^{b}
Cashew/maize 2	6.50^{b}	715^{d}	70^{b}	215^{a}	45.17^{a}	30.05^{a}	4.21^{a}	9.61^{a}	6.63^{b}	1.75^{a}	1.60^{a}	0.18^{b}	19.77^{a}	130.25^{a}	115.14^{a}	12.10^{a}
Maize 1	6.80^{a}	748^{b}	71^{a}	181^{c}	25.25^{c}	18.15^{c}	2.07^{c}	7.55^{c}	5.03^{c}	0.45^{c}	0.37^{d}	0.20^{a}	13.66^{c}	103.54^{c}	85.25^{b}	9.09^{d}
Maize 2	6.30^{c}	795^{a}	60^{d}	145^{d}	18.70^{d}	13.05^{d}	1.85^{d}	6.78^{d}	4.15^{d}	0.30^{d}	0.40^{c}	0.15^{c}	11.80^{d}	125.00^{b}	75.15^{c}	10.14^{c}

Values within a column followed by different letter are significantly different according to new Duncan Multiple Range Test at $p < 0.005$.

Table 2. Physico-chemical properties of soil (15 – 30 cm) in the early cropping season.

Plot	pH in 1 M KCl	Sand gkg $^{-1}$	Clay gkg $^{-1}$	Silt gkg $^{-1}$	P mg kg $^{-1}$	OC gkg $^{-1}$	N gkg $^{-1}$	Ca cmol kg $^{-1}$	Mg cmol kg $^{-1}$	Na cmol kg $^{-1}$	K cmol kg $^{-1}$	Exchangeable acidity cmol kg $^{-1}$	CEC cmol kg $^{-1}$	Fe cmol kg $^{-1}$	Mn mg kg $^{-1}$	Zn mg kg $^{-1}$
Cashew/maize 1	6.30^{b}	748^{b}	72^{b}	180^{c}	30.42^{b}	18.14^{b}	2.46^{b}	6.92^{b}	4.05^{b}	1.15^{b}	1.25^{a}	0.18^{c}	13.55^{b}	80.65^{d}	33.60^{d}	7.99^{b}
Cashew/maize 2	6.60^{a}	720^{d}	83^{a}	197^{a}	36.58^{a}	20.98^{a}	2.70^{a}	8.09^{a}	5.65^{a}	1.18^{a}	1.07^{b}	0.25^{a}	16.24^{a}	85.18^{b}	75.14^{a}	11.20^{a}
Maize 1	6.70^{a}	745^{c}	70^{c}	185^{b}	24.95^{c}	12.17^{d}	1.38^{d}	5.55^{d}	2.00^{d}	0.65^{c}	0.40^{c}	0.25^{a}	8.85^{d}	98.10^{a}	62.01^{b}	6.55^{c}
Maize 2	6.30^{b}	780^{a}	61^{d}	159^{d}	17.17^{d}	13.00^{c}	1.59^{c}	6.65^{c}	2.95^{c}	0.55^{d}	0.33^{d}	0.22^{b}	10.70^{c}	85.15^{bc}	60.98^{c}	5.98^{d}

Values within a column followed by different letter are significantly different according to new Duncan Multiple Range Test at $p < 0.005$

having significantly ($p < 0.005$) highest value. There was a direct positive relationship, separately, between OC and CEC; and OC and the extractible micronutrients (Fe, Mn and Zn). It is therefore important to note here that TN, available P, CEC and extractible cations were OC dependent.

Table 2 shows the results of soil samples taken to the depth 15-30 cm from the four plots before maize seeds were planted in the early season of 2002. The observed trend of higher values of OC, TN, exchangeable cations and extractible cations at the topsoil than the subsoil could be attributed to the fact that most of the plant nutrients in their available form domicile in the topsoil. These findings agreed with those reported in earlier studies of Agboola (1982) and Nill and Nill (1993). Tables 3 and 4 show the results of the soil samples taken to the depths 0-15 and 15-30 cm from the four plots after the early season maize had been harvested, but before the planting of late season maize. Tables 3 and 4 further show clearly that TN, available P, CEC and extractible cations were OC dependent. Also, cashew/maize plots showed superiority of all these soil chemical properties over sole maize plots.

The soil chemical properties measured in cashew/maize intercrop plots are generally higher in values than in the sole maize plots despite the 4 years of fallow. Rind-weeding of cashew stands and slashing of weeds in between the rows of cashew stands were regularly carried out before maize was intercropped with cashew 4 years after establishment. These were litter falls that positively enhanced the organic matter content and all the OC dependents (TN, available P, CEC and extractible cations). This agreed with the earlier findings of Kang (1993) that TN and available P are organic matter dependent.

The mean yields of maize seed obtained at full maturity are presented in Table 5. Mean yield of SUWAN-I-Y maize seed of 1.34 t ha^{-1} from cashew/maize intercrop was significantly higher than 1.05 t ha^{-1} from sole maize in the early season cropping. Similar trend in the mean yields of maize seed were obtained in the late season cropping of cashew/maize intercrop and sole maize but at a lower magnitude. First set of

Table 3. Physico-chemical properties of soil (0 – 15 cm) in the late cropping season.

Plot	pH in 1 M KCl	Sand gkg $^{-1}$	Clay gkg $^{-1}$	Silt gkg $^{-1}$	P mg kg $^{-1}$	OC gkg $^{-1}$	N gkg $^{-1}$	Ca cmol kg $^{-1}$	Mg cmol kg $^{-1}$	Na cmol kg $^{-1}$	K cmol kg $^{-1}$	Exchangeable acidity cmol kg $^{-1}$	CEC cmol kg $^{-1}$	Fe cmol kg $^{-1}$	Mn mg kg $^{-1}$	Zn mg kg $^{-1}$
Cashew/maize 1	6.40^{b}	750^{b}	65^{c}	185^{b}	30.55^{b}	21.56^{b}	2.45^{b}	8.00^{b}	5.54^{a}	1.85^{a}	1.15^{b}	0.18^{b}	16.72^{a}	88.65^{d}	50.25^{d}	10.86^{a}
Cashew/maize 2	6.60^{ab}	710^{c}	73^{a}	217^{a}	48.67^{a}	28.80^{a}	3.06^{a}	8.50^{a}	3.58^{d}	1.74^{b}	1.78^{a}	0.20^{a}	15.85^{b}	95.05^{c}	105.15^{a}	10.35^{b}
Maize 1	6.60^{ab}	750^{b}	71^{b}	179^{c}	24.85^{c}	16.57^{c}	1.48^{c}	6.00^{d}	4.10^{b}	0.55^{c}	0.40^{c}	0.20^{a}	11.35^{d}	95.17^{b}	100.67^{b}	8.10^{a}
Maize 2	6.70^{a}	790^{a}	61^{d}	149^{d}	22.77^{d}	10.10^{d}	1.35^{d}	6.56^{c}	4.05^{c}	0.51^{d}	0.38^{d}	0.20^{a}	11.94^{c}	108.17^{a}	80.65^{c}	7.30^{d}

Values within a column followed by different letter are significantly different according to new Duncan Multiple Range Test at $p < 0.005$.

Table 4. Physico-chemical properties of soil (15 – 30 cm) in the late cropping season.

Plot	pH in 1M KCl	Sand gkg $^{-1}$	Clay $^{-1}$ gkg	Silt gkg $^{-1}$	P mg kg $^{-1}$	OC gkg $^{-1}$	N gkg $^{-1}$	Ca cmol kg $^{-1}$	Mg cmol kg $^{-1}$	Na cmol kg $^{-1}$	K cmol kg $^{-1}$	Exchangeable acidity cmol kg $^{-1}$	CEC cmol kg $^{-1}$	Fe cmol kg $^{-1}$	Mn mg kg $^{-1}$	Zn mg kg $^{-1}$
Cashew/maize 1	6.50^{c}	719^{d}	69^{c}	212^{a}	30.42^{b}	21.50^{b}	2.15^{b}	5.18^{b}	4.00^{b}	1.06^{a}	1.36^{b}	0.18^{b}	11.80^{a}	69.52^{c}	89.96^{a}	6.57^{c}
Cashew/maize 2	6.70^{a}	725^{c}	77^{a}	198^{b}	30.65^{a}	22.85^{a}	2.29^{a}	4.95^{c}	4.07^{a}	0.95^{b}	1.50^{a}	0.20^{a}	11.72^{b}	63.31^{d}	86.10^{b}	6.62^{b}
Maize 1	6.60^{b}	740^{b}	72^{b}	188^{c}	21.18^{c}	13.10^{c}	1.38^{c}	4.98^{c}	3.33^{c}	0.70^{c}	0.36^{c}	0.20^{a}	9.62^{c}	79.96^{b}	57.15^{c}	7.10^{a}
Maize 2	6.60^{b}	773^{a}	63^{d}	164^{d}	21.00^{d}	12.06^{d}	1.19^{d}	6.00^{a}	2.27^{d}	0.32^{d}	0.36^{c}	0.20^{a}	9.20^{d}	100.27^{a}	56.67^{d}	5.88^{d}

Values within a column followed by different letter are significantly different according to new Duncan Multiple Range Test at $p < 0.005$.

Table 5. Mean yield of maize (t ha $^{-1}$) as affected by different farming practices*.

Farming practice	Early season	Late season
Cashew/maize	1.34^{a}	1.02^{a}
Maize	1.05^{b}	0.81^{b}

Values within a column followed by different letter are significantly different according to new Duncan Multiple Range Test at $p < 0.05$, *Native soil fertility (No application of fertilizer).

matured nuts of cashew that dropped in 2002 was 92 kg ha $^{-1}$ and this could serve as additional income to the collaborating farmer.

Conclusion

The rate of soil nutrient depletion in cashew/maize intercropped compared with sole maize plots was low. OC, TN, available P, CEC and extractible cations values were higher under cashew/maize intercropped compared with sole maize plots. This could be attributed to the canopies of cashew trees protecting the topsoil and nutrients' input from the decomposed litter falls from cashew trees. The study concludes that agroforestry in the traditional farming system of this nature helps to reduce the rate of soil nutrient depletion, while the yield of 'participating crop'; maize could still be reasonably high

Conflict of Interests

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

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Vol. 9(27), pp. 2124-2131, 3 July, 2014
DOI: 10.5897/AJAR10.592
Article Number: 3459D6B45988
ISSN 1991-637X
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http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Effects of organic amendments and fungicides on the survival of collar rot fungus of soybean incited by *Sclerotium rolfsii*

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Received 21 July, 2010; Accepted 12 June, 2014

Soil-borne plant pathogenic fungi cause heavy crop losses all over the world. With variable climate from region to region, among tropical and subtropical land crops, soybean [*Glycine max* (L.) Merill]. is an important oil seed crop, providing vegetable oil as human food. Results revealed that alone fungicidal seed treatment (main), alone soil application of organic amendments (sub) and their interactions significantly reduced the pre-, post- and average mortality induced by *Sclerotium rolfsii* in soybean Cv. MAUS-71 over untreated control. All the seed dressing fungicides tested were found at par and recorded significantly least pre-emergence mortality in the range of 05.80 to 06.35%, post-emergence mortality in the range of 05.48 to 05.61 with average mortality in the range of 05.71 to 05.98%. All the seed dressing fungicides tested were found at par and recorded significantly maximum number of pods per plant in the range of 25.40 to 26.30, test weight in the range of 05.79 to 05.85 g and seed yield in the range of 849.95 to 870.72 kg/ha over untreated control. Similarly, alone soil application of organic amendments was found effective against *S. rolfsii* and significantly reduced the pre- and post-emergence mortality and increased the number of pods per plants, test weight and seed yield in soybean Cv. MAUS-71 over untreated control. Of the six organic amendments tested, neem cake recorded significantly reduced pre-emergence mortality (05.63%); post-emergence mortality, (05.47%); maximum pods / plant, (25.70); highest test weight, (05.82 g) and highest seed yield (849.70 kg/ha). Among the interactions, Carbendazim + Captan x Neem cake recorded significantly least pre-emergence mortality (01.66%). Significantly reduced post-emergence mortality was recorded with treatment interactions of Captan x fym (01.23%). The treatment interactions of Carbendazim + Captan x sunflower cake recorded significantly increased number of pods/ plant (37.00). Significantly highest test weight was recorded with the treatment interactions of Carbendazim + Captan x Neem cake (12.50 g). The treatment interactions of Carbendazim + Captan x sunflower cake recorded significantly highest seed yield (2040.00 kg/ha).

Key words: *Glycine max, Sclerotium rolfsii,* organic amendments, fungicides.

INTRODUCTION

Soybean (*Glycine max* L. Merill), the native of China is the leguminous crop belonging to the family *Leguminoseae*. It is an important grain legume and its importance is increasing day- by- day due to its nutritive

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value. The crop is grown in most of the countries *viz.*, United States, Brazil, Argentina, China, India and other countries of the world. It is the primary source of vegetable oil (20%) without cholesterol, proteins (40%), carbohydrates (23%) and valuable amino acids. In addition, it contains a good amount of minerals, salts and vitamins (Thiamine and Riboflavin). As soybean is the cheapest source of proteins, hence called 'poor man's meat'. Soybean, also called 'golden bean' is one of the solution to overcome world's protein hunger. Soybean cultivation throughout world has been found to be affected by several biotic and abiotic factors, of which biotic (fungi, bacteria and viruses) factors were found to be the major constraints in the cultivation of soybean. More than 100 pathogens have been reported to affect soybean and at least 66 fungi, 6 bacteria and 8 viruses have been reported to infect soybean (Sinclair, 1978) and were reported to cause globally the seven million tonnes of losses in soybean (Sinclair, 1982). The pathogen (*Sclerotium rolfsii* Sacc.) is polyphagous infecting the crops like soybean, pigeon pea, groundnuts, sunflower etc. and cause considerable yield losses to the tune of 25 to 30% (Mulrooney, 1988). The fungus survives as sclerotia in soil and plant debris, and remains viable for 2 to 3 years. High temperature 30°C and high soil moisture (>70%) at sowing encourages the disease. Muthusmy and Mariappan (1991) reported 77% losses due to *Rhizoctonia bataticola* and 14 to 74% due to *S. rolfsii*. Manglekar and Raut (1997) have reported 30% yield loss in soybean due to *Rhizoctonia* root/stem rot in Vidharbha region of Maharashtra, India. For management of the disease, different oil cake extracts of organic amendments and fungicides were evaluated against the pathogen.

MATERIALS AND METHODS

The field experiment was planned conducted during *Kharif*, 2007 on research farm of the Department of Plant Pathology, College of Agriculture, Latur (MS), India. Two seed dressing fungicides *viz.,* Carbendazim and Captan, (alone and in combination), and six oil cake extracts of organic amendments *viz.*, groundnut cake, safflower cake, sunflower cake, neem cake, cotton cake and fym were evaluated against *S. rolfsii*, the incitant of collar rot of soybean. Effected soybean plants with characteristics symptoms of the disease were selected from the field. Blackened stem at collar region were cut into small pieces, and dipping in 1% mercuric chloride solution for a minute for surface disinfection and dried with sterile towel and inoculated on PDA media for isolation of Sclerotia species. Inoculated plants were examined for the symptoms of disease. The fungicides were applied as seed treatment before sowing. All the oil cake extracts were dried and powdered with mixture-cum-grinder and applied (at 500 Kg/ha) in the field one week before sowing. One plot per replication was maintained without application of any amendment as untreated control. The details of the experiment are Design: Factorial Randomized Block Design (FRBD), Replications: Two, Treatments: Main: Four, Sub: Seven, Variety: MAUS- 71, Plot Size: 3.0 × 2.1 m^2, Spacing: 30 × 10 cm and Treatment details: Main treatments (ST with fungicides): M_1: Carbendazim at 1.5 g/kg seed, M_2: Captan at 3 g/kg seed, M_3: Carbendazim + Captan at 1.5 g + 3.0 g/kg seed, M_4: Control (untreated) and Sub treatments (organic amendments): S_1 :Groundnut cake (314 g/plot), S_2: Safflower cake (314g/plot), S_3: Sunflower cake (314 g/plot), S_4: Neem cake (314 g/plot), S_5: Cotton cake (314 g/plot), S_6: FYM (314 g/plot), S_7: Control (untreated).

Soybean was sown on 30th June, 2007. All the recommended agronomical and intercultural practices were strictly followed and the crop was given protective irrigation as and when required. Observations on seed germination were recorded one week after sowing and computed for pre- emergence mortality. Observations on post emergence seedling mortality were recorded at 30 days after sowing. Applying 0-9 grade disease rating scale (Mayee and Datar, 1986) pre- and post- emergence mortality were recorded. Based on numerical rating/ score percent disease incidence (PDI) and percent disease control (PDC) were worked out applying formulae:

$$\text{PDI} = \frac{\text{Sum of numerical rating}}{\text{No. of plant examined} \times \text{max. rating scale}} \times 100$$

$$\text{PDC} = \frac{\text{PDI in untreated plot} - \text{PDI in treated plot}}{\text{PDI in untreated plot}} \times 100$$

Further at harvest, observations on number of pods per plant, test weight and grain yield were recorded. The yield data was recorded and statistical analysis was made according to Panse and Sukhatme (1964).

RESULTS AND DISCUSSION

Field evaluation

The fungicidal seed treatments (main treatments), alone soil application of organic amendments (sub treatments) and their interactions were found effective against *S. rolfsii*, inciting collar rot of soybean. Both the treatments (main and sub) significantly reduced pre- and post-emergence mortality and thereby increased the number of pods/ plant, test weight (100 seeds wt.) and seed yield (kg/ha) in soybean Cv. MAUS-71 over untreated control (Table 1). All the seed dressing fungicides (Carbendazim at 1.5 g/kg, Captan at 3.0 g/kg and Carbendazim + Captan at 1.5 + 3.0 g g/kg seed) were found effective and at par, which recorded significantly reduced pre-emergence mortality (06.04, 06.35 and 05.80%, respectively) and post emergence mortality (05.48, 05.61 and 05.61% respectively) over untreated control (06.41%). Similar trend was also observed in respect of the average mortality. All the seed dressing fungicides tested were also found at par and recorded significantly maximum number of pods per plant (range: 25.40 to 26.30), increased test weight (range: 05.79 to 05.85 g) and seed yield (range: 849.95 to 870.72 kg/ ha) over untreated control.

All the oil cake extracts applied alone as organic amendments (sub treatments) were also found effective and recorded significantly reduced pre- and post-emergence mortality, increased the number of pods per plant, test weight and seed yield in soybean Cv. MAUS-

Table 1. Efficacy of fungicides and organic amendments against *S. rolfsii* infecting soybean.

Treatments	**% Mortality***		**Av. % mortality**	**No. of pods***	**Test wt. * (g)**	**Seed Yield* (Kg/ha)**
	Pre-emerg.	**Post- emerg**				
Seed treatments (Main)						
Carbendazim (at 1.5 g/ka)	06.04(11.86)**	05.48(10.40)	05.76	26.10(05.39)#	05.81(11.73) Δ	869.35(1780.86)Δ
Captan (at 3.0 g/kg)	06.35(13.11)	05.61(10.95)	05.98	25.40(05.11)	05.79(11.64)	849.95(1697.29)
Carb. + Captan (1.5 + 3.0 g/kg)	05.80(10.89)	05.61(10.95)	05.71	26.30(05.48)	05.85(11.86)	878.72(1818.07)
Control (untreated)	06.41(13.13)	06.31(13.73)	06.36	23.30(04.29)	05.58(10.78)	796.92(1491.00)
S.E. ±	00.32	00.11	--	00.04	00.02	08.80
C.D.	00.92	00.33	--	00.12	00.07	25.54
Organic amendments (Sub)						
Groundnut cake	05.76(10.74)	05.59(10.86)	05.68	26.00(05.34)	05.85(11.88)	872.95(1795.00)
Safflower cake	05.89(11.24)	05.34(09.87)	05.62	25.40(05.11)	05.79(11.65)	859.36(1740.63)
Sunflower cake	05.84(11.05)	05.62(10.99)	05.73	26.10(05.38)	05.81(11.72)	873.12(1795.88)
Neem cake	05.63(10.23)	05.47(10.37)	05.55	25.70(05.22)	05.82(11.77)	849.70(1702.00)
Cotton cake	06.16(12.34)	05.96(12.32)	06.06	25.50(05.16)	05.76(11.52)	845.11(1683.63)
FYM	06.37(13.19)	05.58(10.83)	05.98	24.60(04.81)	05.76(11.52)	829.95(1619.00)
Control (untreated)	07.40(17.30)	06.69(15.27)	07.05	23.60(04.38)	05.54(10.65)	712.07(1541.50)
S.E. ±	00.24	00.08	--	00.03	00.02	06.65
C. D. (P = 0.05)	00.70	00.25	--	00.09	00.06	19.30
Interaction (MxS)						
S.E. ±	00.63	00.22	--	00.08	00.05	17.60
C. D. (P = 0.05)	01.84	00.65	--	00.24	00.15	51.08

*: Mean of two replications, ** : Figures in parenthesis are arc sine transformed values, # : Figures in parenthesis are square root transformed values, Δ: Figures in parenthesis are normal transformed values.

71 over untreated control. Of the six organic amendments tested, neem cake followed by groundnut cake and FYM were found at par and recorded significantly reduced pre-emergence mortality, respectively of 05.63, 05.76 and 06.37% and post-emergence mortality of 05.47, 05.59 and 05.58%, respectively. This was followed by Sunflower, Safflower and Cotton which were at par and recorded pre-emergence mortality respectively of 05.84, 05.89 and 06.16% and post-emergence mortality respectively of 05.62, 05.34 and 05.96%. Significantly minimum average mortality was recorded with the test fungicides and organic amendments, which were ranged from 05.71 to 05.98 and 05.55 to 06.06, respectively per cent over untreated control (06.36 and 07.05%). All the treatments (main and sub) were found at par and significantly increased the number of pods/ plant (24.60 to 26.30), test weight (range: 05.76 to 05.85 g) and seed yield (range: 829.95 to 878.72 Kg/ ha). However, highest number of pods/ plant (26.30), test weight (05.85g) and seed yield (878.72 Kg/ ha) were recorded with treatment Carbendazim + Captan (seed treatment). This was followed by the treatment Sunflower cake (soil application) which recorded second highest number of pods / plant

Table 2. Interaction effects of fungicides and organic amendments on percentage pre-emergence mortality* caused by *S. rolfsii* in soybean under field conditions.

Fungicides / org. amend.	*Carbendazim*	Captan	*Carbendazim + Captan*	Untreated
Groundnut cake	02.62 (09.30)	03.81 (11.16)	02.14 (08.40)	05.95 (14.12)
Safflower cake	04.04 (11.59)	04.04 (11.59)	02.38 (08.88)	05.00 (12.91)
Sunflower cake	04.28 (11.94)	03.33 (10.51)	03.57 (10.88)	03.57 (10.88)
Neem cake	02.86 (09.70)	04.76 (12.60)	01.66 (07.38)	03.80 (11.24)
Cotton cake	03.81 (11.05)	05.48 (13.50)	04.04 (11.59)	05.23 (13.22)
FYM	05.09 (13.21)	06.43 (14.66)	04.76 (12.60)	04.52 (12.27)
Control (untreated)	07.85 (16.27)	09.28 (17.74)	08.09 (16.52)	10.24 (18.66)
S.E. ±			00.63	
C. D. (P = 0.05)			01.84	

*: Mean of two replications, Figures in parenthesis are arc sine transformed values.

(26.10), test weight (05.81g) and seed yield (873.12 Kg/ ha). Rest of the treatments (main and sub) were also found significantly superior over untreated control with reduced number of pods/ plant (23.30 to 23.60), test weight (05.54 to 05.58 g) and seed yield (712.07 to 796.92 Kg/ ha).

Results obtained on interaction effects of fungicidal seed treatment and soil application of organic amendments, revealed that all the treatment interactions significantly reduced pre-emergence mortality caused by *S. rolfsii* in soybean Cv. MAUS-71 over untreated control (07.85%) (Table 2). Among the interactions of fungicidal seed treatment + organic amendments, treatment Carbendazim + Captan x Organic amendments was found most superior over rest of the interactions and recorded least pre-emergence mortality in the range of 01.66 to 04.76%. However, the interaction of Carbendazim + Captan x Neem cake recorded significantly least pre-emergence (01.66%) mortality. This was followed by the interactions, Carbendazim + Captan x Groundnut cake (02.14%). The interaction of Carbendazim + Captan with Cotton cake and FYM were found at par and recorded, respectively 04.04 and 04.76% pre-emergence mortality. The second best interactions of fungicidal seed treatment and organic amendments recorded was Carbendazim seed treatment x soil application of organic amendments. However, interactions of Carbendazim x Groundnut cake recorded least pre-emergence mortality (02.62%), followed by Carbendazim x Neem cake (02.86%) and Carbendazim x Cotton cake (03.81%). The interactions of Captan x Organic amendments were also found effective which recorded significantly minimum pre-emergence mortality in the range of 03.33 to 06.43%. However, interactions of Captan x Sunflower cake and Captan x Groundnut cake recorded least pre-emergence mortality, respectively of 03.33 and 03.81% and both of which were at par. Soil application of organic amendments without any fungicidal seed treatment was found comparatively most effective than fungicidal seed treatment alone and recorded significantly reduced pre-emergence mortality in the range of 03.57 to 05.95%, over untreated (without fungicidal seed treatment) control (10.28%).

Results revealed that interaction effects of fungicidal seed treatments and organic amendments caused similar effects on post-emergence mortality as that of pre-emergence mortality in soybean (Table 3). Among the interactions of fungicidal seed treatments x oil cake extracts of organic amendments, the interaction of Carbendazim seed treatment x organic amendments was found most effective with significantly reduced post-emergence mortality in the range of 01.41 to 04.38%. However, significantly least post-emergence mortality was recorded with the interaction of Carbendazim x Cotton cake (01.41%), followed by Carbendazim x Groundnut cake (01.86%), Carbendazim x Safflower cake (02.39%) and Carbendazim x Neem cake (02.85%) and all the interactions were at par. The interaction of Carbendazim with Sunflower cake and FYM was found at par and recorded post-emergence mortality, respectively of 03.87 and 04.38%. The second best interaction of fungicidal seed treatment with organic amendments, found was Carbendazim + Captan x Organic amendments, which recorded post-emergence mortality in the range of 01.83 to 04.70%. However, significantly least post-emergence mortality was recorded with interaction of Carbendazim + Captan x Neem cake (01.83%), followed by Carbendazim + Captan x Groundnut cake (02.34%) and Carbendazim + Captan x Sunflower cake (02.42%) both of which were at par. The interactions of Carbendazim + Captan with Sunflower cake, Cotton cake and FYM were found at par and recorded post-emergence mortality, respectively of 03.70, 04.22 and 04.70%.

Results on interaction effects of fungicidal seed treatment and soil application of organic amendments on yield and yield contributing parameters in soybean, revealed that all the treatment interactions recorded significantly increased number of pods / plant, test weight and seed yield (kg/ha) over untreated control (Table 4).

Table 3. Interaction effects of fungicides and organic amendments on post-emergence mortality* (%) caused by *S. rolfsii* in soybean under field conditions.

Fungicides /Org. amendments	*Carbendazim*	Captan	*Carb.* + *Captan*	Control (untreated)
Groundnut cake	01.86 (07.87)	04.35 (12.04)	02.34 (08.80)	06.47 (14.73)
Safflower cake	02.39 (08.88)	02.65 (09.35)	02.42 (08.94)	04.56 (12.32)
Sunflower cake	03.87 (11.34)	03.45 (10.70)	03.70 (11.09)	03.53 (10.81)
Neem cake	02.85 (09.72)	04.95 (12.86)	01.83 (07.76)	04.60 (11.13)
Cotton cake	01.41 (06.81)	06.43 (14.66)	04.22 (11.85)	05.32 (13.33)
FYM	04.38 (12.07)	01.23 (06.35)	04.70 (12.53)	04.58 (12.36)
Control (untreated)	07.68 (16.08)	07.85 (16.27)	07.18 (15.54)	10.35 (21.43)
S.E. ±	00.22			
C. D. (P = 0.05)	00.65			

*: Mean of two replications, Figures in parenthesis are arc sine transformed values.

Table 4. Interaction effects of fungicides and organic amendments on yield and yield contributing parameters in soybean.

Treatments	No. of pods/ plant*				Test wt. (g)*				Yield (kg/ha)*			
	Carb.	Captan	Carb.+ Captan	Control (Untr.)	Carb.	Captan	Carb.+ Captan	Control (Untr.)	Carb.	Captan	Carb.+ Captan	Control (Untr.)
Groundnut cake	33.00(05.79)	25.00(05.05)	35.50(06.00)	20.00(04.53)	12.13	11.42	12.30	10.90	1933.50	1712.50	1976.50	1557.50
Safflower cake	28.00(05.34)	23.50(04.90)	32.50(05.74)	19.50(04.47)	11.65	12.05	12.13	10.78	1800.00	1737.50	1970.50	1507.50
Sunflower cake	27.00(05.24)	31.00(05.61)	37.00(06.12)	20.00(04.53)	11.70	12.05	11.98	11.15	1785.00	1818.50	2040.00	1540.00
Neem cake	31.00(05.61)	28.50(05.39)	32.00(05.70)	17.00(04.18)	11.88	11.85	12.55	10.80	1823.00	1660.00	1857.50	1467.50
Cotton cake	35.00(05.96)	28.00(05.34)	29.50(05.48)	18.50(04.36)	12.38	11.76	11.30	10.63	1832.00	1725.00	1735.00	1442.50
FYM	27.50(05.29)	25.50(05.10)	25.00(05.05)	16.50(04.12)	11.73	11.58	11.89	10.93	1655.00	1715.00	1622.50	1483.50
Control (untreated)	19.50(04.47)	18.50(04.36)	17.50(04.24)	14.50(03.87)	10.63	10.80	10.88	10.30	1637.50	1512.50	1577.50	1438.50
S.E. ±	0.08				0.05				17.60			
C.D. (P=0.05)	0.24				0.14				51.08			

*: Mean of two replications, Figures in the parenthesis are square root transformed values.

Among the various treatment interactions, the interaction of Carbendazim + Captan x Organic amendments recorded significantly increased number of pods / plant in the range of 25.00 to 37.00, test weight in the range of 11.30 to 12.55 g and seed yield in the range of 1622.50 to 2040.00 kg/ha. This was followed by interaction of Carbendazim x Organic amendments and Captan x Organic amendments which recorded maximum number of pods / plant, respectively in the range of 27.50 to 35.00 and 23.50 to 31.00; test weight, respectively in range of 11.65 to 12.38 g and 11.42 to 12.05 g and grain yield, respectively in the range of 1655.00 to 1933.50 kg/ha and 1660.00 to 1818.50 kg/ha. However, the interaction of Carbendazim + Captan x Sunflower cake recorded significantly highest yield (2040.00 kg/ha), followed by Carbendazim + Captan x

Table 5. Pot culture evaluation of fungicides and organic amendments against *S. rolfsii* infecting soybean.

Treatments	% Mortality*		Av. mortality (%)
	Pre-emerg.	Post- emerg.	
Seed treatments (main)			
Carbendazim (at1.5 g/ka)	06.11 (11.68)	05.50 (10.10)	05.81
Captan (at3.0 g/kg)	06.34 (13.12)	06.13 (12.64)	06.24
Carbendazim + Captan (1.5 + 3.0 g/kg)	05.96 (11.48)	05.69 (10.86)	05.83
Control (untreated)	06.44 (13.65)	06.45 (13.96)	06.45
S.E. ±	0.13	0.19	-
C.D. (P = 0.05)	0.37	0.54	-
Organic amendments (sub)			
Groundnut cake	04.29 (10.77)	05.60 (10.51)	04.95
Safflower cake	05.83 (10.09)	05.49 (10.06)	05.66
Sunflower cake	06.07 (11.77)	05.69 (10.86)	05.88
Neem cake	05.82 (11.04)	5.49 (10.06)	05.65
Cotton cake	06.09 (12.19)	06.05 (12.30)	06.07
FYM	06.19 (12.27)	05.81 (11.36)	06.00
Control (untreated)	7.68 (18.24)	7.48 (18.04)	07.58
S.E. ±	0.10	0.14	-
C. D. (P = 0.05)	0.28	0.41	-
Interaction (M x S)			
S.E. ±	0.26	0.38	-
C. D. (P = 0.05)	0.75	1.09	-

* : Mean of two replications, Figures in parenthesis are arc sine transformed values.

Groundnut cake (1976.50 kg/ha), Carbendazim + Captan x Safflower cake (1970.50 kg/ha) and Carbendazim x Groundnut cake (1933.50 kg/ha). Rest of the treatment interactions also recorded significantly increased seed yield in the range of 1622.50 to 1857.50 Kg/ ha over untreated control (1438.50 kg/ha).

Pot culture evaluation

Results revealed that all the treatments (fungicides, organic amendments and their interactions) were found effective against *S. rolfsii* and significantly reduced the per- and post-emergence mortality in soybean Cv. JS-335 (Table 5). Seed treatment alone with fungicides was found most effective which significantly reduced the pre- as well as post-emergence mortality in soybean over untreated control. All the fungicidal seed treatments recorded pre-mergence and post emergence mortality, respectively in the range of 05.96, to 06.34 and 05.50 to 06.13%. However, fungicides Carbendazim, Captan and their combination were found at par and recorded pre-emergence mortality of 06.11, 06.34 and 05.96%, respectively over untreated control (06.44%). Similarly the post-emergence mortality recorded with these treatments was 05.50, 06.13 and 05.69%, respectively over untreated control (06.45%). Average mortality recorded with all the fungicidal treatments was ranged from 05.81 to 06.24% over untreated control (06.45%). Soil application of organic amendments alone was also found equally effective against *S. rolfsii* and recorded significantly minimum pre- and post-emergence mortality, respectively in the range of 04.29 to 06.19 and 05.49 to 06.05%. However, groundnut cake recorded significantly reduced pre-emergence (04.60%) mortality with average mortality of (04.95%). Rest of the treatments were found at par and significantly superior over untreated control in reducing pre-, post- and average mortality.

Results obtained on interaction effects of fungicidal seed treatment and soil application of organic amendments; revealed that all the interactions significantly reduced pre-emergence mortality in soybean over untreated control (Table 6). Among the interactions, the interactions of seed treatment with Carbendazim + Captan and Carbendazim with all the organic amendments were found most effective which recorded pre-emergence mortality in the range of 02.18 to 05.00 and 02.18 to 04.50%, respectively. However, the interactions of Carbendazim x Groundnut cake and Carbendazim + Captan x Groundnut cake were found significantly superior over rest of the treatment interactions which recorded least pre-emergence

Table 6. Interaction effects of fungicides and organic amendments on pre-emergence mortality* (%) caused by *S. rolfsii* in soybean in pot culture.

Fungicides / Org. amend.	*Carbendazim*	Captan	*Carb+ Captan*	Untreated
Groundnut cake	02.18 (08.48)	04.00 (11.54)	02.18 (08.48)	06.35 (14.59)
Safflower cake	03.43 (10.66)	03.70 (11.09)	02.50 (09.10)	05.45 (13.50)
Sunflower cake	04.43 (12.15)	03.80 (11.24)	04.45 (12.17)	03.98 (11.50)
Neem cake	04.18 (11.79)	04.45 (12.17)	02.33 (08.77)	03.93 (11.42)
Cotton cake	03.30 (10.46)	05.93 (14.09)	03.88 (11.35)	04.65 (12.85)
FYM	04.50 (12.24)	04.40 (12.10)	05.00 (12.92)	04.20 (11.83)
Control (untreated)	07.58 (15.98)	11.25 (19.59)	09.10 (17.56)	11.50 (19.82)
S.E. ±		00.26		
C. D. (P = 0.05)		00.75		

* : Mean of two replications, Figures in parenthesis are arc sine transformed values.

Table 7. Interaction effects of fungicides and organic amendments on post-emergence mortality* (%) caused by *S. rolfsii* in soybean in pot culture.

Fungicides / Org. amend.	*Carbendazim*	Captan	*Carb. + Captan*	Untreated
Groundnut cake	01.33 (06.61)	03.50 (10.78)	03.07 (10.07)	06.35 (14.59)
Safflower cake	02.88 (09.76)	02.48 (09.04)	02.23 (08.58)	04.95 (12.85)
Sunflower cake	04.18 (11.79)	02.98 (10.06)	03.45 (10.69)	03.58 (10.88)
Neem cake	02.53 (09.13)	04.35 (12.04)	01.53 (07.07)	04.33 (12.00)
Cotton cake	01.60 (07.22)	07.83 (16.24)	04.03 (11.57)	05.98 (14.15)
FYM	03.83 (11.28)	02.50 (09.09)	04.46 (12.18)	04.98 (12.89)
Control (untreated)	06.63 (14.91)	13.10 (21.22)	07.50 (15.89)	11.88 (20.16)
S.E. ±		00.38		
C. D. (P = 0.05)		01.09		

*:Mean of three replications, Figures in parenthesis are arc sine transformed values.

mortality of 02.18%. This was followed by the interactions of Carbendazim + Captan x Neem cake, Carbendazim + Captan x Safflower cake, Carbendazim x Cotton cake and Carbendazim x Safflower cake which recorded pre-emergence mortality, respectively of 02.33, 02.50, 03.30 and 03.43%.

Results revealed that all the treatment interactions significantly reduced the post-emergence mortality in soybean (Table 7). Among various treatment interactions, the fungicidal seed treatment with Carbendazim, followed by Carbendazim + Captan and Captan all of which when interacted with organic amendments, recorded significant reduction in the post-emergence mortality. However, Carbendazim interacted with organic amendments recorded least post-emergence mortality in the range of 01.33 to 04.18%, followed by Carbendazim + Captan x organic amendments and Captan x organic amendments which recorded post-emergence mortality in the range of 01.53 to 04.60% and 02.50 to 07.83%, respectively. Among the interactions of Carbendazim with organic amendments, Carbendazim x Groundnut cake and Carbendazim x Cotton cake recorded least pre-emergence mortality, respectively of 01.33 to 01.60%. This was followed by the interactions of Carbendazim x Neem cake (02.53%), Carbendazim x Sunflower Cake (02.88%) and Carbendazim x FYM (03.83%). Among the interactions of Carbendazim + Captan with organic amendments, the interaction of Carbendazim + Captan x Neem cake recorded least post-emergence mortality of 01.53 per cent. This was followed by the interactions of Carbendazim + Captan with safflower cake (02.33%), Groundnut cake (03.07%) and Sunflower cake (03.45%). Application of soil amendments without any fungicidal seed treatment was found comparatively most effective than alone fungicidal seed treatment and recorded significant reduction in both pre-as well as post-emergence mortality induced by *S. rolfsii* in soybean.

The similarly results of the present studies obtained on the effectiveness of seed dressing fungicides alone, soil application of organic amendments alone and their interactions against *S. rolfsii,* the incitant of collar rot of soybean are inconformity with those reported earlier by several workers. Fungicides, Carbendazim and Captan (alone and in combination) applied as seed dresser or soil drench were reported effective in controlling pre- as well as post-emergence mortality induced by *S. rolfsii* in the crops like Soybean, Groundnut, Pigeonpea, Chickpea, Chilli, Sunflower and Tuberoses, earlier by several workers (Dharamvir, 1974; Patil et al., 1976; Anilkumar et al., 1976, Diamond and Beute 1977; Patil and Mayee, 1977; Zote et al., 1982; Gangopadhyay et al., 1996; Das et al., 1997; Tewari and Mukhopadhyay, 2003; Santha and Lakshmi, 2007; Konde et al., 2008; Nene and Thapliyal, 1979).

Organic amendments *viz.*, oil cake extracts of Neem, Groundnut, Karanj, Castor, Sunflower and fym applied in soil were reported fungitoxic / fungistatic against soil borne plant pathogens like *S. rolfsii*, *R. solani, M. phaseolina, S. sclerotiorum* and *Fusarium* spp. inducing root rot, stem rot, collar rot, wilt in the crops like Soybean, Sunflower, Cotton, Sesamum, Groundnut, Safflower, Fenugreek, etc. earlier by several workers (Cook, 1977; Gautam and Kolte, 1979; Ramkrishnan, 1981; Purkayastha and Menan, 1985; Narsimhalu and Bhaskaran, 1987; Waghe and Lanjewari, 1991; Kulkarni et al., 1995; Karthikeyan and Karunanidhi, 1996; Johnson et al., 2003; Mathur et al., 2006; Kulkarni and Kulkarni, 1998; Gerard, 1994; Singh and Dwivedi, 1989; Yadav, 1986).

Conflict of Interests

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

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academicJournals

Vol. 9(27), pp. 2132-2141, 3 July 2014
DOI: 10.5897/AJAR2013.7471
Article Number: F7C833245993
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Effects of nitrogen rates and application time on popcorn

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Received 11 June, 2013; Accepted 16 June, 2014

Among the various limiting factors in the production of Brazilian popcorn, paucity of information on cultural practices is highlighted, with emphasis on the management of fertilizer, especially nitrogen (N) topdressing. This mineral nutrient is of great importance in several agronomic characteristics of corn plants, mainly components of production. The aim of this study is to evaluate the effects of N management on popcorn (*Zea mays* L. subsp. *everta*) in two growing seasons (during 2007 and 2008 agricultural years) in Maringá, Northeast of Parana, Brazil. Experiment was conducted as a factorial arrangement in randomized complete blocks design with four replications. The treatments were a combination of five N rates (0; 45; 90; 135; 180 kg ha^{-1}), two seasons of topdressing applications (development stages V_4 and V_8) and two varieties of popcorn (BRS-Angela and IAC-125). The N topdressing rates increased plant height, leaf area index, and ear length, number of grains per row, thousand grain weight, and grain yield of popcorn. The highest yields (3.94 t ha^{-1} and 3.24 t ha^{-1}) were obtained with the estimated rates of 130.1 and 131.5 kg N ha^{-1} for the cultivars BRS-Angela in V_8 and IAC-125 at V_4, respectively. On the other hand, the economic rates of N topdressing were 73.76 and 78.42 kg N ha^{-1} for BRS-Angela and IAC-125 cultivars, respectively. The N rates and time of application did not influence the capacity for expansion, and only the effect in this genetic trait was observed.

Key words: Zea mays *L*., nutrient, corn, nutrient, productivity, fertilization.

INTRODUCTION

Among the various limiting factors in the production of Brazilian popcorn, paucity of information on cultural practices is highlighted, with emphasis on the management of fertilizer, especially N topdressing. N is of great importance in several agronomic characteristics of corn plants and can raise thousand grain weight and number of ears per plant (Melgar et al., 1991), ear length (Hanway, 1963), plant height and the weight of ears (Araújo et al., 2004), dry matter (Araújo et al., 2004; Duete et al., 2008) and grain yield (Mar et al., 2003; Araújo et al., 2004; Silva et al., 2005, 2006; Duete et al., 2008; Okumura et al., 2011).

It should be noted that good results seen in only one of these traits does not provide a good economic

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Table 1. Chemical and physical characteristics of soil in 0.00 - 0.20 m layer.

Solo	pH	C	*P	*K^{+}	**Ca^{+2}	**Mg^{+2}	**Al^{+3}	SB	CTC	V
	CaCl$_2$	(g dm^{-3})	(mg dm^{-3})			(cmol$_c$ dm^{-3})				(%)
F	4.60	11.51	11.30	0.08	1.09	0.54	0.00	1.71	4.44	38.5
FN	5.00	21.96	8.20	0.58	3.34	1.60	0.00	5.52	10.48	52.6
	Solo		Areia			Silte			Argila	
						(g kg^{-1})				
	F		760			10			230	
	FN		340			140			520	

* Mehlich 1 (Mehlich, 1978). ** KCl 1 mol L^{-1} (Defelipo and Ribeiro, 1981).

productivity of the crop (Sawazaki et al., 2000). Although the increase of productivity is always desired, it is the expansion capacity that plays a decisive role in commercial value of popcorn (Ceylan and Karababa, 2002); there is no information in the literature regarding the effects of N and its application forms on the expansion capacity index of popcorn.

Among the producers of popcorn, it is observed that it is common to use technical recommendations of fertilizer for common corn and popcorn. This is mainly due to the scant results on experimental results for the growing of corn. What has been made available, most of the time are technical data published by private companies, which are based on adaptations of the recommendations of the common corn for popcorn. However, due to potential differences in production between them, the doses of fertilizers used for popcorn may be overestimated and/or underestimated (Nunes, 2003).

The best timing of N application must be taken into consideration for the correct handling of topdressing N. According to Ritchie et al. (1993), it is within the 4 fully expanded leaves period (V_4 stage) that the plant has its production potential defined by the differentiation of the apical meristem, justifying the importance of N availability. At this stage, one can see the definition of the reproductive organs in the stem and leaves of the plant (Ritchie et al., 1993), while in the V_8 stage (8 fully expanded leaves) the root system is already well developed, favoring the use of N by the plant (Ritchie et al., 1993).

Based on these considerations, this work was developed with the aim of evaluating the response of popcorn to rates and timing of N topdressing applications in the cropping season of 2007/2008 summer harvest and 2008 interim-harvest.

MATERIALS AND METHODS

The experiments were conducted in the field at the Experimental Farm of Iguatemi (FEI), State University of Maringá (UEM), located in the Iguatemi District, in Maringa, Northeast of Parana, Brazil (23º21' S and 52°04' W, with an average altitude of 550 m). The climate is the Cfa type, according to the Köppen classification, that is, subtropical climate with average temperature below 18°C in spring months (mesothermal) and above 22°C in summer (warm), infrequent frosts and rainfall concentration during summer, but without dry season in the year.

The soils of the experimental areas were classified as Ferralsol and Ferralic Nitisol (Embrapa, 2006b) for the 2007/2008 summer harvest and 2008 Interim-harvest, respectively. The chemical and physical characteristics of soil from the experimental sites, 0.00 - 0.20 m layer, are shown in Table 1.

The experiments consisted of two crops of popcorn conducted during the summer harvest of 17th October, 2007, and the interim-harvest of 19th March, 2008. The spacing used between rows was o0.90 m, and of 0.20 m between plants, establishing a population of 55,000 plants ha^{-1}. The liming of the area, according to the need demonstrated by the result of the analysis of soil to increase the base saturation to 60% (Embrapa, 2006a), was carried out prior to the planting of each experiment. The sowing fertilization in the summer crop cultivation was of 24, 80 and 60 kg ha^{-1} and in the interim-harvest it was of 24, 50 and 50 kg ha^{-1} of N, P_2O_5 e K_2O, respectively, using ammonium sulfate (AS), triple superphosphate (TSP), and potassium chloride (K_2O).

Experiment was conducted as a 5 x 2 x 2 factorial arrangement in randomized complete blocks design with four replications. The treatments were a combination of five N rates (0; 45; 90; 135; 180 kg ha^{-1}), two seasons of topdressing applications (development stages V_4 and V_8) and two varieties of popcorn (BRS-Angela and IAC-125) (Ritchie et al., 1993).

The plots consisted of five rows (6.0 m long) of plants. The evaluations were performed in 3 central rows of each plot, excluding the 2 border strips, and 0.5 m from each end of the plot, totaling 13.5 m^2 of useful area.

Initially, for the control of weeds, the vegetation of the experimental area was desiccated with application of the glyphosate herbicide, seven days before sowing, at a rate of 960 g of the active ingredient (a.i.) ha^{-1} (Andrei, 2005). Prior to sowing the seeds were treated with Imidacloprid (240 g a.i. per 100 kg) and Thiodicarbe (700 g a.i. per 100 kg) insecticides, according to Andrei (2005). This was done to control initial pests of crops.

Before sowing of the popcorn, the field was cultivated with black oat. Sowing was done manually using truncheons, and two seeds were placed in a hole. After seedling emergence, at V_2 stage (Ritchie et al., 1993), thinning was performed, in order to eliminate the less vigorous plant. The weed control was carried out with the application of the Atrazine herbicide at a rate of 3.25 kg i.a. ha^{-1} in post-emergence, while for pest control, Methamidophos and Lufenuron insecticides were used (Andrei, 2005).

The following traits were evaluated in the field: plant height (PH), distance (m) between the ground level and the apex of the tassel; and the leaf area index (LAI), according to Francis et al. (1969). These traits were measured on ten plants in each plot. The harvest, performed manually, was conducted on the 29th of February, 2008

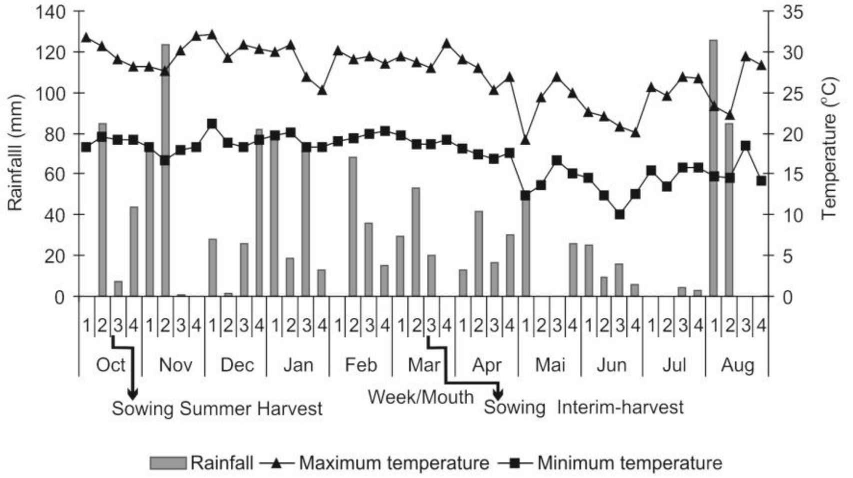

Figure 1. Rainfall and air temperatures for a week, from October, 2007 to August, 2008. Font: Laboratory of Seed Analysis from Iguatemi Experimental Farm – FEI/UEM.

for the summer crop and 30th August, 2008 for the interim-harvest. After harvesting, the samples were sent to the Laboratory of Crop Physiology of the Center for Research Applied to Agriculture (Nupagri). They were evaluated for ear length (EL) and number of grains per row (NGR), both evaluated using ten corn ears randomly chosen from the sample plot; thousand grains weight (TGW) according to Brasil (2009); grain yield (GY), and expansion capacity of the endosperm (ECE). The GY was determined by weighing the grain harvested from the useful area of the plot (13.5 m^2), correcting the moisture in the grain to 14% and subsequently transforming the data obtained for kg ha^{-1}.

The process of popping the kernels to obtain the ECE trait of the endosperm was initiated when the samples reached a grain moisture content of about 11.5%. Subsamples with a weight of 30 g of grains (bulk popcorn - BP) were subjected to a temperature of 280°C for two minutes and ten seconds under constant agitation (Roshdy et al*.,* 1984; Metzger et al., 1989; Song et al., 1991.) It was then determined the amount of popcorn expanded volume (PEV, mL) with a 2000 mL beaker and the expansion capacity of the endosperm was calculated (ECE, mL $g^{-1)}$ by the expression: ECE = (VPE / BP) (Scapim et al., 2010).

The data obtained in the two experimental periods were subjected to the Levene test (Box, 1953) for homogeneity of variances and to the Shapiro-Wilk test (Shapiro and Wilk, 1965) for normality of errors. Once the basic assumptions of the analysis of variance were met, the data were subjected to an individual analysis of variance (Steel and Torrie, 1960). Then, the data were subjected to a joint analysis of variance, and the means of the effect of topdressing of N rates on the variables response were subjected to regression analysis (Cruz and Regazzi, 2001).

RESULTS AND DISCUSSION

The rainfall recorded during the cultivation cycle of popcorn of the 2007/2008 Summer Crop was 767.9 mm (Figure 1), sufficient for development of cultivation (Aldrich et al*.,* 1982; Matzenauer and Sutili, 1983). However, the culture went through drought periods between stages V_8 and V_T. When considering the period between the days from 16th November, 2007 to 20th December, 2007, the rainfall observed did not reach the mark of 30 mm, and the maximum drought period was 20 days, which occurred between the days from 16th November to 05th December (Figure 1). This fact, coupled with the soil texture of the experimental area (Table 1), compromised the development of the popcorn plants.

During the 2008 interim-harvest, due to the use of irrigation during scarcity of water (Figure 1) and increased water demand by plants due to differentiation of reproductive organs, tasseling and silking (Ritchie et al*.,* 1993), the crop did not suffer stress from lack of water. In turn, the cultivation suffered due to the occurrence of low temperatures in the first week of May and mid-June (Figure 1), a time when the temperatures were lower than the base temperature (10 ºC) for the growth and development of the popcorn plant (Tollenaar et al*.,* 1979).

The results of the analysis of variance for the PH, LAI, EL and NGR traits were significant for the N rate and cultivar factors; the agricultural year factor was not significant only for the EL trait and the stage of N application factor was not significant for any of the traits in question (Table 2). All interactions between factors were significant for PH, except the interaction cultivar x stage of N application. In relation to LAI, only the interaction of N rate x agricultural year was significant, as well as the agricultural year x cultivar interaction for EL. In the NGR trait, a significant interaction was observed between N rates x cultivar, cultivar x agricultural year and N rate x cultivar x stage of N application.

The PH for both cultivars was influenced by the use of N in topdressing applications, either application in the V_4 or V_8 stages, with quadratic regression adjustments being obtained in both cases (Figure 2a and b). The increase in PH is due to the fact that adequate nutrition of plants with

Table 2. Summary of variance analysis of the characteristics plant height (PH), leaf area index (LAI), ear length (EL) and number of grains per row (NGR) of popcorn plants.

Source of variations	DF	Mean squares							
		PH		LAI		EL		NGR	
N rate (N)	4	0.05160	*	0.23759	*	7.17097	*	65.56625	*
Cultivar (C)	1	0.56525	*	6.50039	*	5.61376	*	46.11756	*
Stage of N application (S)	1	0.00008	ns	0.10353	ns	0.16706	ns	0.06006	ns
Agricultural year (A)	1	2.43296	*	4.30008	*	1.75771	ns	166.66806	*
N x C	4	0.00623	*	0.00846	ns	1.18916	ns	13.95819	*
N x E	4	0.00381	*	0.01718	ns	0.21784	ns	1.94881	ns
N x A	4	0.00976	*	0.15581	*	0.96968	ns	3.17338	ns
C x S	1	0.00023	ns	0.10973	ns	1.82116	ns	0.66306	ns
C x A	1	0.02139	*	0.08696	ns	3.02225	*	64.64306	*
S x A	1	0.01040	*	0.00176	ns	0.00053	ns	7.70006	ns
N x C x S	4	0.00549	*	0.02358	ns	0.61285	ns	9.69213	*
N x C x A	4	0.00284	*	0.03663	ns	1.00699	ns	6.59619	ns
C x S x A	1	0.02003	*	0.15438	ns	0.04796	ns	5.14806	ns
N x C x S x A	4	0.00121	*	0.03537	ns	0.40416	ns	3.40400	ns
Block(A)	6	0.00013	ns	0.66907	*	1.53981	*	7.77965	*
Error	118	0.00044		0.06277		0.50254		3.78665	
MSE1		0.00011		0.07043		0.57008		5.05313	
MSE2		0.00059		0.05888		0.44783		2.65757	
>MSE/<MSE		5.26786		1.19615		1.27297		1.90141	
CV (%)		1.18		10.62		5.05		6.07	
General mean		17.92		23.58		140.41		32.05	

*:significant and ^{ns}: non -significant ($P < 0.05$) by F test.

N enables a greater vegetative development, since the nutrient directly influences cell division and expansion and photosynthetic process (Taiz et al., 2006). However, higher doses of N possibly provide the plant with luxury product consumption but reduce the PH (Melo et al., 2011).

The highest PH was observed for the BRS-Angela cultivar (Figure 2a). Similar results were observed by Gökmen et al. (2001) for popcorn crops. Mar et al. (2003), Silva et al. (2005), Cruz et al. (2008), Lana et al. (2009), Soratto et al. (2010) and Okumura et al. (2011) also obtained response of PH for common corn with increased N rates.

On the other hand, Ferreira et al. (2001), Casagrande and Fornasieri (2002), Melo et al. (2011) and Biscaro et al. (2011) found no influence of N fertilization on PH of common corn. Magalhães and Jones (1990) claim that the stem serves as a reserve structure of photo-assimilated compounds that are translocated to the grains. This leads to larger plants, due to the larger size of the stem, which is usually associated with a higher filling of grains and productivity.

The LAI for the BRS-Angela cultivar was not influenced by N rates applied either at the V_4 or the V_8 growth stages, with mean values of 2.56. However, the LAI of the IAC-125 cultivar showed a growing linear response to the use of N in the V_4 stage (Figure 2c). This suggests a better utilization of N for the formation of leaves of this cultivar at this stage, given that a positive response was not obtained when the N was applied at the V_8 stage, with mean values of 2.11. Similarly, Tomazela et al. (2006) and França et al. (2011) found a positive response of N rates on LAI of common corn.

The means of EL for the BRS-Angela cultivar adjusted in linear and quadratic forms the V_4 and V_8 stages, respectively (Figure 2d). In turn, the IAC-125 cultivar showed EL with quadratic adjustment when the N was applied in the V_4 stage, but in the V_8 stage EL responded linearly to the use of N in topdressing applications (Figure 2e).Gökmen et al. (2001) observed that increasing rates

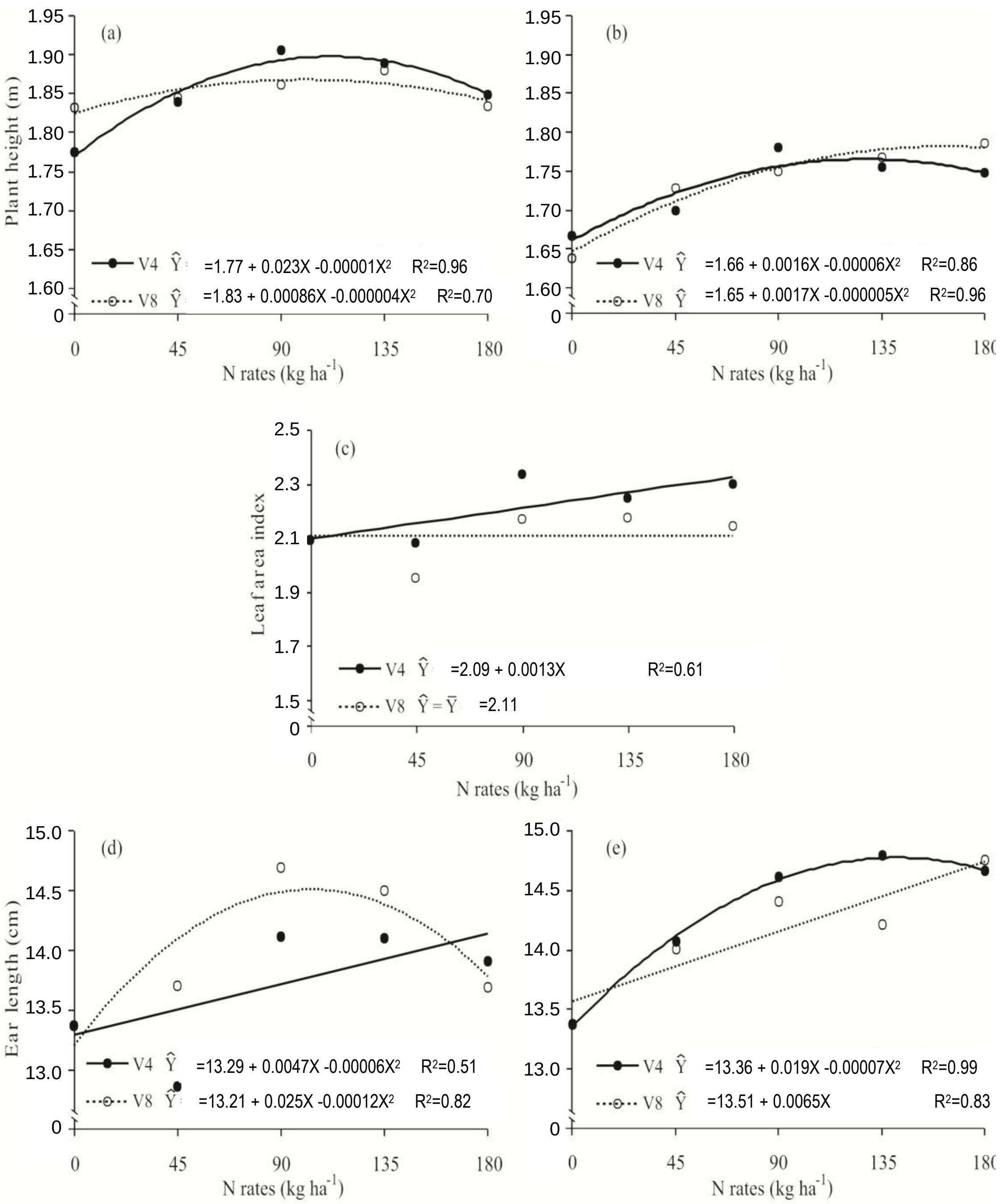

Figure 2a-e. Effect of N rates inside cultivars of popcorn and stage of N application for plant height of the cultivars (a) BRS-Angela and (b) IAC-125; (c) leaf area index of the cultivar IAC-125; ear length of the cultivars (d) BRS-Angela and (e) IAC-125.

of N used in popcorn crops provided the significant increase of the EL, and the highest values of EL were obtained with higher N rates used (250 kg ha^{-1}), while Lourente et al. (2007) observed a significant effect of N rates on the EL of common corn. However, Biscaro et al. (2011) pointed out that EL on common corn was not affected by increased levels of N. Nitrogen topdressing has also provided an increased NGR to the two cultivars of popcorn, and a quadratic regression adjustment has been observed, except for the IAC-125 cultivar when the N was applied at the V_8 stage (Figure 3a and b). At this time of applying N on the IAC-125 cultivar, it was noted an increasing linear regression adjustment in agreement with the results observed for the EL trait (Figure 2d and

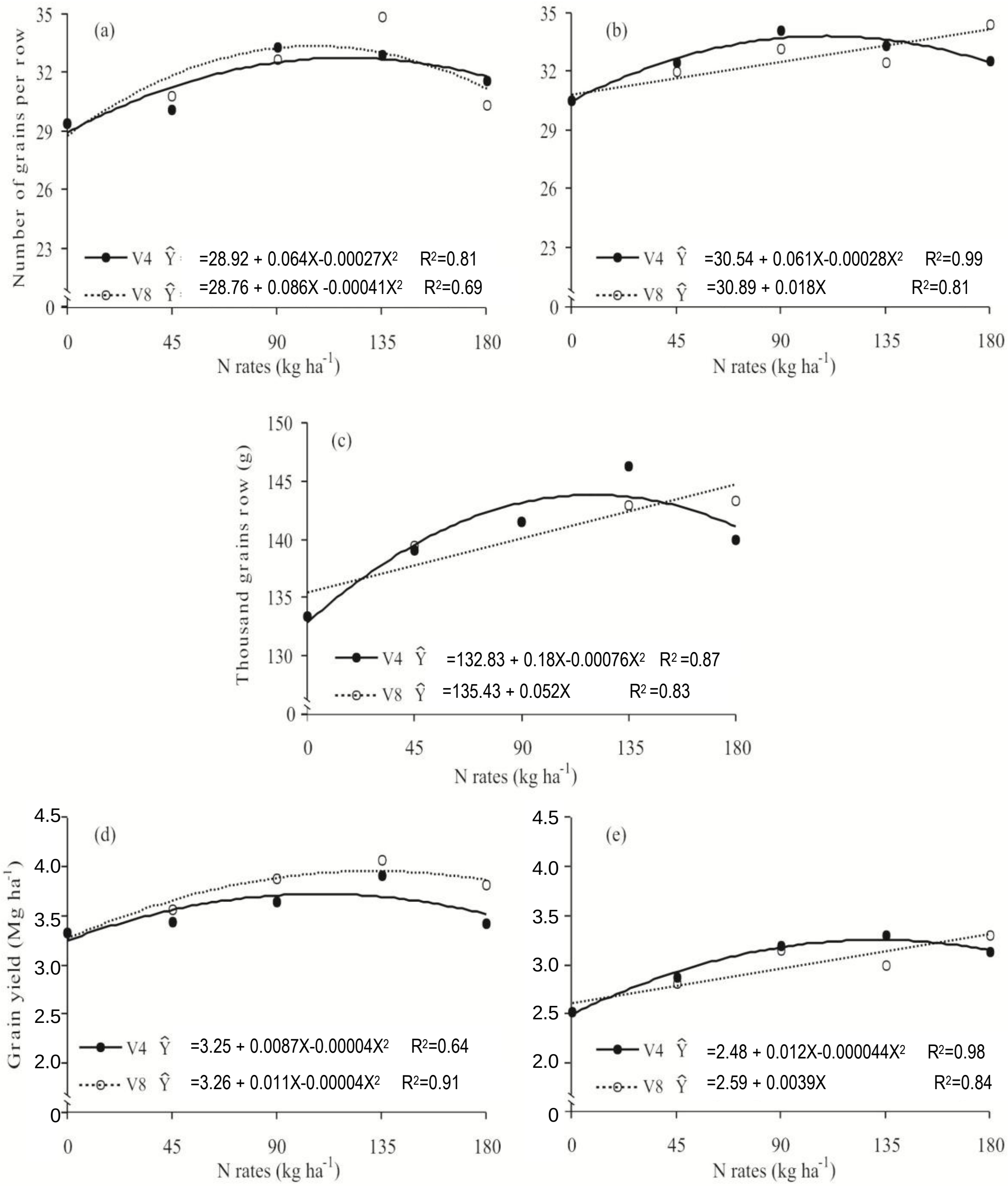

Figure 3a-e. Effect of N rates inside cultivars of popcorn and stage of N application for number of grains per row of the cultivars (a) BRS-Angela and (b) IAC-125; (c) thousand grain weight of the cultivar IAC-125; grain yield of the cultivars (d) BRS-Angela and (e) IAC-125.

2e). Similarly, Biscaro et al. (2011) observed a significant effect, with quadratic adjustment on the NGR common corn using N rates of 0, 90, 180, 270 and 320 kg ha^{-1}. On the other hand, Casagrande and Fornasieri (2002) found no effect of N rates in topdressing applications on NGR in field corn grown in the interim-harvest. The adequate supply of N in the initial stages of the corn plant development interferes with the process of floral differentiation and defines the yield potential of the crop; thus it can increase some production components, such as EL and NGR (Crawford et al., 1982; Bredemeier and Mundstock, 2000; Taiz et al., 2006).

The results of the analysis of variance for the TGW, GY and ECE traits were significant for the cultivar and crop

Table 3. Summary of analysis of variance of traits; thousand grain weight (TGW), grain yield (GY) and expansion capacity of the endosperm (ECE) of popcorn.

Source of variations	DF	Mean squares					
		TGW (g)		GY (Mg ha^{-1})		ECE (mL g^{-1})	
N rate (N)	4	106,40991	*	2,17689	*	0,54826	ns
Cultivar (C)	1	1.824,12036	*	17,86901	*	1.038,00438	*
Stage of N application (S)	1	1,91844	ns	0,17889	ns	1,85977	ns
Agricultural year (A)	1	2.900,20900	*	65,76147	*	963,48948	*
N x C	4	192,52197	*	0,24822	ns	2,81163	ns
N x E	4	70,83445	ns	0,14199	ns	14,47884	*
N x A	4	27,34857	ns	0,08819	ns	4,42002	ns
C x S	1	3,09136	ns	0,51438	ns	1,61002	ns
C x A	1	6.662,59344	*	31,67866	*	59,40188	*
S x A	1	12,45456	ns	0,22967	ns	12,42668	ns
N x C x S	4	2,96855	ns	0,05717	ns	4,44905	ns
N x C x A	4	84,95957	ns	0,27126	ns	4,62444	ns
C x S x A	1	40,88484	ns	0,01384	ns	15,09827	ns
N x C x S x A	4	4,87855	ns	0,03165	ns	3,51547	ns
Block(A)	6	84,58378	*	0,30672	ns	34,82106	*
Error	118	37,98142		0,16941		5,77634	
MSE1		37,61520		0,19789		4,52606	
MSE2		38,27805		0,13014		6,60397	
>MSE/<MSE		1,01762		1,52058		1,45910	
CV (%)		4,51		12,48		8,75	
General mean		136,70		3,30		27,47	

*: significant and ^{ns}: non significant ($P < 0.05$) by F test.

year factors, while the N rate factor was not significant only for the ECE trait, and the N application stage factor was not significant for all traits (Table 3). The interactions between cultivar and growing season were significant for all traits, and the N rate and cultivar interaction was also significant as well as the interaction for TGW trait and N rate x stage of N application for the ECE trait.

The regression analysis of the effects of N rates within combinations of cultivars and times of N application showed no significant adjustment regression of the TGW trait for the BRS-Angela cultivar; it has verified mean values of 133.57 and 133.07 g for applications in V_4 and V_8 stages, respectively. Regarding the IAC-125 cultivar, there was quadratic regression adjustment with a TGW maximum of 143.4 g obtained with the rate of 118.4 kg N ha^{-1}, when it was used in the V_4 stage (Figure 3c). In turn, when N was applied at the V_8 stage, the adjustment was a linear increase, indicating that the application of the highest rate of N (180 kg ha^{-1}) was not sufficient to reach the maximum response of the TGW trait to N application (Figure 3c). The TGW response to only N for the IAC-125 cultivar was mainly attributed to the fact that this is a hybrid, which has better production characteristics, due to its genetic potential (Cruz et al., 2008), and the corn hybrid is typically more responsive to N fertilization practices.

The results observed for the BRS-Angela cultivar are in agreement with those obtained by Gökmem et al. (2001) for the popcorn crop and by Casagrande and Fornasieri (2002) and Gomes et al. (2007), who also found no effect of N rates on the TGW of common corn. Other authors such as Ferreira et al. (2001), Soratto et al. (2010) and Biscaro et al., (2011) observed that the averages of TGW showed a quadratic adjustment to the applications of N rates, as well as the results obtained with the application in the V_4 stage of this work. In turn, the adjustment of a growing linear regression of the TGW to rates of N obtained by Lana et al. (2009) was of 0, 30, 60 and 90 kg ha^{-1}, possibly due to lower doses. Nitrogen plays a key role in the formation of amino acids, the main components of proteins (Taiz et al., 2006). Thus, just like the grain formation is dependent on plant proteins, the grain weight is directly related to the supply of N (Crawford Junior et al., 1982; Bredemeier and Mundstock, 2000).

The BRS-Angela cultivar presented GY higher than the IAC-125 cultivar (Figure 3d and e). These results disagree with the statement by Cruz et al. (2008) that higher yields of corn are obtained with hybrids, in view of the genetic potential associated with these plants.

The results of GY adjusted in a quadratic form to the BRS-Angela cultivar in both times of application of N, whose maximum yield (3.94 Mg ha^{-1}) was obtained with the N estimated maximum rate of 130, 1 kg ha^{-1}, applied at the V_8 stage (Figure 3d). The higher N rates possibly provide the plant with a luxury consumption leading to an increase in leaf N content, but reducing grain yield (Melo et al., 2011).

In turn, the IAC-125 cultivar showed a quadratic regression adjustment and linear increase in the application of N at the V_4 and V_8 stages, respectively (Figure 3e). This cultivar had the highest yield (3.24 Mg ha^{-1}) with the application of maximum N rate of 131.5 kg ha^{-1} and at the V_4 stage. While the application of N at the V_8 stage provided an increase of 3.9 kg ha^{-1} in GY for each kg of N increased per hectare. The linear adjustment observed for the application of N at the V_8 stage followed the results of yield components observed in this study.

Gökmen et al. (2001) observed that the lower N rates (0, 50 and 100 kg ha^{-1}) resulted in significant increases in the GY of popcorn, while the higher rates of N (150, 200 and 250 kg ha^{-1}) did not significantly increase. In works with common corn, Mar et al. (2003), Silva et al. (2005), Lana et al. (2009), Biscaro et al. (2011) and Melo et al. (2011) obtained the quadratic adjustments of GY to top dressed N rates. Other studies developed by Araújo et al. (2004), Duete et al. (2008) and Soratto et al. (2010) verified increases in the production of common corn with the use of N in topdressing, but the results adjusted in an increasing linear form, not getting the maximum technical performance.

The positive effect of N on yield components and grain yield is possibly associated with the effect of N in the definition of the reproductive capacity of the plant, which occurs in early stages in corn crops (Ritchie et al., 1993), when cell division is intense (Taiz et al., 2006). The N supply to the plants provides increased levels of cytokinin in the aerial part, increasing cell division (Samuelson et al., 1992), positively influencing the formation of the reproductive organs (Ritchie et al., 1993). Nitrogen plays a fundamental importance as a constituent of amino acids; main components of proteins, with the formation of grains being dependent on them; therefore, the grain weight and productivity are directly linked to the supply of N (Taiz et al., 2006).

The lower productivity of the BRS-Angela cultivar observed with the application at the V_4 stage (Figure 3d) in relation to application at the V_8 stage may be attributed to the greater immobilization of N, due to the greater amount of crop residues present on the soil surface when the topdressing was performed (Basso and Ceretta, 2000; Lara-Cabezas et al., 2000; Lara-Cabezas and Couto, 2007). It is worth mentioning that in the summer crop at the experimental area the sequence of crops was oats-cassava-corn, while in the period following the interim-harvest the sequence of crops was oats-corn. On the other hand, Silva et al. (2005) observed that the use of N in topdressing applications between the V_4 to V_6 stages provided a higher GY of common corn than when N was applied between the V_8 to V_{10} stages, since, when the late application of N was performed, the culture had already defined their productive potential (Ritchie et al., 1993). Similar results were obtained by Silva et al. (2006), in which the authors observed higher productivity of common corn crops, when N was applied at the V_4 stage, compared to V_8.

Economically analyzing the results and using the values of R $ 0.71 kg^{-1} grain, and U.S. $ 3.62 kg^{-1} N (Seab, 2011) for popcorn and N, the economic rate of N in topdressing applications obtained was of 73.76 and 78.42 kg ha^{-1} for the BRS-Angela (V_8) and IAC-125 (V_4) cultivars, respectively.

Therefore, despite that the observed maximum N rates were 130.1 and 131.5 kg ha^{-1} for the BRS-Angela and IAC-125 cultivars, respectively, the financially recommended rates of N are much smaller, as they may provide higher returns from the crops to the farmer. Biscaro et al. (2011) obtained the highest N rate for common corn of 300 kg ha^{-1}, but the economic rate of N was only 90 kg ha^{-1}. Pavinato et al. (2008) observed similar higher rate of N (283 kg ha^{-1}) with Biscaro et al. (2011), but with higher economic rate of N (156 kg ha^{-1}). In this sense, it is worth emphasizing the importance of this study, since there is no information about the economic rate of N recommended for topdressing applications in popcorn crops.

The ECE did not show a significant response in relation to the doses of N, as well as to the stages of N application. There was only a significant effect of cultivars on the ECE trait, and the means obtained by the IAC-125 cultivar (ECE = 30.01 and 30.02 ml g^{-1}, respectively) were superior to the BRS-Angela cultivar (ECE = 24.71 and 25.13 ml g^{-1}, respectively). The means results of the ECE of popcorn were classified as: regular (26.77 ml g^{-1}) and good (33.08 ml g^{-1}), according to Green and Harris (1960), for the BRS-Angela and the IAC-125 cultivars, respectively.

The ECE presented by popcorn cultivars in this study was higher than the highest value in the results of the national popcorn test (20.8 ml g^{-1}), held in the 1991/1992 harvest (Sawazaki et al., 2000). In addition, the ECE was influenced by genetic difference between cultivars and not by rate or time of application of N, so that such differences have possibly been conditioned by the traits of each grain cultivar such as size, thickness, pericarp and water content (Sawazaki et al., 1986; Ruffato et al., 2000).

Conclusion

Plant height and leaf area index were influenced by N topdressing, with exception of the latter for the BRS-Angela cultivar. Nitrogen application in both V_4 and V_8 stages had significant effects on yield components: ear length, number of grains per row, thousand grains weight and grain yield of popcorn. The highest grain yields were obtained with estimated rates of 130.1 and 131.5 kg ha^{-1} of N for BRS-Angela and IAC-125 cultivars, respectively. On the other hand, the economic analysis indicated rates of 73.76 and 78.42 kg ha^{-1} of topdressing N, as that which will provide the greatest financial return for the cultivation of BRS-Angela and IAC-125, respectively. Despite the good expansion capacity index achieved by the cultivars, there was no significant effect of the application stages and rates of N, and only significant differences in the genetic order of cultivars used regarding the traits of popcorn were observed.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

This study was made possible with financial support from CNPq and Capes-Brazil. We also appreciate them for their scholarship and support for this research work.

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