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Full Length Research Paper

Growth regulators in the development of potted *Epidendrum radicans* orchid

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Epidendrum is a terrestrial orchid with great potential for commercialization. However, its considerable height makes it difficult for transport and commercialization. Many species have been controled with growth regulators, including orchids and other ornamental plants. The aim of this study was to evaluate the efficiency of two plant growth regulators, paclobutrazol and chlormequat chloride (CCC), on the vegetative growth of potted *Epidendrum radicans* orchid aiming height control. Paclobutrazol (Cultar) was applied at doses of 0, 5, 10 and 20 mg L^{-1}, and the CCC (Cycocel) at doses of 0, 2000, 4000 and 6000 mg L^{-1}. The regulators were applied once or twice a month, via substrate irrigation. Plants were assessed every two months for plant height, number of shoots per pot and number of inflorescences per pot. CCC had no effect on the final height of *Epidendrum radicans* at the doses applied. Paclobutrazol was effective in controlling plant height at doses of 10 and 20 mg L^{-1}. None of the products influenced the number of inflorescences produced. Chlormequat chloride at a dose of 6000 mg L^{-1} stimulated the production of shoots.

Key words: Paclobutrazol, chlormequat chloride, reduction in height.

INTRODUCTION

Epidendrum radicans or *Epidendrum ibaguensis*, is a terrestrial plant that grows in large tangled, prostrate clumps. The stems are leafy and can be up to one meter long. It puts out many aerial roots. The flowers can be red, yellowish-orange or pink and are grouped in compact inflorescences. The plant can flower many times in a year (Suttleworth, 1994).

The literature documents some studies that have been carried out using growth regulators on *Epidendrum radicans* orchids (Pateli, 2004) to reduce final plant height; on Phalaenopsis hybrids (Wang and Hsu, 1994) to control the length of inflorescences and on *Cattleya mossiae* (Torres and Mogollon, 2002) to achieve a reduction in the number of shoots. Various growth regulators are commercially available, including chlormequat chloride (CCC) and paclobutrazol (Grossi et al., 2009).

According to Barret (2001), chlormequat chloride (known commercially as Cycocel) is recommended for poinsettias, azaleas, geraniums and hibiscus. It can be sprayed onto the plant or applied directly to the substrate (1000 to 4000 mg L^{-1}), but it is not as effective at

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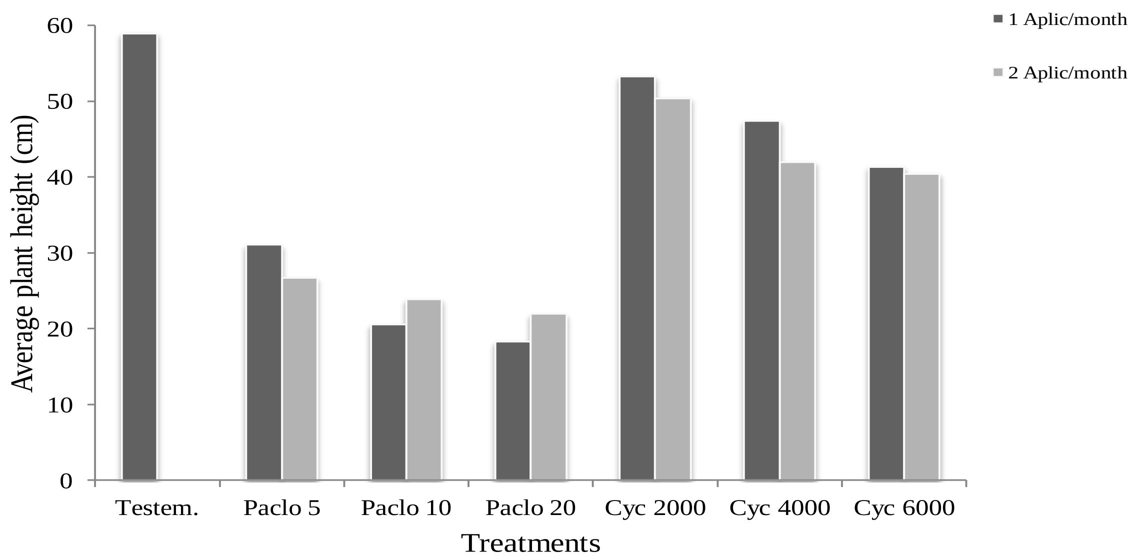

Figure 1. Plant height of *Epidendrum radicans* one year after commencing applications of paclobutrazol and chlormequat chloride (CCC) growth regulators once or twice a month.

controlling growth as other products. It is considered of low efficacy in controlling plant growth, merely preventing excessive plant size. A number of applications are necessary to obtain any results. When sprayed onto the plant, chlorotic spots are produced on expanding leaves and high doses can cause necrotic spots on the plant (Barret, 2001).

The aim of this study was to assess the efficiency of two growth retardants, paclobutrazol and chlormequat chloride, on the growth and development of potted *Epidendrum radicans* orchids.

MATERIALS AND METHODS

The experiment was conducted in a greenhouse with 50% shading, between June 2008 and January 2010, at the Agronomy Department of the State University of Londrina, Paraná State, Brazil. The coordinates are: 23°23'S latitude, 51°11'W longitude and 566 m elevation. Seedlings (approximately 24 months old) of the red variety of *Epidendrum radicans* Lindt., (Figure 1), were originally obtained by *in vitro* micropropagation. Two seedlings with an initial height of 35 cm were planted in each 2-liter black plastic pot (12 cm high and 13 cm diameter), filled with a mixture of sand + Plantmax commercial substrate (1:1 v:v). Fertilizer was applied every three months by fertigation: NPK (10-30-20) at 1 g L^{-1}. Watering was carried out manually twice a week (200 ml per watering).

The growth regulators used were paclobutrazol (Cultar 250 g L^{-1}) and chlormequat chloride (Cycocel 11.8 %). Treatments with paclobutrazol were dosed at 0, 5, 10 and 20 mg L^{-1}, and with chlormequat chloride at 0, 2000, 4000 and 6000 mg L^{-1}. These solutions were applied directly to the plant substrate (100 ml per pot) and the application frequency was once and twice a month (every fortnight), for 5 months.

The plants were assessed every 2 months for the following characteristics: plant height, number of shoots per pot and number of inflorescences per pot. The experiment was set up using a 6 x 2 + 1 (control) factorial arrangement. A random block design was used with 10 repetitions. The data were subjected to analysis of variance and means compared using the Tukey's test at 5%.

RESULTS AND DISCUSSION

On analyzing the results obtained, it can be seen from Table 1 and Figure 1 that there was a significant difference in average plant heights of 10 replicates. It should be observed that the initial height of the seedlings was 35 cm and the height of the shoots after the start of treatment was less in many cases. This is due to the fact that these growth regulator products has an effect only on new shoots and not in already emerged buds.

Five assessments were performed after the completion of regulatory applications. Height was measured with a tape, the neck of the plant to the base of the inflorescence (cm) on all shoots born. It can be seen from the results in Table 1, that there was no significant interaction between growth regulator application and frequency of application. The shortest plants were those treated with 20 mg L^{-1} paclobutrazol, and the average height of plants treated with 10 mg L^{-1} did not produce any statistical difference from the average height of plants treated with 5 and 20 mg L^{-1}. The highest plant height figures were obtained for treatments with CCC at all three doses, and plants treated with 2000 mg L^{-1} were the tallest, differing from those treated at other doses.

The control (no growth regulator applied) was the tallest (58,93 cm), but did not differ from treatments with the CCC growth regulator at doses of 2000 mg L^{-1} (applied once or twice a month) and 4000 mg L^{-1} (applied

Table 1. Average plant height of *Epidendrum radicans* one year after commencing applications of paclobutrazol and chlormequat chloride (CCC) growth regulators once or twice a month.

Regulator	Application frequency			
	Dose (mg L^{-1})	Once a month	Twice a month	Mean
Paclobutrazol	5	31.04	26.71	28.87 B *
Paclobutrazol	10	20.55	23.87	22.11 BA
Paclobutrazol	20	18.30	21.92	19.88 A
CCC	2000	53.22**	50.38**	51.80 D
CCC	4000	47.36 **	41.97	44.49 C
CCC	6000	41.34	40.42	40.85 C
Mean		34.86 a	35.09 a	
CV (%)		18.9		
Control		58.93 cm		

* Means followed by the same uppercase letter in the column and lowercase letter in the row did not differ statistically in the Tukey test at 5%. Plant height (cm), **Means followed by ** did not differ statistically from the Control in the Tukey test at 5%.

once a month). This result is in line with Stefanini et al. (2002), who observed that bushy mat grass continued to grow after application of CCC at doses of 1000 and 2000 mg L^{-1}. Holcomb and Gohn (1995) also failed to observe any reduction in the height of poinsettias treated with CCC at 3000 mg L^{-1}.

These results differed from those obtained by Ghora (1998) working with red raspberry, who verified the dose of CCC that reduced plant height without affecting the number of fruits and nodes was 500 mg L^{-1}, and that doses of 1000, 2000 and 4000 mg L^{-1} were toxic. Paclobutrazol at 500 and 1000 mg L^{-1} reduced plant height, but higher doses produced many dwarf plants.

Similar results were obtained by Pateli et al. (2004) working on the *Epidendrum radicans* orchid and using doses of paclobutrazol (5, 10 and 20 mg L^{-1}) and CCC (2000, 4000 and 6000 mg L^{-1}). The authors verified a reduction in main stem length as the regulator dose was increased, but plant height differences were not significant, and found that plant height figures dropped as the growth regulator dose increased and the shortest plants were obtained by treating with paclobutrazol.
Treatments with paclobutrazol at 5 mg L^{-1} (once a month), CCC at 6000 mg L^{-1} (once or twice a month) and CCC at 4000 mg L^{-1} (twice a month) resulted in intermediate plant height, and there was no statistical difference between these treatments.

Analyzing the application frequencies of the growth regulators (once or twice a month), we found that at a frequency of once a month paclobutrazol produces the shortest plants. Treatment applied twice a month with CCC produced the shortest plants. In terms of growth regulator doses, the shortest plants were produced by dosing paclobutrazol at 20 mg L^{-1}, followed by 10 and 5 mg L^{-1}. The similar concentration dependent manner was found for CCC, plants were shortest at 6000 mg L^{-1}, followed by doses of 4000 mg L^{-1} and 2000 mg L^{-1}. Comparing the two regulators, paclobutrazol produced the shortest plants.

When the results for each dose of paclobutrazol at each application frequency (once or twice a month) are compared, there is little difference between them: paclobutrazol at 5 mg L^{-1} produced plant heights of 31,04 to 26.71 cm; 10 mg L^{-1} produced plant heights of 20.55 to 23.87 cm; and 20 mg L^{-1} produced plant heights of 18.30 to 21.92 cm. Comparing CCC for each dose applied and at each application frequency (once or twice a month), it can be seen that 2000 mg L^{-1} for both application frequencies produced plant heights of 53.22 to 50.38 cm; 4000 mg L^{-1} applied once a month CCC produced plant heights of 47.36 cm, which did not differ from the control (58.93 cm).

In terms of number of shoots on the *Epidendrum* plants, there were statistical differences between the treatments, with the highest number of shoots found on plants treated with 6000 mg L^{-1} CCC at both application frequencies (once and twice a month). The lowest number of shoots was obtained for treatments once a month with 20 mg L^{-1} and 5 mg L^{-1} paclobutrazol, as shown in Table 2 and Figure 2. At an application frequency of once a month, the highest numbers of shoots produced, in decreasing order, were for treatments at 6000 mg L^{-1}, 2000 mg L^{-1} and 4000 mg L^{-1} CCC, and 10, 5 and 20 mg L^{-1} paclobutrazol. There was no statistical difference between treatments at doses of 5 and 20 mg L^{-1} paclobutrazol.

At an application frequency of twice a month, the highest numbers of shoots produced, in decreasing order, were for treatments at 6000 mg L^{-1} and 4000 mg L^{-1} CCC; 10 and 20 mg L^{-1} paclobutrazol; 2000 mg L^{-1} CCC and 5 mg L^{-1} paclobutrazol. There were no statistical differences between treatments at doses of 5, 10 and 20 mg L^{-1} paclobutrazol and 2000 mg L^{-1} CCC.

On analyzing the two application frequencies for

Table 2. Average number of shoots on *Epidendrum radicans* one year after commencing applications of paclobutrazol and chlormequat chloride (CCC) growth regulators with an application frequency of once or twice a month.

Regulator	Number of new shoots per pot		
	Application frequency		
	Dose mg L^{-1}	Once a month	Twice a month
Paclobutrazol	5	12.44 ^{Da} *	15.11 ^{Db}
Paclobutrazol	10	15.78 ^{Ba}	16.78 ^{Da}
Paclobutrazol	20	12.33 ^{Da}	16.00 ^{Db}
CCC	2000	20.00 ^{Bb}	15.44 ^{Da}
CCC	4000	17.22 C^{a} **	19.55 C^{b} **
CCC	6000	27.00 ^{Ab}	25.11 ^{Ba}
Mean		17.46 ^{a}	18.00 ^{a}
CV(%)		8.93	
Control		18.00	

* Means followed by the same uppercase letter in the column and lowercase letter in the row did not differ statistically in the Tukey test at 5%. **Means followed by ** did not differ statistically from the Control in the Tukey test at 5%.

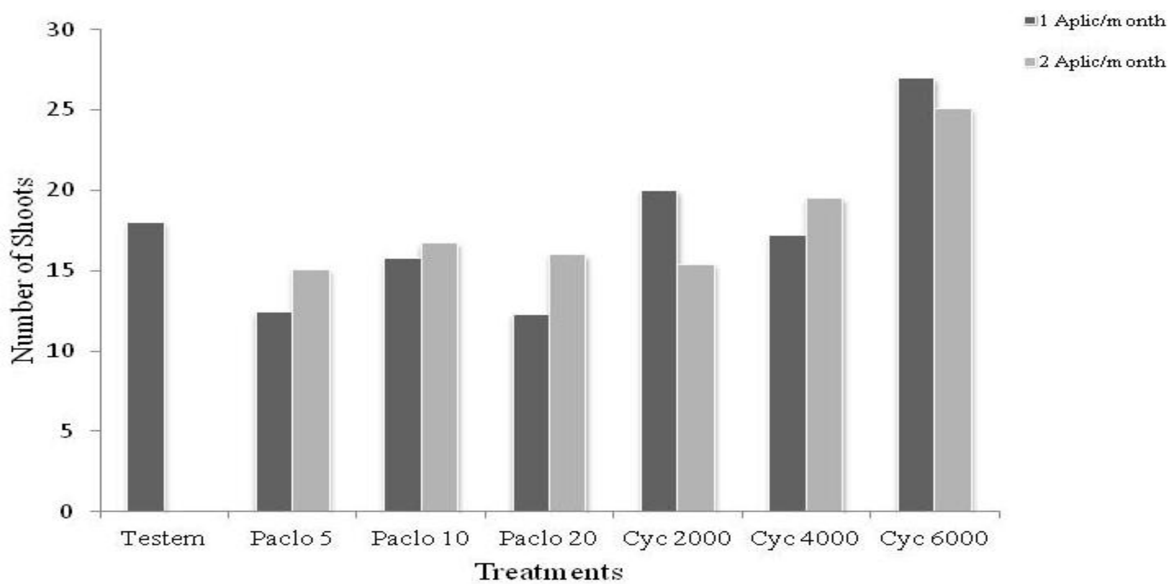

Figure 2. Number of shoots on *Epidendrum radicans* one year after commencing applications of paclobutrazol and chlormequat chloride (CCC) growth regulators with an application frequency of once or twice a month.

Each dose and both regulators, it can be seen that the only instance in which there was no difference between the results for the two application frequencies (once and twice a month) was the treatment with paclobutrazol at 10 mg L^{-1}.

Twice monthly treatments with 5 and 20 mg L^{-1} paclobutrazol and 4000 mg L^{-1} CCC produced a greater number of shoots, and this result differed statistically from the number of shoots produced when the regulators were applied once a month.

Treatment once a month with 2000 mg L^{-1} and 6000 mg L^{-1} CCC produced a greater number of shoots, and this result was statistically higher than the number produced when the regulator was applied twice a month.

Similarly, working with *Epidendrum*, Pateli et al. (2004) treated the plants with two applications per month of paclobutrazol (5, 10 and 20 mg L^{-1}) and CCC (2000, 4000 and 6000 mg L^{-1}) and observed that the number of shoots was not affected by the treatments. These results conflicts with those obtained by Hojjati et al. (2009), who

Table 3. Average number of inflorescences of *Epidendrum radicans* one year after beginning applications of paclobutrazol and chlormequat chloride (CCC) growth regulators once or twice a month.

Regulator	Number of inflorescences per pot			
	Application frequency			
	Dose (mg L^{-1})	Once a month	Twice a month	Mean
Paclobutrazol	5	2.33	3.00	2.67^{A}*
Paclobutrazol	10	2.00	3.33	2.67^{A}
Paclobutrazol	20	2.44	2.67	2.55^{A}
CCC	2000	2.44	3.44	2.94^{A}
CCC	4000	2.11	3.11	2.61^{A}
CCC	6000	2.89	5.00	3.94^{A}
Mean		2.37^{a}	3.42^{b}	
CV (%)		35.05		
Control		2.22	-none differs	

* Means followed by the same uppercase letter in the column and lowercase letter in the row did not differ statistically in the Tukey test at 5%.

observed an increase in the number of side shoots on Zinnia only at a dose of 2000 mg L^{-1} CCC. Bettoni et al. (2009), working with kalanchoe and using doses of 1000 and 2000 mg L^{-1} CCC, found that the number of shoots remained unchanged with two applications of the regulator.

Delaune (2005) obtained different results, working with Clerodendrum. Applications of paclobutrazol at doses of 15, 20 and 35 mg per pot caused a reduction in the number of side shoots on *Clerodendrum ugandense* when applied once a week for three weeks. The residual effect of paclobutrazol was verified by Pateli et al. (2004) in an experiment with *Epidendrum radicans* to be 7.5 months after the last application, but Lever (1986) estimated this effect could vary between 3 and 12 months.

In this study, for plants treated with a dose of 20 mg L^{-1} this effect lasted 19 months, since compact shoots continued to be produced. The leaves on all plants treated with paclobutrazol were a darker green than those of plants treated with CCC. In terms of the number of inflorescences produced during the experiment, there were no statistical differences between the growth regulators, doses and application frequencies by comparison with the control, as can be seen in Table 3 and Figure 3.

When each dosage of paclobutrazol and CCC, and each application frequency (once or twice a month) were compared, there were no statistically significant differences. The results for the increase in the number of inflorescences for all doses of both products at both application frequencies show no statistical differences. This is in line with the findings of Delaune (2005), working with species of *Clerodendrum* treated with applications of paclobutrazol. There was no difference in the number of inflorescences produced by *Clerodendrum ugandense* and *Clerodendrum bungei*. However, it conflicts with the results obtained by Hojjati et al. (2009), who found that applying 2000 mg L^{-1} CCC to *Zinnia* increased the number of flowers.

Wang and Hsu (1994) observed that applications of paclobutrazol at doses of 50, 100, 200 and 400 mg L^{-1} to *Phalaenopsis* orchids did not produce any statistical differences in the number of lateral inflorescences when treated plants were compared with controls. The results differ from those obtained by Wilkinson and Richards (1991) working with azaleas. They applied paclobutrazol at doses of 0.1, 0.2, 0.3 and 0.4 g per pot and found that the number of buds increased as the doses increased, reaching a total of 80 buds at the highest dose, compared with 4 buds on the control plants.

Working with CCC applied to *Kalanchoe*, Bettoni et al. (2009) observed no differences in the number of flowers at either of the doses used (1000 and 2000 mg L^{-1}), in line with the results obtained in this study. At the end of the experiment, the control plants and those treated with CCC reached heights of around 58 cm, whereas plants treated with paclobutrazol were no taller than 30 cm (Figure 4).

Conclusion

Paclobutrazol was more effective in controlling the plant height of the *Epidendrum radicans* orchid at doses of 10 and 20 mg L^{-1}. Chlormequat chloride (CCC) growth regulator at doses of 4000 mg L^{-1} (twice a month) and 6000 mg L^{-1} (twice a month) had an effect in reducing the height of the *Epidendrum radicans* orchid.

The growth regulators did not influence the number of inflorescences produced. The number of shoots produced was higher for plants treated with chlormequat

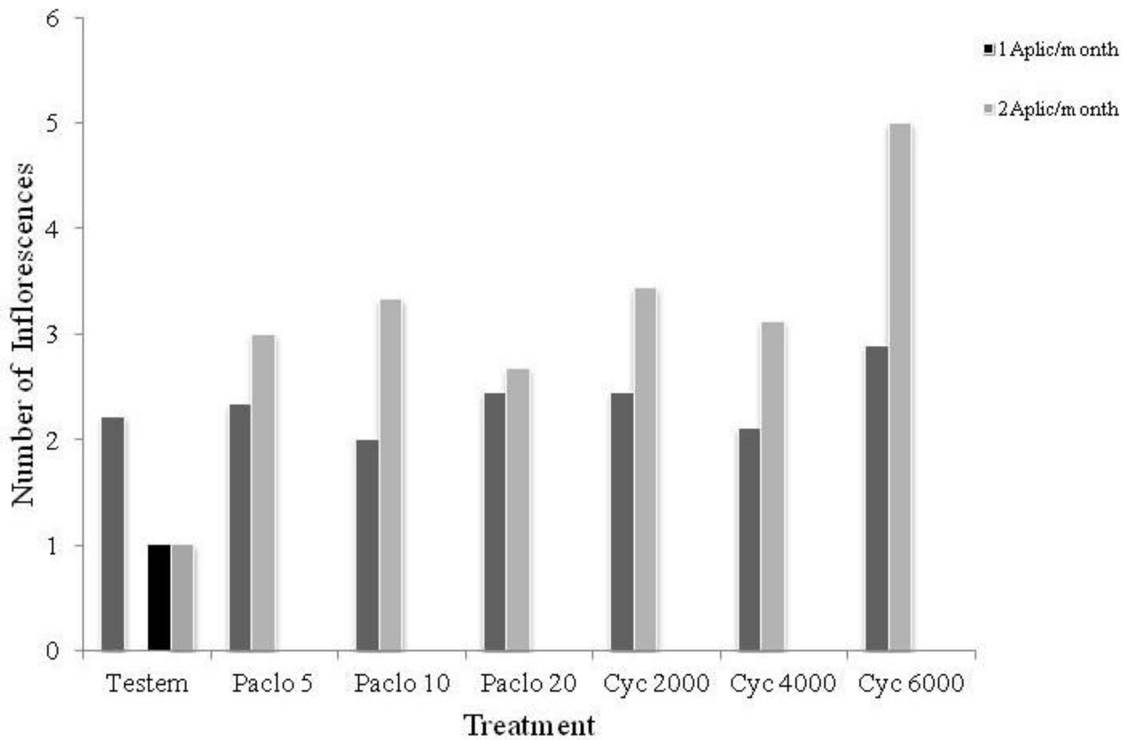

Figure 3. Number of inflorescences of *Epidendrum radicans* one year after beginning applications of paclobutrazol and chlormequat chloride (CCC) growth regulators once or twice a month.

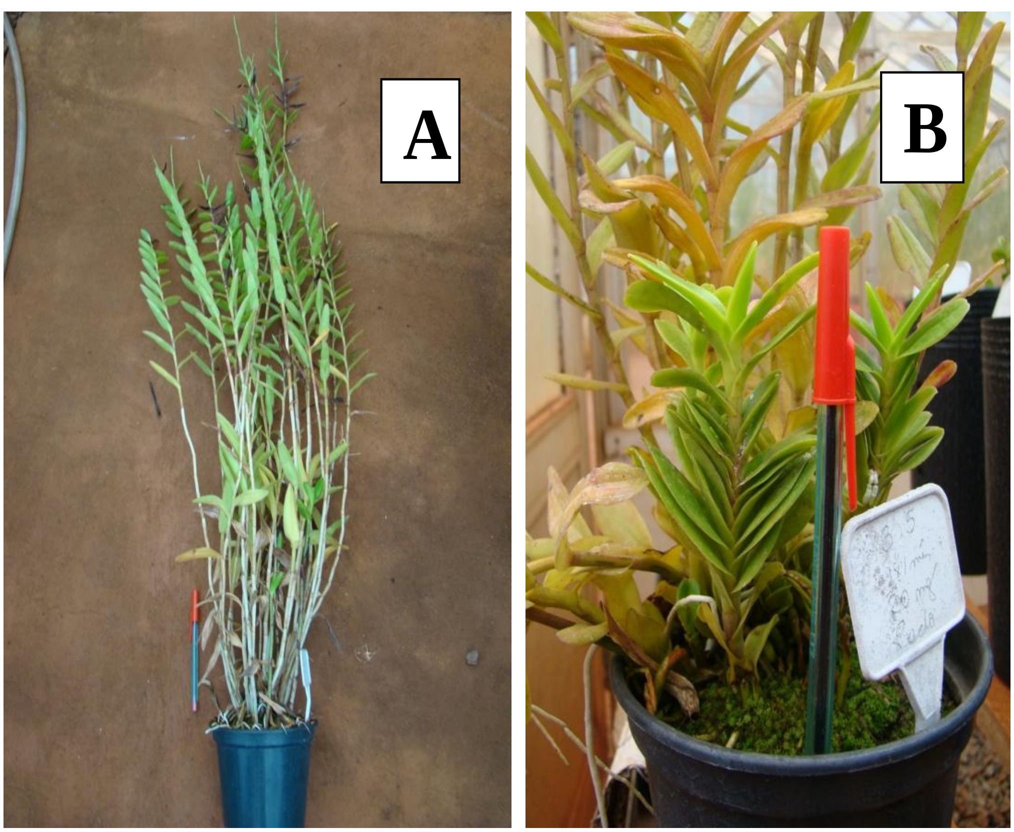

Figure 4. Epidendrum plants with treatments: (A) Control plant and (B) Paclobutrazol (20 mg L^{-1}).

chloride at a dose of 6000 mg L^{-1}, whereas the number of new shoots dropped when paclobutrazol was used, whatever the dose.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

To study the nutrient status in soil and plant after the harvesting of the herbal crops under three-tier agroforestry system

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The present study was conducted to find out the nutritional status in soil and plants of herbal crops under Sapota-Jatropha based three-tier agroforestry system at the Agronomy Farm (Block-E), ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari (Gujarat) during rainy season 2011 and 2012. Three medicinal plants *viz*., Basil (*Ocimum sanctum* L.), Kalmegh (*Andrographis paniculata* Well.) and Mint (*Mentha arvensis* L) were selected for the present study. The observations *viz*. organic carbon, N, P, K, Ca, Mg, Fe, Mn, Zn and Cu in soil were analyzed after harvesting. Intercropping of Basil, Kalmegh and Mint recorded higher nutrients namely, organic carbon, N, P, K, Ca, Mg, Fe, Mn, Zn and Cu in soil as well as in plant under Sapota – Jatropha cropping system as compared to sole crop. The trend was same in both the years as well as in pooled.

Key words: Agroforestry, basil, herbal, intercropping, kalmegh, mint, nutrient.

INTRODUCTION

Medicinal plants growing in forests require partial shade, moist soils rich in organic matter, high relative humidity and mild temperatures. Cultivation of such medicinal plants can be taken up in thinned forests, cleared forest patches, and as intercrops in orchards and new forest plantations (Venugopal et al., 2008).There are number of indigenous under storey herbs and shrubs that can be produced as a part of forest farming or in new forest plantation to improve economic return as well as soil health from the forests in India. Newly established forest plantations can be intercropped with medicinal plants similar to food crops until the trees cover the ground.

The participation of the local people with the right to share benefits of the plantations, especially ownership to crops, has helped government to establish plantations without conflict with the local people in many Asian countries. The same approach can be employed for the cultivation of medicinal plants in the new plantations. In the rehabilitation of degraded forest lands, participating, planning and implementation with local communities and economic benefits from an early stage onwards will ensure commitment of the people. The intensity of shade experienced by the under storey medicinal plants growing in forests and tree plantation affects their growth and chemical composition.

In recent year's attention has focused on the diversified

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medicinal plant production system for maximizing utilization of resources as compared to the monoculture cropping systems. This allows judicious use of the internal spaces of the trees and crops promoting diversification, enhancing per capita land productivity and cultivation of the crops in demand (Willey, 1979). Medicinal plants in the nature are now under great pressure due to their excessive collection and exploitation (Laloo et al., 2000). Continuous exploitation of several medicinal plant species and substantial loss of their habitats have resulted in the population decline of many high value medicinal plant species over the years (Kala and Sajwan, 2003). As such there is no sufficient work on agroforestry system of horticultural, silvicultural and medicinal crops in India with regards to soil health and leaf nutrition.

MATERIALS AND METHODS

The experiment was conducted under rainfed conditions during *kharif* season (June to July) 2011and 2012 at Navsari Agricultural University, Navsari, Gujarat. The climate of the area is characterized by three well defined seasons namely monsoon, winter and summer. The seven year old plantation of Sapota (*Manilkara acharas* (Mill) Fosberg.) at 10.0 x 10.0 m spacing, inter cropped with five year old plantation of Jatropha (*Jatropha curcus* L.) at 2.5 x 2.5 m spacing were used for intercropping study. Three herbal medicinal plants *viz*. Basil (*Ocimum sanctum* L.) at 50 x 40 cm, Kalmegh (*Andrographis paniculata* Well.) at 50 x 40 cm and Mint (*Mentha arvensis* L) at 30 x 45 cm were selected for the present study.

The statistically, experiment was laid out in randomized block design with replicated four times with following treatments that is T_1 – *Manilkara achras* + *Jatropha curcas* + *Ocimum sanctum*, T_2 – *Manilkara achras* + *Jatropha curcas* + *Andrographis paniculata*, T_3 – *Manilkara achras* + *Jatropha curcas* + *Mentha arvensis*, T_4 – *Ocimum sanctum* sole, T_5 – *Andrographis paniculata* sole, T_6 – *Mentha arvensis* sole. Farm Yard manure was applied at 20t/ha to all the plots uniformly and was incorporated into the soil at the time of land preparation. Nitrogen, phosphorus and potash were applied at the rate of 40:15:15 Kg per hectare (for Basil), 40:20:40 kg per hectare (for Kalmegh), 120:50:60 kg per hectare (for Mint) respectively. All intercultural operations were done when it was necessary. Soil analysis techniques are:

Nutrient analysis of soils

Experimental block's soil sample (0 to 30 cm) were collected before and after the experiment and used for determining the basic physico-chemical properties. The soil samples were dried in shade, processed and used for further analysis.

Nutrient analysis of plants

Plant samples used for studying dry matter production were used for estimating nutrient content in whole plant. The samples were powdered and stored in plastic container and were used for further analysis.

Statistical analysis

The collected data were analyzed statistically as per the appropriate procedure by using randomized block design in four replicates for each treatment as described by Panse and Sukhatme (1978) and the treatment means were compared by means of critical differences at 5% level of probability.

RESULTS AND DISCUSSION

Nutrient status in soil after the harvesting of the herbal crops

Organic carbon status (g kg^{-1}) in soil

The data regarding organic carbon status of the soil after the harvest of herbal crops during June to July, 2011, 2012 and in their pooled analysis are presented in Table 1. The result revealed that the status of organic carbon in soil at harvest was significant during both the years of experimentation and in their pooled data.

The data indicates that intercrop of basil (T_1, 7.10 g kg^{-1}) recorded significantly higher organic carbon status in. While in plots with kalmegh and mint recorded maximum organic carbon status in soil when grown under Sapota-Jatropha (T_2, 6.78 g kg^{-1} and T_3, 6.94 g kg^{-1}, respectively) during 2011. During the year 2012, significantly higher organic carbon status in soil was observed in basil, kalmegh and mint when these were grown under Sapota-Jatropha (T_1, 7.25 g kg^{-1}, T_2, 6.91 g kg^{-1} and T_3, 7.07 g kg^{-1}, respectively) compared to sole basil, kalmegh and mint (T_4, 6.37 g kg^{-1}, T_5 6.15 g kg^{-1} and T_6, 6.30 g kg^{-1}) respectively.

In pooled analysis the same trend of organic carbon in soil was observed as per the trend of second year results. The per cent increase in organic carbon in soil in the first year was recorded maximum in basil (11.99 %) followed by kalmegh (10.78 %) and mint (10.69 %). With regards to the second year and pooled data, it showed the similar trend to those of the results of first year. Content of organic carbon in soil was higher under intercrop of basil, kalmegh and mint under Sapota-Jatropha as compared to sole cropping of basil, kalmegh and mint. This may be due to more litterfall from trees and it may also be due to decomposition of litter. This is supported by Jaimini et al. (2006).

Available nitrogen status (kg ha^{-1}) in soil

The mean data pertaining to variation in the available nitrogen status in the soil after the harvest of herbal crops are presented in Table 2. The results were found significant during both the years (2011 and 2012) and in pooled analysis. The available nitrogen status in the soil was recorded higher when herbal crops are grown under Sapota-Jatropha as compared to sole cropping. It is evident from data that significant difference in the nitrogen status in soil was observed in all the herbal medicinal plants grown under Sapota-Jatropha and in sole crops. Significantly higher nitrogen in soil was

Table 1. Organic carbon and major nutrients available in soil at harvest of herbal crops as influenced by Sapota-Jatropha three-tier agroforestry system.

Treatment	Organic Carbon (g kg^{-1})			Nitrogen (kg ha^{-1})			Phosphorus (kg ha^{-1})			Potassium (kg ha^{-1})		
	2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled
T_1 - Basil Intercrop	7.10 (11.99)*	7.25 (13.81)*	7.18 (13.07)*	271.22 (22.91)*	274.73 (22.41)*	272.97 (22.66)*	437.78 (16.08)*	448.35 (15.58)*	443.06 (15.83)*	38.84 (23.30)*	40.09 (26.27)*	39.47 (24.79)*
T_2 - Kalmegh Intercrop	6.78 (10.78)*	6.91 (12.36)*	6.85 (11.56)*	249.73 (13.79)*	252.49 (13.62)*	251.11 (13.71)*	419.64 (17.65)*	431.77 (17.48)*	425.71 (17.57)*	35.56 (13.90)*	36.81 (16.97)*	36.19 (15.44)*
T_3 - Mint Intercrop	6.94 (10.69)*	7.07 (12.22)*	7.00 (11.29)*	261.08 (18.35)*	264.59 (17.93)*	262.83 (18.14)*	425.00 (15.79)*	439.50 (16.28)*	432.25 (16.03)*	36.70 (16.69)*	37.95 (19.72)*	37.33 (18.21)*
T_4 - Basil Sole	6.34	6.37	6.35	220.67	224.43	222.55	377.13	387.90	382.51	31.50	31.75	31.63
T_5 - Kalmegh Sole	6.12	6.15	6.14	219.46	222.22	220.84	356.67	367.54	362.10	31.22	31.47	31.35
T_6 - Mint Sole	6.27	6.30	6.29	220.60	224.36	222.48	367.05	377.98	372.52	31.45	31.70	31.58
S. Em ±	0.224	0.246	0.166	8.765	12.710	7.720	20.132	20.247	14.276	1.893	1.604	1.240
CD at 5 %	0.67	0.74	0.48	26.41	38.30	22.29	60.67	61.02	41.23	5.70	4.83	3.58

*Figure in parenthesis indicates percentage increases over respective sole cropping.

Table 2. Secondary nutrients available in soil at harvest of herbal crops as influenced by Sapota-Jatropha three-tier agroforestry system

Treatment	Calcium (mg kg^{-1})			Magnesium (mg kg^{-1})		
	2011	2012	Pooled	2011	2012	Pooled
T_1 - Basil Intercrop	6085.16 (0.03)*	6090.16 (0.06)*	6087.66 (0.04)*	1815.50 (0.10)*	1817.54 (0.16)*	1816.52 (0.13)*
T_2 - Kalmegh Intercrop	6082.17 (0.10)*	6086.17 (0.09)*	6084.17 (0.10)*	1814.10 (0.12)*	1815.11 (0.11)*	1814.61 (0.12)*
T_3 - Mint Intercrop	6084.18 (0.04)*	6087.18 (0.01)*	6085.68 (0.03)*	1814.42 (0.07)*	1816.43 (0.14)*	1815.42 (0.11)*
T_4 - Basil Sole	6083.22	6086.72	6084.97	1813.65	1814.66	1814.16
T_5 - Kalmegh Sole	6076.12	6080.62	6078.37	1812.00	1813.03	1812.51
T_6 - Mint Sole	6081.85	6086.35	6084.10	1813.10	1813.80	1813.45
S. Em ±	341.240	402.493	263.839	98.046	121.114	77.913
CD at 5 %	NS	NS	NS	NS	NS	NS

*Figure in parenthesis indicates percentage increases over respective sole cropping.

recorded when basil, kalmegh and mint grown under Sapota-Jatropha (T_1, 271.22 kg ha^{-1}, T_2, 249.73 kg ha^{-1} and T_3, 261.08 kg ha^{-1}) followed by sole basil, kalmegh and mint (T_4, 220.67 kg ha^{-1}, T_5, 219.46 kg ha^{-1} and T_6, 220.60 kg ha^{-1}) respectively.

In second year, significantly higher nitrogen in soil was recorded when basil grown under Sapota-Jatropha (T_1, 274.73 kg ha^{-1}) which was followed by sole basil (T_4, 224.43 kg ha^{-1}). Mint showed same trend that of as basil. While nitrogen was maximum in soil was noted when kalmegh grown under Sapota-Jatropha (T_2, 252.49 kg ha^{-1}) which was at par with sole kalmegh (T_5, 222.22 kg ha^{-1}). The results of pooled analysis showed the same trend of the first year result. Percent increase in nitrogen in soil in the first year was observed maximum in basil (22.91%) followed by mint (18.35 %) and kalmegh (13.79%). Similar trend was found in second year and pooled data also.

Table 3. Micro nutrients available in soil at harvest of herbal crops as influenced by Sapota-Jatropha three-tier agroforestry system.

Treatment	Iron (mg kg^{-1})			Manganese (mg kg^{-1})			Zinc (mg kg^{-1})			Copper (mg kg^{-1})		
	2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled
T_1 - Basil Intercrop	5.12 (0.79)*	5.22 (2.15)*	5.17 (1.37)*	10.54 (1.05)*	10.56 (1.05)*	10.55 (1.05)*	0.85 (1.19)*	0.88 (4.76)*	0.86 (2.38)*	2.89 (3.21)*	2.91 (3.56)*	2.90 (3.20)*
T_2 - Kalmegh Intercrop	5.06 (0.80)*	5.08 (0.79)*	5.07 (0.80)*	10.34 (0.78)*	10.36 (0.78)*	10.35 (0.78)*	0.79 (3.95)*	0.81 (5.19)*	0.80 (3.90)*	2.74 (3.01)*	2.76 (3.37)*	2.75 (3.00)*
T_3 - Mint Intercrop	5.08 (0.99)*	5.10 (0.99)*	5.09 (0.99)	10.43 (0.68)*	10.46 (0.77)*	10.44 (0.68)*	0.83 (0.00)*	0.84 (0.00)*	0.83 (0.00)*	2.84 (2.16)*	2.86 (2.51)*	2.85 (2.52)*
T_4 - Basil Sole	5.08	5.11	5.10	10.43	10.45	10.44	0.84	0.84	0.84	2.80	2.81	2.81
T_5 - Kalmegh Sole	5.02	5.04	5.03	10.26	10.28	10.27	0.76	0.77	0.77	2.66	2.67	2.67
T_6 - Mint Sole	5.03	5.05	5.04	10.36	10.38	10.37	0.83	0.84	0.83	2.78	2.79	2.78
S. Em ±	0.263	0.173	0.157	0.354	0.417	0.273	0.045	0.046	0.032	0.087	0.102	0.067
CD at 5 %	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*Figure in parenthesis indicates percentage increases over respective sole cropping.

Available phosphorus status (kg ha^{-1}) in soil

The data regarding phosphorus status in soil of different herbal crops are presented in Table 1. The results were found significant during both the years (2011 and 2012) and in pooled analysis. From data, it can be seen that in first year of study, basil grown under Sapota-Jatropha ($T_{1,}$ 38.84 kg ha^{-1}) noted significantly higher phosphorus in soil which was followed by sole basil ($T_{4,}$ 31.50 kg ha^{-1}). Kalmegh and mint recorded maximum phosphorus in soil when this grown under Sapota-Jatropha ($T_{2,}$ 35.56 kg ha^{-1} and $T_{3,}$ 36.70 kg ha^{-1}, respectively) cropping system. In second year, the significantly higher phosphorus recorded in soil when basil grown under Sapota-Jatropha ($T_{1,}$ 40.09 kg ha^{-1}) which was followed by sole basil ($T_{4,}$ 31.75 kg ha^{-1}). In the pooled analysis, the similar scenario of phosphorus in soil of all herbal crops (basil, kalmegh and mint) was observed.

Available potassium status (kg ha^{-1}) in soil

The mean data pertaining to variation in the available potassium status in the soil after the harvest of herbal crops are presented in Table 1. The results were found significant during both the years (2011 and 2012) and in pooled analysis. Maximum potassium in soil was noted when basil grown under Sapota-Jatropha ($T_{1,}$ 437.78 kg ha^{-1}) cropping system. Significantly higher potassium in soil was recorded when kalmegh and mint grown under Sapota-Jatropha ($T_{2,}$ 419.64 kg ha^{-1}, T_3 425.00 kg ha^{-1}) as compared to sole kalmegh and mint ($T_{5,}$ 356.67 kg ha^{-1} $T_{6,}$ 367.05 kg ha^{-1}). The results of second year showed the same trend as that of first year results.

In pooled analysis, significantly higher potassium in soil was recorded when basil grown under Sapota-Jatropha ($T_{1,}$ 443.06 kg ha^{-1}) was followed by sole basil ($T_{4,}$ 382.51 kg ha^{-1}) kalmegh and mint. Content of major nutrients such as N, P, K in soil were higher under intercropping of basil, kalmegh and mint under Sapota-Jatropha as compared to sole cropping of basil, kalmegh and mint.This may be due to higher microbial activities coupled with recycling of nutrients through leaf litter and more favorable physical condition *viz*., soil moisture, temperature under trees than sole. This is supported by Vanlalhluna and Sahoo (2010), Qaisar et al. (2007), Jaimini et al. (2006), Kaur et al. (2002) and Menezes et al. (2002) and Shinde (2001).

Secondary nutrients (Ca, Mg) (mg kg^{-1}) in soil

The available calcium and magnesium status of the soil after the harvest of herbal crops under Sapota-Jatropha and sole crops are depicted in Table 3. Content of secondary nutrients like Ca and Mg in soil under intercropping of basil, kalmegh and mint under Sapota-Jatropha as compared to sole cropping of basil, kalmegh and mint were found non-significant difference in oth the years and in pooled. This may be due to all these nutrients are not added in significant quantity via process of recycling by leaf litter added by Sapota-Jatropha.

Micro nutrients (Fe, Mn, Zn, Cu) (mg kg^{-1}) in soil

The data with respect to iron, manganese, zinc

Table 4. Organic carbon and major nutrients content in plant at harvest of herbal crops as influenced by Sapota- Jatropha three-tier agroforestry system.

Treatment	Organic Carbon (g kg^{-1})			Nitrogen (kg ha^{-1})			Phosphorus (kg ha^{-1})			Potassium (kg ha^{-1})		
	2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled
T_1 - Basil Intercrop	43.80 (5.75)*	44.33 (5.80)*	44.06 (5.76)*	1.458 (0.97)*	1.459 (0.90)*	1.458 (0.90)*	0.141 (5.22)*	0.143 (4.38)*	0.142 (5.19)*	1.344 (1.20)*	1.346 (1.20)*	1.345 (1.20)*
T_2 - Kalmegh Intercrop	42.65 (5.54)*	42.90 (5.41)*	42.78 (5.47)*	1.126 (0.54)*	1.128 (0.45)*	1.127 (0.54)*	0.123 (2.50)*	0.126 (2.44)*	0.125 (3.31)*	1.226 (0.25)*	1.229 (0.41)*	1.228 (0.33)*
T_3 - Mint Intercrop	43.40 (5.44)*	43.70 (5.68)*	43.55 (5.55)*	1.360 (0.37)*	1.361 (0.22)*	1.361 (0.37)*	0.128 (4.07)*	0.130 (4.00)*	0.129 (4.03)*	1.287 (0.23)*	1.290 (0.31)*	1.288 (0.23)*
T_4 - Basil Sole	41.42	41.90	41.66	1.444	1.446	1.445	0.134	0.137	0.135	1.328	1.330	1.329
T_5 - Kalmegh Sole	40.41	40.70	40.56	1.120	1.123	1.121	0.120	0.123	0.121	1.223	1.224	1.224
T_6 - Mint Sole	41.16	41.35	41.26	1.355	1.358	1.356	0.123	0.125	0.124	1.284	1.286	1.285
S. Em ±	1.352	1.803	1.127	0.040	0.049	0.032	0.005	0.005	0.003	0.045	0.054	0.035
CD at 5 %	NS	NS	NS	0.12	0.14	0.09	0.01	0.01	0.00	NS	NS	NS

*Figure in parenthesis indicates percentage increases over respective sole cropping.

And copper status in soil of herbal crops under Sapota-Jatropha and sole crops of basil, kalmegh and mint are furnished in Table 2. The results were found non-significant during 2011, 2012 and in their pooled data. The presented data clearly revealed that content of micro nutrients such as Fe, Mn, Zn and Cu in soil under intercropping of basil, kalmegh and mint with Sapota-Jatropha as compared to sole cropping of basil, kalmegh and mint were found non-significant. Sapota-Jatropha as tree component have failed in altering the status of micronutrients through addition of leaf litter.

Leaf nutrient content in herbal crops

Organic carbon content (%)

The result reveals that organic carbon content after the harvest of herbal crops was non - significant during both the years of experimentation and in their pooled data. It is evident from results presented in Table 4 that organic carbon content was found non - significant in basil, kalmegh and mint under Sapota-Jatropha as compared to sole crop of basil, kalmegh and mint. It might be due to that organic carbon content being the basic building blocks are ought to be the same, however, in term of total biomass the organic carbon will differ greatly.

Nitrogen content (%)

The maximum content of nitrogen was recorded in intercropping of all herbal crops grown under Sapota-Jatropha as compared to sole cropping (Table 4). In the first year data, the content of nitrogen by the basil, kalmegh and mint grown under Sapota-Jatropha treatment ($T_{1,}$ 1.458, $T_{2,}$ 1.126 and $T_{3,}$ 1.360%) noted maximum. Further perusal of data reveals that herbal crops (basil, kalmegh and mint) in second year and pooled analysis showed the similar trend and result as that of first year.

Phosphorus content (%)

The data show in Table 4 that in the first year of study, higher content of phosphorus was found when basil, kalmegh and mint grown under Sapota-Jatropha ($T_{1,}$ 0.141%, T_2, 0.123% and $T_{3,}$ 0.128%) cropping system. The mean data of second year (2012) trial and pooled analysis showed the same result and same trend in total content of phosphorus of all herbal crops (basil, kalmegh and mint) as per the trend of first year results.

Potassium content (%)

The total content of potassium by herbal crops at harvest between intercrops and sole crops given

Table 5. Secondary nutrients content in plant at harvest of herbal crops as influenced by Sapota-Jatropha three-tier agroforestry system.

Treatment	Calcium (%)			Magnesium (%)		
	2011	2012	Pooled	2011	2012	Pooled
T_1 - Basil Intercrop	1.745 (0.06)*	1.748 (0.17)*	1.746 (0.06)*	0.469 (0.21)*	0.472 (0.21)*	0.470 (0.00)*
T_2 - Kalmegh intercrop	1.456 (0.14)*	1.458 (0.14)*	1.457 (0.14)*	0.438 (0.23)*	0.440 (0.00)*	0.439 (0.00)*
T_3 - Mint Intercrop	1.687 (0.12)*	1.690 (0.12)*	1.688 (0.12)*	0.446 (0.22)*	0.450 (0.90)*	0.448 (0.45)*
T_4 - Basil Sole	1.744	1.745	1.745	0.468	0.471	0.470
T_5 - Kalmegh Sole	1.454	1.456	1.455	0.437	0.440	0.439
T_6 - Mint Sole	1.685	1.688	1.686	0.445	0.446	0.446
S. Em ±	0.05	0.06	0.04	0.014	0.017	0.011
CD at 5 %	0.16	0.19	0.12	NS	NS	NS

*Figure in parenthesis indicates percentage increases over respective sole cropping.

in Table 4 during 2011, 2012 and their pooled data. All the herbal intercrops in their sole stand recorded non-significant results in their respective intercropping systems during the study. Looking to the data presented that higher content of major nutrients N, P, K were found under intercropping of basil, kalmegh and mint under Sapota-Jatropha as compared to sole crop of basil, kalmegh and mint. The content of all these nutrients increased with increased shade. Higher nutrient in intercropping which might be due to lesser weed competition there by higher absorption and utilization. Similar result was reported by Mohsin (2005) in mint and Rao et al. (2000) in nutrient removal in palmarosa and blackgram intercropping system.

Calcium content (%)

The data on first year presented in Table 5 indicates that basil, kalmegh and mint when grown under Sapota-Jatropha (T_1, 1.745%, T_2, 1.456% and T_3, 1.687%, respectively) observed higher content of calcium. In second year and in pooled analysis, the similar scenario of total content of calcium in basil, kalmegh and mint herbal crops was observed as in the case of first year results. The content of secondary nutrients Ca was found significant and Mg was found non - significant under Sapota-Jatropha of basil, kalmegh and mint as compared to sole crop of basil, kalmegh and mint. The content of all these nutrients increased with increase in shade. Higher nutrient in intercropping which might be due to lesser weed competition there by higher absorption and utilization.

Magnesium content (%)

The data regarding total content of magnesium at harvest between intercrops and sole crop are in Table 5. The statistical comparison showed that content of magnesium by herbal crops as affected by intercropping and sole cropping are found non-significant for both the years as well as in pooled analysis also.

Iron content (ppm)

The total content of iron by crops recorded higher when herbal crops were grown under Sapota-Jatropha as compared to their respective sole cropping (Table 5). In the first year data showed that the content of iron in the basil, kalmegh and mint intercrop under Sapota-Jatropha treatment (T_1, 134.76%, T_2, 112.22% and T_3, 122.33%) noted maximum. In second year and pooled analysis data showed the similar trends as in case of the first year.

Manganese content (ppm)

The data regarding total content of manganese at harvest of different herbal crops is presented in Table 6. The data showed that in the first year of study, higher content of manganese was found when basil, kalmegh and mint were grown under Sapota-Jatropha (T_1, 55.65%, T_2, 48.54% and T_3, 52.54%) cropping system. The second year and in pooled analysis data showed the same trend in total content of manganese of all the herbal crops (basil, kalmegh and mint) as per the trend of first year.

Zinc content (ppm)

The result summarized in Table 6 indicates that

Table 6. Micro nutrients content in herbal crops as influenced by Sapota-Jatropha three-tier agroforestry system.

Treatment	Iron (ppm)			Manganese (ppm)			Zinc (ppm)			Copper (ppm)		
	2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled
T_1 - Basil Intercrop	134.76 (0.03)*	136.22 (0.90)*	135.47 (0.43)*	55.65 (0.02)*	56.15 (0.47)*	55.90 (0.23)*	27.35 (0.18)*	27.60 (0.18)*	27.48 (0.18)*	12.44 (0.16)*	12.69 (0.16)*	12.57 (0.16)*
T_2 - Kalmegh Intercrop	112.22 (0.04)*	114.22 (0.48)*	113.22 (0.26)*	48.54 (0.02)*	49.03 (0.49)*	48.78 (0.23)*	22.26 (0.04)*	22.51 (0.04)*	22.39 (0.04)*	9.45 (0.21)*	10.00 (3.31)*	9.73 (1.78)*
T_3 - Mint Intercrop	122.33 (0.07)*	124.24 (0.94)*	123.24 (0.43)*	52.54 (0.06)*	53.29 (0.06)*	52.92 (0.06)*	26.65 (0.04)*	27.15 (0.97)*	26.90 (0.49)*	12.42 (9.72)*	12.67 (9.51)*	12.55 (9.61)*
T_4 - Basil Sole	134.72	135.01	134.89	55.64	55.89	55.77	27.30	27.55	27.43	12.42	12.67	12.55
T_5 - Kalmegh Sole	112.18	113.68	112.93	48.53	48.79	48.67	22.25	22.50	22.38	9.43	9.68	9.56
T_6 - Mint Sole	122.24	123.08	122.71	52.51	53.26	52.89	26.64	26.89	26.77	11.32	11.57	11.45
S. Em ±	4.52	5.51	3.56	1.647	1.877	1.249	0.848	0.913	0.623	0.403	0.507	0.324
CD at 5 %	13.61	16.62	10.29	4.96	5.66	3.61	2.55	2.75	1.80	1.21	1.53	0.93

*Figure in parenthesis indicates percentage increases over respective sole cropping.

during first year study, when basil, kalmegh and mint were grown under Sapota-Jatropha ($T_{1,}$ 27.35%, $T_{2,}$ 22.26% and $T_{3,}$ 26.65 %) had, higher content of zinc. In second year and in pooled analysis, the similar scenario of total content of zinc in basil, kalmegh and mint herbal crops were observed as in the case of first year result.

Copper content (ppm)

The total content of copper by crops was recorded higher when herbal crops were grown under Sapota-Jatropha as compared to their respective sole cropping (Table 6). In the first year basil, kalmegh and mint when grown under Sapota-Jatropha treatment ($T_{1,}$ 12.44%, $T_{2,}$ 9.45% and $T_{3,}$ 12.42%) noted maximum content of copper. Further perusal of data reveals that herbal crops (basil, kalmegh and mint) in second year and pooled analysis exhibited similar trends as that of the first year. Percent increase in content of copper in plant was recorded maximum in mint (9.72%) which was followed by kalmegh (0.21%) and basil (0.16%). In the the second year and pooled data, it showed the similar trend to those of the results of first year. Higher content of micro nutrient *viz.,* Fe, Mn, Zn, Cu were found under intercropping of basil, kalmegh and mint under Sapota-Jatropha as compared to sole crop of basil, kalmegh and mint. All these nutrients are increased with increase in shade probably due to their accumulation under shaded condition. It also may be due to a possible synergistic effect caused by relative shading and due to more contribution of organic matter to the soil by Sapota and Jatropha.

Conclusion

The organic carbon, N, P, K, Ca, Mg and micronutrients in soil was noted significantly higher under Sapota-Jatropha as compared to sole crops of basil, kalmegh and mint. The trend was same in both the years of study as well as in pooled analysis. Similarly, higher organic carbon content, N, P, K, Ca, Mg and micronutrients in leaf was noted significantly higher under Sapota-Jatropha cropping system as compared to sole crops of basil, kalmegh and mint in plant. The trend was observed same in individual year and as well as in pooled analysis.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Effect of honeybee (*Apis mellifera*) pollination on seed yield and yield parameters of *Guizotia abyssinica (L.f.)*

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A flower of *Guizotia abyssinica* (L.F.) opens and liberates pollen early in the morning, the style emerges about midday and the plant is thus basically self-sterile. Hence *G. abyssinica* is a cross pollinated crop with cross pollination percentage ranging from 0 to 100 percent. Locally, the role of honeybees' pollination is still poorly understood and till now is not sufficiently appreciated. Hence, this experiment was carried out to evaluate the effect of the honeybee pollination on seed yield and yield parameters of *G. abyssinica* at the farm of Mekelle Agricultural Research Center. The study had three treatments; these were crops caged with honeybee, caged without honeybee and open pollinated. The obtained data related to seed yield and yield parameters were statistically analyzed using one way analysis of variance (ANOVA). The highest seed yield/ha was found in crops caged with honeybees (16.7 quintal) followed by open pollinated crops (13.3 quintal), while crops excluded from insects had the lowest yield (9.6 quintal). So the study discovers that honeybees and other insect pollination had a significant effect on seed yield of *G. abyssinica*. Therefore, it is recommended to keep sufficient number of honeybee colonies in the vicinity of *G. abyssinica* fields during its flowering period to increase the pollination efficiency and thereby enhance seed productivity.

Key words: *Guizotia abyssinica*, honeybee, insects, pollination.

INTRODUCTION

Guizotia abyssinica (L.f.) is one of the indigenous and important oil crops both for domestic and commercial uses in Ethiopia (Weiss, 2000; Ethiopian Ministry of Agriculture, 2011). It is commonly known as Ramtil, Kalatil, Gurellu, Tilangi, Neuk, Noog and Nug (Dhurve, 2008). *G.abyssinica* has the highest share and contributes up to 50% of the Ethiopian oil seed crop production (Weiss, 2000; Ethiopian Ministry of Agriculture, 2011). Honeybees visit its flowers for harvesting pollen and/or nectar (Haftom et al., 2014), which in turn results into floret cross pollination (Dhurve, 2008).

G. abyssinica flower opens and liberates pollen early in the morning, while the style emerges about midday and the plant is thus basically self-sterile, although self-pollination has been recorded (Weiss, 2000). *G. abyssinica* is a cross pollinated crop with cross pollination percentage ranging from 0 to 100% depending on the genotype and other environmental factors (Subhas, 2005). However, the effect of insect foragers more

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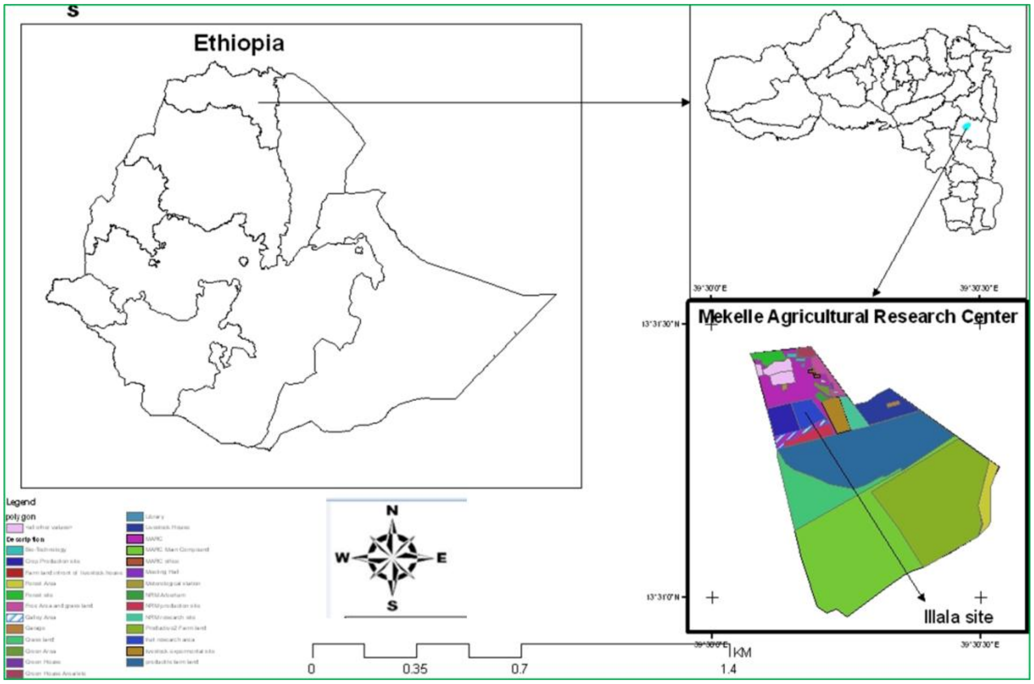

Figure 1. Location map of Mekelle Agricultural Research Center.

particularly honeybees have not so far been exclusively studied locally. Even honeybee pollination is important in crop production as water or fertilizer (Jacobs et al., 2006), local farmers keep honeybees for honey and/or wax uses only (Gidey and Mekonen, 2010). Moreover, the role of honeybees for pollination of the local farming systems is still poorly understood and till now not sufficiently appreciated (Jacobs et al., 2006). Despite local knowledge on the economic importance of honeybee pollination, it is also common to see insecticide application when honeybees are at high traffic. Hence, this study was designed to determine the effect of honeybee pollinationon seed yield and yield parameters *G. abyssinica*.

MATERIALS AND METHODS

Description of study areas

The study was conducted during the 2013 cropping season at Mekelle Agricultural Research Center, Illala site (Figure 1). It is located North East of Mekelle at an elevation of 2012 m and at N13°31'21. 2" latitude and E39°30'14.7" longitude.

Experimental setup

For this experiment plants were grown with the recommended agronomic package practices. The crop was planted with a seed rate of 10 kg/ha, 40 cm distance spacing between rows and 10 cm distance between plants. Diammonium phosphate and Urea were applied immediately after sowing and tinning of seedlings at a rate of 100 kg/ha, respectively. Tinning of seedlings was done two weeks after sowing. The study was conducted in a complete randomized block design (RCBD) with three treatments and four replications in an experimental plot size of 3 m × 3 m. The treatments were crops caged with honeybee (one colony of five combs), caged without honeybee and open pollinated (exposed to all insects including honeybees) (Figure 2). The cages were put immediately before the beginning of blossom and colony transferring was done at 5 to 10% flowering stage of the plant. This stage of flowering was selected to secured feed (pollen and nectar) for the honeybee pollinatores.

Number of head flowers, plant height and flowering period

The total number of flowers/plant was determined by counting the total number of head flowers. The height of the plant was measured from ground level to the tip of the longest branch with the help of a measuring tape. The flowering period of the plant was determined by recording the flower starting and ending date of the plants. Nine plants were selected to study the effect of mode of pollination on flowering period of the plant. To study the number of head flowers/plant and plant height ten plants were also selected.

Number of pods and seeds per plant and seeds per pod

Seeds were measured after drying the plants. The seed yield/ha was obtained by taking the weight of clean grains collected in the central area of each net plot (1 m by 1.2 m) in all treatments. To obtain the average number of pods per plant, samples were taken from five randomly selected plants from each plot. The number of seeds per pod was determined by taking five seed pods/plant from a total of five plants per plot. Evaluation of average weight of seeds was made through weighing of 1000 seeds. To know the total number of seeds/plant, the seeds were separated and counted manually.

Figure 2. The treatment: Crops caged with honeybee, caged without honeybee and open pollinated.

Table 1. Number of head flowers, flowering period and plant height.

Treatment	Number of head flowers	Height (cm)	Flowering period (days)
Open pollinated	52.6 (1.71)[b]	106.0	20.61[c]
Caged with honeybees	48.3 (1.67)[b]	108.4	24.58[b]
Caged without Insects	64.8 (1.79)[a]	108.9	28.78[a]
SE	0.02	2.0	0.71
LSD	0.04	NS	1.99
P value	<0.001	0.559	<0.001

Figures in the parentheses are head flowers per plant (Log (base10) transformed values. Means in rows followed by the same letter are not significantly different at P<0.05 probability level. NS =non significant

Harvesting time

Date of harvest was investigated by recording the number of days starting from its time of sowing to its time of harvesting. Time of harvest was identified by observing plants that start to shatter their seeds or plants that open their seed pods. The harvesting was made immediately after the seeds start to shatter.

Statistical analysis

The obtained data related to seed yield and yield parameters were statistically analyzed using one way analysis of variance (ANOVA) and least significant difference /LSD/ was calculated to identify the significant differences among the treatments means. The data for the number of seeds/pod, head flowers/plant and seeds/plant were subjected to ANOVA after data transformed using *log(base 10).* The data were analyzed using Genstat 14th version statistical software.

RESULTS AND DISCUSSION

Number of head flowers, flowering period and plant height

Flowering period and number of head flowers of *G. abyssinica* were significantly affected by the mode of pollination. Plants caged without honeybees had the highest number of head flowers/plant, while plants caged with honeybees had the smallest number (Table 1). Crops caged without insects had also the longest flowering period (28.8 days), whereas open pollinated crops had the smallest flowering period (20.6 days). Similarly, Oz et al. (2009b) revealed flowering period and number of flowers/plant affected by the mode of pollination and the longest flowering period was reported in canola crops caged without bees followed by open pollinated crops. This might be the reason for the early maturation of the plants exposed to insects, that is, open pollinated crop was harvested 8 days earlier than plants caged without insects. This may indicate that mode of pollination had a great contribution for early maturation of seeds.

Plant height was not significantly affected by the mode of pollination (Table 1). Plants caged without honeybees and those caged with honeybee had 108.9 cm and 106.0 cm height, respectively. Also in Faba bean (*Vicia faba* L.), self-pollinated crops had higher height than plants pollinated by bees (Musallam et al., 2004).

Number of pod, seed per pod and seed per plant

Significant variation was observed in number of seeds/pod among the treatments (Table 2). Plots caged with honeybees had the highest number of seeds/pod (30.9), while the plants caged without insects had the least number of seeds/pod (7.8). Sattigi et al. (2004) also

Table 2. Number of seed pod, seed per pod and seed per plant.

Treatment	Number of seed pod/plant	Number of seeds/pod	Number of seeds/plant
Open pollinated	47.3	18.2 (4.03)[b]	702.2 (25.249)[b]
Caged with honeybees	51.8	30.9 (5.46)[a]	1089.7 (32.356)[a]
Caged without Insects	62.0	7.8 (2.63)[c]	656.4 (24.410)[c]
LSD	NS	0.740	4.500
P value	0.052	<.001	0.001

Figures in the parentheses are head flowers per plant (Log (base10) transformed values. Means in rows followed by the same letter are not significantly different at P<0.05 probability level. NS =non significant

Table 3. Seed yield/ plant and seed yield/ ha.

Treatment	Seed weight per plant (gm)	Seed yield/plot (gm)	Seed yield/ha (kg)
Open pollinated	3.0 (1.65)[b]	159[ca]	1324[ac]
Caged with honeybees	5.7 (2.32)[a]	200[a]	1669[a]
Caged without Insects	2.9 (1.63)[b]	115[c]	960[c]
LSD	0.30	57.1	475.9
P value	< 0.001	0.03	0.03

Means in rows followed by the same letter are not significantly different at P<0.05 probability level.

found the highest (33.0) and the least number of seeds/pod (17.8) in crops caged with bees and without honeybees, respectively. In sunflower, crops caged with honeybees increased significantly the percentage of seed setting, number of filling seeds/head, compared with crops caged without honeybees (Oz et al., 2009a). As indicated in Table 2, the highest number of seeds/plant (1089.7) were found in plants caged with honeybee followed by open pollinated plants (702.2), whereas the least number of seeds/plant was found in plants caged without insects (656.4). However, the number of pods/plant was not affected by the mode of pollination and non-significant difference was noticed among the treatments (Table 2).

Seed yield/plant and seed yield/ha

Significant variation was observed among the treatments regarding seed yield/plant and seed yield/ha (Table 3). Plant caged with honeybees had the highest seed yield/plant (5.7 g), while plants caged without honeybees had the lowest yield (2.9 g).

Mode of pollination had a significant effect on the seed yield/ha (Table 3). The highest seed yield/ha was obtained from crops caged with honeybees (16.7 quintal) followed by open pollinated plots (13.3 quintal), whereas crops excluded from insects had the lowest yield (9.6 quintal). The higher yield of crops caged with honeybees might be due to the higher pollination efficiency of the honeybees inside the cage. Rao and Suryanarayana (1990) also reported three times higher yield in plots caged with honeybees as compared with plots caged without honeybees.

CONCLUSION AND RECOMMENDATION

This study revealed that honeybees and other insect pollinators had a significant effect on seed yield of *G. abyssinica*. The highest seed yield/ha was obtained from crops caged with honeybees (13.3 quintal), whereas crops excluded from insects had the lowest yield (9.6 quintal).

Therefore, it is recommended to keep sufficient number of honeybee colonies in the vicinity of *G. abyssinica* fields during its flowering period to increase the pollination efficiency and thereby enhance seed productivity.

Conflict of Interest

There are no conflicts of interests regarding this publication.

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Full Length Research Paper

Adoption of improved wheat varieties in Robe and DigeluTijo Districts of Arsi Zone in Oromia Region, Ethiopia: A double-hurdle approach

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The study investigates the determinants of adoption of improved wheat varieties in Robe and Digelu-Tijo Districts in Oromia Region. The objective of this study was to determine factors that affect the adoption and intensity of use of improved wheat varieties production in Arsi zone with specific reference to Robe and DigeluTijo Districts. The study finds that the level of adoption of improved wheat varieties in Arsi Zone is very high; about 68% of the households grow improved wheat varieties. About 53% of the wheat area is planted to improved varieties, indicating a high intensity of adoption. To identify the determinants of adoption and level of adoption of improved wheat varieties, a Double-hurdle (D-H) model was employed. The results of the D-H model provided empirical evidence of a positive impact of household head sex, field day participation, access to all weather roads, and district in enhancing the adoption of improved wheat varieties. With regard to the intensity of use of improved wheat varieties, household head sex and access to all weather roads had a significantly negative impact on intensity of use of improved wheat varieties while access to credit, active family force, market distance and district had a positive impact on intensity of use of improved wheat varieties. The overall findings of the study emphasized household head sex, field day participation, access to all weather roads, access to credit, active family force, district and market distance as being key determinants on the intensity and adoption of use of improved wheat varieties. Hence, development intervention should give emphasis to these variables in order to increase the probability of adoption and intensity of use of improved wheat varieties.

Key words: Improved wheat varieties, adoption, intensity, tobit model, double hurdle model.

INTRODUCTION

Wheat crop is the main staple foods in highland areas of Ethiopia, and selling wheat is generally not a primary economic activity for producers (Schneider et al 2010). On the consumption side, it is estimated that an average person in Ethiopia consumes about 29.6 kilos of wheat per year (Berhanu et al., 2011) which stands third next to

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maize and sorghum, 37.7 and 32.2 kilos per year, respectively.

In Ethiopia, according to (Central Statistical Authority (CSA) 2010/2011) average national productivity of wheat is 1.84 ton/hectare which is too low compared to the potential productivity of 4 to 8 ton/hectare at farmers' field. In an effort to improve wheat productivity and production, the country through its research centers has released so many improved wheat varieties.

However the uptake of these wheat technologies in the country by farmers is low. For instance, in 2010/2011 cropping season in the country, the use of improved wheat varieties at national level were only 7% which is too low (Central Statistical Authority (CSA) 2010/2011). To this end understanding of the reasons behind the low adoption of improved wheat varieties has a paramount importance in improving and enhancing the uptake of wheat technologies.

Adoption studies in Ethiopia have been carried out by different authors (Asfaw et al., 1997; Bekele, et al., 2000; Yu et al., 2011; Alene et al., 2000). Although there have been quite a large number of studies on adoption studies, to the best of the author no studies of technology adoption conducted in the study area and used double hurdle model in Ethiopia except (Berhanu and Swinton, 2003; Hailemariam et al., 2006; Hassen et al 2012).

The double hurdle (D-H) model originally due to Cragg (1971) extensively applied in several studies such as (Berhanu and Swinton, 2003) and (Hailemariam et al., 2006). The Tobit model used to analyze under the assumption that the two decisions are affected by the same set of factors. In the double-hurdle model, on the other hand, both hurdles have equations associated with them, incorporating the effects of farmer's characteristics and circumstances. Such explanatory variables may appear in both equations or in either one. Most importantly, a variable appearing in both equations may have opposite effects in the two equations (Moffatt, 2005). Therefore, this study has two major contributions; the first contribution is that it provides information regarding the adoption of improved wheat varieties. To this end, the paper reveals different sets of factors that determine the decisions to adopt and the intensity of use of improved wheat. The second contribution of the study relates to the choice of an estimation technique (that is, The Tobit and D-H model). The general objective of this study is to assess factors affecting the adoption and intensity of use of improved wheat varieties production in Arsi zone with specific reference to Robe and DigeluTijo Districts.

METHODOLOGY

Sampling procedure

In this study two stage sampling techniques were used to carry out the data collection. At the first stage, Digelu-tijo and Robe were purposively selected by the EAAP project based on wheat production potential and presence of wheat technology interventions and also they were the project (EAAPP) districts. At the second stage, three Kebeles were randomly selected from each district and accordingly, six Kebeles were selected and used for the survey. At the final stage of sampling procedure, lists of household heads (HH) with in the Kebele were made and total of 150 farm households were selected by systematic sampling technique with probability proportional to size of households.

Methods of data collection

Both primary and secondary data were used in this study. The primary data pertaining to the year 2011 crop season were collected from sample respondents during May and June 2012 through a structured questionnaire. A pre-tested structured questionnaire was used to generate data on some social, institutional and economic variables. Secondary data were acquired from different sources such as reports of Ministry of Agriculture (MOA) at different levels, Central Statistics Agency (CSA), Districts' Administrative Office, Non-governmental Organizations (NGOs), different research reports, Internet and other published and unpublished materials, which were found to be relevant to the study.

Methods of data analysis

In order to realize the objectives of the study, it used two analytical tools. Descriptive statistics and econometric models are the two analytical tools.

Descriptive statistics

Descriptive statistics was used describe the socioeconomics and demographic characteristics of the sample households. Means, percentage, and frequency were analyzed using SPSS computer program and significance test was conducted using t-test, and Chi-square.

The Tobit model

To analyze the adoption of improved wheat varieties using farm household survey data, the Tobit and a more flexible parameterization to the tobit model (the double hurdle model) were considered. The tobit (Tobin, 1958) model specification is defined as:

$$\begin{cases} y_i = y_i^* & \text{if } y_i^* > 0 \\ y_i = 0 \text{ Otherwise} \end{cases} \quad (1)$$

The latent function y_i^* that defines household adoption decision and intensity of use improved wheat varieties is given by:

$y_i^* = x_i'\beta + \varepsilon_i$, where $\varepsilon_i \sim N(\mu_i, \sigma^2)$ and i = 1,…, n

The latent variable y_i^* is defined as a variable that may or may not be directly observable and y_i is the corresponding actual observed intensity of the use of an improved wheat variety measured in terms of proportion of wheat area allocated to improved wheat variety. x_i is a set of individual characteristics that explain both adoption and intensity of use of improved wheat variety, and β is a vector of Tobit maximum likelihood estimates, μ_i the independently and normally distributed error term assumed to be normal with mean zero and constant variance σ. The value of y_i for all non-users equals zero (Alene et al., 2000). ε_i is assumed to be a homoskedastic, normally distributed error term. Equation (1) states that the observed intensity of use of an improved wheat variety becomes positive continuous values if only positive intensity of use of improved wheat varieties is desired, but zero otherwise. This shows the observed 0's on $y_i$can mean either a "true" 0 (that is, due to the individual's deliberate choice) or censored 0 (that is, those caused by survey design) (Wodajo unspecified).

The Tobit model is estimated using maximum likelihood methods. The log-likelihood function verifying equality of the coefficients in the adoption equation to those in the intensity of use equation is:

$$\text{LnL}_T = \sum_{y_i = y_i^*} \frac{1}{2}\left[\ln(2\pi) + ln\sigma^2 + \frac{(y_i - x_i'\beta)^2}{\sigma^2}\right] + \sum_{y_i=0} ln\left[1 - \Phi_i\left[\frac{x_i'\beta}{\sigma}\right]\right] \quad (2)$$

Where Φ_i denotes the standard normal distribution function evaluated at $\frac{x_i'\beta}{\sigma}$ and the summation indexes refer to the limit and the non-limit observations. The first term on the right hand side of the Equation (2) is the contribution of the non-limit observations to the log-likelihood function, while the remaining terms represent the contribution of the limit observations (Reynolds, 1990).

The double-hurdle model

The D-H model is a parametric generalization of the Tobit model, in which two separate stochastic processes determine the decision to adopt and the intensity of use of technology (Hailemariam et al., 2006). The first equation in the D-H model relates to the decision to adopt (y) can be expressed as follows:

$$y_i = 1 \quad \text{if } y_i^* > 0 \text{ and } 0 \text{ if } y_i^* \leq 0 \quad (3)$$

$$y_i^* = x_i'\alpha + \varepsilon_i \text{ (Adoption equation)}$$

Where: $y_i^*$is latent adoption variable that takes the value of 1 if a household grew improved wheat variety and 0 otherwise, x is a vector of household characteristics and α is a vector of parameters. Equation (3) is a probit model that examines the probability that the i[th] farmer would make a decision to adopt improved wheat varieties. The second hurdle, which closely resembles the Tobit model, is expressed as:

$$\begin{cases} t_i = t_i^* > 0 \text{ and if } y_i^* > 0 \\ t_i^* = Z_i\beta + u_i \; and \; y_i^* = x_i'\alpha + \varepsilon_i \\ t_i = 0 \;\; \text{Otherwise} \end{cases} \quad (4)$$

$t_i^* = Z_i\beta + u_i$(Intensity equation)

Where: t_i is the observed response on how much land one allocated to improved wheat varieties, $Z_i$is a vector of the household characteristics and β is a vector of parameters (Mignouna et al., 2011). ε_i and u_i are error terms. Where, $\varepsilon_i \sim N(0,1)andu_i \sim N(0,\sigma^2)$. Following Cragg (1971) model, the study assumes independence between the two error terms. The log-likelihood function for the D-H model is given as:

$$\text{LnL}_{dh} = \sum_{+} \ln\left[\Phi(Z_i'\beta)\frac{1}{\sigma}\phi\left(\frac{y_i - x_i'\beta}{\sigma}\right)\right] + \sum_{0} ln\left[1 - \Phi[x_i'\alpha]\Phi\left[\frac{Z_i'\beta}{\sigma}\right]\right] \quad (5)$$

Where,Φ and Ø are the standard normal cumulative distribution function and density function, respectively. When either the assumption of normality or homoskedasticity is violated, maximum likelihood estimation produces inconsistent parameter estimates (Carroll et al., 2005). However handling heteroskedsticity and non - normality violations are beyond the scope of this study.

The double hurdle model of Equation (3) (that is, the first hurdle) is a probit model that examines the probability that the i[th] farmer would make a decision to adopt improved wheat varieties. Equation (4) (that is, the second hurdle) is a truncated regression model that examines the intensity of use improved wheat varieties (Bhunbaneswar et al., 2008). Therefore, the log-likelihood of the D-H model is the sum of the log-likelihood from a probit model and the truncated regression model (Adam et al., 2011).

Whether a tobit or a double hurdle model is more appropriate can be determined by separately running the tobit and the double hurdle models and then conducting a log likelihood ratio test that compares the tobit with the sum of the log likelihood functions of the probit and truncated regression models (Berhanu and Swinton, 2003).

$$\text{LR} = -2[LogL_T - (LogL_P + LogL_{TR})] \sim \chi_k^2 \quad (6)$$

Where $LogL_T$= log-likelihood for the Tobit model, $LogL_P$= log-likelihood for the Probit model, $LogL_{TR}$= log-likelihood ratio for the Tobit model and k is the number of independent variables in the equations (Hailemariam et al., 2006).

Definition of variables

Variables are classified into dependent and independent variables as can be seen in Table 1.

RESULTS AND DISCUSSION

Descriptive statistics

In the current study, farmers who did not grow improved variety of wheat were considered as non- adopters and while the farmers who grow an improved variety of wheat varieties at least in one of their plots were taken as adopters. The improved wheat varieties still widely grown by farmers in the two districs are Tuse, Galama, Kubsa, Hawi, Medawalabu and Digelu. However, Tuse, Galama, Kubsa, and Hawi were released and introduced more than a decade ago and are considered as local wheat varieties. Similarly, (Bekele et al., 2000) used the same definition on adoption study of wheat technologies in Bale highlands of Ethiopia. Hence, for this study Digelu and Medawalabu are considered as improved wheat varieties. Medawalabu is selected as an improved variety because of its current performance with respect to disease resistance, tillering, and resistance to shattering, grain size and straw palatability.

Rate of adoption and intensity of improved wheat varieties

In the two districts, all the sample respondents were smallholder farmers practicing mixed crop-livestock farming. Table 2 shows the distribution of sample

Table 1. Summary of definitions and measurements of probit and truncated model variables.

Dependent variables	Measurement of variables with	Their expected signs
Adoption of improved wheat varieties	Dummy (Yes/no)	
Proportion of area allocated to improved wheat varieties	continuous	
Independent variables		
Distance to nearest market	In kilometers	-
Access to all- weather road	Dummy (Yes/no)	+
Age of the household head	continuous	+
Education of the household head		+
(i) Not read and write (reference group)	Yes/no	
(ii) Read and write	Yes/no	
(iii) Primary and junior	Yes/no	
(iv) Secondary and above	Yes/no	
Active labour force	Number of households age between 18 and 60	+
Family size	Number of family members	+
Farm size	Cultivated area in ha	+
Plot fragmentation	Number of plots	-
Livestock owned	TLU	+
Sex of the household head	Male/female	+
Access to field day	Yes/no	+
Access to extension service	Yes/no	+
Off/non- farm income	continuous	+
Access to credit	Yes/no	+
Farm income	continuous	+
Area of faba bean cultivated	continuous	+
District (dummy)	yes/no	-
(i) Digelu (reference group)		
(ii) Arsi-robe		
Asset ownership	continuous	+
Media ownership (radio, television and phone)	continuous	+
Wheat income	continuous	
Soil fertility status	Yes/no	+

Table 2. Rate of adoption of improved wheat varieties.

	Non- adopters		Adopters		Total sample	
Total	N=48	%	N=102	%	N=150	%
	48	32.00	102	68.00	150	68.00

Computed from survey data.

households' rate of adoption of improved wheat varieties. As shown in the table, the rate of adoption in the study area is 68%. In this study the intensity of adoption of improved varieties is assessed by using the proportion of area allocated to wheat varieties. Table 3 presents the share of the household's wheat area allocated to improved wheat varieties. About 53% of the area under wheat in the survey districts is planted with improved wheat varieties.

The descriptive analysis for continuous and dummy variables (Tables 3 and 4) results reveals that there are significant differences between adopters and non-adopters in terms of family size, proximity to market area, credit access and farm income. However; no significant

Table 3. Wheat adoption intensity across the two districts.

Wheat area	DigeluTijo N=75	Arsi robe N=75	Total sample N=150
Total wheat area in (ha)	100.245(7.624)	76.06(24.872)	176.31 (25.751)
Area under improved wheat varieties	36.375 (5.380)	56.86 (24.872)	93.24(25.418)
Share of improved varieties in total area (%)	36.3	74.76	53.0

Computed from survey data (Std. dev in parenthesis).

Table 4. Characteristics of sample wheat farmers by adoption levels: continuous variables.

Variables	Adoption category				Total sample		T test
	Non-adopters		Adopters				
	Mean	StDv	Mean	StDv	Mean	StDv	
Household size	6.21	2.221	7.44	2.84	7.05	2.72	-2.6455***
Age of household head	42.58	13.01	44.13	12.34	43.63	12.53	-0.7028
Livestock ownership	7.38	4.325	6.78	4.035	6.91	4.093	0.09
Ox ownership	2.45	1.54	2.21	1.45	2.28	1.28	1.0645
Land holding size	2.44	1.36	2.19	1.22	2.27	1.27	1.44
Farm income	12,524.17	19,516.76	8,306.28	14,146.92	9,656.00	16,115.53	1.51*
Market distance	6.34	3.97	5.27	4.16	5.60	4.12	1.46*

Computed from survey data, *** and *significant at 1 and 10%, respectively.

differences were observed between adopters and non-adopters in terms of age, farm size, education, livestock ownership, extension contact, access to Media, participation in field day, soil fertility status and participation in off farm activities (Table 5).

Econometric results

In order to check whether the two districts from which the samples were drawn were homogeneous or not, F-test and chi-square test were used for continuous and dummy variables, respectively (Appendices 1 and 2). The homogeneity test indicates that the two districts were homogeneous with respect to most of the variables in the model. Based on statistical test and other social and agro-climatic conditions, the two districts were, thus, found to be homogenous. We thus carried out the analysis by combining samples taken from the two districts.

Because of minor heteroskedasticity problem, the variance was estimated using robust standard error estimation. To check Multicollinearity problem variance inflation factors (VIF) and contigencey coefficients were computed for continuous and categorical variables respectively. For continuous variables the VIF values shown in Appendix 1 indicate that all the continuous explanatory variables have no serious multicollinearity problem. Similarly, contigencey coefficient computed for categorical variables were less than 0.75 (Appendix 2). Hence there is no serious collinearity problem among the categorical variables used. To eliminate skewness and kurtosis, all numerical variables should be subjected to a log transformation (Gujarati**,** 2004). Therefore; farm income, wheat income, asset ownership and faba bean area were found skewed and transformed using log transformation.

Model specification

The LR result (Table 6) rejects the null hypothesis that the Tobit model is appropriate and indicates that the estimated D-H model is preferred .The test statistic for log likelihood is 66.76 which exceed the critical chi-square value of 35.17 at 23 degrees of freedom and at a less than one percent level of significance in favor of the D-H model. This shows the existence of two separate decision making stages during the adoption process. This result provides an empirical result of farmers' independent decisions making regarding the adoption and intensity of use of improved wheat in the study areas. In general, the estimated results for D-H model shows some variables appearing in both equations have opposite influences in terms of both signs and level of significance. For instance, the variables sex, livestock ownership, wheat income, farm income, asset ownership, access to-all weather roads, faba bean area, media

Table 5. Characteristics of sample farmers by adoption group: categorical variables (% age of farmers).

Variables	Category	Adoption category		Total sample	X^2-Value
		Non-adopters	adopters		
Sex	Male	29.63	70.37	89.89	3.49*
	Female	53.33	46.67	11.11	
		Education level			
No formal education	Yes	22.92	19.61	20.67	3.3236
Read and write	Yes	16.67	11.76	13.33	
Primary and junior	Yes	39.58	54.90	50.00	
Secondary and above	Yes	20.83	13.73	16.00	
Participation in off-farm activities	Yes	25.00	23.53	23.57	0.039
		Soil fertility status			
Low fertile	Yes	9.76	3.45	5.47	2.218
Medium fertile	Yes	34.15	39.08	37.50	
fertile	Yes	56.10	57.47	57.03	
Extension services	Yes	77.05	75.25	75.84	0.0598
Field day participation	Yes	12.50	18.63	16.67	0.882
Credit access	Yes	58.33	77.45		5.83**
Access to Media	Yes	56.25	49.02	51.33	0.683
Off-farm activities	Yes	6.25	6.86		
Non- farm activities					
Employment	Yes	4.17	1.96		
Running own business	Yes	22.92	26.47		

Computed from survey data, ** &* imply significant at 5% and 10% ,respectively.

Table 6. Test statistics of double hurdle and Tobit models.

Test statistics	Probit	Truncated regression	Tobit regression
$Chi^2(23)$	39.72**	108.31***	2.18***
Log-L	-57.52	2.18	-88.72
Number of observation (N)	119	80	119
LR-statistics	66.76***	χ2(23)= 35.1725	
AIC (-Log-L+k)/N	.68	0.26	0.94

Model output, **,*** significant at 5 and 1% respectively.

access, market distance, fertility dummy, read and write, and primary and junior have conflicting signs in the adoption and intensity of use equation. While only field day participation variable was found to have significant effect in explaining the adoption equation but not in the intensity of use equation. Credit access, active family force, and market distance were found to have significant effects in explaining the intensity of use equation but not in the adoption equation. However; household head sex, access to all weather roads, and district have significant effect on the adoption and intensity of use improved wheat varieties. The significance level in explaining for both equations is at 10**%** or lower.

Determinants of improved wheat varieties adoption

As the results of the probit (the first hurdle) model of the (D-H Table 7) revealed that four factors are significant in influencing farmers' decision to adopt improved wheat varieties. Of which household head sex and access to all weather roads are significant at 1% significance level, while field day participation and district are significant at 10% significance level. According to the estimated

Table 7. MLE estimates of the double hurdle and Tobit models.

Variable	Double hurdle method				Tobit	
	Probit		Truncated			
	Coef.	Robust Std. Err.	Coef.	Robust Std. Err.	Coef.	Robust Std. Err.
Sex	0.9782027	0.443547**	-0.3076001	0.1288704**	0.1413219	0.2083692
Age	0.0065074	0.012194	0.001939	0.0027316	0.005949	0.0048993
Family size	0.0609412	0.0499462	0.0050288	0.0126119	0.0209533	0.0194343
Livestock ownership	-0.0288787	0.035086	0.006254	0.0075998	-0.0022434	0.0131086
Field day participation	0.6617587	0.3658628*	0.1134966	0.0741423	0.2082209	0.1188375*
Extension contact	-0.3211232	0.324678	-0.029555	0.0780122	-0.0379125	0.1322245
Wheat income	0.02265	0.0368344	-0.0032831	0.0079421	-0.0019682	0.0137343
Credit access	0.3195893	0.3238696	0.1326978	0.0739258*	0.0927695	0.1159641
Active family force	0.0759834	0.0807019	0.0310214	0.0138348**	0.0305217	0.0247885
Off/non-farm income	-0.0108761	0.029651	-0.0027783	0.0056399	-0.0011894	0.009738
Land	-0.1577308	0.1508263	-0.0372391	0.0315535	-0.0822875	0.0517672
Farm income	-0.0788125	0.070292	0.0162741	0.0130459	-0.0158276	0.026609
Asset ownership	0.1231097	0.1348131	-0.0067319	0.0303974	0.0390767	0.0443361
Access to all weather	10.110665	0.3653074***	-0.1644118	0.0921883*	0.2046066	0.1665001
Faba bean area	0.0461639	0.0724403	-0.0150811	0.0170818	0.0039679	0.0303268
District_dummy	0.4970154	0.2907411*	0.3054746	0.0667247***	0.4675793	0.100305***
Media access	-0.0723019	0.5018602	0.0260896	0.0886621	-0.0740319	0.1997599
Market distance	-0.0093286	0.039271	0.0139318	0.007836*	0.0076614	0.0149063
Fertilizer_dummy	0.5295778	0.6589114	-0.0300438	0.1571444	0.2110419	0.3201833
Read and write	0.471886	0.4670686	-0.1531037	0.1154068	0.1160601	0.1755644
Primary and Junior	0.5588071	0.3656688	-0.017951	0.0823127	0.1825006	0.1411816
Secondary and above	0.2567801	0.4789546	0.1910707	0.1224142	0.2610926	0.2116417
Fragmentation	-0.126675	0.1258379	-0.0243679	0.0232128	-0.0327636	0.0438789
_cons	-2.97725	1.553186*	0.561459	0.3701076	-10.069543	0.5896386*

Model output *, **,***significant at 10, 5 and 1% respectively.

marginal effects of adoption of improved wheat varieties of the probit model Appendix 3, the likelihood (rate or probability) of adoption of the improved wheat varieties was high. An average farmer had a 72.3% predicted probability of adopting improved wheat varieties.

Household head sex

The model results (Table 7) show that household head sex is associated with adoption decision of improved wheat varieties positively and significantly at 1% probability level. The model result confirms that as compared to female-headed farmers, male-headed farmers are more likely to adopt improved wheat varieties than female headed farmers. Possible explanations for these may be; female headed households have a lower labor endowment, lower farm income and less access to information on improved wheat varieties compared to male headed households counterpart. This result is in line with studies of (Hailemariam et al., 2006).

Participation in field day

Participation on field day is one of the means of teaching and learning process of improved technologies. The effect of field day participation was found to be positive and significant at 10%, Table 7. Suggesting that the more farmers participate in field day, the more likely the farmers are willing to adopt high yielding improved wheat varieties. Similar results were found by (Asfaw et al., 1997).

Access to all weather roads

From the result of probit model Table 7, the effect of access to all weather roads is found to be positive and significant at a less than 1% significance level, suggesting that farmers who have access to all weather roads are more likely to adopt improved wheat varieties. Access to all weather roads is essential for timely input delivery and output disposal. It also decreases the transportation cost of inputs; hence, investment in improved road infrastructure is crucial for promoting adoption and welfare gains (Hassen et al., 2012). The result is consistent with the findings of Croppenstedt and Demeke (1996) and Hassen et al. (2012).

District

According to the results of the probit model Table 7, the district dummy variable was found to have a positively significant impact on adoption of improved wheat varieties at 10% significance level. This implies relative to farmers in Digelu-tijo (the reference group in the present analysis), farmers in Robe district are more likely to adopt improved wheat varieties. The plausible explanation for this is like the agro-climatic differences. This finding is in contrast with (Solomon , Bekele and Franklin 2010) who found farmers near to research center, main road and market are more likely adopters than farmers far away.

Determinants of intensity of use of improved wheat varieties

The determinants of the intensity of use of improved wheat varieties was estimated using the second double hurdle (Truncated regression) model. The empirical result from Table 7 of Truncated regression model indicated that household head sex, credit access, active family force, access to all-weather roads, district and market distance had a significant effect on the intensity of use of wheat varieties at different significance levels.

Household head sex

The negative significant coefficient of household head sex on the intensity of use of improved wheat varieties was a surprising finding (Table 7). This indicates that female headed households (the reference group) use more improved wheat varieties per hectare. The possible explanation for this is that if female farmers are provided with equal access to technology, resources and information with their counterparts, they will be the higher level of technology users. This finding is consistent with the result of (Croppenstedt and Demeke, 1996).

Credit access

The results of the study provided empirical evidence of a positive impact of credit service on intensity of use of improved wheat varieties. The result of the truncated model revealed that the intensity of use of improved wheat varieties is positively and significantly affected by access to credit at 10% significance level. This suggests that access to credit has a paramount importance in intensification of improved wheat varieties by financing agricultural inputs, that is, improved seeds and fertilizers. Hence, if farmers can get credit access, they can buy more improved wheat varieties. The finding is consistent with other study (Hassen et al., 2012)

Access to all weather roads

With regard to access to all weather roads, the result of the Table 7 of the truncated regression indicated significantly a negative effect on the intensity of use of improved wheat varieties. This was not the prior expectation. This implies when farmers have access to all weather roads, they have a lot option and tend to decrease wheat intensification and focus on other market oriented cash crops and off/non-farm activities. This result was not in agreement with the findings of (Croppenstedt and Demeke, 1996) and (Hassen et al., 2012). This also may show that the absence of all weather roads could not hinder them to use improved wheat varieties if convinced they will get higher yield and make cost saving.

District

The effect of district variable on the intensity of wheat use was found to be positive and significant at 5%. This implies farmers in Robe District devote more of their wheat land to improved wheat varieties. Robe District is high moisture area, this may cause farmers to use more improved wheat varieties than local varieties to adapt and get more wheat production.

Active family force

According to the result of the Table 7 in the truncated model, labor force had a positive impact on the intensity of use of improved wheat varieties at 5% significance level. This explains that new improved wheat varieties appear to be labor intensive. Suggesting that farmers who have more active family labor force allocate more area to improved wheat varieties since they can supply the required labor for different production activities of improved wheat varieties. This result is in conformity with other findings of Alene et al. (2000) and Hailu (2008).

Market distance

The effect of market distance on the intensity of use of improved wheat varieties was negative and significant at

10%, which was against the prior expectation (Table 7). The plausible explanation for this might be farmers nearer to market tend to focus on market oriented crops compared to wheat crop. In the study area wheat crop is mainly for household consumption and the low commercial level of wheat crop may be associated with local bad market for wheat crop. Besides, there are market constraints with regard to improved wheat varieties. Hence farmers nearer to the market allocate their farm land to other crops. This result is in conflict with the finding of Hassen et al. (2012).

Conclusions

The study was conceived with the objective of examining the rate of adoption of and intensity of use of improved wheat varieties and identifying key factors influencing probability of adoption of improved wheat varieties and intensity of use of improved wheat varieties in two districts of Arsi zone.

Using the double hurdle model the study empirically provides farmers' separate decisions making regarding the adoption and intensity of use of improved wheat varieties. Based on the findings of the study, the following points are recommended to improve farmers' adoption and intensity of use of improved wheat varieties. The fact that there are crosscutting and specific factors implies appropriate policy measures should be designed in promoting technology adoption in wheat.

More emphasis has to be given towards farmers' practical knowledge on improved wheat varieties by arranging farmers' field days and related promotional activities. With respect to credit service, much provision of credit access especially from formal sources directed to the promotion of wheat development would, therefore, be important to advance the adoption of improved wheat varieties. Having the vital role of access to better roads for promoting adoption and productivity gains, the effort of government in providing improved roads infrastructure should be enhanced to achieve increased wheat production and ensure food security.

Improve the intensity of adoption of improved wheat varieties by addressing the resource and information constraints of female-headed households. Additionally, this study recommends further research based on gender oriented by taking more sample of female headed households. Efficient wheat marketing system encourages farmers to allocate more farm lands to improved wheat varieties. In this vein, measures need to be taken to correct input and output market problems of improved wheat varieties especially the provision of an effective improved wheat variety seeds distribution through market, and price information for wheat output market.

Finally, the fact that the majority of the significant variables affected the intensity of use of wheat varieties than the adoption of improved wheat, implies that decision on how much to allocate land (intensity of use) to improved wheat variety is central in adoption of improved wheat varieties. Thus greater attention should be given to creation of access to the varieties by addressing those factors.

Conflict of Interest

The authors have not declared any conflict of interest.

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APPENDICES

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of sex is the same across categories of district.	Independent-Samples Mann-Whitney U Test	.058	Retain the null hypothesis.
2	The distribution of filddaypinf is the same across categories of district.	Independent-Samples Mann-Whitney U Test	.049	Reject the null hypothesis.
3	The distribution of extofcrpinfo2 is the same across categories of district.	Independent-Samples Mann-Whitney U Test	.737	Retain the null hypothesis.
4	The distribution of crdit is the same across categories of district.	Independent-Samples Mann-Whitney U Test	.857	Retain the null hypothesis.
5	The distribution of pnfminc is the same across categories of district.	Independent-Samples Mann-Whitney U Test	.703	Retain the null hypothesis.
6	The distribution of accwtrd is the same across categories of district.	Independent-Samples Mann-Whitney U Test	.390	Retain the null hypothesis.
7	The distribution of rwrite_illitrt is the same across categories of district.	Independent-Samples Mann-Whitney U Test	.632	Retain the null hypothesis.
8	The distribution of prmryjun_illitrt is the same across categories of district.	Independent-Samples Mann-Whitney U Test	.255	Retain the null hypothesis.
9	The distribution of secondtert_illitrt is the same across categories of district.	Independent-Samples Mann-Whitney U Test	1.000	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
10	The distribution of persuitfmw is the same across categories of district.	Independent-Samples Mann-Whitney U Test	.904	Retain the null hypothesis.
11	The distribution of adopsnew3 is the same across categories of district.	Independent-Samples Mann-Whitney U Test	.727	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Appendix 1. Test for homogeniety of variances between the two districts among catagorical variables.

Appendix 2. Test for homogeneity of variances between the two districts among continuous variables.

Independent samples test		Levene's test for equality of variances		t-test for equality of means		
		F	Sig.	t	df	Sig. (2-tailed)
age	Equal variances assumed	4.274	0.040**	-0.487	148	0.627
	Equal variances not assumed			-0.487	140.081	0.627
famsize	Equal variances assumed	1.660	0.200	0.690	148	0.491
	Equal variances not assumed			0.690	142.216	0.491
tlu	Equal variances assumed	3.646	0.058	-2.106	148	0.037
	Equal variances not assumed			-2.106	142.446	0.037
wheatinc	Equal variances assumed	0.124	0.725	-0.318	148	0.751
	Equal variances not assumed			-0.318	142.100	0.751
actvefmfr	Equal variances assumed	0.253	0.616	-0.532	146	0.596
	Equal variances not assumed			-0.532	145.516	0.596
land	Equal variances assumed	0.049	0.825	-1.183	147	0.239
	Equal variances not assumed			-1.184	146.595	0.238
oxen	Equal variances assumed	1.232	0.269	0.145	147	0.885
	Equal variances not assumed			0.145	145.129	0.885
lnfminc1	Equal variances assumed	5.402	0.021**	-1.107	148	0.270
	Equal variances not assumed			-1.107	135.963	0.270
lnassow	Equal variances assumed	0.166	0.684	0.433	148	0.666
	Equal variances not assumed			0.433	146.366	0.666
lnarfbn0	Equal variances assumed	0.008	0.929	-2.247	148	0.026
	Equal variances not assumed			-2.247	147.362	0.026
nowhtplt	Equal variances assumed	0.025	0.874	-1.331	148	0.185
	Equal variances not assumed			-1.331	143.485	0.185
Markt_di	Equal variances assumed	0.077	0.781	0.713	142	0.477
	Equal variances not assumed			0.713	141.947	0.477

Appendix 3. VIF for continuous variables.

Variable	VIF	1/VIF
Oxen	1.69	0.591473
Land	1.69	0.592406
Lnassown	1.44	0.694212
Actvefmfrce	1.43	0.697559
Nowhtplt	1.31	0.762127
Lnfminc	1.21	0.827613
Lnwheat	1.12	0.890789
Famsize	1.11	0.898943
Tlu	1.09	0.919715
Age	1.08	0.926548
Lnarfbn	1.05	0.949842
Mean VIF	1.29	

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Effectiveness of cypermethrin against diamondback moth (*Plutella xylostella* L.) eggs and larvae on cabbage under Botswana conditions

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The efficacy of cypermethrin against the diamondback moth (DBM) on cabbage was studied at Botswana College of Agriculture, Gaborone, Botswana. Using five concentrations of cypermethrin: 1.2, 1.6, 2.0, 2.4 and 2.8 g/L, bioassays were conducted against DBM eggs and second instar larvae at 30±5°C. Each treatment was replicated three times. Probit analysis was used to determine LD_{50} and LD_{90} values for the treatments against eggs and larvae. When the treatments were assessed at 48, 72 and 96 h, LD_{90} values against larvae were 2.01, 1.82 and 1.19 g/L, whereas they were 1.69, 1.63 and 1.40 g/L against eggs. This indicated that cypermethrin was highly effective against both eggs and larvae. The slopes of the probit lines for larvae assessed at 48, 72 and 96 h after application were 0.999, 0.995 and 0.949, while those against eggs were 0.973, 0.961 and 0.945. This indicates a rapid change in mortality with increase in pesticide dosage for both eggs and larvae. The study shows that cypermethrin can still be used to achieve effective control of DBM eggs and larvae under Botswana conditions especially when used in combination with other control methods in an integrated pest management programme.

Key words: Cypermethrin, efficacy, diamondback moth, cabbage.

INTRODUCTION

Cabbage (*Brassica oleracea* var. *capitata* L.) is an extensively grown vegetable in the world (Sances, 2000). It is among the most popular food crops in Botswana households; it grows well in many parts of the country (Bok et al., 2006). However, its production is seriously affected by a wide range of pests including the diamondback moth (*Plutella xylostella* L.), bagrada bug (*Bagrada hiliaris* Burn) and the cabbage aphid (*Brevicoryne brassicae* L.) (Munthali, 2009). The most serious among these is DBM, which has a cosmopolitan distribution; it is believed to be the most universally distributed species among the Lepidoptera; and it occurs wherever brassicas are grown (Talekar and Shelton, 1993). DBM was first recorded as an important pest of cabbage in Southern Africa as early as 1917 (Charleston and Kfir, 2000). It is highly migratory; and its seasonal movements have been well documented (Talekar and Shelton, 1993). Its exceptional pest status is due to

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several factors: The diversity and abundance of host plants, the disruption of its natural enemies, its high reproductive potential (with over 20 generations per year in the tropics), and its genetic elasticity which leads to rapid development of resistance to insecticides (Kahuthia-Gathu et al., 2009; Shelton, 2004). DBM is most destructive in areas where there is frequent application of insecticides. In Botswana and other Southern African countries the control of DBM relies heavily on the use of synthetic insecticides (Talekar et al., 1990). However, it has been demonstrated that DBM quickly develops resistance to many new insecticides (Fahmy and Miyata, 1991; Shelton and Nault, 2004). It has reportedly developed resistance to most synthetic pyrethroids, organophosphates, carbamates, and actinomycetes in many cabbage growing areas of the world (Talekar et al., 1990; Sereda et al., 1997); this represents a serious threat to its effective management.

Cypermethrin is one of the most widely used insecticides in Botswana (Obopile et al., 2008). Like other synthetic pyrethroids, cypermethrin has a chemical structure that is based on natural pyrethrum extracted from flowers of chrysanthenum (Ware and Whitacre, 2004). It is a mixture of eight isomers (USDA, 1995). Cox (1996) reported that cypermethrin was used worldwide to control many pests, including lepidopteran pests of cotton, fruit, and vegetable crops. It affects target insects by disrupting normal functioning of the nervous system (Cox, 1996). Cypermethrin delays the closing of the "gate" that allows the sodium flow along the nerve. This results in multiple nerve impulses instead of the usual single impulse. In turn, these impulses cause the nerve to release the neurotransmitter acetylcholine which stimulates other nerves (Eells, 1992).

Cypermethrin inhibits the γ-aminobutyric acid receptor, causing excitability and convulsions (Cox 1996). It also inhibits calcium uptake by the nerves. Cypermethrin affects the enzyme adenosine triphosphate, which is not directly involved with the nervous system; but is involved in cellular energy production, transport of metal ions and muscle contraction (El-Toukhy and Girgis, 1993).

Although cypermethrin is the most popular insecticide for the control of DBM in Botswana, its broad spectrum characteristic causes mortality of non-target beneficial arthropods in the field; and reduction in invertebrate biodiversity. This loss of biodiversity is undesirable, especially because it can lead to insecticide induced pest resurgence (Hardin et al., 1995).

Farmers chose to use cypermethrin against destructive pests such as DBM because they believe that it provides rapid, effective and economic control. However, the widespread and frequent use exerts a heavy selection pressure on the pest population which has resulted in the development of pest resistance to it (Baek et al., 2010; Furlong et al., 2008). The efficacy of cypermethrin against DBM has not been evaluated in Botswana despite the fact that the pesticide has been used to control the pest for over 10 years. This study evaluated the efficacy of cypermethrin against DBM eggs and larvae under Botswana conditions.

MATERIALS AND METHODS

The experiment was conducted at the Botswana College of Agriculture in Gaborone, Botswana (24° 34' 25''S, 25° 95' 0" E; altitude: 998 m) in cages that were placed in a greenhouse, at an average temperature of 30 ± 5°C. The cabbage seedlings were initially raised in nursery trays and transplanted into small black plastic sleeve pots filled with loam soil; each pot was 12 cm in diameter and 15 cm in depth. Cabbage seedlings at the 5 leaf stage were used to rear the diamond back moth to ensure adequate host substrate for oviposition of eggs by adults. The seedlings were watered regularly adlib to prevent wilting. Nine potted plants were placed in each of six insect rearing cages. Each cage was 45 cm long, 45 cm wide and 40 cm high; it was covered with clear lumite netting of 32 mesh size; this was to prevent pest infestation from natural populations or escape of insects from the artificially infested plants in the cage. Every cage had a door with a sleeve that was used during the watering of plants and their artificial infestation, the application of sprays, feeding of adult insects and the removal of plants at each pest assessment.

Bioassay methods

Cypermethrin; emulsifiable concentrate (Avi-sipermetrin®), registered for use in Botswana, was used in the bioassay experiment. A small hand held trigger sprayer that produced a fine spray of a relatively narrow range of droplet sizes was used to apply spray solutions. Six treatments comprising five cypermethrin concentrations (1.2, 1.6, 2.0, 2.4 and 2.8 g/L water) and distilled water were used. The recommended rate (2.0 g/L) was included as a check. The 6 treatments were arranged in a completely randomized design. Each treatment had nine seedlings. The sprays against eggs were applied when each plant had more than 50 eggs; and those against larvae were made when plants had more than 30 larvae each. Each seedling was sprayed separately. The bioassay was repeated 3 times. This gave a total of 54 treated plants per bioassay and 162 sprayed plants all together. Each pot had a label which indicated the treatment and its date of application. The bioassay was conducted on eggs and second instar larvae (the first instar larvae are leaf miners which are not susceptible to a pesticide with a contact and stomach poison mode of action such as cypermethrin). DBM eggs used in the bioassay were obtained by placing 50 laboratory bred pupae in each of six insect rearing cages that contained 9 potted cabbage seedlings. Adults emerging from the pupae were left to oviposit on the seedlings for 4 days before they were removed from the cages. Each seedling was examined using a hand lens at 10x magnification; the eggs laid on the leaves were counted. The artificially infested seedlings were sprayed with 5 concentrations of the insecticide and water which was the control treatment.

Assessment of egg and larval mortality

As viable DBM eggs take an average of 4 day to hatch at 25±5°C (Chan et al., 2008), treatments against eggs were applied 3 days after oviposition. The eggs oviposited on each plant were counted immediately before application of treatments followed by counts at 48, 72 and 96 h intervals. Egg mortality was determined by comparing the number of eggs prior to application of treatments with numbers found after treatment. The eggs found unhatched after each treatment were considered dead. For larval mortality, the

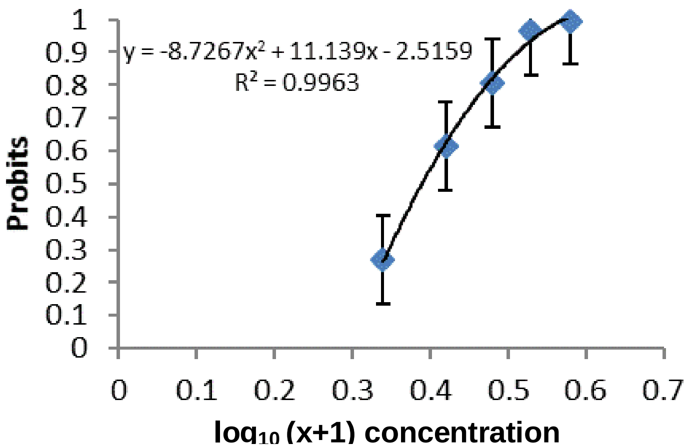

Figure 1. The Probit mortality of DBM larvae 24 h after application of different doses of cypermethrin.

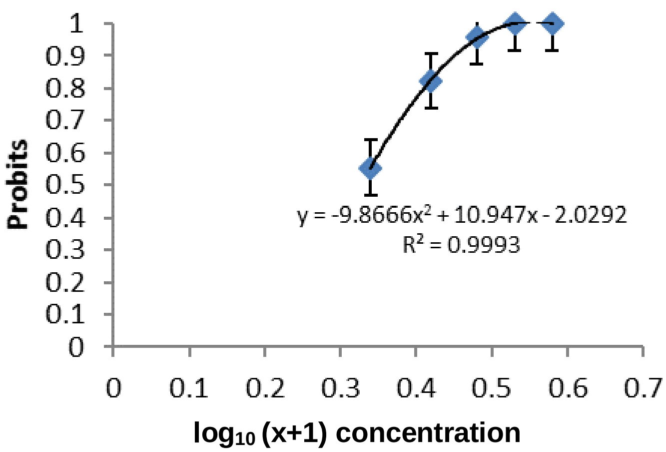

Figure 2. The Probit mortality of DBM larvae 48 h after application of different doses of cypermethrin.

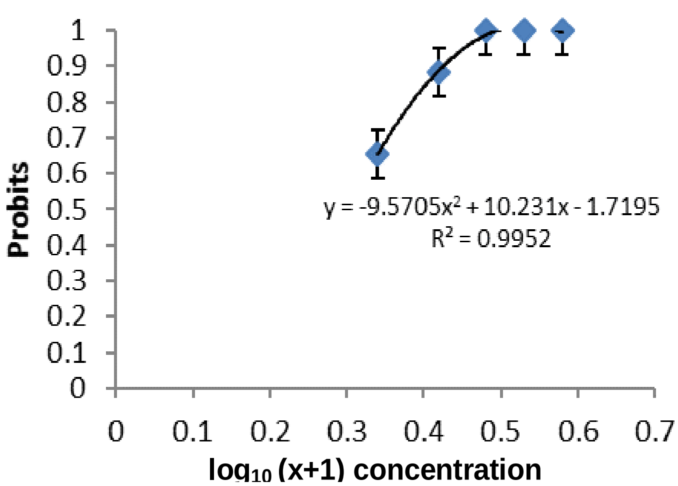

Figure 3. The Probit mortality of DBM larvae 72 h after application of different doses of cypermethrin.

eggs were allowed to hatch into first instars and to develop into second instar larvae; first instar larvae are leaf miners and second instar larvae are surface feeders therefore they were easy to differentiate; these were counted before treatment. The larvae were assessed at intervals of 24, 48, 72, 96, 120 and 144 h after treatment. Any larvae that did not show signs of life after prodding with a needle were counted as dead.

Plant damage assessment

Plant damage assessments in each treatment were conducted 14 days after DBM eggs had hatched. The total number of leaves per plant was recorded; the number of leaves with damage symptoms was counted; and the results were used to calculate the percentage of damaged leaves per plant. The number of windows per leaf for each plant was also recorded and used to estimate the intensity of damage caused per plant. The experiment was repeated 3 times.

Data analysis

Probit analysis (Finney, 1971; Mead and Curnow, 1983) was used to analyse mortality results. The mortality data were transformed to probits while the dosages were transformed to $\log_{10}$ (x+1) before analysis. LD_{50} and LD_{90} values were estimated from the probit lines. Relative susceptibilities of eggs and second instar larvae were compared using LD_{50} values and slopes of probit lines. LD_{90} values were used to compare the mortalities that the recommended dosage caused to the mortalities that were achieved by treatments at different periods of exposure to cypermethrin.

The results on percentage seedling damage were transformed to arcsines before analysis in order to normalize them. Using the MSTATC (1985) statistical package, analysis of variance (ANOVA) was used to analyse the data. Averages were separated using the Tukey's Honestly significant difference test (Zar, 1984) where significant effects were found.

RESULTS

DBM larval mortality

Figures 1 to 4 show positive curvilinear relationships between log dose and probit mortality caused by cypermethrin (correlation coefficients of 0.996, 0.999, 0.995 and 0.949), when treatments were assessed at 24, 48, 72 and 96 h after pesticide application. Figure 1 shows that LD_{50} of 1.50 g/L and LD_{90} of 2.31g/L were achieved 24 h after application. The recommended dose (2.0 g/L) of the pesticide showed a probit value of 0.806 (equivalent to 63.87% larval mortality) during this exposure period. Figure 2 indicates that the LD_{90} of cypermethrin after 48 h exposure was 2.01 g/L. At the recommended dose, cypermethrin only achieved 0.959 on the probit scale, which is equivalent to 78.32% larval mortality. When assessed at 72 h after application, the LD_{90} of cypermethrin was 1.82 g/L (Figure 3). The recommended dosage achieved 1.0 on the probit scale, which is equivalent to 100% larval mortality after 72 h exposure. Figure 4 shows an LD_{90} value of 1.19 g/L when the treatments were assessed at 96 h after application. The mortality achieved by the recommended dose was 1.0 on the probit scale, which is equivalent to 100% larval

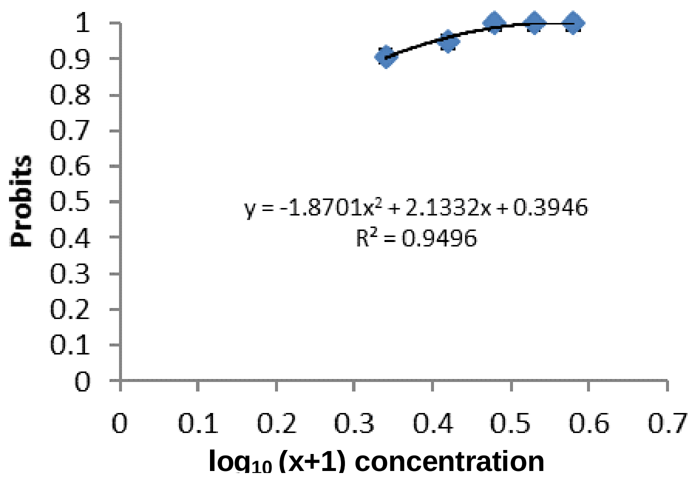

Figure 4. The probit mortality of DBM larvae 96 h after application of different doses of cypermethrin.

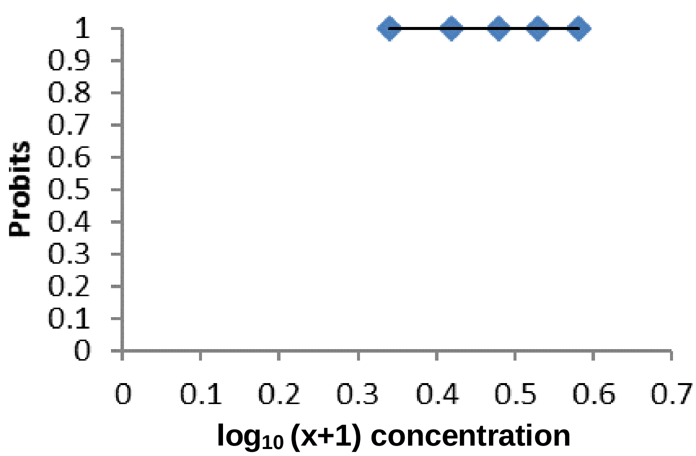

Figure 5. The probit mortality of DBM larvae 120h after application of different doses of cypermethrin.

mortality. Figures 5 and 6 show that when assessed 120 and 144 h after application all cypermethrin concentrations achieved 100% larval mortality.

The results in Table 1 show that both the concentration and the period after pesticide application significantly affected average mortality of DBM larvae per plant (ANOVA, P < 0.05%). The interactions were also significant. The greatest mortality (91.7 to 100.0%) occurred at 120 h after the application of 1.2 and 1.6 g/L concentrations. The recommended dose of 2.0 g/L achieved 91.3% larval mortality during the 72 h assessment period. The results also show that the lowest mortality of 5.0 to 15.0% per plant occurred in the control treatment throughout the assessment period. The overall treatment averages show that cypermethrin concentrations also had a significant (Tukey, P<0.05) effect on the mortality of larvae. The mortalities differed significantly from each other and increased in the order of 11.1 < 67.9 < 77.3 < 89.3 < 95.7 = 96.9% on plants treated with 0.0, 1.2, 1.6, 2.0, 2.4 and 2.8 g/L. The results of overall exposure period were also significantly (Tukey, P<0.05) different, and increased in the order of 53.9 < 65.9 < 71.9 ≤ 77.6 ≤ 82.9 < 85.8 when assessed at 24, 48, 72, 96, 120 and 144 h.

DBM egg mortality

Figures 7 to 9 show a positive curvilinear relationship between the log dose and the mortality of DBM eggs (r values of 0.973, 0.960 and 0.945). The LD_{90} of cypermethrin against eggs was 1.69 g/L when assessed at 48 h (Figure 7). During this period, the recommended dose of 2.0g/L gave a probit value of 1.0, which is equivalent to 100% egg mortality. When assessment was done at 72h, the LD_{90} was 1.63 g/L (Figure 8). The mortality caused by the recommended dose was 1.00 on the probit scale, which is equivalent to 100% egg mortality. The LD_{90} value at 96 h was 1.40 g/L (Figure 9). These results show that the toxicity of cypermethrin to eggs increased with each increase in dosage.

Table 2 shows that the cypermethrin concentration and the period after application significantly affected the average mortality of DBM eggs per plant (ANOVA, P < 0.05%). The interactions were also significant (ANOVA, P<0.05). The greatest egg mortality (100%) occurred on plants which were treated with 2.0 g/L and assessed at 48 h; the lowest egg mortality (60.0%) was on plants treated with 1.2 g/L and assessed at 48 h (Tukey, P,<0.05). The overall treatment averages indicate that concentrations higher than 2.0 g/L caused the greatest mortality (100%) and the lowest concentration (1.2 g/L) caused the least mortality (62.3%). The overall period averages indicate that cyprmethrin caused the greatest mortality (89.8%) when treatments were assessed at 96 h and the lowest mortality (87.9%) when treatments were assessed at 48 h.

DBM damage on cabbage plants

Table 3 shows that damage caused by DBM larvae on plants was significantly (Tukey, P<0.05) affected by the concentration of cypermethrin. DBM larvae caused 79.0% leaf damage on untreated plants; but on plants treated with cypermethrin concentrations of 1.2 and 1.6 g/L the leaf damage caused was 10.3 and 1.7%. DBM larvae on plants treated with the recommended (2.0 g/L) or higher dose did not cause any leaf damage.

DISCUSSION

From the results in Figures 1 to 6 and Tables 1 to 3 several observations can be made: When exposure

Table 1. Effect of cypermethrin concentration and period of exposure on larval mortality.

Period after application (h)	0 g/L	1.2 g/L	1.6 g/L	2.0 g/L	2.4 g/L	2.8 g/L	Overall period averages
24	5.0^{k§}	33.3^{ij}	53.3^{gh}	65.0^{efgh}	80.0^{bcde}	86.7^{abcd}	53.9$^{e¥}$
48	10.0^{k}	50.6^{hi}	66.7^{efg}h	79.3^{bcde}	93.9^{abc}	95.0^{ab}	65.9^{d}
72	11.7^{k}	56.7^{fgh}	72.0^{defg}	91.3^{abcd}	100.0^{a}	100.0^{a}	71.9^{c}
96	11.7^{k}	75.0^{cdef}	79.0^{bcde}	100.0^{a}	100.0^{a}	100.0^{a}	77.6^{bc}
120	13.3^{k}	91.7^{abc}	92.8^{abc}	100.0^{a}	100.0^{a}	100.0^{a}	82.9^{ab}
144	15.0^{jk}	100.0^{a}	100.0^{a}	100.0^{a}	100.0^{a}	100.0^{a}	85.8^{a}
Overall treatment averages	11.1$^{e\$}$	67.9^{d}	77.3^{c}	89.3^{b}	95.7^{a}	96.9^{a}	73

§Interaction averages in the body of the table followed by the same letters are not significantly different (Tukey's Honestly significant difference test (P<0.05). ¥Averages in the column followed by the same letters are not significantly different (Tukey's Honestly significant difference test (P<0.05). $Averages in the row followed by the same letter are not significantly different (Tukey's Honestly significant difference test (P<0.05).

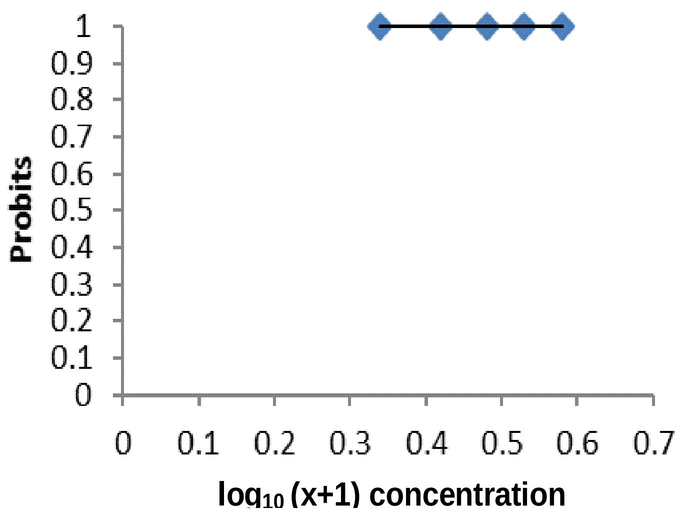

Figure 6. The probit mortality of DBM larvae 144h after application of different doses of cypermethrin.

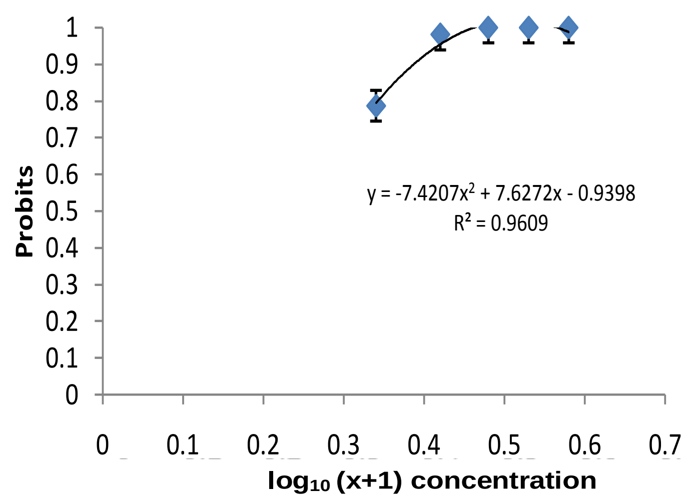

Figure 8. Probit mortality of DBM eggs exposed to different doses of cypermethrin assessed 72 h after expected time of hatching.

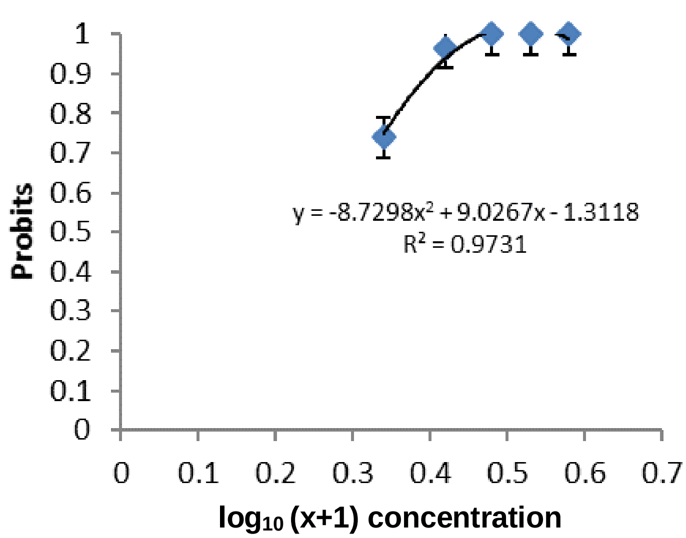

Figure 7. Probit mortality of DBM eggs exposed to different doses of cypermethrin assessed 48 h after expected time of hatching.

periods increased, dosages lower than the recommended dose of cypermethrin were able to cause 90 to 100% larval mortality; the recommended and higher dosages of cypermethrin achieved total protection of the crop from larval damage; when LD_{90}s are used alone to assess the effectiveness of cypermethrin, the mortality level caused by the lowest dose during the 144 h study period, appears to be sufficient to achieve effective control; the level of pest decline was sufficient to significantly (Tukey, $P < 0.05$) reduce crop damage to levels achieved by higher dosages.

The slopes of the probit lines in Figures 1 to 6 shows that only slight increases in the dosage of cypermethrin are needed to cause large increases in mortality of DBM larvae. Cypermethrin provided a rapid pest control per unit concentration of the pesticide. The fact that dosages higher than the recommended dosage of cypermethrin only took 48 h to achieve 90 to 100% mortality shows that higher concentrations can be used to achieve earlier control of DBM larvae. One of the desirable properties of

Table 2. Effect of cypermethrin concentrations and period of exposure on egg mortality.

Period after expected date of hatching (h)	1.2 g/L	1.6 g/L	2.0 g/L	2.4 g/L	2.8 g/L	Overall time averages
48	60.0[d§]	79.0[c]	100.0[a]	100.0[a]	100.0[a]	87.8[b¥]
72	63.0[d]	82.0[bc]	100.0[a]	100.0[a]	100.0[a]	89.0[ab]
96	64.0[d]	85.0[b]	100.0[a]	100.0[a]	100.0[a]	89.8[a]
Overall treatment averages	62.3[c$]	82.0[b]	100.0[a]	100.0[a]	100.0[a]	88.9

[§]Interaction averages in the body of the table followed by the same letters are not significantly different (Tukey's Honestly significant difference test, P<0.05). [¥]Averages in the column followed by the same letters are not significantly different (Tukey's Honestly significant difference test, P<0.05). [$]Averages in the row followed by the same letter are not significantly different (Tukey's Honestly significant difference test, P<0.05).

Table 3. Leaf damage caused by DBM larvae on cabbage plants treated with different cypermethrin dosages.

Cypermethrin concentration	0 g/L	1.2 g/L	1.6 g/L	2 g/L	2.4 g/L	2.8 g/L
Treatment averages	79.0[a§]	10.3[b]	1.7[b]	0.0[b]	0.0[b]	0.0[b]

[§]Averages in the row followed by the same letter are not significantly different (Tukey's Honestly significant difference test, P<0.05).

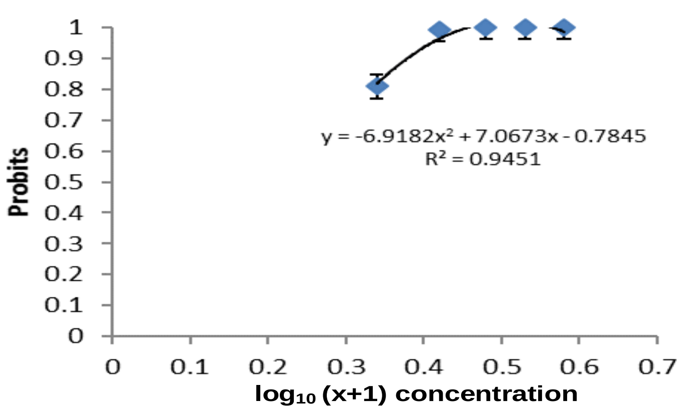

Figure 9. Probit mortality of DBM eggs exposed to different doses of cypermethrin assessed 96h after expected time of hatching.

pyrethroids (including cypermethrin) is that they have a quick knockdown effect (Ware and Whitacre, 2004). The quick knockdown effect can be attributed to the dual mode of action (contact and stomach poison) of cypermethrin (Tomlin, 1994). While DBM eggs can only acquire the lethal dose through contact, larvae can acquire the lethal dose through contact and ingestion of the pesticide material as they feed. This may explain the relatively faster mortality of DBM larvae compared to that of eggs. The fast action of cypermethrin against larvae is a desirable property as this is the damaging developmental stage of the pest.

In this study, the recommended dose achieved 100% egg mortality, when exposed for only 48 h (Figure 7), suggesting that cypermethrin is highly effective against DBM eggs. As cypermethrin is both a contact and stomach poison (Tomlin, 1994), the egg mortalities were due to direct hit or contact with the active ingredient which spread from deposits on the leaf surface to the eggs. The high egg mortality achieved with cypermethrin sprays means that the buildup of larval populations from hatching eggs would be reduced, thereby minimizing subsequent damage by DBM larvae on host plants. Therefore, when using cypermethrin against DBM, the egg is the most susceptible stage to target.

CONCLUSIONS AND RECOMMENDATIONS

The objective of applying insecticides against crop pests at the recommended dose is to ensure the production of large quantities of high quality crop yields by using minimum amounts of active ingredient. It can be concluded from this study that cypermethrin can offer effective control of DBM eggs and larvae and prevent serious damage to cabbage. Lower dosages than those recommended can be used to control DBM, particularly when applications target the egg stage and when long exposure periods are allowed. Since the population in this study did not show any signs of cypermethrin resistance, it is recommended that the use of cypermethrin for the control of DBM in Botswana should continue. However, lower dosages need to be evaluated to validate their effectiveness under field conditions. Reduction in dosages would result in reduction in cost of controlling DBM by farmers and slow down the development of resistance in subsequent populations.

Conflict of Interest

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

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Full Length Research Paper

Effect of agronomic practices on growth, dry matter and yield of Rajmash (*Phaseolus Vulgaris* L.)

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Rajmash (*Phaseolus vulgaris* L.) is an important cash crop widely grown under temperate and subtropical regions. Being a pulse crop it is good substitute of vegetables. To sustain the productivity of such a wonder crop and fulfill the nutritional demand of the ever growing population under changing climate it is necessary to apply integrated agronomic approaches. Integrated management of agronomic practices plays a significant role in the proper growth and development of crops. To test this hypothesis, a field experiment was conducted using Rajmash as a test crop during two consecutive years that is, 2008-2009 and 2009-2010. The experiment was designed using split plot technique. Method of sowing (flat and raised bed) and moisture regime (0.6, 0.8 and 1.0 IW/CPE) was the main plot factor and four nutrient supply systems that is, 100% recommended dose of Nitrogen (NPK) fertilizer – RDF [120:60:40 kg /ha supplied through standard grade Urea (46%N), DAP (46 and 18% P & N) and], 75% RDF +25% through FYM, 75% RDF + 25% by Biocompost and 75% through NPK + 25% N by Azotobactor was taken as sub plot. A total of 24 treatment combinations were replicated three times. Various growth parameters e.g. plant height (cm), number of branches per plant and leaf area index (%), dry matter accumulation (g/plant) at 30, 60, and 90 and at harvest stage as well as grain and straw yield were recorded. Raised bed technique of sowing with moisture regime of 1.0 IW/CPE along with 75% RDNF+25 % N through bio-compost was found most suitable in term of highest total dry matter production. This increase was positively attributed by significant increase in plant height, number of branches per plant and leaf area index of crop. Application of 100% RDNF increased the seed and straw yield significantly in first year while during second year it was maximum, 23.5 q/ha with the application of 75% RDF + 25% N through bio compost and followed by 100% RDF NPK. Minimum seed and straw yields were obtained under 75% RDF + Azotobactor during both the years while highest values were recorded at F_3 and 1.0 IW/CPE ratio. Highest disparity in plant height and leaf area index, under various treatment combinations was recorded at 60 days after sowing of crop.

Key words: Sowing methods, nutrient supply system, moisture regime, food security.

INTRODUCTION

Meeting food demand for the burgeoning population has become a major challenge over entire Asian continent. Agriculture is in the forefront of national and international agenda to assume food security and sound management of natural resource. The challenge to world agriculture is immense. The ever mounting magnitude of the predicted climate change and ever increasing population pressure on future food security have created a major concern for policy makers and scientific community. Agriculture is really suffering due to technological advances because most of the technologies developed are limited only to the laboratory. Prime aim of this research is to find out sustainable agronomic techniques that can improve the production potential without much impairing our natural resources.

Rajmash is famous in the world by its different names viz. in forms of vegetable it is named as French bean, common bean, snap bean and green bean where as in form of pulse it is famous as haricot bean, dry bean, *Rajmash* and navy bean. In Maharashtra region of India it is commonly known as *Shravan* and in Orissa region it is known as *Ghevada* (Singh et al., 1996). Most commonly cultivated *Rajmash* is of two types namely the pole or climber type and the bush or dwarf type. It has very high nutritional value containing 20.69 to 25.81% crude protein, 1.72% fats, 72.42% carbohydrates and 5.83 mg of iron. Moreover, it has good amount of ash content, crude fiber, and total sugars. It is rich in amino acids like tryptophan, methionine, and some phenolic compounds like tannin and polyphenol oxidase (Sood et al., 2003). *Rajmash* is being conventionally cultivated as a mixed crop in the hilly tract of north eastern region of the country. With the improved agronomic practices and application of biotechnical approaches, it could be possible to grow this crop successfully in plains during the winter season. After the development of suitable varieties, the crop has become a major cash crop for the farmers of Gangatic Plain Zone. It has a great potential and will be a good crop to mitigate the nutritional requirement of the increasing population under adverse climatic conditions. From the last two decades, per capita availability of pulses has been progressively declined. Introduction of new pulse crop in non-traditional areas and high yielding varieties as well as intensive techniques, offers possibilities for increasing pulse production. Research workers in India and abroad have found positive response of *Rajmash* to major and minor plant nutrients, sowing time, irrigation and pot culture experiments (Ahlawat, 1996). Though various technological evidences have been carried out after the green revolution but the work is out of reach of the farmer due to inefficient extension services and lack of awareness. No doubt, the crop is one of the most nutritious vegetable but has a total production of only 18 million tones worldwide (provide citation here). Farmers are growing the crop in marginal land with poor management practices and this is one of the reasons for low productivity. Proper management of nutrients and water is one of the prime concerns for the successful cultivation of the crop. Proper seeding technology is also an important factor that decides the plant population which directly affects the total production.

To understand the growth habit under different environmental situations, the plant ideotype is a significant aspect. It is a fact that similar species can behave in different manner under different ideotypic situation. Due to this reason the search for better and more efficient techniques of planting to exploit the full potential of crop has become crucial for agronomists. Selection of proper sowing method plays a very important role to provide favorable condition like placement of seed for their proper germination and subsequent growth. Sowing pattern may depend upon different parameters based on the availability of resources such as soil water, type of soil, time of sowing, environmental condition (Reddy et al., 2010). Irrigation and proper supply of nutrients are important parameters for better growth and development of the crop. It is well know that Pulses are more susceptible to water as compare to other crops. One has to know the amount and stage of irrigation which would be profitable both in term of crop yield and sustainable management of natural resources. In area subjected with water stress, land may not be the limiting factor but in case of water it will be demanding in future. Under those circumstances total return per unit of water is more profitable as compare to return per unit of land (Pereira et al., 2002). Poor management of water resources or irrigation has negative impact on both soil as well as the crop (Kar et al., 2007). Excessive irrigation may cause imbalance in nutrient uptake from field and delays in maturity (Zwart et al., 2004), loss of soil nutrient in the form of leaching and percolation (Jiajie et al., 2013), under stress situation reduces cell division; cell elongation and growth of cell (Kramer, 1972). To maximize return per unit of water application, irrigation should be based on crop demand (Allen et al., 1998). Proper scheduling of irrigation in the context of changing climate helps to improve growth and development of the crop and to maximize yield and minimize input requirement which is more important for the economy of a developing country like India. Integrated nutrient management plays a key role in sustaining soil fertility and crop productivity as well as minimizing the risk of climate change. Improper amount of nutrient supply in crop cause malnourishing or under-nourishing that reduces the production of crop, even all the practices are adopted in appropriate manner (Rajput et al., 2006). Proper amount and method of fertilizer application is far from efficient management in agriculture due to lack of proper awareness that are also main constraint to obtain

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maximum productivity (Patra et al., 2000). Efficient supply system of nutrients aims to use nutrients to target yield depend upon soil and climatic situation. Proper understanding of correlation of various nutrients with each other and combination of minerals and organic fertilizer is necessary to minimize the need of chemical fertilizers. A proper nutrient management will conserve the natural resources by reducing runoff and loss of nutrient from soil. That will help to maintain the sustainable equilibrium within the ecosystem.

The effect of planting methods should be assessed under varying environmental conditions and management practices before the development of appropriate package of technology. Hence, the study has been carried out to find the suitable method of sowing, moisture regime and nutrient supply system for *Rajmash*. Moreover, to study the interaction effect of sowing method, moisture regime and nutrient supply system for different treatments.

MATERIALS AND METHODS

Description of the experimental site

The experiment was conducted at the Agronomy Research farm of the Narendra Deva University of Agriculture and Technology, Narendra Nagar, Kumarganj, Faizabad (U.P.) during Rabi seasons of 2008-2009 and 2009-2010. The experimental site is situated at 26.47°N latitude, 82.120E longitude on altitude of 320 meter. Study site comes under subtropical zone the average rainfall is 1120 mm and temperature varies from 3°C (January) to 41°C (May). It is at a distance of about 42 km from Faizabad district headquarters. The soil of experimental site was clay loam with alkaline pH of 8.1 but the availability of NPK is quite well that is, 105.40, 16.80 and 240.60 kg respectively.

Experimental design and agronomic operations

The split-split-plot experimental design used to test the crop performance with two levels of sowing methods (a). Flat bed [M_1] and (b) Raised bed [M_2] and three moisture regime levels (a) Irrigation at 0.6 IW/CPE [I_1] (b) Irrigation at 0.8 IW/CPE [I_2] (c) Irrigation at 1.0 IW/CPE [I_3] in as main plots and four levels of nutrient supply system (a) 100% Recommended Dose of Fertilizer (RDF) N.P.K [F_1] (b) 75% N.P.K+25% N through F.Y.M [F_2] (c) 75% N.P.K+25% N through Biocompost [F_3] and (d) 75% N.P.K+ 25% N through Azotobactor [F_4] in sub plot. Irrigation was applied only when the IW/CPE ratio value was (i) 0.6 (ii) 0.8 and (iii) 1.0 each treatment combination was replicated thrice and distributed randomly to minimize the error difference between the plots. Each treatment combination was repeated in same way in both years.

After harvest of previous crop, the experimental field was ploughed once with soil turning plough and crossed harrowed. After each operation, leveling was done to obtain the fine tilth. Finally layout was done and plots were marked by small sticks and rope in each block. Total 72 plot with the gross area of 15 m^2 (5x3 m) and net plot size was 10.40 m^2 (4 x 2.60 m) was used to sown the crop. The variety Amber was used as test crop which was the selection of germplasm entry “EC 94457” and was developed at Indian Institute of Pulse Research (IIPR) Kanpur by the concerted efforts of IIPR and All India Co-ordinated Pulse Improvement Project which identified and release in 2006. One hundred seed of Rajmash were tested to know the germination percentage. Germination test was done under laboratory conditions using germination test paper, 92% germination was recorded. After making individual experimental plots, the amount of fertilizer was applied uniformly through urea, single super phosphate, and muriate of potash. One third dose of nitrogen and total phosphorous and potash were applied as basal application. Remaining dose of nitrogen was applied as top dressing in two equal doses each at branching and flowering stage, respectively. Treatment wise urea, single super phosphate and muriate of potash were applied as basal. The seed were sown about 5 to 6 cm deep in rows as per treatment with the help of *kudal* (a hand drawn tillage equipment) at 125 kg/ha and planking was done after sowing. The crop was sown on 23 and 14 November in 2008-2009 and 2009-2010 respectively. One hand weeding was done with the help of Khurpi (state what this is here) before first irrigation. Harvesting was done at physiological maturity when pods turned straw yellow. Harvesting of each plot was done and the net plot size was obtained by leaving 0.50 m at both side in length and 0.60 m at each side in width. The harvested produce was brought to threshing floor after proper tagging. The bundle of harvested produce of each net plot was weighed after complete drying in the sun. The threshing was done manually. The yield and moisture content of grain and straw were recorded. Grain yield was converted at 14% moisture content and straw at oven dry weight basis. Irrigation was scheduled on the basis of IW/CPE ratios.

$$I = \frac{IW}{CPE}$$

Where, I= Irrigation scheduling; IW= Depth of irrigation (cm); CPE= Cumulative pan evaporation.

Volumetric method was applied to measure the irrigation water (m^3/sec.), on the basis of which time required for each plot for irrigation with 6 cm depth was calculated. Time of irrigation given as per treatment which was worked out on the basis of formula given as under:

$$T_a = \frac{AD}{Q}$$

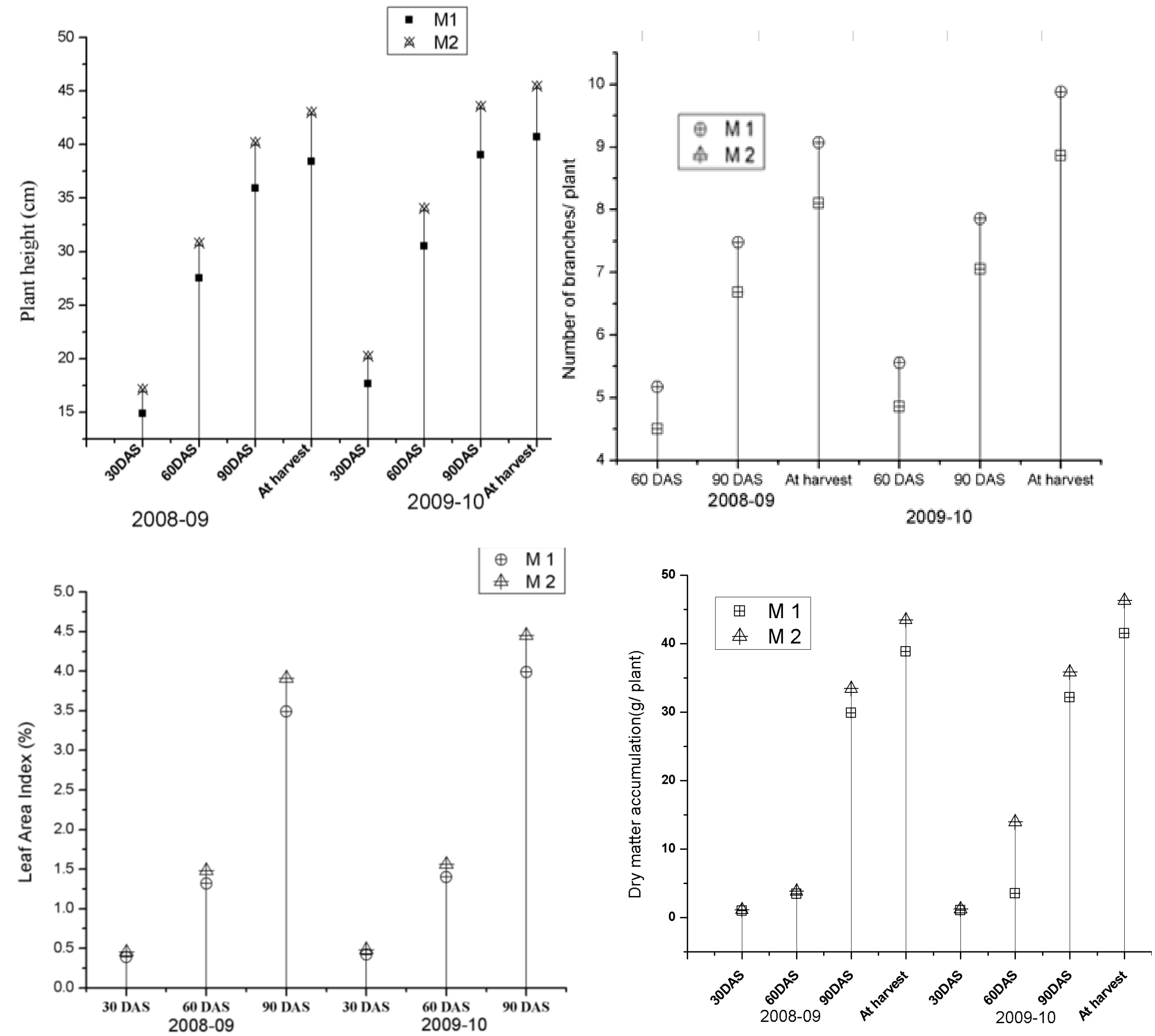
Where, T_a = time of application of water (seconds); A = area of plot to be irrigated ($m^{2)}$; D = depth of water to be provided (mm) Q = discharge liters/sec.

Discharge was measured with the help of parshall flume, which was installed in the irrigation channel as per method described by Parshall (1941). Statistical differences between different planting methods, moisture regime and nutrient supply system levels and their interaction effects on plant height, number of branches/plant, LAI and total dry matter accumulation were tested with Fisher’s least significant difference (p=0.05) test (Fisher and Yates, 1949) using analysis of variance (ANOVA) for a split plot design as described by Panse and Sukhatme (1967). All the statistical analyses were done by using SPSS 8.0 and graphs were prepared with Origin plot 8.0.

RESULTS AND DISCUSSION

Plant height

A cursory glance over the data of plant height revealed that the rate of growth was initially slow and attained maximum between 30 to 90 DAS that may be considered as grand growth phase. Thereafter, it increased with



M_1-Flat bed; M_2-Raised bed

Figure 1. Number of primary branches/plant, Leaf Area Index (%), Plant height (cm), Dry matter accumulation (g/plant) at various growth stages of Rajmash crop as affected by planting methods.

relatively slow rate. A significant difference (p=0.05) in plant height was found under raised and flat bed sowing (Figure 1 and Table 1).

Maximum plant height was observed at 30, 60, 90 DAS and at harvest. During both years increase in plant height was observed under raised bed because of full utilization of applied water that enhances water use efficiency and also due to the elimination of the crust form below root zone that improves physical property of soil (Fahong et al., 2004). Different moisture regimes did not affect the plant height at 30 DAS in 2008-2009 season while it influenced the height significantly at 90 DAS and at harvest in both year (Figure 1). Moisture regimes of 1.0 IW/CPE performed significantly better than 0.6 IW/CPE and at par with 0.8 IW/CPE. This is most probably due to increase in root proliferation resulting in increase in uptake of nutrients which translated into higher crop growth (Sarkar, 2005). In case of nutrient supply system, the maximum plant height was observed under F_1 (100% RDF NPK) although the differences in plant height at 30 DAS were not significant in 2008-2009 (Figure 1). In year 2009-2010 highest plant height was recorded under F_3 (75% RDF + 25% N through bio-compost) this was significantly higher with F_2 and F_3 and at par with F_1.addition of bio-compost enhanced nutrient uptake mainly NPK resulting in increase in plant height

Table 1. Analysis of variance for different parameters at 90 DAS.

Parameter	Source of variation							
	Years	**M**	**I**	**M X I**	**F**	**M X F**	**I X F**	**M X I X F**
Seed yield (q/ha)	2008-2009	**	***	ns	**	ns	*	ns
	2009-2010	**	***	*	**	ns	**	ns
Straw yield (q/ha)	2008-2009	**	***	ns	***	ns	ns	ns
	2009-2010	*	***	ns	**	ns	ns	ns
Plant height (cm) at 90 DAS	2008-2009	**	*	ns	***	ns	ns	ns
	2009-2010	**	*	ns	***	ns	ns	ns
Number of branches per plant at 90 DAS	2008-2009	**	**	ns	***	ns	ns	ns
	2009-2010	ns	ns	ns	ns	ns	ns	ns
LAI at 90 DAS	2008-2009	***	**	ns	***	ns	ns	ns
	2009-2010	***	**	ns	***	ns	ns	ns
Dry matter accumulation (g/plant) at 90 DAS	2008-2009	***	**	ns	**	ns	ns	ns
	2009-2010	***	**	ns	**	ns	ns	ns

Where , M= Methods of Sowing, I= Moisture regieme and F = Fertilizer management

(Adesemoye et al., 2008).

Number of branches per plants

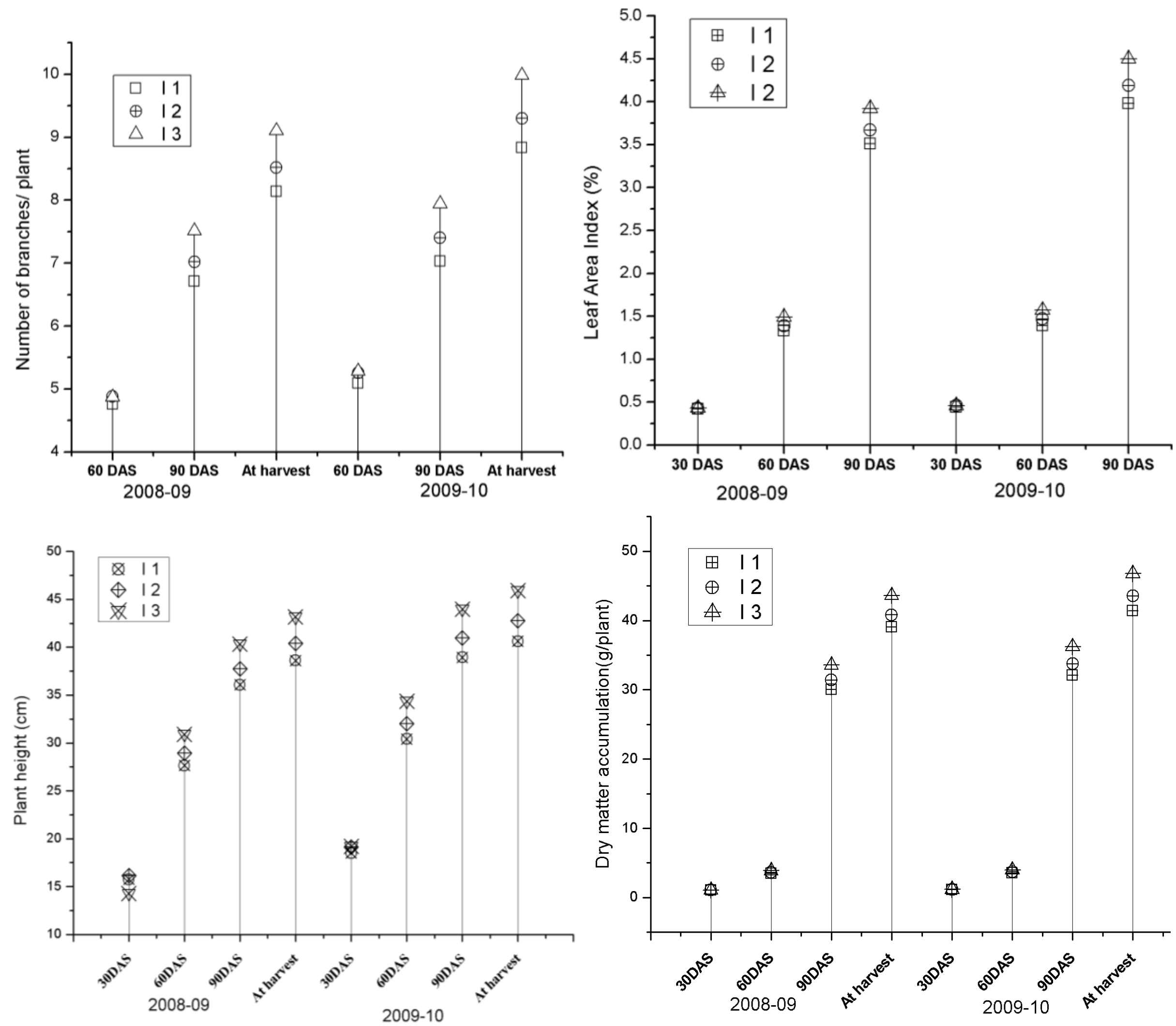
The data with respect to number of branches plant^{-1} as influenced by sowing methods, moisture regimes and nutrient supply systems are presented in Figure 1. The data indicated that the significantly higher number of branches plant^{-1} was recorded under raised bed sowing as compared to flatbed sowing at 60, 90, DAS and at harvest (Table 1). Similar trend was observed during second year of experimentation at 60, 90 DAS and at harvest. This might be due to favorable conditions provided by raised bed technique by improving emergence and reducing soil resistance (providing better tilth to germinate the plant) (Valenciano et al., 2006). The various moisture regimes did not affect the number of branches/ plant at 60 and 90 DAS during first year while at harvest significantly more branches plant^{-1} were observed under 1.0 IW/ CPE as compared to 0.6 and 0.8 IW/CPE (Figure 3).

In case of nutrient supply system, significantly higher number of branches were observed with (100% RDF NPK) as compared to F_2 (75% RDF NPK + 25% N through FYM) and F_4 (75% RDF NPK + Azotobactor) and was at par with F_3 at all the growth stages in year 2008-2009 while in the second year maximum branches were recorded under F_3 (75% RDF NPK + 25% N through biocompost) as compared to F_2 (75% RDF NPK + 25% N through FYM) and F_4 (75% RDF NPK + Azotobactor) and at par with F_1 (100% RDF NPK) at all the growth stages (60, 90 DAS and at harvest) (Figure 3). This might be due to increase in decomposition of nitrogenous fertilizer which enhances the rate of cell division resulting in more branches (Phiri et al., 2000).

Leaf area index (%)

The periodic data on leaf area index (LAI) have been presented in Figure 2. A cursory glance over the data indicated that leaf area index was increased up to 90 DAS stage because up to that period plant is in active growth phase (Sinclair, 1994) after that it enters into senescence phase.

In case of planting pattern higher leaf area index was recorded at 30 DAS in both the year under raised bed sowing as compared to flatbed sowing because of improvement in translocation of nutrient and water in raised bed (Sardana et al., 2000). The various moisture regimes did not influence the leaf area index at 30 DAS during both years. Significantly higher leaf area index was recorded with the moisture regime of 1.0 as compared that 0.6 and 0.8 IW/CPE at 60 and 90 DAS in both years (Figure 2 and Table 1). The various nutrient supply systems did not affect the LAI at 30 DAS during both years of investigation. At 60 and 90 DAS significantly higher LAI was recorded under treatment F3 (100% RDF NPK through chemical fertilizers) and this was significantly higher than that recorded under F_2 and F_4 and at par with F_1 (Figure 3). Raised bed technique



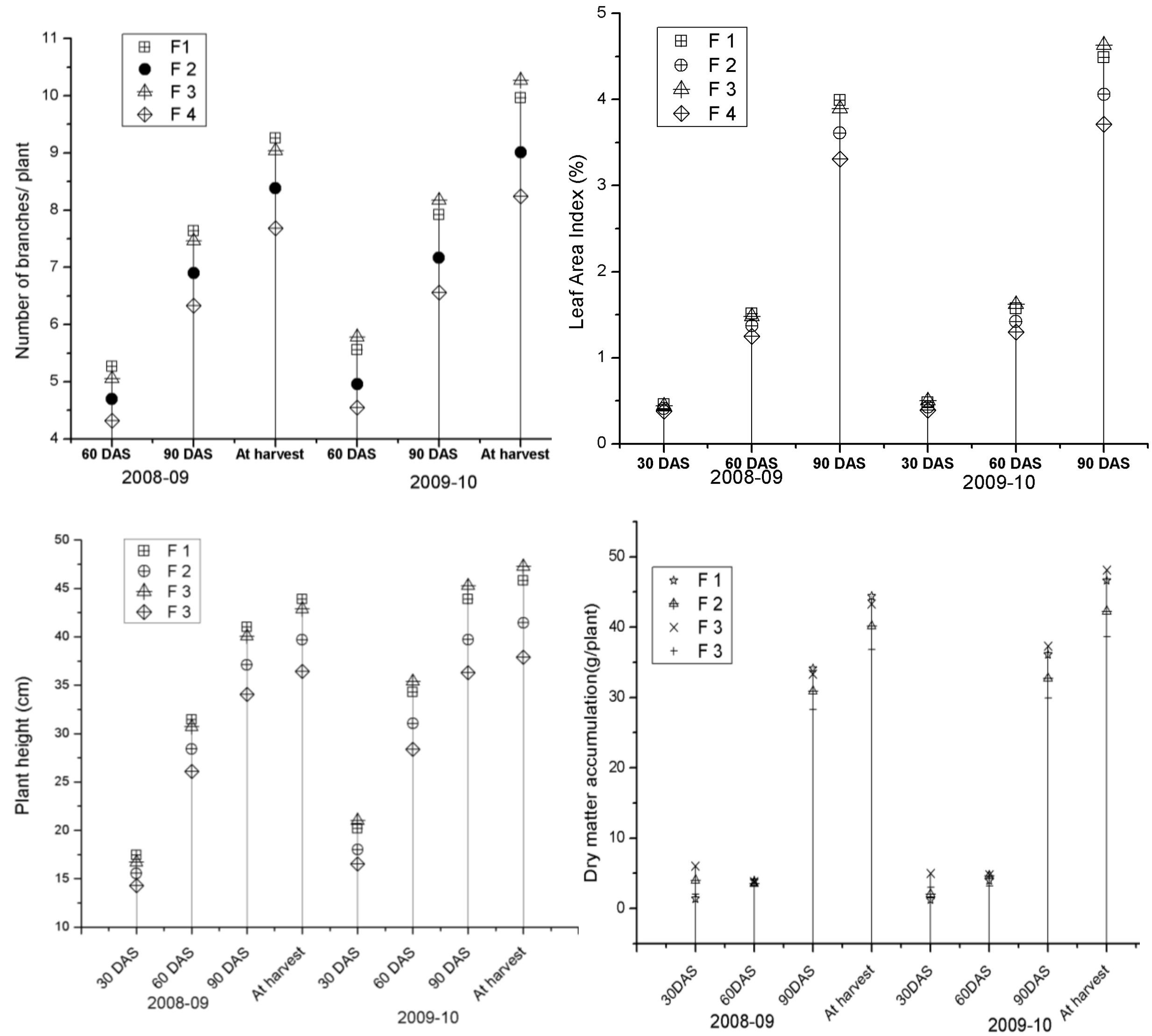
I_1 - 0.6 IW/CPE; I_2 - 0.8 IW/CPE and I_3 -1.0 IW/CPE

Figure 2. Number of primary branches/plant, Leaf Area Index (%), Plant height (cm), Dry matter accumulation (g/plant) at various growth stages of Rajmash crop as affected by Moisture regime IW/CPE.

under efficient supply of water and proper nutrient management improve the root growth of plant which enhances leaf area duration as well as size of leaf this might be reason for highest LAI (Kundu and Sarkar, 2009).

Dry mater accumulation

Analogous to growth character, the dry matter production increased with the age of crop (Kiziloglu et al., 2010) increased rate in dry matter content was noticed between 60 to 90 DAS closely followed by 30 to 60 DAS indicated that the active growth period prolonged between 30 to 90 DAS while highest value was observed at harvest. The higher dry matter accumulation was noticed with raised sowing as compared to flat bed at 60, 90 DAS and at harvest stages of crop growth (Figure 3) in both years while at 30 DAS the value was not significant for the year 2008-2009 due to poor establishment of seedlings. A cursory glance over the data presented in Figure 3 revealed that moisture regime affected the dry matter accumulation from initial stages of growth till harvest. The differences between successive levels of moisture were significant at all the growth stages of crop except at 30 DAS. Maximum dry matter production was noticed under 1.0 IW/CPE (43.62) which was 19 and 10% higher than those obtained under 0.6 and 0.8 IW/CPE ratios in both years (Figure 3). This might be due to improvement in physiological processes



F$_1$-100% RDF, N.P.K; **F$_2$**-75% N.P.K+25% through F.Y.M; **F$_3$**-75% N.P.K+25% through Biocompost and **F$_4$**-75% N.P.K+25% through Azotobactor

Figure 3. Number of primary branches/plant, Leaf Area Index (%), Plant height (cm), Dry matter accumulation (g/plant) at various growth stages of Rajmash crop as affected by Nutrient supply system.

in the plant that are directly responsible for increase in dry matter production in the plant (Lu et al., 2000). Different fertility levels did not influence dry matter accumulation per plant at 30 DAS, significantly probably due to less absorption of nutrient during early stage and low radiation use efficiency (Cirilo and Andrade, 1994) but at 60, 90 DAS and at harvest the maximum dry matter accumulation was recorded under F_1 (100% RDF NPK) as compared to F_2 (75% RDF NPK +25% N through FYM) and F_4 (75% RDF NPK + Azotobactor) and at par with F_3 (75% RDF NPK + 25% N through biocompost). A similar trend in dry matter accumulation was observed for next year (Figure 3).

Seed, straw and biological yield

The data on seed and straw yields obtained as influenced by sowing methods moisture regimes and nutrient supply system have been given in Table 2. An examination of data manifests that sowing methods had significant impact (Table 1) on seed yield of Rajmash. The more seed yield of 30.22 q/ha was obtained under raised bed sowing than that obtained under flat bed sowing (27.36 q/ha) respectively. During next year the same trend was also found. Moisture had significant impact on seed yield of *Rajmash* with increasing moisture supply from 0.6 to 1.0 IW/CPE. The maximum seed yield of (23.05 q/ha)

Table 2. Seed Yield, straw yield and biological yield as influenced by sowing methods, moisture regimes and nutrient supply system.

Treatment	2008-2009			2009-2010		
	Seed Yield (q/ha)	Straw yield (q/ha)	Biological yield (q/ha)	Seed Yield (q/ha)	Straw yield (q/ha)	Biological yield (q/ha)
Sowing methods						
M_1-Flat bed	20.77	27.36	42.31	21.1	28.86	42.31
M_2-Raised bed	21.74	30.22	41.43	22.5	31.08	42.17
SEM±	0.31	0.4	0.2	0.4	0.62	0.13
CD AT 5%	0.97	1.25	0.63	1.26	1.94	0.41
Moisture regime IW/CPE						
I_1 - 0.6 IW/CPE	18.38	22.07	44.76	17.12	22.71	43.05
I_2 - 0.6 IW/CPE	22.33	30.85	40.45	23.86	33.05	41.97
I_3- 0.6 IW/CPE	23.05	33.45	40.41	24.43	34.15	41.69
SEM±	0.38	0.49	0.25	0.49	0.75	0.16
CD AT 5%	1.19	1.53	0.77	1.54	2.37	0.5
Nutrient supply system						
F_1-100% RDF, N.P.K	20.71	31.02	41.7	23.03	31.34	42.39
F_2-75% N.P.K+25% Through F.Y.M	22.25	29	41.97	21.03	29.05	42.01
F_3-75% N.P.K+25% Through Biocompost	19.67	29.84	40	23.5	33.67	40.9
F_4-75% N.P.K+25% Through Azotobacter	0.34	25.31	43.82	19.66	25.85	43.66
SEM±	0.97	0.5	0.61	0.44	0.74	0.58
CD AT 5%		1.44	1.75	1.26	2.11	1.67

was credited under wettest moisture regimes of 1.0 IW/CPE followed by 0.8 IW/CPE (22.33 q/ha) and minimum seed yield (18.38 q/ha) was recorded at 0.6 IW/CPE (Driest regimes). Wettest moisture regime (1.0 IW/CPE) registered significant increase than 0.6 IW/CPE and at par with 0.8 IW/CPE and this is 45.25 and 14.34% higher than those of 0.6 and 0.8 IW/CPE, respectively. In next year same trend was found. Different nutrient supply systems influenced the seed yield of *Rajmash* significantly. It increased significantly due to nutrients supply system under F_1 (100% RDF NPK) (22.38 q/ha) as compared to F_2 (75% RDF NPK + 25% N through FYM) and F_4 (75% RDF NPK + azotobacter) and at par with treatment F_3 (75% RDF NPK +25% N through bio-compost) respectively. While in next year the maximum seed yield was recorded under F_3 (75% RDF NPK + 25% N through biocompost) (23.50 q/ha) which was significantly higher than that recorded under F_2 and F_1 and at par with F_1 (100% RDF NPK) respectively.

Conclusion

Set of data presented in the study revealed that in case of sowing methods significant increase in plant height, number of branches plant^{-1} leaf area index as well as dry matter accumulation were observed with raised bed sowing method due to improvement in root proliferation and proper uptake of nutrient and water from soil. While in case of various moisture regimes significant increase in plant height, number of primary and secondary branches per plant, leaf area index as well as dry matter accumulation was observed with increasing levels of moisture. The wettest moisture regime (0.1 IW/CPE) exhibited its superiority with recording highest values of almost all the growth parameters. In case of different nutrient supply systems application of 100% RDF, NPK increased the plant height, number of primary and secondary branches per plant, leaf area index, total dry matter production, significantly at all the growth stages. While during second year all the above parameters recorded highest values at application rates of 75% RDF NPK + 25% N through bio-compost. Adequate moisture supply favorably increased the response of different nutrient supply systems in terms of growth and biomass production. The highest values of all the growth and yield parameters were recorded at F_3 and 1.0 IW/CPE ratio while the minimum values were noticed under the driest moisture regime (0.6 IW/CPE) with F_4. Finally it has been concluded that the maximum value of all the parameter was observed under raised bed planting method with moisture regime of 1.0 IW/CPE along and nutrient supply system of 75% RDF (120, 60, 40 NPK) + 25% N through bio compost. Thus it is to be considered as best combination of agronomic practices for the successful cultivation of *Rajmash* in plains of Uttar Pradesh, India.

Conflict of Interest

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

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Review

Success factors for sustainable irrigation development in Sub-Saharan Africa

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Majority of farming in sub-Saharan Africa depend solely on rainfall for food production. This results in low productivity and famine, especially during the dry season when there is little or no rainfall. Owing to its far reaching benefits, irrigation systems have been identified and adopted globally as a key approach to addressing agricultural water challenges. However, the annual growth rate of irrigation systems in sub-Saharan Africa, particularly large-scale public schemes, has rather decreased since the late 1970s and currently at 2%, is the slowest in the world. This study examines the factors that influence its development. Secure access to land and water, efficient technologies, stable input/output markets, favorable policies, effective institutions and reliable farmer support environment were identified as vital factors for sustainable irrigation development in the region. A suitable relationship was developed between these factors as a chain of shackles with the chain as strong as the weakest shackle. This theory has been tested on some irrigation systems across sub-Saharan Africa with various degrees of success, and has proven to reveal the sources of success and failure. In the reviewed cases, the weakest factors were secure access to land and water, effective institutions and favorable policies.

Key words: Sustainable irrigation development, sub-Saharan Africa, factors affecting growth, irrigation systems.

INTRODUCTION

Irrigated agriculture has been a major solution to the water challenges affecting food production in areas with unreliable rainfall patterns. Historically, irrigation had a large positive impact on poverty reduction in both rural and urban areas, producing relatively cheap food and providing employment opportunities for the landless poor (Hussain, 2005). Irrigation produces secondary benefits for the economy at all levels; increased productivity of rural labour, promotion of local agro-enterprises, and stimulation of the agricultural sector as a whole (Faurès et al., 2007).

Investments in irrigation development in sub-Saharan Africa have been driven by government policies, multinational donor agencies, private investors, markets, technology and innovations. As a result, several types of irrigation systems have been introduced in sub-Saharan

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Africa over time. This study reviews the scientific and professional literature on irrigation development in sub-Saharan Africa by looking at the trends of irrigation, the challenges facing irrigation development and analyses factors that have contributed to successful irrigation development in sub-Saharan Africa.

The aim is to gain an improved understanding of the conditions under which irrigation development is successful and sustainable in sub-Saharan Africa, based on existing literature and publications.

TREND OF IRRIGATION DEVELOPMENT IN SUB-SAHARAN AFRICA

The last 50 years have seen massive investments in large-scale public surface-irrigation infrastructure as part of a global effort to rapidly increase staple food production and avoid devastating famine. Investment in irrigation accelerated in the 1960s and 1970s, with area expansion in developing countries at 2.2% per year reaching 155 Mha in 1982 (Carruthers et al., 1997). According to Rosegrant and Svendsen (1993) and Kikuchi et al. (2002), unprecedented high food prices during the two food crises in the 1970s induced huge irrigation investments in developing countries as shown in Figure 1.

The decline in annual growth rate for irrigation development as reported by Faurès et al.(2007) has been attributed to underperformance (Chambers, 1988), reduced donor interest (Merrey et al, 1997), concerns over negative social and environmental impacts, changes in competing water uses, and declining cereal prices. These factors have slowed growth in input use and investment in infrastructure (Rosegrant and Svendsen, 1993; Carruthers et al., 1997). In view of the above mentioned factors, more rehabilitation projects of large-scale irrigation schemes were implemented by governments and international donors during the late 1970s (Innocencio et al., 2007).

The advent of affordable drilling and pumping technologies in India and Pakistan in the mid-1980s, led to rapid development of shallow tube-wells and conjunctive use of surface and groundwater (Shah, 1993; Palmer and Mandal, 1987). These technologies were successfully applied in private development of groundwater irrigation when public and international donor funding declined in the 1990s in sub-Saharan Africa. This development has spread in rural, urban and peri-urban areas in response to higher demand for fresh fruits and vegetables by growing cities (FAO, 2005).

Various studies conducted on the scale of development of irrigation in Sub-Saharan Africa give different figures of irrigated areas. According to FAO (1995a), the sub-region has an irrigation potential of approximately 42 Mha out of which, only 13.33% (5.6 Mha) is actually irrigated. More recent data from FAO shows that in 2003 (after 8 years), actual irrigated area in the sub-region had increased by 1 Mha. This increases the fraction of actual irrigated land to 15.71%, reflecting a growth rate of approximately 0.2975% per annum (FAO, 2005).

CHALLENGES OF IRRIGATION DEVELOPMENT IN SUB-SAHARAN AFRICA

Possessing 42 Mha of irrigable land with the slowest rate of irrigation development in the world, sub-Saharan Africa has the highest potential in accelerating irrigated agriculture. However, FAO (2003) projects a much slower rate of expansion (0.6% per year) over the next 2 to 3 decades. This is 1% less of the annual growth rate recorded between 1960 and 1990. In a study on small-scale irrigation systems across sub-region, Barnett (1984) identified six problems affecting small-scale irrigation development: (1) Balancing social benefits, national economic strategies and perceived producer benefits; (2) Control (over decision-making, marketing, water use and etc.); (3) Hierarchy and technical requirements; (4) Planning production units and processes; (5) Water use and adaptation to farmer experiences; and finally (6) Planning for change.

In similar studies, Awulachew et al. (2005) and Moris and Thom (1990) reported the high costs of investment and negative rates of return; technical flaws in infrastructural design such as seepage, sedimentation, cracks in dams and silting up of reservoirs; high input costs; pests and diseases; high interest rates on loans; management failures; political difficulties; and marketing problems as contributory factors to broken down machinery and schemes.

Furthermore, mismanagement, high cost of working capital, poor linkages to credit, input and output markets, institutional vacuum, land tenure issues, improper management transfers, damaged soils, expensive and ineffective mechanization, poor farmer capacity and lack of farmer entrepreneurship development were reported by Shah et al. (2002) as inhibiting factors to irrigation development in sub-Saharan Africa. The commonalities between the challenges observed by various studies are identified in Table 1.

High costs of irrigation development

The average cost of a new irrigation scheme in sub-Saharan Africa as reported by Inocencio et al. (2007), is 141.67% higher than costs involved in other developing parts of the world (that is, USD14,500/ha in sub-Saharan Africa and USD6000/ha elsewhere). Namara et al. (2010) attributed this to the lack of local expertise and hence, the involvement of expensive expatriates in planning, designing and construction of irrigation projects. In addition, reports suggest that the best areas for developing irrigation

Figure 1. Trend of large-reservoir irrigation development in sub-Saharan Africa. Source: Aquastat, available at: http://www.fao.org/nr/water/aquastat/main/index.stm.

Table 1. Common challenges affecting irrigation development in sub-Saharan Africa.

Challenges	Authors		
	Barnett (1984)	**Awulachew et al. (2005)**	**Shah et al. (2002)**
High irrigation development cost	New schemes involve huge investment	high costs of investment, high input cost	High cost of working capital
Lack of access to credit	Governments cut down on operation cost by removing credits for farmers	High interest rates on loans	Poor linkages to credit, input and output
Unreliable markets and lack of access	Artificial market pricing by management of public schemes	Marketing problems	Poor linkages to market
Ineffective institutions	the problem of control, balancing social, national and producer benefit; hierarchy and technical requirements; adaptation to farmer experiences	negative rates of returns; management failures; political difficulties	Improper management transfers; land tenure issues; institutional vacuum
Choice of technology and maintenance of infrastructure	Problems with adequate and reliable water supply	technical flaws in infrastructural design, cracks, siltation and seepage in reservoirs; lack of maintenance and spare parts of machinery	Expensive and ineffective mechanisation
Low productivity	problems with production units and processes	Pests and diseases, high fertilizer cost	Damaged soils, poor farmer capacity

schemes in sub-Saharan Africa are nearly exhausted. This according to Faurès et al. (2007) will further increase the construction cost of future irrigation projects. Some governments set up administrative structures to manage irrigation schemes by compelling the direct producers to comply with enforced artificial pricing of commodities. This however, creates challenges where social, economic and producer benefits cannot be balanced and eventually result in low productivity due to lack of farmer interest (Barnett, 1984).

Lack of access to credit

In line with severe international economic crisis in the 1980s, developed countries adopted series of policies to adjust their capital flows (Edwards and van Wijnbergen, 1992). Introduction of the Structural Adjustment Program (SAP) changed the paradigm of irrigated farming in general and that of the poor in particular. There was a drastic drop in government support to inputs and credit. In Ghana the budget share of agriculture dropped from

12 to 2% in the 1990s. This resulted in huge cuts in formal credit and input supply programmes, and reduction in subsidies for fertilizer, credit, and animal traction equipment (Reardon et al., 1994). Loans to small-scale farmers have virtually evaporated after the liberalization of interest rates by the banks. According to Evans and Ngau (1991), Reardon et al. (1994) and Schrieder and Knerr (2000) in cases of credit constraints and a risky environment, farmers may use off-farm income to invest in agriculture and thus increase the farm productivity. Even in cases where some credit markets exist, off-farm income may serve as collateral for example in Benin (Hoffman and Heidhues, 1993).Under such circumstances agricultural communities are forced to resort to activities that secure a more stable income stream. These include rural-urban migration or local non-agricultural employment (Yilma et al., 2004).

Marketing and access to markets

The unreliability of input and output markets limit the benefits obtainable from irrigated agriculture. Marketing of irrigated products in sub-Saharan Africa at local, regional and global markets have numerous challenges for example in Ghana, national vegetable market channels are controlled by highly organized women trader organizations which exert a large degree of control on commodity prices, and frequently manipulate prices to the farmer's disadvantage (Laube et al., 2008). Factories could process perishable vegetable crops such as tomatoes to help save losses and stabilize the market. Local farmers face huge competition from European and Asian countries such as Italy, Holland, Spain and China, where the production of vegetables is highly subsidized, and large quantities of vegetables and vegetable products (such as tomato pastes) are dumped on the Ghanaian market. Artificially low world market prices negatively affect local prices and marketing chances (Laube et al., 2008).

Ineffective institutions

Effective institutions are required from the farm level, catchment level to the national level. These institutions are responsible for planning of irrigation development, managing of impacts due to irrigation development, formulating and implementing policy directives and funding towards sustainable irrigation development. Within the past 15 to 20 years there have been some institutional reforms in many countries in sub-Saharan Africa with a focus on withdrawing government from management. Management responsibilities have therefore been transferred from centralized bureaucratic management to lower levels (FAO, 1997). However, effective institutional arrangements for irrigation still remain a challenge (Faurès et al., 2007).

Samad and Merrey (2005) and Merrey et al (1997) pointed that, sustainable institutional reforms have the following characteristics: They give legal recognition to farmers and farmer groups, clearly recognize sustainable water rights and water service, specify management functions, provide compatible infrastructure with water service, create effective accountability and incentives for management, have viable arrangements for conflict resolution, mobilize adequate resources for irrigation and ensure that farmer investments are proportional to benefits. According to Merrey et al(2007), institutional reforms backed by strong political commitment are needed for sustainable irrigation development in sub-Saharan Africa.

Choice of technology and maintenance of infrastructure

Experience in many parts of Sub Saharan Africa has shown that with adequate community involvement in planning, design and management, small scale irrigation schemes can be more viable and sustainable than conventional large-scale schemes (Merrey et al., 2002). Top-down implementation process mostly leads to non-acceptance of irrigation schemes by farmers. A classic example is the Meki-Ziway Scheme in Oromia, Ethiopia, which failed largely because farmers could neither get spare parts for the imported pumps nor afford the electricity fees to run the pumps. For sustainable schemes, irrigation technologies must match the capacity of the users (Awulachew et al.,2005). In addition, designs must fit other user conditions such as climate, soil types, crops to be cultivated and method of management of irrigation infrastructure. One of the biggest constraints is that there are few experts who can fine-tune all these elements in a design to actually work in practice.

The reasons for poor maintenance as identified by Sijbrandij and van der Zaag (1993) are; (1) restrictions on cost of maintenance of irrigation schemes; (2) neglect of duty by maintenance sections; (3) lack of accountability; (4) lack of channels for expressing water users opinion on canal maintenance problems; (5) informal participation of farmers in maintenance and (6) apathy from water users due to the perception that they are not responsible for care of the facilities. Lessons need to be drawn from these challenges to create functional maintenance culture and strategies among management and water users to sustain irrigation projects.

Low productivity

According to statistics by FAO, productivity in Africa lags far behind other regions of the world and is well below the growth required to meet food security and poverty reduction goals set forth in national and regional plans. Lower use of fertilizer is one of the major factors

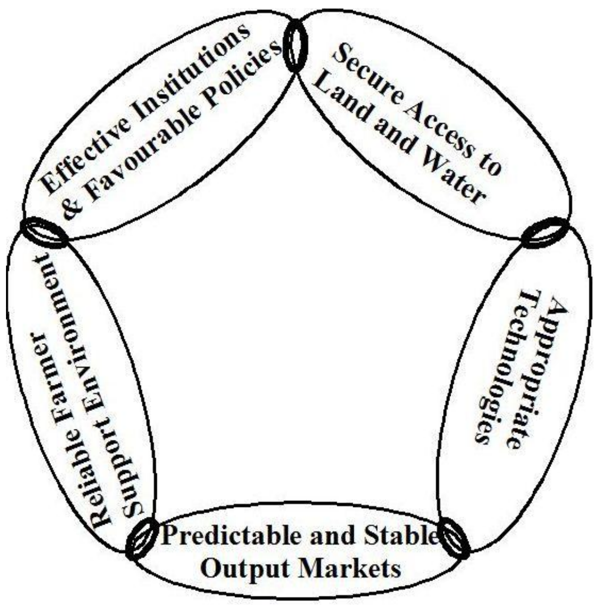

Figure 2. Chain of Success Factors for sustainable Irrigation Development. Source: modified from Vishnudas et al., 2007.

explaining lagging agricultural productivity in Africa. In 2002, the average fertilizer use in Sub-Saharan Africa was only 8 kg ha^{-1} of cultivated land which was low in comparison with records for other developing regions (e.g. 78 kg/ha in Latin America, 96 kg/ha in East and South-East Asia and 101 kg/ha in South Asia) (Morris et al., 2007). There are numerous challenges facing improving fertilizer application in Africa. For example in Ethiopia, organized input supply through government or government-supported channels are often available only for the major rainy season. Farm inputs, especially fertilizer, are scarce and relatively expensive during the irrigation season which leads to lower yields. In some instances, farmers attempt to substitute mineral fertilizers with farmyard manure but this is often not available in desired quantities (Awulachew et al., 2005). Policies and programmes must encourage fertilizer use in a sustainable manner (Morris et al., 2007) to ensure that Sub-Saharan Africa meets its agricultural targets. Also, horticultural crops that are highly vulnerable to pests and diseases must be introduced together with programs for pest and disease management. This will reduce losses associated with such diseases and pests (Awulachew et al., 2005).

SUCCESS FACTORS FOR ACHIEVING PRODUCTIVE AND SUSTAINABLE IRRIGATION DEVELOPMENT IN SUB-SAHARAN AFRICA

Irrigation productivity relates to the net socioeconomic and environmental benefits achieved through the use of water for irrigation. One of the necessities that demands increased irrigation productivity is the need to meet rising food demand for a growing, wealthier and increasingly urbanized population. Improved irrigation productivity will therefore contribute to poverty reduction, productive employment and economic growth (Molden et al., 2003). Achieving productive and sustainable irrigation development hinges on enabling factors which according to Penning De Vries et al. (2005) present the five ‘capitals’; (1) human capital (skills and knowledge, labor, health), (2) natural capital (water, land, genetic resources), (3) social capital (organization, regulations, policies, trust and security, gender equity), (4) financial capital (savings, loans, markets) and (5) physical capital (infrastructure, technology, equipment). However, these capitals are far too broadly defined to be of much conceptual help-sharper definitions of relevant aspects of these capitals are required.

Success factors for sustainable irrigation development

The following success factors have been identified as vital for sustainable irrigation development in sub-Saharan Africa: (1) Secure access to land and water; (2) Appropriate technologies; (3) Predictable and stable input/output markets; (4) Favorable policies and effective institutions; (5) Reliable farmer support environment. A suitable relationship between these five factors is a chain of shackles, where the chain is as strong as the weakest shackle (Penning De Vries et al., 2005; Vishnudas et al., 2007) as shown in Figure 2. The factors identified under this study are not very different from what Namara et al. (2014) identified as inhibiting the wider application of small-scale water lifting technologies (poorly developed supply chains, lack of access to finance, high operational and maintenance costs, high output price risks and lack of institutional support).

Secure access to land and water

The prevailing land tenure system is a challenge usually associated with accessing land and the security over the landholding. Often, lack of clarity among the plot-holders about what their rights precisely are with respect to their plots seems more problematic than the absence of ownership (Shah et al., 2002). Acquisition of land for irrigation is done in consideration with accessing potential water sources for irrigation such as groundwater and surface water. Institutional arrangements must therefore allow and protect water access to help promote irrigation development.

Appropriate technology

Irrigation development involves technology for abstraction, transportation, distribution and application of water. Infrastructural and technological development forms the most expensive aspect of irrigation development and as such, requires investment from both government and private initiatives. There is the need to invest in new irrigation systems and technologies as well as improvements in existing ones to enhance productivity.

The nature of investments should promote innovative and appropriate technologies which empower users and also, fit into their local context (socio-economy, geography, soils, crops and sources of water). Different technologies enable and/or constrain certain types of organization of irrigators (centralized/de-centralized) and coalesce with different modalities of investment. New technologies may unlock some entrepreneurial investments that are so far unexploited (Ofosu et al., 2010).

Reliable and stable input/output markets

Markets are key in irrigation development, particularly output markets. Output markets can either be the driving force behind several irrigation developments or the reason for their collapse. Produce markets that are predictable and reliable produce markets enhance the economic viability of irrigation farming and as such, is a pre-requisite for successful irrigation development. Unfavorable market conditions such as artificial low pricing by governments and market fluctuations or failure are detrimental to successful irrigation development in sub-Saharan Africa (Aw and Diemer, 2005).

Effective institutions and favorable policies

In order to ensure sustainability, there is the need for institutions to effectively take care of the public interests through leadership and management of resources. The characteristics of effective irrigation management institutions as studied by Perry (19950), Merrey et al. (2007) are: (1) A defined boundary (e.g. hydrological); (2) Provision of incentives for stakeholders; (3) Adequate infrastructure to deliver services in terms of rules and allocations; (4) Has the capacity to adapt to changing circumstances; (5) Employs cost recovery mechanisms and is equipped with legal instruments for implementing and enforcing policies and laws; (6) Has decentralized, integrated and transparent functions; and (7) Involves stakeholder participation by creating a platform that represents all interest groups at all levels.

Policies that improve credit accessibility of farmers, stimulate entrepreneurship abilities of farmers and/or reduce the capital cost of the producer will contribute positively to irrigation development.

Reliable farmer support environment

The accessibility and reliability of farmer support services can boost farmer confidence and lead investment in irrigated agriculture. Farmers also depend on information on markets, seeds, soil requirements and fertilizer for their produce. The availability of affordable credit facilities gives farmers the opportunity to improve and expand production.

Farmers have sometimes been introduced to certain irrigation technologies without technical support for maintaining them. As a result, productivity dropped because farmers could not find spare parts and skilled labor to repair their broken down equipment. Availability of reliable technical advisory services such as extension services or farmer advisory centers are crucial. An enabling environment where all these supports are accessible by farmers is important for sustainable irrigation development.

IMPACT OF SUCCESS FACTORS ON SOME IRRIGATION SCHEMES/SYSTEMS IN SUB-SAHARAN AFRICA

The five success factors identified in the previous section have been tested on selected irrigation schemes across sub-Saharan Africa including; the Office du Niger irrigation scheme under two different periods (1932-1982 and 1982-present), the Niger Valley irrigation schemes, the Sakassou Rice irrigation system in Cote d'Ivoire, the Ng'uuru Gakirwe irrigation system in Kenya, the Mukuria-Kyambogo group irrigation scheme in Kenya, the Community Empowerment Irrigation Project in Northwest Somalia and, finally, the Usangu irrigation system in Tanzania. These success factors were tested on a scale of weak, intermediate and strong. The factor is classified as weak if the contribution of the factor is adversely affecting the productivity and sustainability of the irrigation scheme. The factor is classified as intermediate if its contribution to the success of the scheme is not sustainable. Finally, the factor is classified as string if it is sustainable and also contributes positively to the productivity and sustainability of the scheme.

The results as summarized in Table 2 show that, (1) these five factors are relevant; and (2) the irrigation schemes/systems are as successful as the weakest of the five factors identified. The successful irrigation schemes and systems have been tagged as bright spots of irrigation development across sub-Saharan Africa (Penning de Vries et al., 2005).

Conclusions

The rate of irrigation development in sub-Saharan Africa is the slowest compared to other regions of the world and

Table 2. Measure of success factors on some irrigation systems in Sub-Saharan Africa.

Irrigation project	Type	Secure access to land and water	Appropriate technology	Predictable and stable input/ output markets	Reliable farmer support environment	Effective Institutions and favourable policies	Measure of success
Office du Niger in Mali (1932-1982) (Source: Aw and Diemer, 2005)	Government-led scheme	Land security absent – (*weak)*	Government investment – (*strong)*	poor output market - (*weak*)	Heavily indebted farmers, lacked incentives to raise yields couldn't hire labour *(weak)*	Government monopolised management, Artificial market prices for products (*weak*)	*Weak*
Niger Valley Irrigation Schemes in Niger (Source: Abernethy et al., 2000)	Government-led scheme	Secured by government for farmers - issues of landownership prevailing (*intermediate)*	Developed by Government and Donors but Farmers pay high fees for services and maintenance (*intermediate)*	High demand for products from local market *(strong)*	accessible credits for farmers payable in a year *(strong)*	Managed by Cooperatives overseeing Irrigator Organizations, Both institutions lack management skills due to illiteracy and Ineffective management transfers, *(intermediate)*	*Intermediate*
Sakassou Rice Irrigation System in Côte d'Ivoire (Source: Hundertmark and Abdourahmane, 2003)	Government-led scheme	Land availability with accessibility constraints and poor water services during peak periods (*intermediate*)	Irrigation system developed by government *(intermediate)*	The Farmer Cooperative assists farmers with Inputs and marketing (*strong*)	Farmers are assisted with inputs payable at the end of the season, abundant labour for farmers *(strong)*	Managed by Farmer groups and Water Management Committee with Technical Assistance provided by public agency (*strong*)	*Intermediate*
Office du Niger in Mali (1982 – Present) (Source: Aw and Diemer, 2005)	Government-led scheme reformed by Water User Association	Farmer-friendly land-tenure security (*strong*)	Government and Donor Investment (*strong*)	Vibrant Private sector participation in input and output markets; doubling of rice price (*strong*)	Farmers access credit from private sector, abundant labour *(strong)*	Farmers have access to credit, no price controls, Farmers unions involved in management (*strong*)	*Strong*
Ng'uuruGakirwe irrigation in Kenya (Source: Mati and Penning de Vries, 2005)	Private-led system with government intervention	Land owned by farmers, water is easily accessible by all. Water limitation factor for expansion *(intermediate)*	Farmers converted a water supply-system into irrigation. Later government loaned farmers to expand system (*strong)*	Farmers have their own processing and packaging factory. Products are sold to European Markets *(strong)*	Farmers get inputs and credits from the processing company owned by farmers, abundant labour *(strong)*	Farmers have organised union. Special training package is organised for farmers by the European Markets *(strong)*	*Intermediate*

million hectares out of which only 13.33% is developed, making sub-Saharan Africa a potential bread-basket for the future global population. This potential can be realized if the identified success factors are present, that is, (1) secure access to land and water, (2) appropriate technology, (3)

Table 2. Contd.

Mukuria-Kyambogo Group Irrigation Scheme in Kenya (Source: Mati and Penning de Vries, 2005)	Outgrower small-scale farmers	Land tenure is individual ownership with title deed, adequate water supply controlled by farmers *(strong)*	Started with a loan secured by a group of 15 farmers *(strong)*	Are outgrower farmers for large-scale commercial farmers who provide inputs and markets *(strong)*	Credit is accessed by the group on-behalf of members *(strong)*	Organised farmer group having effective collaboration with commercial farmers. Small-scale farmers are trained by commercial farmers *(strong)*	*Strong*
Community Empowerment Irrigation Project in Northwest Somalia (Source: Omar and Yonis, 2005)	Government-Led with Donor (IFAD) Support	Farm plots are owned by the farmers *(strong)*	Farmers were given loans by the project to develop shallow wells *(strong)*	Farming communities gain access to market through rehabilitation of feeder roads *(strong)*	Farmers are given credits in ploughing and in cash and can also access credit through rural financial services instituted by the project *(strong)*	Comprehensive program for strengthening local institutions, agricultural extension services for farmers *(strong)*	*Strong*
Irrigation in Usangu in Tanzania (Source: Lankford and Beale, 2007)	small-scale private individuals irrigation system	Control of land is generally inflexible, governed by money, location prestige and time occupied, unreliable water source *(weak)*	Private individuals secure loans to investment in technology. *(intermediate)*	Capital-rich farmers have good access to markets than the poor farmers. *(intermediate)*	Accessible credits from a small credit union, however capital-rich farmers have good access than poor farmers *(intermediate)*	Weak institutions, resulting in competition for land and water. Unresolved downstream impacts from upstream irrigation *(weak)*	*Weak*

can be linked to the following unresolved challenges: High development cost of irrigation, lack of access to credits for farmers, unreliable and unpredictable markets, ineffective institutions, low productivity, and finally inappropriate technologies coupled with poor infrastructural maintenance.

The potential irrigable area of sub-Saharan Africa is 42 predictable and stable input/output markets, (4) reliable farmer support environment, and (5) effective institutions with favorable policies. These factors function as a chain of shackles, the chain being as strong as the weakest shackle. This theory has been tested on some irrigation systems across sub-Saharan Africa with various degrees of success and has proven to reveal the sources of success and failure. In the reviewed cases the weakest aspects were insecure access to land and water, ineffective institutions and unfavorable policies.

Conflict of Interest

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

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Effect of different spacing on newly planted guava cv. L- 49 under ultra high density planting system

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Trees of guava (*Psidium guajava* L.) cv. Sardar were planted in September, 2010 at 2.0 x 2.0, 2.0 × 1.5, 1.5 × 1.5, 2.0 x 1.0 and 1.0 × 1.5 m spacing in 6.0 x 6.0 m size blocks to determine the effect of planting distance on tree growth, light interception, chlorophyll content, leaves Nitrogen, Phosphorous, and Potash (Potassium) (NPK), flowering, yield and quality parameters. The experiment was laid out in randomized block design with four replications at Instructional Farm, Department of Horticulture, Rajasthan College of Agriculture, Udaipur, Rajasthan, India. Vegetative growth characters of guava plant thou not influenced at the early stage by plant density however, at later stage, it was significantly influenced by various spacing treatments. Difference in two measurements was taken as "gain" and pruning was done during 11 September (first); 12 February; 12 September and 13 February (fourth). Mean maximum gain of shoot (46.7, 67.1 and 76.5 cm, respectively) and (53.7, 77.2 and 90.4 cm, respectively) at 60, 120 and 180 days second to third pruning (September, 2011 to February, 2012) and third to fourth (February, 2012 to September, 2012) respectively were recorded under treatment T_1 (2.0 × 2.0 m) and minimum recorded under treatment T_5 (1 × 1.5 m). Similarly, after two years of planting maximum plant; E-W (1.19 m) and N-S (1.32 m), girth of stem (3.75 cm), leaf area (97.16 cm^2), light interception below canopy (356 μ Mol / m^2 S), flowers $plant^{-1}$ (88.40), number of fruits $plant^{-1}$ (17.20), fruit weight (77.50 g), yield $plant^{-1}$ (1.32 kg) and TSS/acid ratio (33.14) recorded under 2.0 × 2.0 m spacing and minimum under 1.0 x 1.5 m spacing, maximum plant height (1.58 m), leaf area index (LAI) (3.29) and estimated yield (5.72 t ha^{-1}) were recorded under 1.0 × 1.5 m spacing and minimum plant height recorded under 2.0 × 2.0 m spacing. Further, trees spaced at 2.0 × 2.0 m produced better quality fruits as compared to other spacing treatment.

Key words: Guava, Ultra High Density Planting (UHDP), planting spacing,

INTRODUCTION

The continuing decline in the availability of cultivable land, rising energy, taxes, production cost and land cost together with the mounting demand of horticultural produce, have given thrust to the concept of high density planting of horticultural crops. It is an intensive form of horticulture production which has high relevance to the nutritional security of our ever-increasing population. In general, guava is cultivated mainly through a traditional

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system, under which it is difficult to achieve desired levels of production because large trees provide low production per unit area and needs high labour inputs (Araujo et al., 1999; Reddy et al., 1999; Singh et al., 2003). Getting increased yield of guava per unit area can be made possible by increasing the plant population (Singh et al., 1980; Mitra et al., 1984). Moreover, large trees take several years before they come into bearing and overall cost of production per unit area is further increased. Ultra high density planting not only provides higher yield but also provides higher net economic returns per unit area in the initial years and also facilitates more efficient use of inputs (Reddy, 2004).

One of the ways used for efficient and profitable land use is to work on tree spacing. Its basic function is to confine the exploitation zone of the plant with regard to light, water and nutrients so that the highest total yield potential can be reached in the smallest possible area (Singh, 2005). Studies on high-density planting in guava have increased and the results were published by Chapman et al. (1979), Singh et al. (1980), Lal et al. (1996) and Singh (2004).

MATERIALS AND METHODS

Experimental site and climate

The field experiment was conducted at Instructional-Cum-Research Farm, Department of Horticulture, Rajasthan College of Agriculture (MPUAT) Udaipur, India, situated at 24° 35' N latitude and 73° 42' E longitude at an elevation of 582.17 m above mean sea level. The region falls under agro climatic Zone IV A (Sub-humid Southern Plain and Aravalli Hills) of Rajasthan. It has a typical sub-tropical climate, characterized by mild winters and summers. The average rainfall of this tract ranges from 592.5 mm to 650 mm year^{-1}. More than 90% of rainfall is received from Southwest Monsoon during the months of June to September with scanty showers during winter months. The minimum temperature may reach the extreme of 0°C in winter and the maximum temperature may reach another extreme of 43°C during summer. The relative humidity varies from 75.0 to 95.0% in Monsoon, with the annual/average being 57.8%. The winter season rudiments from second half of October and continues up to February. The summer season lasts longer compared to winter, beginning from March to the middle of July. Mechanical analysis of soil showed that the soil contains 37.01% sand, 29.10% silt and 33.89% clay portion. Organic carbon, available nitrogen, phosphorus and potassium of soil were 0.67%, 201.1, 19.5 and 272.9 kg ha^{-1}, respectively.

Treatment application

Trees of guava (*Psidium guajava* L.) cv. Sardar were planted in September, 2010 at 2.0 × 2.0 m (T_1), 2.0 × 1.5 m (T_2), 1.5 × 1.5 m (T_3), 2.0 × 1.0 m (T_4) and 1.0 × 1.5 m (T_5) spacing in 6.0 × 6.0 m size blocks and replicated four times in a randomized block design. The number of plants at different plant density ranges from 2,500 to 6,666 plants ha^{-1}. In February, 2011 all the trees were topped at a uniform height of 50 cm from ground level and all side shoots and branches were removed (first pruning). Further, in September, 2011 as shoot mature, they reduced 50% of their total length and 3 to 4 equally spaced shoots plant^{-1} were retained (second pruning). New emerging shoots were pruned by cutting back 50% of their total length in February, 2012 (third pruning). Further in September, 2012 all plants were pruned by hedging and topping (non-selective pruning) (fourth pruning). Difference in two measurements was taken as "gain" and pruning was done during 11 September (first), 12 February, 12 September and 13 February (fourth) respectively.

Observations recorded

The data on shoot gain (cm), plant spread (m), plant height from north-south and east-west (m), stem girth (cm), new emerging shoot diameter (mm), leaf area (cm^2), light interception above and below canopy and LAI were measured before second (September, 2011), third (February, 2012) and fourth (September, 2012) pruning. Whereas, total chlorophyll content and Leaf NPK content were measured during November, 2011 and November, 2012. Further, flowering, yield and quality parameters, that is, number of flower plant^{-1}, fruit set (%), number of fruit plant^{-1}, fruit weight (g), yield plant^{-1} (kg), estimated yield ha^{-1} (t), TSS (%), acidity (%), TSS/acid ratio, ascorbic acid (mg 100 g^{-1} pulp), total sugar (%), organoleptic score were measured during *mrig bahar* (October to November, 2012). The data on gain of shoot after each pruning (cm), tree height (m) and plant spread (E-W and N-S) (m) were recorded using meter scale. Stem girth and new emerging shoot diameter were recorded with vernier callipers and leaf area (cm^2) was measured by a leaf area meter (Systronics). Light interception was measured between 10 to 12 AM by canopy analyzer (LP 80) under natural radiation and expressed in µ mol m^{-2} s^{-1}. Leaf area index was taken with a canopy analyzer (LP-80, LAI meter) between 10 to 12 AM. Total chlorophyll content was analyzed by N-dimethylformamide (DMF) method. NPK content in leaves was measured by Nesseler's reagent colorimetric method (Linder, 1944), Ammonium vanadomolybdo phosphoric acid yellow color method (Richards 1968) and Flame photometer method (Richards 1968) respectively. The total number of flowers set into fruits was counted. Average fruit weight was recorded with the help of electronic balance. Mature fruits were harvested periodically in each treatment separately and weighted on an electronic balance and then the yield per plant was calculated. Estimated yield ha^{-1} was calculated by multiplying the yield plant^{-1} by number of plants per ha^{-1}. Fruit quality (TSS, acidity and ascorbic acid) attributes were analyzed as prescribed standard methods (A.O.A.C., 1990). Total sugar content was determined by using Anthrone reagent method (Dubois et al., 1951).

Statistical analysis

The data obtained on various characters were subjected to reliability block diagram (RBD) analysis and interpretation of the data was carried out in accordance to Panse and Sukhatme (1985).

RESULTS AND DISCUSSION

Growth characteristics

The results of the present investigation revealed that vegetative growth characters of guava plant were not much influenced at the early stage by different plant densities (Tables 1 and 2). However, at later stage (after 2 years of planting) they were significantly influenced by various spacings treatment except new emerging shoot diameter, light interception above canopy, these

Table 1. Effect of different spacings on gain of shoot after first, second and third pruning and plant spread in guava under ultra high density planting system.

Treatment	Gain of shoot after first pruning (cm) (Feb., 2011 to Sept., 2011)			Gain of shoot after second pruning (cm) (Sept., 2011 to Feb., 2012)			Gain of shoot after third pruning (cm) (Feb., 2012 to Sept., 2012)			Plant spread E-W (m)			Plant spread N-S (m)		
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	September, 2011	February, 2012	September, 2012	September, 2011	February, 2012	September, 2012
T_1 (2.0 x 2.0 m)	47.8	68.2	79.7	46.7	67.1	76.5	53.7	77.2	90.4	0.82	1.03	1.19	0.84	1.06	1.32
T_2 (2.0 x 1.5 m)	50.0	70.2	81.3	43.1	62.0	70.2	48.9	71.2	84.0	0.88	0.98	1.16	0.82	1.02	1.22
T_3 (1.5 x 1.5 m)	45.9	67.0	77.8	42.7	60.5	68.4	50.0	70.7	82.8	0.81	0.96	1.12	0.76	0.92	1.14
T_4 (2.0 x 1.0 m)	48.7	68.4	80.0	41.2	59.9	67.2	45.9	64.6	76.2	0.89	0.99	0.97	0.81	0.90	1.16
T_5 (1.0 x 1.5 m)	44.7	65.2	76.4	37.1	53.3	59.7	43.7	60.9	70.3	0.78	0.87	0.92	0.77	0.88	1.15
SEm ±	1.318	1.812	2.344	1.109	1.609	1.800	1.257	1.862	2.156	0.029	0.038	0.053	0.021	0.045	0.031
CD at 5%	NS	NS	NS	3.417	4.957	5.546	3.874	5.738	6.644	NS	NS	0.163	NS	NS	0.096

Note: Feb. – February, Sept. – September.

Table 2. Effect of different spacings on plant height, stem girth, new emerging shoot diameter, leaf area and light interception above canopy in guava under ultra high density planting system.

Treatment	Plant height (m)			Girth of stem (cm)			New emerging shoot diameter (mm)			Leaf area (cm^2)			Leaf area index (%)		
	Sept., 2011	Feb., 2012	Sept., 2012	Sept., 2011	Feb., 2012	Sept., 2012	Sept., 2011	Feb., 2012	Sept., 2012	Sept., 2011	Feb., 2012	Sept., 2012	Sept., 2011	Feb., 2012	Sept., 2012
T_1 (2.0 x 2.0 m)	0.79	0.94	1.32	1.28	2.35	3.75	6.27	6.18	6.93	95.18	87.34	97.16	3.10	2.93	2.80
T_2 (2.0 x 1.5 m)	0.86	1.01	1.38	1.18	2.31	3.54	6.50	6.14	6.84	88.13	77.42	89.99	3.17	3.06	3.02
T_3 (1.5 x 1.5 m)	0.84	1.06	1.37	1.24	2.24	3.49	6.22	6.23	6.81	84.92	81.58	86.62	3.21	3.15	3.13
T_4 (2.0 x 1.0 m)	0.94	1.14	1.47	1.27	2.28	3.46	6.28	6.11	6.80	82.49	79.16	85.29	3.25	3.22	3.17
T_5 (1.0 x 1.5 m)	0.97	1.19	1.58	1.26	2.28	3.33	6.21	6.14	6.69	83.15	77.84	83.31	3.32	3.27	3.29
SEm ±	0.047	0.059	0.038	0.033	0.060	0.082	0.165	0.161	0.154	2.307	2.207	2.355	0.085	0.083	0.082
CD at 5%	NS	NS	0.118	NS	NS	0.252	NS	NS	NS	7.108	6.801	7.258	NS	NS	0.253

Note: Feb. – February, Sept. – September.

parameter significantly were not influenced by various spacing treatments throughout the study period.

After two years of planting, the plant height and LAI increased with the increase in plant density, that is, 2,500 to 6,666 plant ha^{-1} (1.32 to 1.58 m and 2.80 to 3.29, respectively), while the spread of the plant E-W (1.19 to 0.92 m) and N-S (1.32 to 1.15 m), girth of stem (3.75 to 3.33 cm) and light interception below canopy (356 to 276 μ Mol / m^2 S) decreased with the increase in plant population (Tables 1 to 3). Further, leaf area decreased with increasing plant density and maximum (95.18, 87.34 and 97.16 cm^2 respectively, before second, that is, September 2011, third, that is, February, 2012 and fourth pruning, that is, September, 2012) recorded under treatment T_1 (2.0 × 2.0 m) (Table 2). Gain of shoot at 60, 120 and 180 days

Table 3. Effect of different spacings on light interception below canopy, LAI, total chlorophyll content in leaves and leaves NPK content in guava under ultra high density planting system.

Treatment	Light interception above canopy (μ Mol / m^2 S)			Light interception below canopy (μ Mol / m^2 S)			Total chlorophyll content (mg 100 g^{-1} fresh weight)		Leaf N content (%)		Leaf P content (%)		Leaf K content (%)	
	Sep., 2011	Feb., 2012	Sep., 2012	Sep., 2011	Feb., 2012	Sep., 2012	Nov., 2011	Nov., 2012	Nov., 2011	Nov., 2012	Nov., 2011	Nov., 2012	Nov., 2011	Nov., 2012
T_1 (2.0 x 2.0 m)	961	840	941	328	252	356	2.30	2.36	2.68	2.85	0.190	0.192	1.56	1.78
T_2 (2.0 x 1.5 m)	980	828	958	337	269	338	2.14	2.24	2.62	2.77	0.192	0.189	1.60	1.73
T_3 (1.5 x 1.5 m)	964	825	951	339	272	315	2.16	2.22	2.71	2.71	0.180	0.192	1.58	1.72
T_4 (2.0 x 1.0 m)	955	836	940	369	285	286	2.18	2.30	2.58	2.70	0.180	0.175	1.53	1.62
T_5 (1.0 x 1.5 m)	972	815	960	346	260	276	2.10	2.17	2.60	2.62	0.172	0.177	1.60	1.58
SEm ±	25.34	21.81	24.89	11.15	7.638	7.258	0.057	0.060	0.069	0.072	0.006	0.005	0.042	0.057
CD at 5%	NS	NS	NS	NS	NS	22.36	NS	NS	NS	NS	NS	NS	NS	NS

Note: Feb. – February, Sept. – September.

after first to second pruning (February, 2011 to September, 2011) was non-significantly affected due to different spacings treatment. However, mean maximum gain of shoot (46.7, 67.1 and 76.5 cm, respectively) and (53.7, 77.2 and 90.4 cm, respectively) at 60, 120 and 180 days second to third pruning (September, 2011 to February, 2012) and third to fourth (February, 2012 to September, 2012), respectively were recorded under treatment T_1 (2.0 × 2.0 m) and minimum was recorded under treatment T_5 (1 × 1.5 m) (Table 1).

Results similar to present findings are reported earlier by Gaikwad et al. (1981), Mitra et al. (1984), Kundu et al. (1993) in guava, Kumar et al. (2010) in apricot and Dalal et al. (2012) in kinnow. Phillips (1969) reported that the closest spaced trees in Florida, 702 ha^{-1} were significantly taller as compared to 216 trees ha^{-1}. Bharad et al. (2012) reported that plant height would not be directly related to planting density in guava. The plant spread decreased with increasing plant density, while the height of plant increased with increase in plant population in guava (Yadav et al., 1981; Bharad et al., 2012). The girth and volume of tree showed decreasing trend with increasing tree density while tree height increased with increasing tree density in Allahabad Safeda guava (Kumar and Singh, 2000). Increase in plant density markedly increased the plant height while, the basal girth of the plant and spread of the crown decreased in guava cv. L-49 (Kundu, 2007). Singh et al. (2007) recorded maximum plant height and trunk circumference, while minimum canopy spread (NS/EW) in closely spaced guava trees (1.5 × 3.0 m). A possible explanation is the competition for water and soil nutrients (Policarpo et al., 2006), but mainly the competition for light (Johnson and Robinson, 2000; Policarpo et al., 2006), being under higher planting density plant canopies overlap into the rows, reducing light incidence on leaves. Consequently, great part of the canopy contributes little or nothing to the synthesis of carbohydrates necessary for growth. Thus, the competition between plants for light, water and nutrition under closer spacing resulted to less increase in gain of shoot after pruning, spread of the plant, girth of stem and leaf area.

Further under closer spacing, increase in height might be due to competition for light because of insufficient space. Trees spaced at 6×6 m intercepted significantly higher radiation on per tree basis than 6 × 5 m and 6 × 4 m spaced trees (Singh and Dhaliwal, 2007). Better light penetration was observed in the trees planted at 6.0 × 6.0 and 3.0 × 6.0 m than the other distances (3.0 × 3.0 and 3.0 × 1.5 m) at NS/EW canopy edge, inside tree centre, centre between tree in the rows and centre between rows in guava (Singh et al., 2007).

Flowering, yield and yield attributing characteristics

The results obtained in the present investigation revealed that different spacings treatment had significant influence on the number of flowers plant^{-1}, per cent fruit set, number of fruits plant^{-1}, fruit weight, yield plant^{-1} and ha^{-1}. After two years of planting among the different spacing treatment,

Table 4. Effect of different spacings on number of flower plant^{-1}, percent fruit set, number of fruit plant^{-1}, fruit weight, yield plant^{-1}, estimated yield ha^{-1}, TSS, acidity, TSS/acid ratio, vitamin C and total sugar in guava under ultra high density planting system.

Treatment	No. of flower plant^{-1}	Fruit set (%)	Number of fruit plant^{-1}	Fruit weight (g)	Yield plant^{-1} (kg)	Estimated yield ha^{-1} (t.)	TSS (%)	Acidity (%)	TSS/acid ratio	Vitamin C (mg/ 100g pulp)	Total sugar (%)	Organo-leptic score
T_1 (2.0 x 2.0 m)	88.40	43.82	17.20	77.50	1.32	3.30	11.40	0.34	33.14	195.40	8.52	7.20
T_2 (2.0 x 1.5 m)	83.40	45.00	16.50	75.40	1.25	4.17	11.00	0.33	33.04	189.00	8.10	7.00
T_3 (1.5 x 1.5 m)	77.50	41.56	14.20	71.20	1.12	4.97	10.60	0.38	27.89	177.80	7.76	6.50
T_4 (2.0 x 1.0 m)	76.95	40.12	13.81	73.00	1.05	5.25	10.80	0.35	30.58	181.20	7.82	6.90
T_5 (1.0 x 1.5 m)	69.79	38.11	12.20	68.05	0.86	5.72	9.40	0.40	23.75	172.20	7.64	6.20
SEm ±	3.803	1.5057	0.7091	1.8462	0.0658	0.2063	0.433	0.0163	1.1845	5.1454	0.2066	0.2467
CD at 5%	11.719	4.6396	2.1851	5.6888	0.2027	0.6356	NS	NS	3.6497	NS	NS	NS

maximum number of flowers plant^{-1} (88.40), number of fruits plant^{-1} (17.20), fruit weight (77.50 g), yield plant^{-1} (1.32 kg) were recorded under widest spacing treatment (2.0 × 2.0 m), whereas highest fruit set (45.00) was recorded under 2.0 x 1.5 m spacing. Further, minimum values of these parameters were recorded under closest spacing treatment (1.0 × 1.5 m). Estimated yield ha^{-1} showed increasing trend with increasing plant density and maximum (5.72 t) obtained under 1.0 × 1.5 m spacing treatment which remained at photosynthetic active radiation (PAR) with T_4 (2.0 × 1.0 m) (Table 4).

Higher fruit setting in plants under wider spacing seems to be due to greater photosynthetic activity, because of exposure of more number of leaves to sun light, that availability of proper sunlight to the lower branches of the trees at close spacing becomes a limiting factor and it adversely affects the flowering and fruiting. In our study, clear cut relationship was observed in light penetration due to different tree densities. Increase in density delayed the emergence of flower and reduced the flowering period and fruit setting. The maximum fruit set was at the population of 278 plants ha^{-1} (76.8%), while it was low (68.8%) at 1600 plants ha^{-1} (Kundu, 2007). The number of fruits plant^{-1} was found inversely related to planting density. Maximum mean number of 17.20 fruits plant^{-1} were harvested from tree planted at 2.0 × 2.0 m spacing which was significantly higher than the number of fruits harvested from the plant spaced at 1.5 × 1.5; 2.0 × 1.0 and 1.0 × 1.5 m. Higher number of fruits plant^{-1} in wider spacing (2.0 x 2.0 m) might be due to larger canopy volume, further number of flower plant^{-1}, and per cent fruit set were maximum recorded at wider (2.0 × 2.0 m) spacing, therefore, number of fruit plant^{-1} ultimately increased in this treatment. These findings are in consonance with the findings reported by Wagenmaker and Callesen (1989) in apple and Singh and Dhaliwal (2007) in guava.

Maximum fruit weight (77.50 g) was recorded with 2.0 × 2.0 m spacing, which was found at par with T_2 (2.0 × 1.5 m) and T_4 (2.0 × 1.0 m) treatments and minimum at 1.0 x 1.5 m spacing which is accordance with the studies of Feungchan et al. (1992); Kumar and Singh (2000); Singh et al. (2007); Kundu (2007); Singh and Dhaliwal (2007) in guava, Srivastava et al. (2010) in cherry and Kumar et al. (2010) in apricot. This might be due to less per cent radiation interception on per tree basis in closely spaced (1.0 × 1.5 m) trees which led to severe competition for metabolites and caused reduction in fruit weight. An increase in fruit weight in widely spaced (2.0 × 2.0 m) trees may be due to the fact that this part intercepted maximum radiation which inturn had more efficient photosynthetic activities resulting in higher availability of net photosynthesis which enabled the trees to produce fruits with more weight (Singh, 2001). Further, higher fruit weight and higher number of fruit plant^{-1} were observed in T_1 treatment (2.0 × 2.0 m) which was one of the reasons for achieving higher yield of guava (1.32 kg) under this treatment. However, it remained at par with treatments T_2 (2.0 × 1.5 m) and T_3 (1.5 × 1.5 m). Further, at closer spacing, yield was poor due to lower number of flower buds and low fruit set. Number of plant ha^{-1} increased with increasing planting densities (2,500 to 6,666) therefore maximum estimated yield ha^{-1} obtained from closest spacing that is, 1.0 x 1.5 m (T_5) which remained statistically at par with treatment T_4 (2.0 × 1.0 m). Result of present finding are supported by Singh et al. (1980), Mohammed et al. (1984), Chundawat et al. (1992), Kalra et al. (1994), Bal and Dhaliwal (2003) in guava, Kumar et al. (2010) in apricot and Dalal et al. (2012) in kinnow. Closed spacing treatment decreased the fruit weight and size but the yield per unit area increased considerably in guava (Mitra et al., 1984; Kundu et al., 1993).

Trees at 2 × 2 m had a lower yield tree^{-1} than those at 8 × 8 m but produced a 10-fold higher yield ha.$^{-1}$ in guava (Lal et al., 1996). Yield of individual tree showed decreasing trend, whereas yield ha.$^{-1}$ showed increasing trend with increasing tree densities (Kumar and Singh, 2000).

Chemical characters of fruits

Increasing planting density did not change significantly most variables related to fruit quality, such as TSS, acidity, ascorbic acid, sugar content and organoleptic score, however these parameter were recorded higher under wider spacing. Only TSS/acid ratio was significantly different with the planting densities. TSS/acid ratio was maximum (33.14) obtained under 2.0 × 2.0 m spacing and minimum under 1.0 × 1.5 m spacing (Table 4). Therefore, in the present study, high density planting had little influence on fruit quality. Availability of proper sunlight to the lower branches of the trees at close spacing becomes a limiting factor and it adversely affects the fruit quality. Further, under high planting density, besides the changes in the quantity and quality of intercepted light, the partitioning of assimilates between vegetative and reproductive shoots may be responsible for the effects on fruit quality (Policarpo et al., 2006). Similar result was obtained by Kundu (2007) who reported that TSS/acid ratio of fruits were slightly higher in the fruits from the plants under wider spacing in guava. The present results are also supported by the finding of Kumar et al. (2010) in apricot; Singh et al. (1980); Gaikwad et al. (1981); Bal and Dhaliwal (2003); Singh et al. (2007) and Bharad et al. (2012) in guava. The objective of high density planting is the accommodation of maximum plants with higher yield per unit area with normal physico-chemical attributes. Maximum plants can accommodate 1 × 1 m spacing with higher yield per unit area, but will produce poor quality attributes. For growth and fruit weight with yield spacing 2 × 1.5 m closely followed by 1.5 × 1.5 m. 2 × 1 m spacing will be recorded as a satisfactory growth and with significantly higher fruit weight, quality (TSS/acid), yield ha^{-1} and higher accommodation of plants per unit area. Yield level per hectare non significant with 1 × 1 m (T5) and 2 × 1 m (T4), fruit weight non significant with 2 × 2 m (T1) and 2 × 1 m (T4) and fruit quality as TSS/acid non significant with 2 × 2 m (T1), 2 × 1.5 (T2) and 2 × 1 m (T4).

Conclusion

Intensive density of planting system, that is, 2 × 1 m spacing recorded satisfactory growth, light interception below canopy and significantly higher number of flower plant^{-1}, fruit weight, TSS/ acid ratio and estimated yield ha^{-1} with optimum plant per unit area (5000 ha^{-1}).

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Conflict of Interest

The authors have not declared any conflict of interest.

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Review

Role of phosphorus in chickpea (*Cicer arietinum* L.) production

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India is a highly populated country under the category of developing nations. The protein requirement of most of the people is fulfilling through pulses. Production of pulse crops and their yield stagnation last so many years. It has been estimated that India's population would reach 1.68 billion by 2030 from the present level of 1.21 billion. Accordingly, vision of Indian Institute of Pulse Research, 2030, the projected pulse requirement by the year 2030 would be 32 million tons with an anticipated required growth rate of 4.2%. Apart from this, Indian pulse remains competitive to protect the indigenous pulse production. Among the pulses, chickpea (*Cicer arietinum* L.) play a vital role in total pulse production. This review paper highlights the role of phosphorus (P) in chickpea production.

Key words: Chickpea, phosphorus, nutrient management.

INTRODUCTION

Pulses are major sources of proteins among the vegetarians in India, and complement the staple cereals in the diets with proteins, essential amino acids, vitamins and minerals (Pingoliya et al., 2013). They contain 22 to 24% protein, which is almost twice the protein in wheat and thrice that of rice (Shukla et al., 2013). It is an easily available source of protein in the rural heart of India, that is, village. Pulses provide significant nutritional and health benefits, and are known to reduce several non-communicable diseases such as colon cancer and cardiovascular diseases (Jukanti et al., 2012). Pulses can be grown on a wide range of soil and climatic conditions, and play important role in crop rotation, mixed and inter-cropping, maintaining soil fertility through nitrogen fixation, release of soil-bound phosphorus (P), and thus contribute significantly to the sustainability of the farming systems.

India is the largest producer and consumer of pulses in the world. Major pulses grown in India include chickpea or bengal gram (*Cicer arietinum*), pigeonpea or red gram (*Cajanus cajan*), lentil (*Lens culinaris*), urdbean or black gram (*Vigna mungo*), mungbean or green gram (*Vigna*

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radiata), pea (*Pisum sativum* var. arvense), lablab bean (*Lablab purpureus*), moth bean (*Vigna aconitifolia*), horse gram (*Dolichos uniflorus*), grass pea or khesari (*Lathyrus sativus*), cowpea (*Vigna unguiculata*), and broad bean or faba bean (*Vicia faba*).

Among the pulses, chickpea is most important grown in every part of India. It is the largest produced food legume in South Asia and the third largest produced food legume global, after the common bean (*Phaseolus vulgaris* L.) and field pea (*P. sativum* L.). India is the largest chickpea producing country, accounting for 64% of the global chickpea production. The other major chickpea producing countries includes Pakistan, Turkey, Iran, Myanmar, Australia, Ethiopia, Canada, Mexico and Iraq. It is grown in an about 30% of the national pulse acreage which contributes to about 38% of national pulse production in India. Phosphorus is an important fertilizer in chickpea production; it is an import fertilizer which enhanced the cost of production (Dotaniya et al., 2013c; Dotaniya and Datta, 2013). In this review paper, we try to describe the role of P in chickpea production.

PHOSPHORUS FATE IN SOIL

Phosphorus has been recognized as one of the important element in plant nutrition (Dotaniya et al., 2014a). Phosphorus is an important nutrient especially for pulses to enhance their productivity. Phosphorus stimulates early root development, leaf size, tillering, flowering, grain yield and hastens maturity. It is a constituent of certain nucleic acids, that is, phospholipids, chromosomes and the coenzymes nicotinamide adenine dineucleotide (NAD), adenosine triphosphate (ATP) and nicotinamide adenine dineucleotide phosphate (NADP). Phosphorus is essential for cell division, seed and fruit development. A range of research experiments were conducted towards defining its chemistry in the soil- plant system. Soils are known to vary widely in their capacity to supply P to crops, as only a small fraction of it in soil solution is in available form to crops (Dotaniya et al., 2014b). In addition to this, phosphorus occurs in very low concentration in soil solution. Its uptake by crops results in a further decrease of its concentration in the soil solution especially near plant root zone (Dotaniya et al., 2013b). As a result, P deficiency has become a limiting factor in crop production in agricultural soils worldwide (Dotaniya et al., 2013c). In India, P fertilizers are totally imported to meet agricultural and allied needs, indigenous rock phosphate having low concentration of P and high cost of P fertilizers production. The phosphatic fertilizers are costly and their efficiency is very low (15 to 20%). A major portion of added phosphatic fertilizer is either chemically fixed by Ca and Mg in high pH; Al and Fe in low pH soils and/or strongly adsorbed on some soil components. Apart from soil factors, rhizospheric process (Dotaniya and Meena, 2013; Dotaniya, 2014), plant process and climatic factors are influencing the P dynamics in soil (Figure 1). Cordell et al. (2009) predicted that P production will peak in 2033, it means not to exploit of all reserve-to-production (RP) reserve, but afterward, supply is expected to decrease each year, due to economic and energy constraints. This peak indicated that high quality RP reserve will be exploited and, world will go for low grade and alternative P supplying sources. A group of researcher gave the different expected time of rock phosphate reserve exploitation (Table 1).

EFFECT OF PHOSPHORUS ON GROWTH ATTRIBUTES

The number of nodules, number of pods, weight of pods, green pod yield and protein content (per cent) were markedly increased with increasing P levels up to 90 $kgha^{-1}$ over control in cowpea (Baboo and Mishra, 2001). Ram and Dixit (2001) also found that the application of P at 60 kg P_2O_5 ha^{-1} significantly increased the plant height, branches per plant, leaves per plant and dry matter accumulation as compared to control and 20 kg P_2O_5 ha^{-1} in green gram. Later on, it was reported that growth attributes like plant height and dry matter accumulation per plant were significantly higher with 60 kg P_2O_5 ha^{-1} than 30 and 0 kg P_2O_5 ha^{-1} in chickpea (Arya et al., 2002). The positive effect of nitrogen with P fertilizers (20 kg N + 20 kg P_2O_5 ha^{-1}) conducted a field experiment at Jobner with chickpea crop and reported that the fertility levels significantly increased the plant height over control and 10 kg N + 20 kg P_2O_5 ha^{-1} (Khoja et al., 2002). Whereas, number of branches per plant and dry matter accumulation per plant was significantly increased due to 10 kg N + 20 kg P_2O_5 ha^{-1} over control.

In cowpea, crop plant height, pods per plant, length of pods etc were greatly increased by the application of P at 40 kg P_2O_5 ha^{-1} over control (Sharma and Jat, 2003). The application of P at 40 kg P_2O_5 ha^{-1} significantly increased all growths attributes, that is, plant height, number of branches per plant, dry matter accumulation, dry weight and number of nodules per plant in lentil over 0 and 20 kg P_2O_5 ha^{-1} (Singh et al., 2003). Similarly, Sunder et al. (2003) also observed that the application of P at 40 kg P_2O_5 ha^{-1} significantly increased the dry matter accumulation per meter row length by 20.57 and 7.81% over control and 20 kg P_2O_5 ha^{-1}, respectively in cluster bean. The dry matter accumulation per plant and leaf area index (LAI) was significantly increased with the application of 26.4 kg P_2O_5 ha^{-1} over 0 and 13.4 kg P_2O_5 ha^{-1} in gram (Jat and Ahalawat, 2004). The growth characters of chickpea as plant height, number of nodules per plant and dry matter accumulation were significantly increased up to 30 kg P_2O_5 ha^{-1} (Meena et al., 2004). However, the plant growth from 0 to 30 kg P_2O_5 ha^{-1} application was considerably more as compared to 30 to 60 kg P_2O_5 ha^{-1} application.

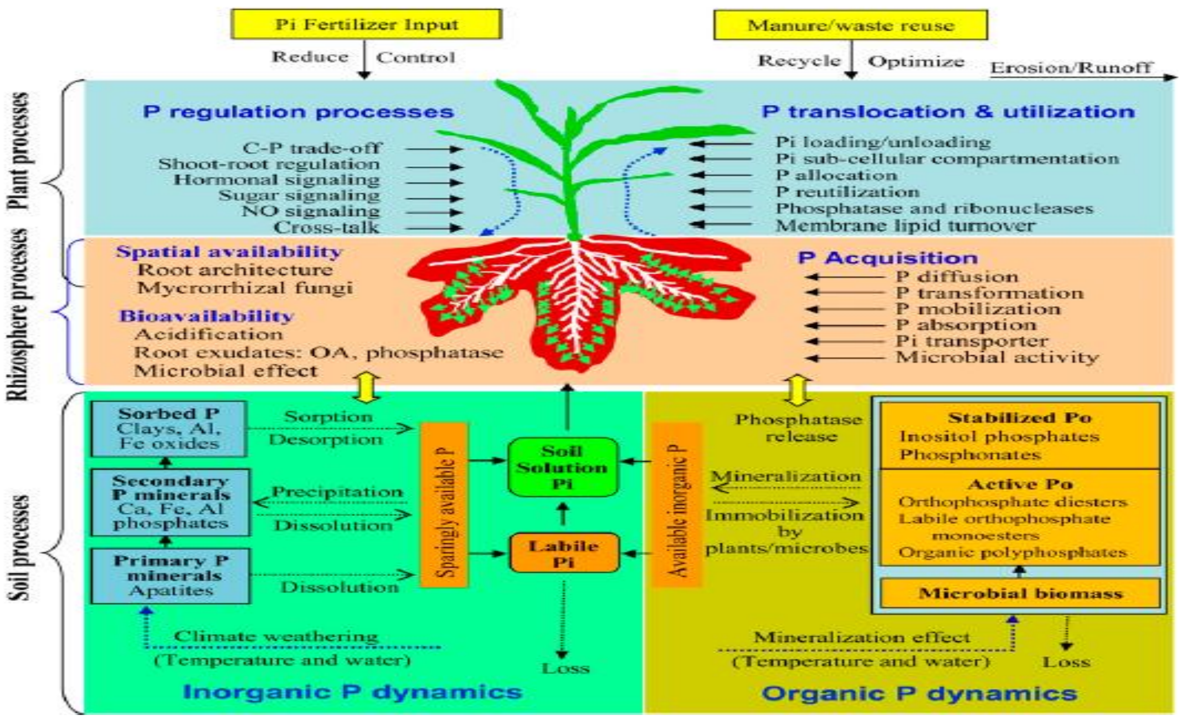

Figure 1. Phosphorus dynamics in soil/rhizosphere-plant continuum (Shen et al., 2011; Dotaniya et al., 2013c).

Table 1. Estimates of availability of remaining phosphate rock reserve.

Author	Estimated reserves (years)	Lifetime assumptions
Steen (1998)	60 - 130	2-3% increase demands rates, most likely 2% increase until 2020 and 0% growth thereafter if efficacy and reuse measures are implemented.
Smil (2000)	80	At current rate of extraction
Smit et al. (2009)	69 - 100	Assuming 0.7-2% increase until 2050, and 0% increase after 2050
Vaccari (2009)	90	At current rate
Fixen (2009)	93	At 2007-2008 production rates

A field experiment was conducted at IARI, New Delhi by Shivkumar et al. (2004) and they reported that the growth attributes viz., plant height, branches per plant and dry matter accumulation were increased with increasing level of P_2O_5 up to 80 kg ha^{-1} over control in chickpea. In the same year, Tripathy et al. (2004) reported that the application of nitrogen at 20 kg ha^{-1} and P at 25 kg P_2O_5 ha^{-1} significantly increased primary, secondary and tertiary branches of chickpea at successive growth stage of 40 and 85 days after sowing and harvest over control. But the application of 60 kg P_20_5 ha^{-1} significantly increased the growth attributes in chickpea like plant height, dry matter accumulation, and pods per plant over the control (Choudhary and Goswami, 2005). Das et al. (2005) also reported that the application of P at 75 kg P_2O_5 ha^{-1} significantly increased growth attributes like plant height and dry root weight over control in vegetable pea (*P. sativum*). The increasing levels of P up to 60 kg P_2O_5 ha^{-1} resulted in a significant increase in dry matter accumulation in chickpea over 0 and 30 kg P_2O_5 ha^{-1} (Meena et al., 2005).

Jarande et al. (2006) reported that the application of P at 37.5 kg P_2O_5 ha^{-1} + vermicompost + phosphate solubilizing bacteria (PSB) + *Rhizobium* recorded higher value of growth as well as yield contributing parameters in chickpea. The acid formation by a micro organism and crop plant roots enhanced the P mobilization in soil (Dotaniya et al., 2013a; Ammal et al., 2001). Sune et al. (2006) conducted a field experiment at College of Agriculture, Nagpur, and reported that the three levels of P in incremental dose increased the plant height, number of branches per plant and dry matter accumulation in linseed and 45 kg P_2O_5 ha^{-1} was the best and superior over 30 and 20 kg P_2O_5 ha^{-1}. Kushwaha (2007) conducted a field experiment on sandy loam soil at Chitrakoot and observed that application of nitrogen at 15 kg ha^{-1} + P at 30 kg P_2O_5 ha^{-1} significantly increased the growth parameters viz., plant height, dry matter accumulation, branches per plant and seeds per pod over control in chickpea. Singh and Prasad (2008) reported that dry matter accumulation and dry weight of nodules increased with levels of P up to 55 kg P_2O_5 ha^{-1}, thereafter increase was not significant. Singh and Yadav (2008) concluded that the application of 60 kg P_2O_5 ha^{-1} being at par with 45 kg P_2O_5 ha^{-1} recorded that the maximum plant height, number of primary branches, dry matter per plant, grain yield, stalk yield and uptake of P in pigeon pea over control. From the results of a field experiment, Ahmed and Badr (2009) concluded that the application of mineral P fertilizer at 46.5 kg P_2O_5 fed^{-1} resulted in a significant increase in growth characters in chickpea over control. Kumar et al. (2009) reported that application of P at 50 kg P_2O_5 ha^{-1} significantly increased the branches per plant, number of pods per plant, number of grains per pod, test weight, grain and straw yield in chickpea over control.

Meena et al. (2010) observed that the increasing levels of P up to 30 kg P_2O_5 ha^{-1} significantly increased the growth attributes in moth bean viz., plant height, branches per plant, dry matter accumulation and chlorophyll content as compared to preceding levels. Singh et al. (2010) observed that the application of 20 and 40 kg P_2O_5 ha^{-1} enhanced dry weight of root and shoot over no application of P in chickpea. Thenua et al. (2010) reported that application of P as single super phosphate (SSP) recorded significantly higher plant height, branches per plant and dry matter accumulation in chickpea.

EFFECT OF PHOSPHORUS ON YIELD AND YIELD ATTRIBUTES

On loamy sand soils of Jobner, Meena et al. (2001) reported that the application of 40 kg P_2O_5 ha^{-1} significantly increased pods per plant, seeds per pod, test weight, seed and straw yield of chickpea over control. They reported that application of 40 kg P_2O_5 ha^{-1} significantly increased number of pods per plant, number of seeds per pod, test weight, grain and straw yield over control and 20 kg P_2O_5 ha^{-1}. However, application of 60 kg P_2O_5 ha^{-1} remained at par with 40 kg P_2O_5 ha^{-1}. Singh and Vaishya (2001) reported that the grain yield increased significantly with increasing P dose and was recorded maximum at 60 kg P_2O_5 ha^{-1} over control in chickpea. Tiwari et al. (2001) also reported that the grain production of chickpea increased with increasing levels of P viz., 0, 40, 60 kg P_2O_5 ha^{-1} and maximum yield was observed at 60 kg P_2O_5 ha^{-1} which was 23.1% higher over no P application. Arya et al. (2002) in a field experiment on chickpea reported that the application of 60 kg P_2O_5 ha^{-1} significantly increased number of pods per plant, number of seeds per pod, test weight, grain and straw yield over control and 30 kg P_2O_5 ha^{-1}. A field experiment conducted by Meena et al. (2002) during the winter season of 1997-1998 and 1998-1999 at IARI, New Delhi reported that the application of P at 60 kg P_2O_5 ha^{-1} significantly increased yield attributes viz., number of nodules per plant and dry weight of nodules in chickpea over control. Lakpale et al. (2003) reported that application of 25.8 kg P_2O_5 ha^{-1} significantly increased number of pods per plant and higher seeds of gram over control. Application of 25.8 kg P_2O_5 ha^{-1} significantly increased the seed yield over control, but remained at par with 12.9 kg P_2O_5 ha^{-1}. Pramanik and Singh (2003) reported that the application of P_2O_5 at 60 kg ha^{-1} significantly increased yield attributes and yield over control in chickpea. Jat and Ahalawat (2004) also reported that the pods per plant, seed and straw yield of chickpea significantly increased with the application of 26.4 kg P_2O_5 ha^{-1} over 0 and 13.2 kg P_2O_5 ha^{-1}.

Meena et al. (2004) reported that the number of grains per pod, grain weight per plant, test weight and straw yield of chickpea increased significantly up to 60 kg P_2O_5 ha^{-1} over control and 30 kg P_2O_5 ha^{-1}. However, application of 60 kg P_2O_5 ha^{-1} significantly increased the seed yield over control, but remains at par with 30 kg P_2O_5 ha^{-1}. Shivakumar et al. (2004) reported that number of grains per pod, grain weight per plant, test weight, grain and straw yield of chickpea significantly increased with each level of P up to 80 kg P_2O_5 ha^{-1}. Choudhary and Goswami (2005) reported that the application of P at 60 and 90 kg P_2O_5 ha^{-1} significantly increased the grain yield of chickpea over control. Kumar and Sharma (2005) reported that each successive increase in levels of P up to 40 kg P_2O_5 ha^{-1} significantly increased the number of pods per plant, number of seeds per pod, test weight, seed and straw yield of chickpea but found statistically at par with 60 kg P_2O_5 ha^{-1}. Tiwari et al. (2005) reported that yield attributes of chickpea like number of pods per plant, test weight, grain and straw yield and harvest index augmented significantly with application of P up to 50 kg P_2O_5 ha^{-1} over 0 and 25 kg P_2O_5 ha^{-1}.

Jarande et al. (2006) conducted a field experiment at Agronomy Farm, College of Agriculture, Nagpur, and reported that the application of P at 37.5 kg P_2O_5 ha^{-1} + vermicopost + PSB + *Rhizobium,* recorded higher yield contributing parameters viz., dry matter per plant, number of seeds per plant, grain yield ha^{-1} and straw yield ha^{-1} in chickpea over control. Sune et al. (2006) conducted a field experiment at College of Agriculture, Nagpur, and reported that the application of 40 kg P_2O_5 ha^{-1} recorded higher value of yield contributing parameters viz., number of capsules per plant, number of seeds per capsule, seed yield and straw yield over control in linseed. Sharma and Abrol (2007) reported that the maximum grain yield of was observed with 60 kg P_2O_5 and 5 kg Zn ha^{-1} over control in chickpea. An investigation was carried out by Singh and Prasad (2008) at Kanpur and they reported that the application of diammonium phosphate (DAP) up to 180 kg ha^{-1} increased the grain yield (20.29 qha^{-1}) and straw (24.69 qha^{-1}) over control in chickpea. Verma and Singh (2008) observed that grain and straw yield of moong bean significantly increased with the application of P (0 to 75 kg P_2O_5 ha^{-1}) along with *Rhizobium* inoculation. Similar results were also observed by Narolia et al. (2013) in isabgol and Pingoliya et al. (2014a, b) in chickpea. A field experiment was conducted by Kumar et al. (2009) at Kanpur and they concluded that the application of 50 kg P_2O_5 ha^{-1} significantly increased average grain yield of chickpea over control. Srividya et al. (2009) conducted a field experiment at Agricultural College Bapalta, India and they concluded that the recommended dose of P at 50 kg P_2O_5 ha^{-1} was supplied through SSP, high grade rock phosphate (P_2O_5 20% by weight) and DAP produced the maximum number of pods per plant, seeds per plant, seed and straw yield of chickpea over control. Meena et al. (2010) revealed that the yield component of moth bean viz., pods per plant, seeds per pod, pod length and test weight increased significantly with increasing levels of P up to 30 kg P_2O_5 ha^{-1} but it remained at par with 45 kg P_2O_5 ha^{-1}. Meena et al. (2010) reported that the application of P at 30 kg P_2O_5 ha^{-1} being at par with 45 kg P_2O_5 ha^{-1} significantly increased the seed yield of moth bean representing an increase of 57.54 and 15.56% over control and 15 kg P_2O_5 ha^{-1} respectively. Rathore et al. (2010) observed that the application of farmyard manure (FYM) at 5 tha^{-1}, 40 kg P_2O_5 ha^{-1} and dual seed inoculation with PSB + vesicular arbuscular mycorrhiza (VAM) significantly increased the seed and stover yield over control in urdbean. Singh et al. (2010) observed that the application of 20 kg P_2O_5 ha^{-1} increased the grain yield in chickpea over no P application.

EFFECT OF PHOSPHORUS ON NUTRIENT CONTENT, UPTAKE AND QUALITY

Ingale and Deshmukh (1986) reported that increasing rates of applied P from 0 to 25 kg P_2O_5 ha^{-1} increased N, P and K uptake and protein content in seeds of chickpea. Raju et al. (1991) reported that increasing levels of P from 20 to 40 kg P_2O_5 ha^{-1} brought about a corresponding significant increase in uptake of N, P and K. Singh and Ram (1992) conducted a field experiment for 2 years (1981-1982 and 1982-1983) with chickpea crop and concluded that application of P up to 60 kg ha^{-1} significantly increased Mn and Fe contents and their uptake in grain and straw, but decreased with further addition of P that is, 90 kg P_2O_5 ha^{-1}. Contents of zinc and copper decreased linearly with increasing levels of P. However, uptake of zinc and copper by grain and straw increased up to 60 kg P_2O_5 ha^{-1} and with further increase in the level of P, there was an appreciable reduction. Singh et al. (1993) conducted a field experiment and concluded that the iron content in grain and straw increased consistently by application of Fe but decreased with P addition (0 to 100 mg kg^{-1}). Enania and Vyas (1994) conducted a field experiment at Udaipur on clay loam soil and revealed that uptake of P increased significantly up to 50 kg P_2O_5 ha^{-1} and zinc up to 25 kg ha^{-1}. Krishna and Yadav (1997) conducted a field experiment with chickpea and concluded that the copper content decreased progressively with increasing doses of P and accordingly minimum Cu content was obtained at 90 kg P_2O_5 ha^{-1} in both grain and straw. Mn and Fe uptake in both seed and straw increased significantly up to 60 kg P_2O_5 ha^{-1} and thereafter decreased. Reddy and Ahlawat (1998) reported that the application of 40 kg P_2O_5 ha^{-1} increased the yield attributes, grain and straw yield, N, P, Zn uptake and protein content in chickpea crop. A field experiment was conducted at agronomy farm, Jobner and found that the application of 45 kg P_2O_5 ha^{-1} significantly increased the N and P content in grain and straw and their uptake by cowpea crop over control (Kumar, 2000). Dadheech (2001) reported that the application of P at 60 kg ha^{-1} significantly increased the N and P content in grain and straw, N and P uptake by grain and straw and protein content in grain over their lower doses in black gram crop. Meena et al. (2001) reported that the protein content in seeds was significantly higher with the application of 60 kg P_2O_5 ha^{-1} over control in chickpea. Patel et al. (2001) also observed that the application of 40 kg P_2O_5 ha^{-1} gave the maximum grains protein and nutrient uptake was also enhanced significantly due to P levels up to 60 kg P_2O_5 ha^{-1} in black gram. Ram and Dixit (2001) conducted a field experiment at Faizabad, and results showed that the application of P at 60 kg P_2O_5 ha^{-1} gave significantly higher value of protein content over control in green gram. Tiwari et al. (2001) reported that the grain production of chickpea increased due to increase in P levels from 0 to 60 kg ha^{-1}. Maximum production was recorded at 60 kg P_2O_5 ha^{-1} over control; similarly, increase in P uptake was also observed due to 40 and 60 kg P_2O_5 ha^{-1} over no P application. Yadav et al. (2002) conducted a field experiment during *Kharif* season of 1997 with mung bean crop and they concluded that P content and uptake by seed and straw and micronutrients (Fe, Mn, Cu and Zn) in seed increased significantly with increasing levels of P but decreased the content and uptake of Fe in seed and straw of mung bean crop. Mishra (2003) conducted a field experiment at Bulandshahar (U.P.) and concluded that P markedly improved the quality of cowpea in terms of protein yield in seeds with increasing levels of P from 0, 30, 60, and 90 kg ha^{-1}. A similar trend was notified for protein yield in stover and total production. A field experiment was conducted by Pramanik and Singh (2003) at IARI, New Delhi and they reported that the application of P significantly increased the P uptake up to 60 kg P_2O_5 ha^{-1} in the 1st year and up to 30 kg ha^{-1} in the 2nd year in chickpea. Singh et al. (2003) found that the application of P up to 40 kg P_2O_5 ha^{-1} significantly increased the uptake of N and P in grain and straw of chickpea over control and 20 kg P_2O_5 ha^{-1}. Sunder et al. (2003) observed that the application of 40 kg P_2O_5 ha^{-1} significantly increased the protein content in seed over control and 20 kg P_2O_5 ha^{-1} in cluster bean. Jat and Ahalawat (2004) reported that application of P up to 26.4 kg P_2O_5 ha^{-1} significantly increased the total uptake of N and P by chickpea over control. Meena et al. (2004) in a field experiment on chickpea crop also found that the application of P up to 60 kg P_2O_5 ha^{-1} significantly increased the uptake of N, P and K and protein content in chickpea over control and 30 kg P_2O_5 ha^{-1}. Shivakumar et al. (2004) conducted a field experiment at IARI, New Delhi and they concluded that the increasing levels of P up to 80 kg P_2O_5 ha^{-1} recorded significantly higher uptake of P with each successive level in chickpea. Meena et al. (2005) in a field experiment conducted at IARI, New Delhi during 1997-1998 and 1998-1999 and they reported that the increasing levels of P up to 60 kg P_2O_5 ha^{-1} resulted in a significant increase in P content, uptake and seed yield of chickpea over control.

Tiwari et al. (2005) reported that application of P up to 26.4 kg P_2O_5 ha^{-1} significantly increased the uptake of N, P and K in grain and straw by chickpea over control and 25 kg P_2O_5 ha^{-1}. Gupta et al. (2006) reported that the response of urdbean to P fertilization was significant up to 60 kg P_2O_5 ha^{-1} for seed and straw yield over control. Phosphorus application also increases the seed protein content, N and P uptake in seed and straw. Kahlon et al. (2006) reported that the application of 50 kg P_2O_5 ha^{-1} resulted in a better uptake of N, P, K, S, Zn, Fe and Cu as compared to other treatments. Kumar and Kushwaha (2006) conducted a field experiment at M.P. during rainy season in 1999-2000 and they concluded that the application of P up to 80 kg P_2O_5 ha^{-1} significantly increased the total P uptake over control in pigeon pea. Bhunia et al. (2006) conducted a field experiment at Sriganganagar, Rajasthan on fenugreek crop and they observed that the application of P increased the N, P and K uptake up to 40 kg P_2O_5 ha^{-1}.

A pot experiment was conducted by Srinivasarao et al. (2007) and they concluded that the application of P up to 27.0 mg kg^{-1} soil significantly reduced the Fe concentration in the plant. Up to 13.5 mg kg^{-1} P application, the Cu concentration increased and thereafter it decreased, while the concentration gradually increased with increasing P levels. Sharma and Abrol (2007) conducted a field experiment at Jammu and they concluded that the uptake of P by chickpea is significantly increased by increasing levels of P up to 60 kg P_2O_5 ha^{-1} over control. Singh and Prasad (2008) reported that the application of P up to 180 kg ha^{-1} by DAP significantly increased the N and P uptake by chickpea over 120 kg DAP ha^{-1}. A field experiment was conducted at Institute of Agricultural Sciences, BHU, Varanasi by Singh and Yadav (2008) and they reported that the maximum N and P uptake were recorded with 60 kg P_2O_5 ha^{-1} which was found significantly superior to the remaining levels except 45 and 30 kg P_2O_5 ha^{-1} by pigeon pea. Kumar et al. (2009) reported that the application of 50 kg P_2O_5 ha^{-1} significantly increased P uptake by grain and straw in chickpea over control.

Meena et al. (2010) observed that the nitrogen content in seed and straw, P content in straw as well as protein content in the seed were significantly higher with 30 kg P_2O_5 ha^{-1} as compared with preceding levels in moth bean. Patel et al. (2010) observed that higher yield as well as nutrient uptake and protein content in seed were recorded with the application of 50 kg P_2O_5 ha^{-1} and FYM at 10 tha^{-1} + seed treatment with *Rhizobium* in cluster bean. Rathore et al. (2010) observed that the higher uptakes of N, P and K in urdbean were recorded by the application of 40 kg P_2O_5 ha^{-1}.

CONCLUSIONS

The growing Indian population enhanced the pulses demand. The burgeoning human population in India needs higher pulses production for fulfilling the dietary protein requirement. It requires to mitigating the demand of protein. In coming years, we will produce the more amounts of pulses. Phosphorus fertilizer increases the cost of production because it is an import fertilizer. We should focus on production of new fertilizer having higher use efficiency. Develop varieties which are heavy higher yield potential with higher resistance to insect-pest and disease. However, a concerted effort by farmers, researchers, development agencies, and government are needed to ensure that India becomes self-sufficient in pulses in the future.

Conflict of Interest

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

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Variation, correlation, regression and path analyses in *Eruca sativa* Mill.

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In the present study variation, correlation, regression and path coefficients in *Eruca sativa* Mill. were analyzed. Great variations were observed with agronomic and oil quality traits in *Eruca*. Partial correlation, stepwise regression and path analyses indicated that the contributions of siliqua number per plant (X_7), seeds per siliqua (X_8), 1000-seed weight (X_9) and siliqua number of main raceme (X_6) to seed yield per plant (Y) were highly significant and positive ($P<0.01$), and those of number of secondary branches (X_4) and plant height (X_1) were also significant and positive ($P<0.05$), while that of branching height (X_2) was significant and negative ($P<0.05$). The regression formula of these agronomic traits to seed yield per plant is $Y= -2.134 + 0.010X_1- 0.011X_2 + 0.049X_4 + 0.028X_6 + 0.019X_7 + 0.056X_8 + 0.465X_9$. Based on the analyses we suggest that future *Eruca* improvement should focus first on siliqua number per plant, then seeds per siliqua, 1000-seed weight, siliqua number of main raceme, number of secondary branches and plant height, but the negative correlations between 1000-seed weight and seeds per siliqua, 1000-seed weight and siliqua number per plant, siliqua number of main raceme and number of secondary branches should also be considered. The *Eruca* materials with higher plant, lower branching height, larger and yellow seeds found in this study will be valuable for future *Eruca* improvement.

Key words: *Eruca sativa*, variation, simple and partial correlation, stepwise regression, path analysis.

INTRODUCTION

Eruca sativa Mill. in the *Brassicaceae* family is an important marginal crop grown on soil with reduced fertility and is preferred over other relative species for its tolerance and adaptability to unfavorable environmental conditions (Gupta et al., 1998; Sastry, 2003; Warwick et al., 2007; Shinwari et al., 2013). *Eruca* is used as salads,

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cooked vegetables and functional plants (Kim et al., 2006). In addition it is also grown as an oilseed crop in India (Gupta et al., 1998), Pakistan (Shinwari et al., 2013), Canada (Warwick et al., 2007) and China (Sun et al., 2004). Its seed oil is used for human nutrition, medicinal and cosmetic properties, and as a lubricant (Yaniv et al., 1998; Warwick et al., 2007). However, its yield capability is very much restricted as it was given very minor weight (Gupta et al., 1998). Through regeneration (Sharma et al., 2012) and genetic transformation system available (Slater et al., 2011) *Eruca* can be developed as a safe industrial crop because of its low cross-ability with the edible oilseed rape (Sun et al., 2005) and its high resistance to powdery mildew (Sastry, 2003), stem rot (Guan et al., 2004) and salt (Su et al., 2013).

Selection based on phenotypic characters is the major method used in breeding programs. Response to selection depends on many factors such as interrelationship of the characters (Joshi, 2005). The correlation between important and non-important traits provides plant breeders with a significant assistance in indirect selection of important traits, through non-important traits as their measurement is easier (Qulipor et al., 2004; Joshi, 2005). Partial correlation coefficient is a measure of linear dependence of a pair of random variables from a collection of random variables in the case where the influence of the remaining variables is eliminated. A partial correlation between two variables can differ substantially from their simple correlation (Dallal, 2001). Regression helps to estimate the functional relationship between variables or the relationship between independent and dependent variables (Joshi, 2005).

Path coefficient analysis is a very important statistical tool that can be used to obtain an indication of which variables exert an influence on other variables, while recognizing the multicollinearity (Dewey and Lu, 1959; Akanda and Mundit, 1996). In this paper variation, simple and partial correlations, regression and path analyses were studied in *Eruca* to reveal their contributions to seed yield per plant and correlations among the agronomic and quality traits to provide clues to *Eruca* breeding and cultivation.

MATERIALS AND METHODS

Seeds of eleven *Eruca sativa* lines from Hubei University were sown on 5th October, 2012 in the farming field at Anyue (30.12N, 105.30E), Sichuan Province, China. Anyue is located in Southwest of China and the soil is neutrally purplish. Completely randomized block designs with three replicates of 6.6 m^2 were used. Farmyard manure was used in the soil before seed sowing. About 400 plants in each plot were kept one month after sowing. In December 562.5 kg urea (about 262 kg pure N) per hectare was applied to promote the seedling growth. Ten mature plants in each plot were sampled on 3rd May, 2013 for investigation of the agronomic traits according to the rapeseed standard (Liu, 1985). Fatty acid compositions and oil contents in the seeds were determined by using gas chromatography machine as described by Li et al. (2012). Data were analyzed on SPSS 19.0 and Excel.

RESULTS

Variations in agronomic traits

Great variations in the agronomic traits were observed in the *Eruca* lines (Table 1). The coefficient of variation was highest for branching height, followed by number of secondary branches, seed yield per plant, siliqua number per plant, siliqua number of main raceme, number of primary branches, seeds per siliqua, length of main raceme, plant height and 1000-seed weight. The highest plant was 153 cm while the lowest was only 17 cm; the highest seed yield was 14.63 g for one single plant while the lowest was only 0.028 g; the highest siliqua number was 474 for one single plant while the lowest was only 3; the highest 1000-seed weight was 3.82 g while the lowest was only 0.82 g. Larger and yellow *Eruca* seeds were noted for the first time in this study (Figure 1).

Fatty acid composition and oil content

In the seed oil of the tested *Eruca* lines, eicosenoic acid showed the highest variation, followed by oleic, linolenic and stearic acids, oil content, linoleic, erucic, palmitic and eicosadienoic acids. The highest eicosenoic acid was 12.06% while the lowest was only 0.31%; the highest oil content was 28.82% while the lowest was only 13.96%; the highest erucic acid content was 50.94% while the lowest was only 31.66% (Table 2).

Simple and partial correlations among agronomic traits

For simple correlations among the ten agronomic traits (X_1-X_9 and Y, Table 3), plant height was significantly and positively correlated with all other agronomic traits ($P<0.01$) except for branching height and seeds per siliqua. Branching height was significantly and positively correlated with 1000-seed weight ($P<0.01$), significantly but negatively correlated with number of primary and secondary branches, siliqua number per plant and seed yield per plant ($P<0.01$); the number of primary branches was significantly and positively correlated with number of secondary branches, length of main raceme, siliqua number of main raceme, siliqua number per plant, seed yield per plant ($P<0.01$) and seeds per siliqua ($P<0.05$); number of secondary branches was significantly and positively correlated with length of main raceme, siliqua number per plant and seed yield per plant ($P<0.01$); length of main raceme was significantly correlated with siliqua number of main raceme, siliqua number per plant, 1000-seed weight and seed yield per plant ($P<0.01$);

Table 1. Mean values of agronomic traits and variation **c**oefficients in *Eruca sativa.*

Eruca Lines	Plant height (X_1, cm)	Branching height (X_2, cm)	No. of Primary Branches (X_3)	No. of secondary branches (X_4)	Length of main raceme (X_5, cm)	Siliqua no. of main raceme (X_6)	Siliqua no. per plant (X_7)	Seeds per siliqua (X_8)	1000-seed weight (X_9, g)	Seed yield per plant (Y, g)
E. sativa cv. hubu-1	75.07±24.36	6.98±6.71	3.64±2.31	3.43±3.52	40.86±18.89	10.64±11.50	50.89±63.81	12.88±5.35	2.02±0.49	1.32±1.92
E. sativa cv. hubu-2	82.23±26.23	14.14±8.49	2.95±2.00	3.00±3.80	44.91±19.07	10.14±9.77	51.50±65.53	13.47±6.55	2.21±0.58	1.21±1.65
E. sativa cv. hubu-3	71.47±14.51	4.57±5.67	5.17±1.91	6.53±6.76	39.10±11.70	12.93±7.86	100.3±82.30	17.12±7.93	1.64±0.37	2.39±2.02
E. sativa cv. hubu-4	84.43±14.00	4.34±5.65	5.38±2.76	6.41±5.25	47.79±13.17	19.90±7.90	114.24±56.84	17.05±5.30	1.37±0.26	2.54±1.67
E. sativa cv. hubu-5	105.71±24.62	18.35±15.54	4.45±2.19	4.68±4.01	60.77±24.87	11.35±10.00	63.13±41.28	14.38±5.60	2.28±0.41	1.78±1.40
E. sativa cv. hubu-6	82.72±30.59	13.52±18.79	5.45±7.47	4.34±3.49	45.52±22.15	13.48±12.05	67.66±58.32	13.69±7.42	2.14±0.59	1.71±1.92
E. sativa cv. hubu-10	88.93±22.30	17.39±11.11	3.93±1.54	2.54±2.27	45.89±20.06	16.89±17.30	54.00±33.06	16.16±5.97	2.24±0.39	1.71±1.28
E. sativa cv. hubu-11	87.64±17.89	12.79±10.38	4.43±2.28	5.64±4.83	45.71±11.24	13.14±12.70	92.36±54.61	16.06±5.59	2.16±0.43	2.37±1.57
E. sativa cv. hubu-12	107.63±22.95	10.60±13.26	6.27±4.25	8.23±8.48	57.33±22.99	16.53±9.62	133.46±108.63	16.94±6.97	2.23±0.56	4.18±3.45
E. sativa cv. hubu-13	84.92±24.90	21.00±25.93	3.25±2.21	3.00±4.95	47.29±15.99	10.5±9.14	31.88±59.73	10.90±6.34	2.17±0.66	0.61±1.58
E. sativa cv. hubu-14	81.10±15.64	8.10±8.58	3.70±1.77	3.60±2.27	49.70±9.17	2.20±3.91	43.10±47.74	10.61±4.96	1.93±0.42	0.94±1.35
Max	153.00	130.00	43.00	35.00	109.00	89.00	474.00	49.00	3.82	14.63
Min	17.00	0	0	0	1	0	3	0.68	0.82	0.03
Coefficient of Variation	28.81	119.51	76.37	108.87	41.22	83.45	93.13	45.21	27.31	105.12

Figure 1. *Eruca* seeds with different sizes and colors.

siliqua number of primary raceme was significantly correlated with siliqua number per plant, seeds per siliqua and seed yield per plant (P<0.01), significantly and negatively correlated with 1000-seed weight (P<0.05); siliqua number per plant was significantly and positively correlated with seeds per siliqua and seed yield per plant (P<0.01), but significantly and negatively correlated with 1000-seed weight (P<0.05); seeds per siliqua was significantly and positively correlated with seed yield per plant (P<0.01), but significantly and negatively correlated with 1000-seed weight (P<0.01).

Further partial correlation analysis (Table 3) indicated that plant height was significantly and positively correlated with number of primary branches, length of main raceme, seed yield per plant, 1000-seed weight (P <0.01) and branching height (P<0.05); branching height was significantly and positively correlated with siliqua number of main raceme and 1000-seed weight (P<0.05), significantly but negatively correlated with number of primary branches, length of main raceme and seed yield per plant (P<0.05); number of primary branches was significantly and positively correlated with number of secondary branches (P <0.01); number of secondary branches was significantly and positively correlated with siliqua number per plant (P<0.01) and seed yield per plant (P<0.05), significantly and negatively correlated with siliqua number of main raceme (P<0.01) and seeds per siliqua (P<0.05); siliqua number of main raceme was significantly and positively correlated with siliqua number per plant and seed yield per plant (P<0.01); siliqua number per plant was significantly and positively correlated with seed yield per plant (P<0.01) and negatively correlated with 1000-seed weight (P<0.01); seeds per siliqua was significantly and positively correlated with seed yield per plant (P<0.01), significantly and negatively correlated with 1000-seed weight; 1000-seed weight was significantly and positively correlated with seed yield per plant (P <0.01).

Table 2. Fatty acid composition (%), oil content (%) and coefficient of variations for *Eruca* lines.

***Eruca* Lines**	**Palmitic acid**	**Stearic acid**	**Oleic acid**	**Linoleic acid**	**Linolenic acid**	**Eicosenoic acid**	**Eicosadienoic acid**	**Erucic acid**	**Oil content (%)**
E. sativa cv. hubu-1	4.70±0.32	0.99±0.11	14.34±2.22	10.50±1.52	12.50±1.43	0.71±0.07	8.33±0.51	47.58±2.50	21.27±4.26
E. sativa cv. hubu-2	4.68±0.06	1.01±0.13	15.13±2.59	11.49±0.54	11.65±0.28	0.67±0.06	8.33±0.69	46.70±2.54	18.02±1.19
E. sativa cv. hubu-3	4.22±0.28	1.16±0.20	25.84±2.38	14.12±0.73	10.92±0.99	0.60±0.12	8.27±0.46	34.59±2.45	21.11±1.09
E. sativa cv. hubu-4	3.81±0.20	0.73±0.09	25.99±1.56	13.24±0.32	9.04±0.97	0.38±0.07	8.72±0.48	37.81±0.83	24.98±3.33
E. sativa cv. hubu-5	4.53±0.23	1.01±0.15	14.58±3.04	11.15±1.65	12.19±1.96	0.65±0.08	8.24±0.69	47.30±3.47	19.29±2.61
E. sativa cv. hubu-6	4.34±0.64	0.90±0.05	13.60±1.48	10.29±1.32	13.58±1.65	0.61±0.06	8.19±0.03	48.20±1.02	20.05±3.42
E. sativa cv. hubu-10	4.02±0.18	1.03±0.19	15.78±1.79	9.95±0.52	11.36±1.21	0.69±0.11	8.55±0.44	48.36±1.83	21.35±0.70
E. sativa cv. hubu-11	4.63±0.01	0.98±0.20	14.14±0.88	11.29±0.97	12.17±1.87	0.63±0.11	8.27±0.40	47.56±0.71	19.69±3.79
E. sativa cv. hubu-12	3.87±0.13	0.89±0.01	14.24±0.37	10.38±0.13	11.99±0.07	0.61±0.01	8.12±0.35	49.61±0.20	22.67±3.38
E. sativa cv. hubu-13	4.81±0.16	1.05±0.21	16.11±4.09	11.82±1.26	11.71±2.32	0.72±0.18	9.11±1.30	44.38±2.25	14.42±0.64
E. sativa cv. hubu-14	3.98±0.26	0.91±0.26	15.65±1.38	10.03±0.67	6.04±8.46	6.27±8.19	8.79±0.62	48.21±2.72	20.72±0.74
Max	5.06	1.45	27.93	14.86	14.74	12.06	10.02	50.94	28.82
Min	3.65	0.63	11.96	8.72	0.06	0.31	7.50	31.66	13.96
Coefficient of Variation	9.28	17.69	29.48	14.89	23.62	210.06	6.53	12.41	14.95

Table 3. Simple and partial correlations among *Eruca* agronomic traits.

Agronomic traits	**Plant height (X_1)**	**Branching height (X_2)**	**No. of primary branches (X_3)**	**No. of secondary branches (X_4)**	**Length of main raceme (X_5)**	**Siliqua No. of main raceme (X_6)**	**Siliqua No. per plant (X_7)**	**Seeds per siliqua (X_8)**	**1000-seed weight (X_9)**	**Seed yield per plant (Y)**
Plant height (X_1)		-0.025	0.324**	0.340**	0.792**	0.217**	0.415**	0.073	0.229**	0.436**
Branching height (X_2)	0.137*		-0.259**	-0.335**	-0.077	0.008	-0.305**	-0.033	0.236**	-0.283**
No. of primary branches (X_3)	0.160**	-0.127*		0.506**	0.210**	0.191**	0.513**	0.142*	-0.042	0.467**
No. of secondary branches(X_4)	0.029	-0.109	0.208**		0.261**	0.025	0.743**	0.033	0.016	0.647**
Length of main raceme (X_5)	0.750**	-0.126*	-0.099	-0.043		0.194**	0.346**	-0.013	0.188**	0.322**
Siliqua no. of main raceme (X_6)	-0.012	0.123*	0.084	-0.422**	0.062		0.401**	0.275**	-0.169*	0.443**
Siliqua no. per plant (X_7)	-0.012	0.031	0.093	0.500**	0.118	0.239**		0.247**	-0.169*	0.848**
Seeds per Siliqua (X_8)	0.091	0.114	0.060	-0.158*	-0.092	0.004	-0.063		-0.385**	0.343**
1000-seed weight (X_9)	0.168**	0.255*	0.019	0.103	0.029	-0.088	-0.269**	-0.383**		-0.079
Seed yield per plant (Y)	0.143**	-0.149*	-0.019	0.149*	-0.099	0.250**	0.564**	0.314**	0.215**	

Up right: simple correlations; bottom left: Partial correlations.

Regression and path analyses

Stepwise regression and path analyses indicated that the contributions of siliqua number per plant (X_7), seeds per siliqua (X_8), 1000-seed weight (X_9) and siliqua number of main raceme (X_6) to seed yield per plant (Y) were highly significant and positive ($P<0.01$), and the contribution of number of secondary branches (X_4) and plant height (X_1)

Table 4. Direct and indirect path coefficients to seed yield per plant in *Eruca.*

Agronomic traits	Direct effect (Py)	via plant height (X_1)	via branching height (X_2)	via No. of secondary branches (X_4)	via Siliqua No. of Main Raceme (X_6)	via Siliqua No. per Plant (X_7)	via Seeds per Siliqua (X_8)	via 1000-seed weight (X_9)
Plant Height (X_1)	0.119		0.0020	0.0415	0.0326	0.2606	0.0130	0.0284
Branching Height (X_2)	-0.078	-0.0030		-0.0409	0.0012	-0.1915	-0.0059	0.0293
No. of Secondary Branches (X_4)	0.122	0.0405	0.0261		0.0038	0.4666	0.0059	0.0020
Siliqua No. of Main Raceme (X_6)	0.150	0.0258	-0.0006	0.0031		0.2518	0.0490	-0.0210
Siliqua No. per plant (X_7)	0.628	0.0494	0.0238	0.0906	0.0602		0.0440	-0.0210
Seeds per Siliqua (X_8)	0.178	0.0087	0.0026	0.0040	0.0413	0.1551		-0.0477
1000-seed weight (X_9)	0.124	0.0273	-0.0184	0.0020	-0.0254	-0.1061	-0.0685	

was significant and positive ($P<0.05$), but the contribution of branching height (X_2) was significant and negative ($P<0.05$). The regression formula was $Y= -2.134 + 0.010X_1 - 0.011X_2 + 0.049X_4 + 0.028X_6 + 0.019X_7 + 0.056X_8 + 0.465X_9$. The determination coefficient of above characters to seed yield per plant was $R^2=0.778$ and that of other agronomic traits was 0.4712. As shown in Table 4, siliqua number per plant showed the greatest direct contribution to seed yield per plant, followed by seeds per siliqua, siliqua number of main raceme, 1000-seed weight, number of secondary branches, and plant height. Number of secondary braches showed the greatest indirect effect to seed yield per plant via siliqua number per plant, followed by plant height, siliqua number of main raceme, seeds per siliqua. Branching height and 1000-seed weight showed a minor negative effect on seed yield per plant via siliqua number per plant.

DISCUSSION

Variations in agronomic and seed quality traits

In *Eruca* considerable variation was available for siliquae per plant, branches per plant, plant height and seed yield (Sastry, 2003). Shinwari et al. (2013) showed that the seed yield per plant, siliquae per plant and plant height in *Eruca* presented larger variations than 1000-seed weight. Yadav et al. (1998) indicated that secondary branches/plant had the highest coefficient of variation, followed by 1000-seed weight and primary branches/plant. Meena (1997) showed that low yielders in *Eruca* basically had lower values for siliqua length and number of seeds per siliqua, while the high yielders had biological yield above average. Rathore (1998) reported that the high yielders and low yielders of *Eruca* differed in number of primary branches per plant, besides secondary branches per plant. In present study branching height showed the greatest variation, followed by number of secondary branches, seed yield per plant, siliqua number per plant, siliqua number of main raceme, number of primary branches, seeds per siliqua, length of main raceme, plant height and 1000-seed weight. Esiyok et al. (2013) reported the highest 1000-seed weight as 1.70 g in *Eruca*, and Liu et al. (2008) reported the range of 0.40 to 2.83 g for 1000-seed weight, which was comparable with the average 2 g from present study. Liu et al. (2008) also reported the 23 to 64 cm plant height with an average of 41.93 cm, 1.74 cm branching height, 117 siliquae per plant, 1.45 g 1000-seed weight. In this study individuals with higher plant (up to 153 cm) and higher seed yield per plant (14.63 g), more siliquae per plant (up to 474), yellow and larger seeds (1000-seed weight up to 3.82 g) were obtained and these materials would be valuable for future *Eruca* improvement. Yellow *Eruca* seeds were reported for the first time here in this study.

Several previous studies showed that the oil contents in *Eruca* ranged from 22.23 to 41.31% (Flanders and Abdulkarim, 1985; Yadava et al., 1998; Yang, 2001; Chakrabarti and Ahmad, 2009), somewhat higher than our results (13.96 to 28.82%). Yadava et al. (1998) reported large variation in the contents of erucic acid (26.7 to 52.4%), oleic acid (14.1 to 23.4%), linoleic acid (6.9 to 15.7%), linolenic acid (8.3 to 15.3%) and eicosenoic acid (9.3 to 18.3%). Yaniv et al. (1998) observed that the contents of erucic acid and eicosenoic acid contents varied from 33 to 45% and 7.3 to 9.8%, respectively, in the *Eruca* collections from Israel.

Yang (2001) indicated that the erucic acid in *Eruca* lines of China was 23.98 to 34.54%, oleic acid was 22.78 to 29.49%, linoleic acid was 12.76 to 17.65%, linolenic acid was 9.98 to 15.40%, palmitic acid was around 4%, eicosenoic acid was around 8%. In present study, eicosenoic acid showed the highest variation (0.31 to 12.06%), followed by oleic acid (11.96 to 27.93%), linolenic acid (0.06 to 14.74%), stearic acid (0.63 to 1.45%), linoleic acid (8.72 to 14.86%), erucic acid (31.66 to 50.94%), palmitic acid (3.65 to 5.06%) and eicosadienoic acid (7.50 to 10.02%). *Eruca* lines with higher unique fatty acids such as erucic acid would be valuable for industrial purposes in the future.

Correlations among the agronomic traits

In previous studies, seed yield per plant in *Eruca* was usually significantly and positively correlated with plant height, primary branches/plant, secondary branches per plant, siliquae/plant and 1000-seed weight (Yadav and Kumar, 1984; Nehra et al., 1989; Sodani et al., 1990; Meena, 1997; Yadav et al., 1998; Kumhar et al., 2007; Keer and Jakhar, 2012; Shinwari et al., 2013). In present study partial correlation analysis indicated that seed yield per plant was significantly and positively correlated with plant height, siliquae of main raceme, siliquae per plant, seeds per siliqua, 1000 seed weight ($P<0.01$) and number of secondary branches ($P<0.05$), significantly but negatively correlated with branching height ($P<0.05$). Siliqua number of main raceme had a significant and positive correlation with siliqua number per plant and seed yield per plant ($P<0.01$). Siliqua number per plant showed a significant and positive correlation with seed yield per plant ($P<0.01$), and a negative correlation with 1000-seed weight ($P<0.01$). Seeds per siliqua presented significant and positive correlation with seed yield per plant ($P<0.01$), and negative correlation with 1000-seed weight. 1000-seed weight (X_9) showed a positive correlation with seed yield per plant ($P <0.01$). The correlations revealed in this study will be valuable for future *Eruca* improvement.

Contributions to seed yield per plant

Sastry (2003) reported that siliquae per plant in *Eruca* had highest positive and direct effect on seed yield, followed by secondary branches, siliqua length and plant height, while oil content had the highest negative direct effect. Therefore he suggested that more attention should be given to siliquae per plant during breeding selection. Secondary branches per plant, plant height and siliqua length were the other characters which should be considered in a selection program for seed yield, as they had positive direct effect on seed yield per plant. Shinwari et al. (2013) reported that number of siliqua per plant, primary branches per plant, siliquae of the main raceme, and siliqua length had significantly positive contribution to seed yield plant per plant. Principal component analysis also revealed that primary branches per plant, siliquae per plant, seeds per siliqua, 1000-seed weight etc., were the most vital characters that accounted for a considerable level of phenotypic variation recorded in the *Eruca* genotypes (Shinwari et al., 2013). Path coefficient analysis revealed that plant height had highest direct effect on seed yield of plant, followed by 1000-seed weight and number of primary branches per plant. Based on correlation and path analysis, it was concluded that plant height, 1000-seed weight and number of primary branches per plant were the most important yield contributing traits in *Eruca* (Keer and Jakhar, 2012). Earlier, positive direct effect of secondary branches per plant on seed yield was reported by Yadav and Kumar (1984) and Nehra et al. (1989), that of siliquae per plant by Nehra et al. (1989). Yadav and Kumar (1984) indicated that secondary branches/plant and number of main-shoot siliquae had the highest direct positive effects on yield. In present study, stepwise regression and path analyses indicated siliqua number per plant had the greatest direct contribution to seed yield per plant, followed by seeds per siliqua, siliqua number of main raceme, 1000-seed weight, number of secondary branches and plant height. Number of secondary braches showed the greatest indirect effect to seed yield per plant via siliqua number per plant, followed by plant height, siliqua number of main raceme, seeds per siliqua. Branching height and 1000-seed weight showed negative effect on seed yield per plant via siliqua number per plant. These findings would also be valuable for future *Eruca* improvement.

Conclusions

Based on our analyses we suggest that future *Eruca* improvement should focus first on siliqua number per plant, then seeds per siliqua, 1000-seed weight, siliqua number of main raceme, number of secondary branches and plant height, but the negative correlations between 1000-seed weight and seeds per siliqua, 1000-seed weight and siliqua number per plant, siliqua number of main raceme and number of secondary branches should also be considered. The materials with higher plant, lower branching height, larger and yellow seeds found in this study will be valuable for future *Eruca* improvement.

Conflict of interest

The authors declare that there are no conflicts of interest in this work.

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Full Length Research Paper

Influence of food resource on the development of *Liriomyza trifolii* Burgess 1880 (Diptera-Agromyzidae)

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In order to limit the devastation caused in the celery (*Apium graveolens* L., 1753) plots by *Liriomyza trifolii* Burgess in Nkolondom, (Southern Cameroon), farmers proceed to the anarchic use of synthetic insecticides in addition to the pruning of the infested leaves as sanitary harvests. These infested leaves resulting from sanitary harvests are immediately abandoned in the furrows. The main objective of the present study was to assess the efficiency of pruning as a control method versus *L. trifolii*. The durations of the development of the pre-imaginal stages, the fitness and the sex-ratio of *L. trifolii* we are were evaluated using both whole plants and pruned parasitized leaves, respectively in the laboratory and the celery plot during the warm-dry and cold-humid seasons. The results obtained showed that the average duration of the pre-imaginal development cycle of *L.trifolii* varied between 16.53 ± 0.26 days in the laboratory with cut leaves during warm-dry period to 21.98 ± 0.3 days with entire plants in the garden during cold-humid period. It was also shown that from infested cut leaves emerged leafminers were able to cause serious damages to healthy celery plants in the plot. No significant difference was observed between the cut leaves sex ratio (1/0.96) and that of the whole plants (1/0.91); (χ^2 = 2.38; df = 1; P=0.12). The *L. trifolii* sex ratio which is slightly biased toward females was not affected by the food resource.

Key words: *Apium graveolens*, *Liriomyza trifolii*, leafminer, pruning, sex ratio, fitness.

INTRODUCTION

The Celery, *Apium graveolens* L., 1753 (Apiaceae) is one of the main market crops produced in urban and suburb areas in Southern Cameroon (Damesse, 2003; Mvogo, 2005). At Nkolondom, in the northern outskirt of Yaoundé, farmer estimated today that plants as celery, nightshade and leek provide respectively incomes of about 1800 CFA/m², 1400 CFA/m² and 1000 CFA/m² per crop cycle (Prolinnova Cameroun, 2011). The celery's yield in individual leafs cropping was 14.3 kg/m^2 (Simon et al., 2010). This vegetable is mostly cultivated in Nkolondom, involving about 60% of farmers (Damesse, 2003; Mvogo, 2005).

Despite the fact that celery is always known at Nkolondom as the most gainful vegetable crop, its

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production undergoes some constraints and difficulties due to the bad cropping management leading to an impoverishment of the soil and the intensive and permanent character of this agricultural type leads to outbreak of insect pests. Among the insect pests, *Liriomyza trifolii* Burgess 1880 (Diptera: Agromyzidae) is the major threat (Nguimdo, 2007) and considered as economically important (Parrella, 1987; Kang et al., 2009). Larvae of these flies feed on the parenchyma of celery leaves, making it dry out and then unsuitable for the consumption. *L. trifolii* is very prolific and adults can easily spread gradually on the whole garden when host plant is present. In many farms, frequent outbreaks of *L. trifolii* caused severe damages which sometimes constrain the farmers to leave their activities. This case was observed at Mvog-Dzigui, a nearby village of Yaoundé, where producers were discouraged and obliged to abandon their celery's plots (Mvogo, 2005). At Nkolondom, in order to control *L. trifolii* population on celery plots, farmers use several techniques including chemical treatments and sanitary harvests. The main problem in this area are related to the anarchic use of chemical products that may induce leafminers resistance to pesticides and a sanitary harvest that's the impact on the biological cycle of the pest remains unknown.

The present study is a contribution to the mastery of *L. trifolii* ecology in the celery's plots in Yaounde neighbourhoods. More specifically, we seek to assess: (1) the duration of the first three development phases of *L. trifolii*; (2) the sex-ratio of *L. trifolii* and (3) the influence of the food resource on the fitness of *L. trifolii*.

MATERIALS AND METHODS

Description of the site

The study was conducted at Nkolondom (03°57'07''N; 11°29'27''E) and at the University of Yaoundé1 (03°51'34''N; 11°33'00''E), particularly in the laboratory of Zoology and on experimental celery plot established near the laboratory building. Both sites are located on the Southern Plateau, with a bimodal humid tropical rainfall regime (Suchel, 1988). However, in their agronomic environments, Nkolondom is surrounded by various market crop plots along a small stream and located in an agronomic landscape. Contrarily to Nkolondom, the University is located in an urban landscape and surrounded by buildings and grasslands. The soils of Yaoundé and its neighbourhoods are lateritic on interfluve (Vicat and Bilong, 1998). On a phytogeographic aspect, Nkolondom is in forest-savannah transition zone (Letouzey, 1968). This region has suffered from heavy anthropogenic disturbances and the remaining natural vegetation is preserved on hill slopes.

METHODOLOGY

Three experimentations were carried out during the present study from August to September 2008 (cold-humid period), from December 2008 to January 2009 (warm-dry period-1) and from February 2009 to March 2009 (warm-dry period-2). The first and the second experimentations were carried out in the laboratory and the experimental plot respectively during the cold-humid and the first warm-dry-1 periods. The third experimentation was carried out in the plot during the warm-dry period-2. During each experimentation, the values of the temperature and the hygrometry of periods of the study were measured using a Wireless Weather Station; Model: H10515/DCF; Version10/2007. These parameters were recorded every day at two hourly intervals between 6 a.m and 6 p.m during the entire study periods. The average daily temperature and average daily hygrometry were then calculated from the seven measurements. This helped to know if the experimental environments differ or not from one period to another.

Duration of development phases of *L. trifolii*

During the first experimentation, five hundred celery seedlings and infested leaves were respectively collected in a nursery and celery farmers' plots at Nkolondom and carried to the University. At the laboratory, the seedlings were transplanted in 120 ml plastic pots filled with manure. Leafminers larvae present in infested leaves were well-attended in the laboratory successively inside transparent rearing boxes (7× 10 × 17cm) and Petri dishes (4 and 6 cm of diameter) until leafminers' imaginal molt. The flies were then counted according to their sex (segregated on the base of the structure of the two last tergites setulae of female that are conspicuously dense and elongated compared to males (Ortiz, 2009)) and used to infest celery plants. Three males, three females and five plants were introduced in each appropriate transparent bucket for 12 h per day in the laboratory. A hundred of these infested plants were kept in the laboratory and the rest was transplanted on celery experimental plot of four ridges. We used only middle plot's ridges plants to avoid border effect characterize by abundance of parasite on the plot's border. In the laboratory or in the plot, the leaf which has the most impacts of egg-laying or of feeding was cut with a pruning shears from 50 plants randomly selected. These leaves are collected and put in five rearing boxes (ten leaves per box) covered with a mosquito net. The boxes with damage leaves were placed in the furrow located between ridges of each plot. On the remainder plants of the laboratory and 50 others randomly selected in the plot, the leaf which has the most impact of egg-laying or of feeding was put in a muff sewn with a special mosquito net of 0.5 mm mesh size. After that, the development of *L. trifolii* larvae was monitored on both cut leaves and whole plants. Once pupae were obtained, they were placed individually in labeled rearing Petri dish at the ambient temperature which mean was around 25°C until imago's emergence. The label indicated the food resource and the milieu of experimentation. A yearly roman calendar was used in order to estimate the duration of each development phase in each milieu are as follow:

(i) The embryonic phase (from laying to hatching marked by the appearance of the galleries);
(ii) The larval phase (from the appearance of the gallery to the exit of the larvae (pre-pupae) from the gallery);
(iii) The pupal phase (from pre-pupae to emergence of imagos).
(iv) The pre-imaginal development duration

The second experimentation was carried out similarly to the first one but in the plot during the warm-dry period -1. Independently to the assessment of the durations of development phases, the pupae obtained from the whole plants and the cut leaves during this experimentation were counted and measured separately using a stereomicroscope provided with a micrometer. The variations of pupae's morphometric characteristics were: diameter (0.44 to 0.92 mm); length (1 to 1.98 mm). The basis of classification depended on the fact that during some preliminaries experiments, we realized that from some pupae did not emerged flies. We measure the length and the diameter of those pupae and from that determined the morphometric characteristics of the two batches. These pupae were classified as follow.

(i) Batch 1; diameter > 0.73 mm, length > 1.74 mm;
(ii) Batch 2; diameter ≤0.73 mm, length ≤1.74 mm.

Then, many comparisons shall be more focused on cut leaves' bathes because it is the hypothetical food resource. A comparison was done to know exactly whether the diameter and length of pupae belonging respectively to cut leaves' batch 1 and batch 2 are different. If it was the case, from the laboratory and the plot, four batches were finally obtained based on the measurements and the foods resources of the pupae. The pupae of each batch was labeled and placed individually in rearing Petri dish at the ambient temperature until imagos' emergence. The label indicated the food resource quality and the batch.

A comparison was done made to know exactly whether the cold-humid period is different to the warm-dry period according to the values of their temperature and their hygrometry. If it was the case, we shall after the first and second experimentations compare development phase's durations and the pre-imaginal development durations according to the experimental environments, the food resources and the seasonal periods of the study.

Once these pre-imaginal development durations obtained, we evaluate the pre-imaginal mean duration of *L. trifolii* obtained respectively in the plot with the cut leaves and entire plant according to the entire year ((pre-imaginal development duration of the warm-dry period + pre-imaginal development duration of the cold-humid period)/2). With this previous result, we calculate the number of generations of *L. trifolii* during the year (365 days/pre-imaginal mean duration).

The fitness of *L. trifolii*

The third experimentation is conducted only in the plot during the warm-dry period -2. After the pupal phase of the second experimentation three lots of 100 plants are respectively infested by the leafminers emerged in the plot from the batch 1 (346 pupae) and batch 2 (58 pupae) of the cut leaves and the batch 1 (196 pupae) of the whole plants. Twenty four leafminers (twelve males and twelve females) from each batch were used for infestation. Those plants are labeled according to the batch of the infesting leafminers. The development of *L. trifolii* is then monitored on the whole plants only as on the first experimentations. Larvae observable through their galleries, pupae and imagos are progressively counted according to each label. The fitness of *L. trifolii* was determined through the larval survival rate ((number of pupae / number of larvae) x 100) and the imago emergence rate ((number of imagos / number pupae) x 100). Two comparisons of larval survival rates and imago emergence rates were done in the aim to know whether the fitness of flies obtained (1) from the cut leaves batches or (2) from the batches -1 of cut leaves and whole plants were respectively different.

Sex-ratio of *L. trifolii*

At the end of the third experimentation, adult flies were counted according to their sex. The numbers obtained allowed us to determine two sex-ratios (number of females /number of males). The whole plants' sex-ratio (obtained with flies emerged from whole plants) which was relative to the natural infestation was then compared to the cut leaves' one (obtained with flies emerged from cut leaves). In fact, the percentage of cut leaves' males and females were compared to the whole plants' males and females to know whether the sex-ratio of *L. trifolii* population was affected by the foods resources.

Data analysis

The development durations of each phase of *L. trifolii* were expressed as mean ± standard deviations and compared using the Wald-χ^2 (General Linear Model procedure) according to the experimental environments, the food resources and the periods of study. We first test the difference in temperature and hygrometry distributions to know whether drastic change existed between the cold-humid and warm-dry periods according to experimental environments using Kolmogorov-Smirnov test (K). Meanwhile, the Pearson correlation test (χ^2) was used to find linear relationship between temperature, humidity and the development stage's entire development durations of *L. trifolii*. The comparisons between the pre-imaginal development durations of *L. trifolii* according to the experimental environments, the food resources and the seasonal periods of the study were then tested using the Mann-Whitney test (U). The lengths or diameters of pupae from batches 1 and 2 were compared using a Turkey-test (T). The fitness of the flies from batches 1 and 2 were also compared using the Chi-square test (χ^2). The Chi-square test (χ^2) was once more used to compare the natural and the experimental sex-ratios. Analyses were done using SPSS (20.0) and the results were appreciated at 5% interval confidence.

RESULTS

L. trifolii development durations

Distribution of the temperature and the hygrometry through the periods of study between the laboratory and the plot

Significant variations of temperature (K = 1; P <0.0001) and hygrometry (K = 1; P <0.0001) existed between the laboratory and the plot during the warm-dry period-1. Similar differences between both sites (temperature: K = 0.931; P <0.0001) (hygrometry: K = 1; P <0.0001) were also observed during the cold-humid period (Table 1). Those results prove that temperature and hygrometry were radically different between the laboratory and the plot during the cold-humid period or the warm dry period.

Distribution of the temperature and the hygrometry between the warm-dry-1 and warm-dry-2 periods in the plot

No significant differences of temperature (K = 1.40; P = 0.65) and hygrometry (K = 1.52; P = 0.41) existed in the plot between the warm-dry-1 and the warm-dry-2 periods (Table 2).

Influence of the experimental environments on *L. trifolii* development phases durations independently to the food resource and the seasonal period

Three comparisons were made between *L. trifolii* developments durations observed in the different experimental environments during our study (Table 3).

Table 1. Comparison of temperature and hygrometry through the periods of study between the laboratory and the plot.

Different samplings	Frequency	Minimum	Maximum	Mean±ESD	K	P
T°LW	30	27.69	31.4	29.109±0.82[a]	1.000	< 0.0001***
T°PW	30	22.87	24.81	24.114±0.45[b]		
H°LW	30	54.12	61.2	56.113±1.55[a]	1.000	< 0.0001***
H°PW	30	71.63	76.47	73.187±1.28[b]		
H°LC	30	73.12	78.63	76.459±1.47[a]	1.000	< 0.0001***
H°PC	30	81.16	86.74	84.787±1.60[b]		
T°LC	30	22.12	24.16	23.231±0.57[a]	0.733	< 0.0001***
T°PC	30	19.8	23.47	21.329±1.08[b]		

*Highly significant, Std= standard deviation.Means followed with the same small letters marked at upper corner of standard deviation are not statistically different. Legend: T=temperature; H=hygrometry; L=laboratory; P=plot; W=warm-dry period; C=cold-humid period.

Table 2. Comparison of temperature and hygrometry through the warm-dry-1 and warm-dry-2 periods in the plot.

Different samplings	Frequency	Min	Max	Mean±ESD	K	P
T°PW-2	28	23.6	24.9	24.11±0.44[a]	1.4	= 0.65*
T°PW-1	28	22.87	24,81	24.18±0.45[b]		
H°PW-2	28	71.3	76.81	73.31±1.30[a]	1.52	= 0.41*
H°PW-1	28	71.63	76,47	73.18±1.28[b]		

*Not significant, Std= standard deviation. Means followed with the same small letters marked at upper corner of standard deviation are not statistically different. Legend: T=temperature; H=hygrometry; P=plot; W-1=warm-dry period-1 W-2=warm-dry period-2.

Table 3. Comparison of the development stage durations of *L. trifolii* according to the experimental environments independently to the food resource and the seasonal period.

Development stage	Sites	Min	Max	Mean	Wald- χ^2
Embryonic	Plot	4.11	4.24	4.17±0.033[a]	Wald- χ^2 = 255.14; df = 1; P<0.0001***
stage	Laboratory	3.38	3.5	3.44±0.032[b]	
Larval	Plot	4.48	4.75	4.62±0.068[a]	Wald- χ^2 = 5.04; df = 1; P = 0.02**
stage	Laboratory	4.28	4.53	4.40±0.066[b]	
Pupal	Plot	9.23	9.93	9.58±0.17[a]	Wald- χ^2 = 0.02; df = 1; P=0.87*
stage	Laboratory	9.21	9.87	9.54±0.17[a]	

*** Highly significant; ** significant; * non significant, Std= standard deviation. Means followed with the same small letters marked at upper corner of standard deviation are not statistically different

Significant differences were assessed between: (i) the development durations of embryonic phase obtained in the experimental plot, Mean = 4.17±0.33 days) and in the laboratory (Mean = 3.44±0.032 days); (Wald- χ^2 =255.14; df = 1; P<0.0001); (ii) the development durations of larval phase obtained in the experimental plot Mean = 4.62±0.68 days) and in the laboratory (Mean = 4.40±0.066 days); (Wald- χ^2 = 5.04; df = 1; P = 0.025).
Meanwhile, no significant differences were observed between the development durations of pupal phase obtained in the experimental plot Mean = 9.58±0.177days) and in the laboratory Mean = 9.54±0.17 days) (Wald- χ^2 = 0.02; df = 1; P = 0.87).

Influence of food resources on L. trifolii development phases durations independently to the experimental environment and the seasonal period

Another series of comparisons were made between *L. trifolii* development phases' durations according to the food resource during our study (Table 4). Significant differences were observed between:

(i) The development durations of embryonic stage of leafminers obtained from cut leaves (Mean = 3.21±0.35 days) and whole plants (Mean = 4.4±0.029 days); (Wald- χ^2 = 683.02; df = 1; P<0.0001);

Table 4. Comparison of the development phases durations of *L. trifolii* according to the foods resources and independently to the experimental environment and the seasonal period.

Development stage	Food resource	Min	Max	Mean	Wald- χ^2
Embryonic stage	Whole plants	4.35	4.40	4.17±0.03[a]	Wald- χ^2 = 683.02; df = 1; P<0.0001***
	Cut leaves	3.14	3.28	3.21±0.03[b]	
Larval stage	Cut leaves	3.96	4.25	4.10±0.06[a]	Wald- χ^2 = 73.13; df = 1;
	Whole plants	4.80	5.03	4.92±0.06[b]	P = 0.0001***
Pupal stage	Cut leaves	8.03	8.77	8.40±0.18[a]	Wald- χ^2 = 88.37; df = 1; P<0.0001***
	Whole plants	10.41	11.03	10.72±15[b]	

*** Highly significant, Std= standard deviation, Means followed with the same small letters marked at upper corner of standard deviation are not statistically different.

Table 5. Comparison of the development phases' durations of *L. trifolii* according to the periods of study and independently to the environment conditions and the food resource.

Development stages	Study period	Development duration			Statistical comparison based on Wald- χ^2 test
		Min Min	Max	Mean ± Std	
Embryonic stage	Warm-dry	3.21	3.34	3.27±0.03[a]	Wald- χ^2 = 543.71; df = 1; P<0.0001***
	Cold-humid	4.28	4.4	4.34±0.03[b]	
Larval stage	Warm-dry	3.90	4.15	4.02±0.06[a]	Wald- χ^2 = 105.04; df = 1; P<0.0001***
	Cold-humid	4.86	5.13	5.00±0.06[b]	
Pupalstage	Warm-dry	7.93	8.59	8.26±0.19[a]	Wald- χ^2 = 112.05; df = 1; P<0.0001***
	Cold-humid	10.51	11.21	10.86±0.17[b]	

*** Highly significant, Std= standard deviation, Means followed with the same small letters marked at upper corner of standard deviation are not statistically different.

(ii) The development durations of larval phase of leafminers obtained from cut leaves (Mean = 4.10±0.73 days) and whole plants (Mean = 4.92±0.061 days); (Wald- χ^2 = 73.13; df = 1; P = 0.0001);
(iii) The development durations of pupal phase of leafminers obtained from cut leaves (Mean = 8.40±0.189 days and whole plants Mean = 10.72±0.157days); (W=88.37; df = 1; P<0.0001).

Influence of seasons on the duration development stages *L. trifolii*

The series of comparisons were made between *L. trifolii* development phase durations according to the seasonal periods of the study, without consideration of neither environment, nor food resource (Table 5). Significant differences were observed between:

(i) The development durations of embryonic phase of leafminers during the warm-dry period (Mean = 3.27±0.32 days) and the cold-humid period (Mean = 4.34±0.033 days); (Wald - χ^2 = 543.71; df = 1; P<0.0001);
(ii) The development durations of larval phase of leafminers during the warm-dry period (Mean = 4.02±0.66 days) and the cold-humid period (Mean = 5.00±0.068 days) (Wald- χ^2 = 105.04; df = 1; P<0.0001);
(iii) The development durations of pupal phase of leafminers during the warm-dry period (Mean = 8.26±0.170 days) and the cold-humid period (Mean = 10.86±0.178 days); (Wald- χ^2 = 112.05; df = 1; P<0.0001).

Comparison of the pre-imaginal durations of L. trifolii according to the seasonal periods of the study

Correlation between the daily means temperature or hygrometry and the pre-imaginal development duration of *L. trifolii* in the laboratory and the plot: The Pearson correlation coefficient showed that the display of previous weather conditions during our study had variable incidences over the *L. trifolii* development cycle duration (Table 6). In the laboratory during the warm-dry periods, the temperature was positively and significantly (r = 0.01; P = 0.008) correlated with the *L. trifolii* pre-imaginal development durations. Under the same conditions, the hygrometry was negatively but not significantly (r = -0.04, P = 0.22) correlated with this duration. Significant and negative correlations (r = -0.17; P <0.001) were highlighted between temperature and development duration in the laboratory in cold-humid period. In the

Table 6. Correlation between the daily means temperature or hygrometry and the pre-imaginal development duration of *L. trifolii* in the laboratory and the plot.

Experimental environments		Study period	Pearson correlation	
Temperature	Laboratory	Warm-dry	r = 0.01 ;	P = 0.008**
		Cold-humid	r = -0.175 ;	P < 0.0001***
	Plot	Warm-dry	r = 0.085 ;	P = 0.019**
		Cold-humid	r = 0.44 ;	P < 0.0001***
Hygrometry	Laboratory	Warm-dry	r = -0.047 ;	P = 0.223*
		Cold-humid	r = -0.58 ;	P = 0.105*
	Plot	Warm-dry	r = -0.292 ;	P < 0.0001***
		Cold-humid	r = 0.412 ;	P < 0.0001***

*** Highly significant; ** significant; * non significant.

Table 7. Comparison of the whole durations of the three development phases of *L. trifolii.*

Experimental environments	Study period	Foods resources	Development durations			U-test
			Min	Max	Mean	
Laboratory	Warm-hot	Cut leaves	13	22	16.53±0.26[a]	U = 3843; df = 1; P<0.0001***
		Whole plants	14	25	17.97±0.03[b]	
	Cold-humid	Cut leaves	15	26	19.98±0.27[a]	U = 5768,5; df = 1; P<0.0001***
		Whole plants	15	26	20.8±0.21[b]	
Plot	Warm-hot	Cut leaves	14	22	17.51±0.03[a]	U = 4802; df = 1; P<0.0001***
		Whole plants	15	25	18.58±0.19[b]	
	Cold-humid	Cut leaves	15	29	20.39±0.4[a]	U = 3726; df = 1; P<0.0001***
		Whole plants	15	29	21.98±0.3[b]	

*** Highly significant, Std= standard deviation. Means followed with the same small letters marked at upper corner of standard deviation are not statistically different.

same site and at the same periods, the humidity was negatively and not significantly correlated (r = -0.58; P = 0,105) to the *L. trifolii* pre-imaginal development durations.

In the plot during the cold-humid period temperature (r = 0.44; P <0.0001) and hygrometry (r = 0.41, P <0.0001) were positively and significantly correlated with *L. trifolii* pre-imaginal development durations.

In the same site during the warm-dry periods, the temperature was positively and significantly correlated (r = 0.08; P = 0.01) with *L. trifolii* development phases durations. The hygrometry was negatively and significantly correlated with *L. trifolii* pre-imaginal development durations (r = - 0.29; P < 0.0001).

Comparison of the pre-imaginal development durations of L. trifolii

The series of comparisons are made between the whole duration of the three development phases of *L. trifolii* observed during the seasonal periods of the study (Table 7). During the warm-dry period, the pre-imaginal development duration of *L. trifolii* varied significantly (U = 3843; P<0.0001) between the cut leaves (Mean = 16.53 ± 0.26 days) and whole plants in the laboratory (Mean = 17.97 ± 0.03 days). In the same site during the cold-humid period, this parameter also varied significantly as previously (5768.5; P<0.0001) between cut leaves (Mean = 19.98 ± 0.26 days) and whole plants (Mean = 20.80 ± 0.21 days).

During the warm-dry period, the pre-imaginal development duration varied significantly (U = 4802; P<0.0001) between the cut leaves (Mean = 17, 51 ± 0.03 days) and the whole plants (Mean = 18.58 ± 0.19 days) in the plot. In the same site during the cold-humid period, that duration also varied significantly (U = 3726; P < 0.001) between the cut leaves (Mean = 20.39 ± 0.4 days) and the whole plants (Mean = 21.98 ± 0.3 days). According to the previous results, the pre-imaginal mean duration of *L. trifolii* obtained in the plot during the entire year were respectively 18.95 ± 0.35 days and 20.28 ± 0.11 days with the cut leaves and entire plants. With these pre-imaginal mean durations we are expected to

Table 8. Number of pupae from different batches obtained at the end of the second experimentation.

Batches from experimentation 2 (Warm-dry-1period)		
Batch 1: whole plant	Batch 1: cut leaves	Batch 2: cut leaves
346	196	58

Legend: P= Plants; E= entire; L= leaves; C= cut.

Table 9. Comparison of the fitness of flies obtained from the batch 1 and the batch 2 of the cut leaves.

Variables	Batch 1	Batch 2	χ^2-test
Larval survival rate (%)	80.7	19.3	$\chi^2 =$ 10.85; df = 1; P<0.0001***
Adult emergence rate (%)	83.9	16.1	χ^2=10.16; df = 1 ; P<0.0001***

*** Highly significant.

have more less 19 and 20 generations of *L. trifolii* respectively with the cut leaves and entire plants during the year.

Fitness of L. trifolii

The results obtained at the end of the second experimentation showed that many pupae were obtained with entire plant than cut leaves during the warm-dry period (Table 8).

Comparison between the lengths and the diameters of pupae of the two batches

The lengths and the diameters of pupae of the two batches were compared using the Turkey test. That comparison showed significant differences between:

(i) The lengths of pupae obtained from batch 1 and batch 2 of cut leaves in the plot during the warm-dry period 1 (t = 0.084; P<0.0001).
(ii) The diameters of pupae obtained from batch 1 and batch 2 of cut leaves in the plot during the warm-dry period 1 (t = 0.045; P<0.0001).

Fitness of the flies obtained from the batch 1 and the batch 2 of the cut leaves

The fitness of the flies obtained from batch 1 and batch 2 of the cut leaves are compared using Chi-square test (χ^2) (Table 9). This comparison showed significant differences between:

(i) Larval survival rate (χ^2 = 10.85; df = 1; P = 0.001);
(ii) Imago emergence rate (χ^2 = 10.16; df = 1; P = 0.001).

Fitness of the flies obtained from batch 1 of the cut leaves and batch 1 of the whole plants

The comparison of the fitness of the flies obtained from batch 1 of the cut leaves and batch 1 of the whole plants showed no differences (Table 10) between:

(i) Larval survival rate (χ^2 = 6.25; df = 1; P = 0.012);
(ii) Imago emergence rate (χ^2 = 0.23; df = 1; P = 0.62).

Variation of sex-ratio of L. trifolii

We have considered that the numbers or percentages of leafminers obtained on cut leaves (males: 117 or 49%; females: 121 or 51%) were theoretical when those obtained on whole plants (males: 320 or 48%; females: 348 or 52%) were observed. Then, the comparison done between the cut leaves sex ratio (1/0.96) and that of the whole plants (1/0.91) showed that no significant difference (Table 11) was observed between the cut leaves and the whole plants sex ratios (χ^2 = 2.38; df = 1; P=0.12). The *L. trifolii* sex ratio which is slightly biased toward females was not affected by the food resource.

DISCUSSION

The duration different development stages of *L. trifolii* varied respectively between indoor environment (laboratory) and outdoor (the plot), the warm-dry period and the cold-humid period, the cut leaves and the whole plants. The consequence of the previous results was the variation of the pre-imaginal development durations. The duration of embryonic and larval stages were significantly shorter indoor than outdoor. On the contrary to outdoor, indoor environment was closed and maintained high and more constant temperature, condition that seems more

Table 10. Comparison between the fitness of the flies obtained from the batch 1 of the cut leaves and the batch 1 of the whole plants.

Variables	Batch 1 (leaves)	Batch 1 (plants)	χ^2-test
Larval survival rate (%)	34.8	65.2	χ^2 = 6.25; df = 1; P = 0.12*
Imago emergence rate (%)	42.5	54.8	χ^2 = 0.23; df = 1; P = 0.62*

*Not significant.

Table 11. Comparison between the natural and the experimental sex-ratio.

Variables	Male	Female	Total	Sex-ratio	χ^2-test
Cut leaves (Experimental)	117 (49%)	121 (51%)	238	1/0.96	χ^2 = 2.38; df = 1; P=0.12
Whole plants (Natural)	320 (48%)	348 (52%)	668	1/0.91	

*Not significant.

suitable for the development of *L. trifolii*. Our observations are thus similar to those of Poe (1981) who showed that at constant temperature of 30°C, the *L. trifolii* larvae achieve their development in 4 days while at 20°C it takes 7 days. On the other hand, various authors including Spencer (1973), Nedstam, (1985), Minkenberg and Lenteren (1986) and Lee et al. (1990a) showed that embryonic development of *Liriomyza bryoniae* (Kaltenbach) requires 4-8 days at mean temperature of 20.6°C. Our results showed that the duration of larval stage varied from 4 to 7 days, and were similar to those of Harris and Tate (1933) who obtained larval stage duration between 4-7 days at mean temperature above 24°C). The *L. trifolii* pupal stage durations did not varied in the laboratory compare to the plot. That result may be due to the fact that pupae were less susceptible to the slight variation of temperature observed during the study than eggs and larvae. During similar studies, the *Liriomyza sativae* Blanchard pupal stages took 7-14 days at temperature comprised between 20 and 30°C (Leibee, 1982).

The *L. trifolii* embryonic, larval and pupal phases durations are significantly shorter with the cut leaves than the whole plants. This result may be due to the fact that the cut leaves are poor in food resource availability than whole plants. Therefore, the limited amount of nutrients in cut leaves due to the non-renewal of the sap may induce the acceleration of the embryonic phase before the depletion of the limited amount of nutrients in the cut leaves. Bruno (1986) considered that temperature and food resource availability are the main factors that affect different stages duration of insect development. Poe (1981) showed that on chrysanthemum, the cycle of *L. trifolii* is achieved in 24 days at 20°C *L. trifolii* is very prolific during the warm-dry period than the cold-humid period according to the significant shorter of its embryonic, larval and pupal phases durations. That result may be due to the action of temperature and hygrometry. During the warm-dry period, the actions of temperature and hygrometry seem to be antagonist even if there is a domination of the temperature. Perhaps the temperature contributed to activate the enzymatic reactions of embryos, larvae and pupae which results in short development durations. Contrarily, hygrometry assured to the leaves a permanent hydration through the phenomenon of revival, a phenomenon limiting the water stress whose consequence is the deceleration of embryonic, larval and pupal growth. During the cold-humid period, the antagonism persisted; but the temperature is not sufficient to dominate as previously the effect of hygrometry. The consequence is the deceleration of embryonic, larval and pupal growth which resulted in long *L. trifolii* development stages durations. Our results concerning the temperature confirmed the ones of Minkenberg (1988) who showed that at 25°C with *L. trifolii* on celery, the embryonic stage requires 2.5 days, 4.6 days for larval stage and 9.3 days for pupal stage. According to Leibee (1982), emergence of adults of all species of the genus *Liriomyza* occurs 7-14 days after pupation, at temperatures between 20 and 30°C.

In this study, the means durations of embryonic, larval stage and pupal stage varied respectively from 3.14 to 4.40 days, 3.90 to 5.13 days and 7.90 to 11.21 days. Maybe, when the egg of *L. trifolii* was particularly influenced by some parameters as experimental environments, foods resources and periods of study, it programs the duration of each development phase. The consequence of that programmation is the significant variation of the whole duration of the pre-imaginal development phases of *L. trifolii* according to the experimental environments, the foods resources and the periods of study. These results are in accordance with those of Mauchamp (1988) who observed that different variations in the *L. trifolii* growth cycle are explained by the fact that insects are cold-blooded animals and their body temperature closely follows room temperature. When the temperature decreases, the activity of the cells decreases. Leibee (1984) showed that on celery whole plants, *L. trifolii* closes its cycle (from the laying to adult emergence) in 12 days at 35°C, 19 days in 25°C, 26 days at 20°C, 54 days at 15°C. Capinera (2006) showed that *L. sativae* development cycle lasts 25 days at 15°C and 15 days at 30°C. Significant differences are obtained between measurements of pupae of batch 1 and batch 2.

Morphometric characters of pupae were: diameter (0.44 to 0.92 mm); length (1 to 1.98 mm). Similar results (1.3-2.3 × 0.5-0.75 mm) were obtained on *L. sativae* (CABI et l'OEPP, 1990) According to their measurements; pupae obtained from batch 1 were different than those of batch 2. In the same way, significant differences are obtained between the fitness of flies obtained from batch 1 and batch 2 of the cut leaves. These differences are showing that the performances of flies obtained from batch 1 are less compare to those of the batch 2. Indeed, contrarily to the whole plants, the larval which fed in the marginal areas leaflets of cut leaves died or were poorly developed as a result of drying or withering of this food parts. This has resulted in a decrease in the number of larvae which performed pupation in cut leaves. Furthermore, from some larvae (diameter > 0.73 mm, length > 1.74 mm) poorly developed which nevertheless performed small sizes pupae, imago did not emerge because of their desiccation. It thus appears from these results that high temperatures of the warm-dry period desiccate the pupae of small sizes. Our results corroborate those of some authors who showed that extreme temperatures were harmful to the overall *L. trifolii* development. Capinera (2005) has estimated that in *L. trifolii*, the development stops at temperatures below 7.5°C or above 12.9°C, depending on the development stage and the host plant; the optimum temperature is around 25°C; above 30°C larval mortality increases. None difference is obtained between the fitness of flies obtained from batch 1 of the cut leaves and batch 1 of the whole plants. These differences are showing that the performances of flies obtained from cut leaves' batch 1 are the same than to those of the entire plants' batch 1. It is worthwhile to note that despite the limited amount of nutrients and the water stress in the cut leaves, many *L. trifolii* have completed their embryonic, larval and pupal stages with success as those obtained with whole plants. These results also showed that the cut leave, synonym of pruning has three drawbacks:

(i) It increase the number of generations of the pest (from 18 with the entire plants to 19 with the cut leaves) in gardens during the year especially during the hot period;
(ii) It does not inhibit the fitness of all adults such as we have great fitness of flies obtained from 50 cut leaves' pupae;
(iii) It reduces the accessibility of some parasitoid larvae to leafminers covered with other cut leaves abandoned in the furrow.

The pruning in the garden contributes to reduce the number of the offsprings and did not affect the fitness of all the leafminers. Great sizes adults resulting from any food resource showed that under natural conditions they are able to provide an offspring that can cause severe devastations in celery plots. Our results on the measurements or the sizes of individuals confirmed those obtained from studies on parasitoids by Van den Assem et al. (1989) and Godfray (1994) which showed that size is a parameter determining the fitness of a parasitoid. In Aphidiidae, it was demonstrated that fertility is proportional to the size of the individual (Elliot et al., 1994). Two reasons showed that a bigger female parasitoid is better: it lives longer and it is more fertile, so that allows it to produce more offsprings and thus increase its fitness (van den Assem et al., 1989).

The increase of the pre-imaginal mortality is so important on cut leaves such as they look like another plant than whole plants. However, the data showed that the pre-imaginal mortality affected similarly males and females. Despite that mortality, no significant difference was observed between the cut leaves sex ratio (1/0.96) and that of the whole plants (1/0.91). Furthermore, the *L. trifolii* sex ratio which is slightly biased toward females.
Our results are collateral to those of some authors who found that the *L. trifolii* sex ratio was also slightly biased toward female with respectively 1:0.75 for castor; 1: 0.8 for cotton; 1:0.6 for cowpea and 1:0.7 for tomato (Sushila Nadagouda et al., 1997).

Conclusion

The present work has shown the capacity of pruning leaves to ensure the entire development of *L. trifolii* from early stages to adult with good fitness. The pruning followed by the abandonment of the infested leaves in the furrow certainly eliminates the pest for a few moments, but cannot be considered as a promotable control method for the protection of celery. It induces the reduction of the development cycle duration and then increase the number of pest generations during the year. Moreover, several individuals obtained throughout that practice have retained an excellent fitness and later infested healthy plants. More efforts will be required in view of establishing an Integrated Pest Management (IPM) which will take into account the preservation of the environment and health of consumers.

Conflict of Interest

The authors have not declared any conflict of interest.

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Evaluation of the agronomic potentials of swine waste as a soil amendment

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The objective of this experiment was to evaluate the agronomic potentials of different rates of swine waste on soil properties, maize growth and yield. Four rates of swine waste namely 0, 7, 13 and 27 t ha^{-1} were laid out in a randomized complete block design (RCBD) and replicated three times at the Teaching and Research Farm of the Faculty of Agriculture and Natural Resources, Enugu State University of Science and Technology, Enugu, South East Nigeria. Oba super 11 hybrid maize was planted to a depth of 5 cm in the prepared beds at a spacing of 25 cm by 75 cm (inter and intra row spacing, respectively). Soil samples were collected from the top soil at a depth of 0 to 15 cm before and 2 weeks after the application of the swine waste. The obtained results showed that the application of different rates of swine waste significantly altered the chemical properties of the soil. The concentration of the exchangeable bases (calcium, magnesium, potassium and sodium) was increased, while exchangeable acidity and cation exchange capacity significantly decreased at a rising rate of swine waste application. There was a significant difference ($p < 0.05$) in soil pH, cation exchange capacity, organic matter content, total nitrogen, organic carbon, available phosphorus, base saturation, bulk density and moisture content among the treatments. The mean plant height at harvest and maize grain yield increased relative to the control treatment. Generally, swine waste was found to be an effective soil amendment in improving the soil properties, growth and yield of maize.

Key words: Swine waste, agronomic potential, soil amendment, maize grain yield.

INTRODUCTION

One of the inherent defects of the soils in the tropics is its low level of fertility status which is a major drawback in the agricultural usefulness of the soil (Schlecht et al., 2007). According to Srivastara (2007), fertile soil is defined as the quality that enables a soil to provide plant nutrients in adequate amounts and in proper balance for growth of specified plants when light, moisture, temperature, tilt and other growth factors are

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favorable. Mafongoya et al. (2007) reported that maintenance of high crop yield under intensive cultivation is possible through the use of fertilizers. Fertilizer can be in form of organic or inorganic. The use of inorganic fertilizers has not been helpful as it is associated with increased soil acidity, leaching and nutrient imbalances (Schlecht et al., 2007). According to Ayoola and Makinde (2006), inorganic fertilizers are usually not available and are always rather expensive for the low income small-scale farmers. Organic manure such as cow-dung, poultry manure, swine waste and crop residues can be used as an alternative for inorganic fertilizers. The use of swine waste which is readily available in the tropics can compensate for the expensive and unreliable supply of inorganic fertilizers for low income small-scale farmers in the tropics.

The main objective of this study was to evaluate the agronomic potentials of swine waste rates as a soil amendment. This will be achieved through evaluating its effect on the soil physical properties, soil chemical properties, growth and yield of maize.

MATERIALS AND METHODS

This experiment was carried out at the Teaching and Research Farm of the Faculty of Agriculture and Natural Resources, Enugu State University of Sciences and Technology, Enugu, South East Nigeria. The site is situated at latitude 06°52' North, longitude 07°15' East and 450 m above sea level. The range of rainfall amount is within 1700 to 2000 mm and it has a bimodal pattern of occurrence. Within April and October it is wet, November and December it is dry. The soil type is Ultisol of sandy-clayey-loam textual class and classified as Tropaquent or Eutric leptosol (Anikwe, 2006). The experiment consisted of four rates of swine waste namely 0 t ha^{-1} (0 kg/plot), 7 t ha^{-1} (6 kg/plot), 13 t ha^{-1} (12 kg/plot) and 27 t ha^{-1} (24 kg/plot) laid out in a randomized complete block design (RCBD) and replicated three times. The swine waste was slurry from pig abattoir that had been air-dried for 40 days. The land was cleared of existing grasses, ploughed and made into beds of 3 by 3 m (9 m^2). A total of 12 beds were made. Each of the bed separated from one another by a spacing of 1 and 1 m pathway between replications. Swine waste was incorporated into the soil to a depth of 0 to 15 cm using the hand hoe. Oba super 11 hybrid maize was planted to a depth of 5 cm in the prepared beds at a spacing of 25 by 75 cm (inter and intra row spacing, respectively) given a total of 48 plants per plot. Planting was done two seeds per hole and thinned to one plant at 2 weeks after planting. The plants at the two centre rows were randomly sampled during data collection. Weeding was done manually whenever necessary throughout the experimental period. Soil samples were collected from the top soil at a depth of 0 to 15 cm before and 2 weeks after the application of the swine waste. Three representative soil samples were collected per plot and bulked to form a composite soil sample for each plot. A total of 12 composite soil samples were collected. Samples were air-dried, grounded and passed through a 2-mm standard mesh. The soil pH was determined with a pH meter using 1:2.5 soils to water ratio according to Page et al. (1982). Organic carbon was determined using the Walkley and Black wet digestion method (Bremmer and Mulvaney, 1982); soil organic matter content was obtained by multiplying the value of organic carbon by 1.724 (Van Bemmeler factor), total nitrogen determined by macro-kjeldahl procedure (Page et al., 1982). Available phosphorus was extracted with Bray II extractant as described by Bray and Kurz (1945) and colorimeterically using ascorbic acid method (Murphy and Riley, 1962). Exchangeable potassium and sodium were extracted using 1N ammonium acetate (NH_4OAC) solution and determined by the flame emission spectroscopy as outlined by Anderson and Ingram (1993). Aluminum and hydrogen content (exchangeable acidity) were determined by the titrimetric method after extraction with 1.0 N KCL (McLean, 1982). The cation exchange capacity was determined by the NH_4OAC displacement method (Rhoades, 1982). Calcium and magnesium was determined by the complexiometeric titration method as described by Chapman (1982). Particle size distribution analysis was done by the hydrometer method (Gee and Bauder, 2002) and the corresponding textural class determined from the United States Department of Agriculture Soil Textural Triangle. Bulk density was determined using the core method as described by Blake and Hartage (1986), total porosity by the method outlined by Anderson and Ingram (1993) and moisture content was obtained by the method stated by Klute and Dirkson (1986). Samples of air-dried swine waste were collected and chemical analysis was done to determine pH, organic carbon, total nitrogen, available phosphorus, potassium, magnesium, calcium, sodium and organic carbon. Data were collected on mean plant height at harvest and maize grain yield after harvest. The data collected were subjected to analysis of variance (ANOVA) as outlined by Gomez and Gomez (1984). Significant means were separated using Fishers least significant difference (F-LSD) at 5% probability level. Statistical analysis was executed using GENSTAT Release 7.2DE Discovery Edition 3 (GENSTAT, 2007) statistical software.

RESULTS

Table 1 shows the chemical properties of the soil before the study. The soil was sandy-clayey-loam texture with pH of 4.60. The soil organic carbon, organic matter content, total nitrogen and base saturation were 7.93, 0.17, 0.03 and 58%, respectively. The exchangeable bases (calcium, magnesium, potassium and sodium) were 0.98, 0.68, 0.09 and 0.11 meq/100 g, respectively, while the available phosphorus was 1.20 ppm.

The impact of swine waste rates on the soil chemical properties of the soil (Table 2) indicates that the soil total nitrogen, available phosphorus, organic carbon, organic matter contents, pH, base saturation, calcium, magnesium, potassium and sodium were significantly ($p <0.05$) increased with increasing rate of swine application. On the contrary, a decrease in exchangeable acidity and cation exchange capacity were recorded at an ascending swine waste application.

The results shown in Table 3 reveals that the application of swine waste significantly ($p < 0.05$) increased the total porosity and moisture content and decreased the bulk density. The highest effects on these physical parameters were observed in plots amended with 27 t ha^{-1} swine waste.

Furthermore, Table 4 shows that the mean plant height at harvest and maize grain yield after harvest were significantly ($p < 0.05$) influenced by the swine waste addition to the soil. The highest plant height (480.00 cm) was recorded at the plots amended with 27 t ha^{-1} and the least (90.00 cm) was observed in the control treatment (0 t ha^{-1}). The dry grain weight increased by about 128.43,

Table 1. Initial soil characteristics and the chemical composition of swine waste.

Properties	Level	Swine waste
Particle size distribution (%)		**-**
Sand	79.00	-
Slit	16.00	-
Clay	5.00	-
Textural class	Sandy-clayey-loam	-
pH (water)	4.60	6.56
Organic matter (%)	0.17	21.46
Organic carbon (%)	7.93	12.45
Available phosphorus (ppm)	1.20	1.64
Total nitrogen (%)	0.03	2.41
Exchangeable bases (meq/100 g)		-
Calcium	0.98	5.27
Magnesium	0.68	0.30
Potassium	0.09	1.52
Sodium	0.11	0.38
Exchangeable acidity (meq/100 g)	1.53	-
Cation exchange capacity (meq/100 g)	3.51	-
Base saturation (%)	51.00	-

Table 2. The effects of swine waste application on the chemical properties of the soil.

Rates	pH	OM	OC	TN	AP (ppm)	Ca	Mg	K	Na	EA	CEC	BS (%)
	(%)					meq/100 g						
0 t ha^{-1}	5.00	0.64	0.37	0.06	1.58	1.12	0.83	0.12	0.14	1.59	5.80	52.00
7 t ha^{-1}	5.16	1.93	1.12	0.09	2.91	2.10	1.00	0.19	0.18	1.36	6.00	62.00
13 t ha^{-1}	5.26	2.05	1.19	0.13	3.03	2.92	1.02	0.20	0.20	1.20	6.30	62.00
27 t ha^{-1}	5.43	2.66	1.54	0.13	3.35	3.01	1.09	0.22	0.28	1.00	6.80	62.00
F-LSD (0.05)	0.50	0.03	0.02	0.04	0.01	0.02	0.02	0.34	0.04	NS	NS	1.91

OM, Organic matter content; OC, organic carbon; TN, total nitrogen; AP, available phosphorus; Ca, calcium; Mg, magnesium; K, potassium; Na, sodium; EA, exchangeable acidity; CEC, cation exchange capacity; BS, base saturation; F-LSD (0.05), significant at 0.05 probability level; NS, non significant.

68.84 and 35.29% for rate of 27, 13 and 7 t ha^{-1}, respectively over the control treatment.

DISCUSSION

Effects of swine waste application on soil physical and chemical properties

The changes in the chemical properties of the soil after swine waste application is related to the chemical composition of the added swine waste. Smiciklas (2007) noted that the swine waste application improved the chemical properties of the soil due to the addition of organic matter. The rise in soil pH was due to decrease in exchangeable acidity and increase in exchangeable bases. The status of available phosphorus and total nitrogen were significantly ($p < 0.05$) increased from 1.58 to 3.35 ppm for phosphorus and 0.06 to 0.13% for total nitrogen, respectively. This result is due to the nitrification of ammonium nitrogen in the swine waste. This observation corroborated the assertions of Chong-Ho et al. (2005) that livestock manure such as swine waste contains ammonium nitrogen. The reduction in bulk density and increase in total porosity and moisture content was as a result of swine waste application which caused a homogenous distribution of manure constituents between soil particle and breakdown of swine waste by micro-organisms which produced essential cementing materials that links soil particles and form soil aggregates. This is in harmony with what Mafongoya et al. (2007) noted that organic manure

Table 3. The effects of swine waste application on the physical properties of the soil.

Rates	Bulk density (g cm^{-3})	Total porosity (%)	Moisture content (%)
0 t ha^{-1}	1.51	43.00	30.00
7 t ha^{-1}	1.46	45.00	40.00
13 t ha^{-1}	1.43	46.00	44.10
27 t ha^{-1}	1.41	46.70	46.00
F-LSD (0.05)	0.15	4.84	6.60

F-LSD (0.05), Significant at 0.05 probability level.

Table 4. The effects of swine waste application on the mean plant height (cm) of maize at harvest and the maize grain yield (t ha^{-1}) after harvest.

Rates	Plant height	Maize grain yield	*Increase over control (%)
0 t ha^{-1}	90.00	1.02	0.00
7 t ha^{-1}	140.00	1.38	35.29
13 t ha^{-1}	300.00	1.67	68.84
27 t ha^{-1}	480.00	2.33	128.43
F-LSD (0.05)	4.35	1.08	

*** =** Maize grain yield increase over control, F-LSD (0.05) - significant at 0.05 probability level.

improves the tilt of surface soil for crop production.

Effects of swine waste application on plant height and maize grain yield

The significant increase in mean plant height and maize grain yield over the control were due to the effect of swine waste application in improving soil aggregates, increasing moisture content and pore space distribution between the soil particles. Another explanation is that organic manure act as complexing agents which minimizes the loss of soil nutrient by leaching from the root zone and thereby increases nutrient availability and supply potentials for plant uptake (Dahdoh and El-Hassanin, 1993). Many studies proves that the use of organic manure such as farm yard manure, sewage sludge, cow dung, goat pellets, etc. as a soil amendment promotes plant growth more than when commercial fertilizers were added. The obtained results from this study tallied with those observed by Elsokkary et al. (1989) that sewage sludge application increased the dry weight and grain yield of alfalfa, wheat, faba bean and soybean. Christodoulakis and Margaris (1996) showed that plant height increased in maize by 77% in sludge amended treatment compared to 25% in the commercial fertilizer amendment.

Conclusion

The results of this study showed that there was a significant difference ($p < 0.05$) among the treatments on the soil properties. The maize plant height and maize grain yield varied over the control treatment. The highest application rate (27 t ha^{-1}) gave the highest grain yield and the impact on soil properties was most pronounced at this rate. This placed 27 t ha^{-1} as a satisfactory rate of swine waste application for maize production. Though, little above this rate could be recommended to combat losses of nutrients by volatilization into the atmosphere and leaching into rivers and streams. Furthermore, continuous use of swine waste application should be discourage as it increases the level of residual toxic effects of some micro nutrients in the soils such as zinc and lead which are harmful to man

Conflict of Interest

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

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Ethiopian beef carcass characteristics

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This study was conducted to evaluate beef carcass characteristics of cattle slaughtered at local abattoirs in Ethiopia. About 10% of carcasses (3080) were collected from Adama, Hawassa, Mekelle and Kombolcha abattoirs between August 2013 and January 2014. The results of the study showed that 98.56% of cattle slaughtered were indigenous cattle while 1.44% was Holstein Frisian. The average carcass weight of indigenous cattle was 135.90 + 0.69 kg. Carcass weight was significantly ($p<0.001$) different between abattoirs, season, conformation grades, fat grades and categories of cattle. Conformation grade 1, 2 and 3 accounted for 30, 34.29 and 35.71% of carcasses evaluated, respectively. Fat grade1, 2 and 3 accounted for 67.5, 23.57 and 8.93% of carcasses evaluated, respectively. Intact bulls, castrated bulls, growing bulls and cows accounted for 26.07, 64.64, 3.95 and 5.36% cattle slaughtered, respectively. Higher carcass weight, higher proportion of superior conformation and fat grade were observed in the wet season compared to the dry season. Inferior conformation and fat grades were relatively higher for cows (80 and 84.42%) and castrated bulls (37.57 and 67.96%) compared to other categories of cattle. From the study it was concluded that the use of dairy beef was very low in Ethiopia. The proportion of carcass with little /no fat cover (fat grade 1) was very high. The relatively better carcasses weight, conformation and fat grades in the wet season compared to the dry season indicates the opportunities to improve carcass weight and quality through better feeding management.

Key words: Beef carcass weight, conformation and fat grades, local abattoirs, Ethiopia.

INTRODUCTION

Livestock plays an important role in the agriculture of Ethiopia. It contributes 15 to17% of gross domestic product (GDP) and 35 to 49% of agricultural GDP (CSA, 2008). Cattle contribute about 80% of GDP that come from livestock (Tefera, 2011). Ethiopia has 53.4 million cattle (CSA, 2011) which represent the largest cattle population in Africa (Negassa et al., 2011).

However, the potential has not been fully utilized. Cattle in Ethiopia produced about 0.331 million tones of meat annually (CSA, 2008). Average carcass weight of cattle was 108 kg/head (Negassa et al., 2011), while Ethiopians consume about 8 kg of meat per capita annually which is far less than what is consumed in developing countries (Betru and Kawashima, 2009).

There is no specialized production system specifically for beef production in Ethiopia. Beef is a by-product in the

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Table 1. Descriptions of the study area.

Abattior	Region	Distance from Addis (km)	Global position	Altitude (MASL)	T°C	RF (mm)
Adama	Oromiya	99 E	8°32'N 39°16E	1712	13 - 27	809
Hawassa	SPNN	250 S	7°03'N 38°28E	1500 - 2000	20 - 25	800 -1000
Kombolcha	Amhara	375 NE	11°4'N 39°44E	1842 - 1915	11 - 26	750 - 900
Mekelle	Tigray	783 N	7°13'N 5°52E	2000 - 2200	11- 24	579-650

MASL, Meters above sea level; mm, millimeters; SPNN, Southern people national and nationalities.

pastoral and mixed crop-livestock production system as cattle are primarily kept for milk and traction purposes, respectively. Cattle are usually sold when they are culled from dairy purpose, too old for draft purpose and usually in a poor body condition. Pastoral, agro-pastoral and mixed crop-livestock production systems accounted for more than 99% of cattle production system practiced in the country (Negassa et al., 2011).

Very little research has been done concerning meat production in Ethiopia (Avery, 2004), and in particular, on carcass quality of beef cattle (Negassa and Jabbar, 2008). Even though Ethiopia has developed a beef carcass classification system in 2012 (ES, 2012), the system was not used to characterize the carcass quality to date. Characterizing carcass traits of cattle is important to develop an appropriate improvement strategy of the sector. Moreover, the tendency to pay beef producers based on carcasses quality and weight is increasing. Carcass quality is mainly determined by age, sex, conformation and fat cover (Lazzaroni and Biagini, 2009). Different proportion of categories of cattle, conformation grade and fat grade were reported for different abattoirs in different countries (Lazzaroni and Biagini, 2009; Weglarz, 2010; Savell et al., 2011).

The objective of this study was therefore to evaluate carcass characteristics of cattle slaughtered at local abattoirs in Ethiopia.

MATERIALS AND METHODS

Study abattoirs

The study region contained more than 95% of cattle population of the country that is, Oromiya - 23 million, Amhara - 13.4 million, SPNN - 11 million and Tigray- 3.6 million (CSA, 2011). The dominant cattle breed slaughtered at Adama and Hawassa abattoirs were Arsi and Bale cattle breeds, while at Kombolcha and Mekelle abattoirs Raya, Wollo highland, Arado and Barka breeds were slaughtered. All cattle slaughtered were produced form mixed crop-livestock production system. However, most cattle supplied to Adama abattoirs were fattened in the feedlot for some period after being purchased from farmers in mixed crop-livestock/agro-pastoral production system. Trekking is common method of transporting cattle to abattoirs. Even though stunning boxes were available at the abattoirs, it was not seen being used in the processes of slaughter. Based on the information from the workers, cattle are not willing to enter into the boxes. Stunning of cattle was made by stubbing sharp knife at attlanto-occipital space. Evisceration took place at the floor by incising the skin at the ventral and central part of the abdomen. Then cattle were hoisted with their hind legs for further processing. It is common to quarter carcasses and transport to butcheries. No refrigeration is used at abattoirs as hot carcasses are supplied to market for consumers. Description of the study areas are shown in Table 1.

Data collection

Information on categories of cattle slaughtered, gender, hot carcass weight, conformation and fat grades, sanitary condition and coat color of the hide were collected from the study abattoirs. Data was collected during 7 to 10 days from 10% cattle slaughtered in each abattoir in the dry and the wet season between August, 2013 and January, 2014. The country has short rainy (March-May), long rainy (June-September) and dry (October-February) seasons.

Conformation and fat scores were recorded by an inspector at all abattoirs studied to avoid subjective difference between evaluators using the standards shown in Table 2. Carcasses were evaluated during slaughtering process on hot carcasses. Half right side of whole carcasses was weighted using a scale sensitive at 100 g. The weight of half right side was multiplied by 2 to estimate whole carcass weight. Carcasses were categorized into cows, growing bulls, intact bulls and castrated bulls based on physiological age (degree of ossification of cartilage of thoracic vertebrae, discs of intervertebral sacral vertebrae) and sex of cattle slaughtered (Table 2). Data was collected on sanitary conditions on the hide of the cattle using mud score technique (Boleman et al., 1998). For the purpose, mud score 0 was given for cattle with no mud; mud score 1 for cattle with mud on legs and mud score 2 for cattle with mud on legs and belly. Data was collected on the hide color of cattle. Hide color were classified based on primary color (>50% total hide surface area) into black, white, red, gray or Holstein Frisian.

Statistical analysis

Data were analyzed using JMP version 8 statistical software. Factors showing significant difference at probability level of $p < 0.05$ were compared using Tukey pairwise comparison procedure. Carcass weight was analyzed using conformation, fat, category and abattoirs as fixed effects. The percentage of different grades of conformation and fat of carcasses was calculated as a ratio of carcasses in each category to the total carcasses evaluated.

RESULTS AND DISCUSSION

Coat color of cattle slaughtered at Adama, Hawassa and Mekelle abattoirs

The coat colors of cattle slaughtered at local abattoirs are

Table 2. Characteristics and description beef carcass classification (ES) system in Ethiopia (ES, 2012).

Conformation	Grade
Carcasses with convex profiles and very well developed muscle	1
Carcasses with straight profiles and good muscle development	2
Carcasses with concave profiles and moderate muscle development	3
Fat	**Grade**
Carcasses with small or no fat coverage	1
Carcasses with visible fat on the whole body with the exception the hind leg and shoulder	2
Whole carcasses covered with fat and fat deposited in the thoracic cavity	3
Descriptions	**Categories**
Carcass of young bull or heifers that weight less than 70 kg	JB
Carcasses of grown up bulls (cartilage of the spine up to four thoracic vertebras show no sign of ossification and from fifth to ninth show sign of ossification; discs of inter-vertebral of sacral vertebrae show sign of ossification)	JM
Carcasses of intact bulls (not castrated; all cartilage of the spine of thoracic vertebras ossified)	M
Carcasses of castrated bulls (castrated; all cartilage of the spine of thoracic vertebras ossified)	O
Carcasses of heifers (undeveloped udder; all cartilage of the spine of thoracic vertebras ossified)	JF
Carcasses of cows (well developed udder; all cartilage of the spine of thoracic vertebras ossified)	F

Table 3. Coat color of cattle slaughtered at local abattoirs.

Abattoirs	Coat color					Total
	>50% Black (%)	>50% Gray (%)	Holstein Frisian (%)	>50% Red (%)	>50% White (%)	
Overall	748 (32.54)	451 (19.62)	33 (1.44)	737 (32.06)	330 (14.35)	2299
Adama	330 (29.41)	275 (24.51)	11 (0.98)	341 (30.39)	165 (14.71)	1122
Hawassa	176 (41.03)	99 (23.08)	0 (0.00)	132 (30.77)	22 (5.13)	429
Mekelle	242 (32.35)	77 (10.29)	22 (2.94)	264 (35.29)	143 (19.12)	748

χ^2 = 138.99; p<.0001.

presented in Table 3. The coat colors of cattle slaughtered during the study period were black, gray, red and white. The difference in the proportion of coat colors between abattoirs indicates the difference in cattle breeds slaughtered at the abattoirs studied. Holstein Frisian cattle account for 1.44% of cattle slaughtered. Most of cattle slaughtered at the abattoirs were indigenous local cattle. The dairy industry is rapidly growing in Ethiopia (Hutcheson, 2006). The present study further confirmed the report by Hutcheson (2006) which suggested the need to exploit dairy beef in Ethiopia.

Carcass weight between abattoirs, season, conformation, fat grades and categories of cattle

Carcass yield difference between abattoirs, season, conformation grades, fat grades and categories of cattle are presented in Table 4. The average carcass weight at local abattoirs was 135.90 ± 0.69 kg. The average carcass weight in the present study was comparable to the report for Boran (98.2 to 135.2 kg) and Ogaden (163 to 182 kg) cattle at research station in Ethiopia and relatively higher than the carcass weight of WASH (74.1 kg) and Sanga (95.3 kg) cattle in Ghana (Lemma et al., 2007; Teye and Sunkwa, 2010; Mekasha et al., 2011). Carcass weight was significantly (p < 0.001) different between abattoirs, season, conformation grades, fat grades and categories of cattle slaughtered. Relatively higher carcass weight was observed in Adama abattoir (161.26 ± 1.05 kg) compared to Hawassa (142.46 ± 1.10 kg) and Mekelle (136.15 ± 1.17 kg) abattoirs. Cattle slaughtered in Kombolcha abattoir had relatively lower carcass weight which was 95.63 ± 0.46 kg. The difference in carcass weight, conformation and fat grade between abattoirs studied in the present study might be

Table 4. Carcass weight between abattoirs, season, conformation and fat grades and categories of cattle.

Variable	Number of observation	%	Mean (kg)	SE
Overall mean	3080		135.90	0.69
Abattoir				
Adama	1122	36.43	161.26[a]	1.05
Hawassa	429	13.93	142.46 [b]	1.10
Kombolcha	781	25.36	95.63[d]	0.46
Mekelle	748	24.29	136.15[c]	1.17
Season				
Dry	1661	53.93	119.56[b]	0.89
Wet	1419	46.07	155.02[a]	0.83
Conformation grade				
1	924	30.00	171.24[a]	1.04
2	1056	34.29	130.39[b]	0.85
3	1100	35.71	111.51[c]	0.89
Fat grade				
1	2079	67.50	120.69[c]	0.70
2	726	23.57	162.59[b]	1.09
3	275	8.93	180.44[a]	1.80
Category				
Cow (F)	165	5.36	103.10[c]	2.24
Growing bull (JM)	121	3.93	132.36[b]	2.57
Intact bull (M)	803	26.07	150.90[a]	1.34
Castrated bull (O)	1991	64.64	132.78[b]	0.83

Means in the same column with different superscript letters differ ($p < 0.001$).

due to the difference in breed and environment in which cattle was managed prior to slaughter. A large proportion of fattening centers is found in and around the city Adama (Little et al., 2010) which serve as source of cattle for the Adama abattoir. Most of cattle slaughtered at Mekelle and Kombolcha abattoirs were supplied directly by the farmers (without going through fattening).

A higher carcasses weight was observed in the wet season (155.02 ± 0.83 kg) compared to the dry season (119.56 ± 0.89 kg). This might be due to the availability of feed and water in wet season which made the cattle finished in good body condition and relatively better slaughter weight. Conformation grade 1 had relatively higher carcass weight (171.24 ± 1.04 kg) compared to conformation grade 2 (130. 39 ± 0.85 kg) and conformation grade 3 (111.51 ± 0.89 kg). This might be due to the better muscle development of carcasses categorized as conformation grade 1 over carcasses categorized in conformation grade 2. The difference in carcass weight between conformation 2 and conformation grade 3 can be explained similarly. Moreover, the significant effect of conformation on carcass weight was well observed in Table 4. Conformation grades 1, 2 and 3 accounted for 30, 34.29 and 35.71% of carcasses evaluated, respectively. The lower proportion of superior conformation and higher proportion of inferior conformation were similarly reported in some other research conducted using SUEROP classification system (Lazzaroni and Biagini, 2009; Méndez et al., 2009; Petroman et al., 2009). Fat grade 3, carcasses had relatively higher weight (180.44 ± 1.80 kg) compared to fat grade 2 carcasses (162.59 ± 1.09 kg) and fat grade 1 carcasses (120.69 ± 0.70 kg). This can be due to the cover of the whole carcasses with fat in grade 3 compared to fat grade 2. Fat grade 1 had little/no fat covering the carcasses. Fat grades 1, 2 and 3 accounted for 67.5, 23.57 and 8.93% of carcasses evaluated, respectively. The proportions of little/no fat carcasses were relatively higher in this study. This indicated that the carcasses produced currently in Ethiopia did not satisfy the consumer preference as Ethiopian prefers high fat meat (Aynalem et al., 2011). Moreover, adequate fat cover must be present to produce corresponding marbling that determines quality of the product. The higher proportion of fat grade 1 in the present study was in contrary to the finding in northern Italy where higher proportion of fat grade 2 carcasses was observed (Lazzaroni and Biagini, 2009). According to these researchers, the higher proportion of fat grade 2 reflects the preference of the consumers for low fat meat. The higher proportion of little/no fat carcasses in the present study might be associated with poor body condition of cattle prior slaughter. Feed shortage was often reported as a major constraint to livestock production in Ethiopia. Natural pasture is the main source of feed for most livestock, complemented by fodder and crop residues during the dry season. Productivity of the rangeland was about 0.15 ton/ha (Halderman, 2004).

In the present study, the proportion of intact bulls, castrated bulls, growing bulls and cows accounted for 26.07, 64.64, 3.95 and 5.36% of carcasses evaluated, respectively. The higher proportion of castrated bulls might be due to the practice of farmers in mixed crop-livestock production system to castrate bulls. It was this system which supplied most cattle for abattoirs studied. The proportion of intact bulls slaughtered at local abattoirs in the present study was less than the proportion reported in Poland, which was about 47% (Weglarz, 2010). No carcasses from immature bulls and heifers were encountered during the study period. This is in contrast to the carcasses produced in USA namely 87.3% bulls and heifers less than 2 years of age (Savell et al., 2011). In contrary to the present finding, about 46.46, 24.69, 15.16 and 13.04% of intact bulls, cows, veal calves and other females, respectively, were slaughtered in north-west Italy (Lazzaroni and Biagini, 2009). Increasing the number of young animals slaughtered is one way of increasing the quality of carcass as the age of the animal is one of the factors affecting carcass quality (Toro et al., 2009; Morales et al., 2012). Farmers should be advised to sell their cattle at young stage. Creating paying market for young cattle encourage farmers to sell excess young animals. In addition to production of quality carcass from young cattle, selling excess young animals will reduce stocking density on the farms. By reducing stocking density on the farm, the body condition of available herd will be maintained in good condition. In the present study, intact bulls had relatively higher mean carcass weight (150.90 ± 1.34 kg) compared to castrated bulls (132.78 ± 0.83 kg), growing bulls (132.36 ± 2.57 kg) and cows (103.10 ± 2.24 kg)(Table 4). The reason for lower carcass weight of castrated bulls and cows compared to intact bulls in the present study might be the old age and poor body conditions of these cattle at time of slaughter as they have been serving for the draft and milking purpose, respectively, before they were used for beef purpose. Intact bulls were usually slaughtered at a young age. Higher carcass weights from intact bulls compared to castrated bulls and cows in present study were similarly reported for Hanwoo cattle in Korean (Park et al., 2002).

Conformation and fat grades of carcasses at Adama, Hawassa, Mekelle and Kombolcha abattoirs

Carcass conformation of cattle slaughtered in Adama, Hawassa, Mekelle and Kombolcha abattoirs is presented in Table 5. A relatively higher proportion conformation grade 1 carcass (superior conformation) was observed in Adama local abattoirs (57.84%) compared to Hawassa (35.90%) and Mekelle (16. 04%) with mean carcass weights of 176.32 ± 1.19, 157.79 ± 1.31 and 161.09 ± 3.95 kg, respectively. No carcass with conformation grade 1 was observed at Kombolcha abattoir. Conformation grade 2 carcasses were relatively higher at Hawassa (45.92%) and Mekelle (44.25%) abattoirs compared to Kombolcha (33.80%) abattoir with carcass weights of 138.14 ± 1.42 kg, 137.60 ± 1.29 kg and 100.29 ± 0.70 kg, respectively. This conformation grade was relatively lower at Adama abattoir (22.46%) with carcass weight of 151.89 ± 1.50 kg. Conformation grade 3 (inferior conformation) were relatively lower at Adama (19.70%) and Hawassa (18.18%) abattoirs compared to Mekelle (39.71%) abattoir with carcass weight of 127.58 ± 2.23 kg, 138.14 ± 2.94 kg and 124.37 ± 1.65 kg, respectively. This conformation grade was relatively higher at Kombolcha abattoir (66.20%) with carcass weight of 93.26 ± 0.57 kg. Proportion of superior and inferior conformations corresponds to heavier and lighter carcass weights, respectively. After all, in local market in Ethiopia, price of live cattle was determined based on conformation as weighting scale was rarely used.

A relatively lower proportion of fat grade 1 carcasses were observed at Adama (28.43%) compared to Hawassa (61.54%) abattoir with the mean carcass weights of 139.48 ± 1.91 and 133.83 ± 1.21 kg, respectively. However, almost all carcasses evaluated at Mekelle (95.59%) and Kombolcha (100.00%) abattoirs were fat grade 1 with the mean carcass weights of 134.49 ± 1.19 and 95.63 ± 0.46 kg, respectively. The proportion of fat grade 2 carcasses at Adama was relatively higher (51.96%) compared to Hawassa abattoir (28.44%) with mean carcass weights of 165.29 ± 1.26 and 148.27 ± 1.98 kg, respectively. The proportion of the same fat grade was very low at Mekelle abattoirs (2.81%) with mean carcass weights of 170.00 ± 0.44 kg. The proportion of fat grade 3 carcasses at Adama and Hawassa were 19.61 and 10.02% with mean carcass weights of 182.15 ± 2.19 and 173.00 ± 2.20 kg, respectively. The proportion of this fat grade was very low at Mekelle abattoirs (1.60%) abattoir with mean carcass weights of 176.00 ± 1.23 kg. No fat grades 2 and 3 carcasses were observed at Kombolcha abattoir during the study period. The explanation made for the difference in carcass weight between abattoirs studied hold true for the difference in conformation and fat grade between abattoirs. Moreover, similar to conformations of carcasses, fat cover had significant role in determining the weight of carcasses as heavier weight corresponds to

Table 5. Conformation and fat grades of carcasses at local abattoirs.

Abattoirs	Conformation					Fat				
	Grade*	Carcass number	%**	Mean weight (kg/ carcass)	SEM	Grade***	Carcass number	%**	Mean weight (kg/carcass)	SEM
	1	649	57.84	176.32^a	1.19	1	319	28.43	139.48^c	1.91
Adama	2	252	22.46	151.89^b	1.50	2	583	51.96	165.29^b	1.26
	3	221	19.70	127.58^c	2.23	3	220	19.61	182.15^a	2.19
	1	154	35.90	157.79^a	1.31	1	264	61.54	133.83^c	1.21
Hawassa	2	197	45.92	138.14^{ab}	1.42	2	122	28.44	148.27^b	1.98
	3	78	18.18	131.06^b	2.94	3	43	10.02	173.00^a	2.20
	1	120	16.04	161.09^a	3.95	1	715	95.59	134.49^b	1.19
Mekelle	2	331	44.25	137.60^{ab}	1.29	2	21	2.81	170.00^a	0.44
	3	297	39.71	124.37^b	1.65	3	12	1.60	176.00^a	1.23
	1	0	0.00	-	-	1	781	100.00	95.63	0.46
Kombolcha	2	264	33.80	100.29^a	0.70	2	0	0.00	-	-
	3	517	66.20	93.26^b	0.57	3	0	0.00	-	-

*1, Superior conformation; 2, moderate conformation; 3, inferior conformation; **, proportion of carcasses in each conformation/fat categories; ***1, carcass with little/no fat; 2, fat cover whole body except hind leg and shoulder; 3, fat cover the whole body; Means in the same column with different superscript letters differ ($p < 0.001$).

Table 6. Conformation and fat grades of carcasses in the wet and the dry season.

Season	Conformation					Fat				
	Grade*	Carcass number	%**	Mean weight (kg/ carcass)	SEM	Grade***	Carcass number	%**	Mean weight (kg/ carcass)	SEM
	1	616	43.41	173.91^a	1.20	1	682	48.06	143.31^c	1.08
Wet	2	494	34.81	143.04^b	1.49	2	473	33.33	157.63^b	1.24
	3	309	21.78	138.98^b	1.01	3	264	18.60	180.63^a	1.87
	1	309	18.60	165.90^a	1.96	1	1397	84.11	109.48^b	0.73
Dry	2	549	33.05	122.67^b	1.28	2	250	15.05	171.87^a	1.98
	3	803	48.34	99.38^c	0.70	3	14	0.84	176.00^a	2.10

*1, Superior conformation, 2, moderate conformation; 3, inferior conformation; **, proportion of carcasses in each conformation/fat categories; ***1, carcass with little/no fat; 2, fat cover whole body except hind leg and shoulder; 3, fat cover the whole body; Means in the same column with different superscript letters differ ($p < 0.001$).

superior fat disposition. After all, some researchers define conformation as thickness of muscle, intramuscular fat and subcutaneous fat relative to the dimension of the skeleton (De Boer et al., 1974). The finding in this study further indicated the need to develop different strategy by different region in fattening cattle before slaughter as conformation and fat grade significantly different from region to region the abattoirs are located.

Conformation and fat grades of carcasses in wet and dry seasons

Conformation and fat grades of carcasses in the wet and dry season is presented in Table 6. Conformation grade 1 (superior conformation) was relatively higher in the wet season (43.41%) with heavier carcass weight of 173.91 ± 1.20 kg compared to the dry season (18.60%) with carcass weight of 165.90 ± 1.96 kg. The proportion of conformation grade 2 was comparable in the wet (34.81%) and the dry season (33.05%) with carcass weights of 143.04 ± 1.49 and 122.67 ± 1.28 kg, respectively. Conformation grade 3 (inferior conformation) were relatively higher in the dry season (48.34%) with the average carcass weight of 99.38 ± 0.70 kg compared to the wet season (21.78%) with the average carcass weight of 138.98 ± 1.01 kg.

A relatively smaller proportion of fat grade 1 carcasses

Table 7. Conformation grades of different categories of cattle.

Categories*	Conformation					Fat				
	Grade**	Number of carcass	%***	Mean carcass weight (kg/carcass)	SEM	Grade****	Number of carcass	%***	Mean carcass weight (kg/carcass)	SEM
Cows (F)	1	21	12.73	140.25[a]	3.00	1	130	84.42	96.37[b]	2.30
	2	12	7.27	126.00[a]	2.50	2	24	15.58	130.00[a]	3.79
	3	132	80.00	95.00[b]	2.24	3	0	0.00	-	-
Growing bull (JM)	1	56	46.28	150.40[a]	2.53	1	65	65.66	126.25[b]	3.12
	2	42	34.71	121.50[b]	2.84	2	24	24.24	138.00[ab]	3.70
	3	23	19.01	115.25[b]	1.96	3	10	10.10	154.00[a]	3.93
Intact bull (M)	1	308	38.36	176.98[a]	1.89	1	495	62.50	136.40[c]	1.46
	2	285	35.49	139.35[b]	1.45	2	230	29.04	172.45[b]	2.04
	3	210	26.15	128.29[c]	2.62	3	67	8.46	189.17[a]	4.32
Castrated bull (O)	1	540	27.12	171.35[a]	1.31	1	1353	67.96	116.77[c]	0.80
	2	703	35.31	127.77[b]	1.10	2	441	22.15	160.29[b]	1.29
	3	748	37.57	109.40[c]	0.87	3	197	9.89	179.89[a]	1.88

*JM, Carcass of grown up bull; M, carcass of mature intact bulls; O, carcass of castrated bulls; F, carcass of cows; **1, Superior conformation; 2, moderate conformation; 3, inferior conformation; ***, proportion of carcasses in each conformation/ fat in each category; ****1, carcass with little/no fat; 2, fat cover whole body except hind leg and shoulder; 3, fat cover the whole body; Means in the same column with different superscript letters differ (p <0.001).

were observed in the wet season (48.06%) with a mean carcass weight of 143.31 ± 1.08 kg compared to the dry season (84.11%) with a mean carcass weight of 109.48 ± 0.73 kg. Relatively higher proportion of fat grade 2 carcasses were observed in the wet season (33.33%) compared to the dry season (15.05%) with carcass weights of 157.63 ± 1.24 and 171.87 ± 1.98 kg, respectively. Moreover, a relatively higher proportion of fat grade 3 carcass was observed in the wet season (18.60%) compared to the dry season (0.84%) with mean carcass weights of 180.63 ± 1.87 and 176.00 ± 2.10 kg, respectively. The explanation made for the difference in carcass weight between the wet and dry seasons hold true for the difference in conformation and fat grade between seasons. The finding in this study further indicated the need to develop strategy of supplementing cattle in the dry season to produce higher yield and quality carcasses.

Conformation and fat grades in different categories of cattle

The conformation and fat grades of different categories of cattle are presented in Table 7. A relatively higher proportion of conformation grade 3 (inferior conformation) was observed in cows (80.00%) with carcass weight of 95.00 ± 2.24 kg compared to conformation grade 1 (12.73%) and conformation grade 2 (7.27%) with carcass weights of 140.25 ± 3.00 and 126.00 ± 2.50 kg, respectively. Moreover, higher proportion of conformation grade 3 (37.57%) was observed in castrated bulls compared to the conformation grade 1 (27.07%) with carcass weights of 109.40 ± 0.87 and 171.35 ± 1.31 kg, respectively. However, the proportion of conformation grade 1 were relatively higher in growing bulls (46.28%) and intact bulls (38.36%) with carcass weights of 150.40 ± 2.53 and 176.98 ± 1.89 kg, respectively compared to the proportion of conformation grade 3 which were 19.01 and 26.03% with carcass weights of 115.25 ± 1.96 and 128.29 ± 2.62 kg, respectively.

The proportion of fat grade 1 carcasses were relatively higher in all categories of cattle that is, 84.42% of cows, 65.66% of growing bulls, 62.50% of mature intact bulls and 67.96% of castrated bulls with carcass weights of 96.37 ± 2.30, 126.25 ± 3.12, 136.40 ± 1.46 and 116.77 ± 0.80 kg, respectively. This indicated the slaughter of all categories of cattle without developing enough fat cover. The development of fat cover corresponds to the proportion of fat with in muscle (marbling) which affect the quality of meat significantly. Hence, it is important to let cattle develop enough fat cover before slaughter. The present study indicated the need to improve the body condition of cattle before slaughter. Appropriate feeding at producer level or prior to slaughter in a feedlot is the only way to improve the quality of the carcasses. Long-term strategy should be developed to improve feed resources at mixed crop-livestock production system. At present condition, cattle produced by small farmers need to be fatten in feedlot for short period prior to slaughter.

Table 8. Mud score of cattle slaughtered at local abattoirs.

Factor	Mud score* (%)			Total	χ2	p-value
	0	1	2			
Overall mean	1903 (82.78)	341 (14.83)	55 (2.39)	2299		
Abattoir					573.247	<0.0001
Adama	990 (88.24)	132 (11.76)	0 (0.00)	1122		
Hawassa	187 (43.59)	187 (43.59)	55 (12.82)	429		
Mekelle	726 (97.06)	22 (2.94)	0 (0.00)	748		
Season					338.556	<0.0001
Dry	869 (98.75)	11 (1.25)	0 (0.00)	880		
Wet	1034 (72.87)	330 (23.26)	55 (3.88)	1419		

*0, No mud; 1, mud on leg; 2, mud on leg and belly.

Fat grade 2 carcasses produced from 15.58% cows, 24.24% growing bulls, 29.04% intact bulls and 22.15% castrated bulls with mean carcass weights 130.00 ± 3.79, 154.00 ± 3.93, 172.45 ± 2.04 and 160.29 ± 1.29 kg, respectively. Fat grade 3 carcasses were produced from 10.10% growing bulls, 8.46% intact bulls and 9.89% castrated bulls with mean carcass weights of 154.00 ± 3.93, 189.17 ± 4.32 and 179.89 ± 1.88 kg, respectively. Fat grade 3 carcass was not observed in the category of cows during the study period. The explanation made for lower carcass weights of cows and castrated bull can apply to the difference in conformation and fat grades of these categories of cattle in the present study. This further confirms the fact that the culled cows were in a very poor condition when they were slaughtered. Higher age at slaughter was reported as one of the reason for poor quality of carcass from cows (Zaujec et al., 2012). Feeding cull cows is a viable option to improve yield and quality grade of carcasses. Some studies reported that cull cows can gain tremendous amounts of weight in relatively short times on high-grain diets (Pritchard and Berg, 1993; Funston et al., 2003). Cow fed for shorter durations was reported more likely to experience more rapid gains (Faulkner et al., 1989). However, it should be noted that cull cows are not efficient in a feedlot and need to have every possible management strategy to maximize feed conversion efficiency.

Mud score of cattle slaughtered at local abattoirs

Mud score of cattle slaughtered at local abattoirs is presented in Table 8. Of all the cattle scored for mud, 82.78% had score of 0 (no mud), 14.83% had score of 1 (mud on leg) and 2.39% had sore 2 (mud on leg and belly). Mud or manure on the skin of animal are the main sources of contamination of carcasses, especially when it is present on the legs and belly of the animal and when there is a hide opening which may introduce this contamination to the carcass (Hanson, 2000). Hence, it is important to develop strategy to minimize mud/manure on the skin before processing animal for meat. Mud scores 1 and 2 were relatively higher in Hawassa (43.59 and 12.82%) compared to cattle slaughtered at Adama (11.76 and 0.00%) and Mekelle (2.94 and 0.00%) abattoirs. Mud scores 1 and 2 were relatively higher in wet season (23.26 and 3.88%) compared to the dry season (1.25 and 0.00%). The difference in sanitations of the skin between abattoirs reflects the difference in management of cattle and level of moisture in different regions. This suggests the need to develop strategy to minimize mud/manure on the hide, particularly, at those abattoirs this problem was relatively high and during wet season. The proportion of cattle with no mud and mud on legs in the present study was comparable to the reported in USA which was 61.6 and 18.8%, respectively. However, the proportion of cattle with mud on leg and belly was relatively lower than the report in USA which was 14.5% (Boleman et al., 1998). This might be due to the difference in number of cattle supplied to abattoirs at a time. In Ethiopia, butcheries brought cattle to abattoirs to get slaughter service which was usually less than five cattle per butchery at a time, while in USA large size of cattle were supplied at a time which might be difficult to control the sanitation of each and every animal. Furthermore in country like USA, cattle are supplied directly from the farm to the abattoirs, while in Ethiopia cattle go through different market structure to reach the destined abattoir. Traders might usually clean their cattle as dirt can divert the attention of the buyers looking for good body condition and conformation. The relatively higher mud score in wet season compared to the dry season in the present study might be the soiling of the skin of animal in the former than the latter season because of the wet ground.

Correlation and regression between conformation, fat and carcasses weight

The correlations between fat and conformation grades, carcass weight and conformation grade, and carcass

Table 9. Prediction of carcasses weight from conformation and fat grades.

Equation	R^2 (%)	P-value	
		Conformation	Fat
$y = 151 - 21.0 x_1 + 19.8 x_2$	46.9	**	**
$y = 197 - 29.5 x_1$	38.9	**	-
$y = 88.1 + 33.8 x_2$	32.8	-	**

** $p < 0.001$; y, carcass weight; x_1, comformation grade; x_2, fat grade.

weight and fat grade were significant ($p < 0.001$) with the correlation value of -0.535, -0.624 and 0.573, respectively. As the conformation of carcasses progress from inferior (grade 3) to superior (grade 1) and the fat grade progressed from low fat (grade 1) to high fat (grade 3), the weight of carcasses had increased from lighter to heavier. This further confirms the significant effect of conformation and fat grade on carcass weight. Similar to the present study, significant correlation value of 0.34 and 0.58 were reported between conformation and carcass weight in Brazil and Spain (Mendizábal, 2006; Cancian et al., 2013).

The prediction of carcass weight from conformation and fat grade is presented in Table 9. The carcass weight was significantly predicted from conformation grade, fat grade and the combination of the two. The coefficient of determination (R^2) indicated that conformation and fat grades predicted carcass weight at lower precision. However, R^2 relatively higher when the carcass weight was determined from combination of conformation and fat grade (46.9%) compared to conformation grade (38.9%) and fat grade (32.8%) separately.

Conclusion

Carcass weight of cattle slaughtered in local abattoirs in Ethiopia was comparable to cattle slaughtered in tropical part of Africa. However, the proportion of carcass with little/no fat was very high. Moreover, the proportion of inferior conformation and fat grades of cows and castrated bulls were relatively higher compared to other categories of cattle. The relatively better carcasses weight, conformation and fat grades in the wet season compared to the dry season indicates the opportunity to improve carcasses weight, conformation and fat grade through better feeding management.

ETHICAL APPROVAL

Permission was obtained from ethical committee of University of Pretoria to carry out the present study.

Conflict of Interest

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

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Full Length Research Paper

Design and development of a power tiller operated seed-cum-ferti till-drill machine

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The adoption of power tiller is slowly increasing in India. However, suitable conservation seed cum fertilizer drill is to be evolved. Therefore, in order to minimize the soil moisture loss and turnaround time and energy loss during seed bed preparation and seeding operations, a seeding attachment was designed and developed for riding type of power tiller at Faculty of Agricultural Engineering, IGKV, Raipur, India. The main design considerations were to place seed and fertilizer with tractive type of tines while rotatilling the field with rotary tiller. The roto tiller need not to remove as it developed back thrust and increased pulling capacity of power tiller, which was revealed by work done and fuel consumption of power tiller with and without developed machine attachment. Thus seeding and tilling accomplished in single pass with conserving energy and in situ soil moisture. It saved operational time and cost of operation. The developed machine consisted a seed cum fertilizer box, four fluted feed rollers, four rigid tines mounted on toolbar with reversible shovels, ground wheel and adjusting devices. Fabrication cost of the machine was worked out about Rs. 6000.00 per unit and its total weight was about 32 kg. All the components of machine worked satisfactory.

Key words: Power tillers, design, development, seed-cum-ferti drill, riding type.

INTRODUCTION

In view of soil compaction, soil health and sustainable agricultural production, the power tiller and animal farming systems seems better scope than the tractor farming. Nowadays use of animal is found difficult for seed bed preparation and proper placement of seed and fertilizer. Farmers too show-least interest in animal farming due to laborious walking-tillage-seeding system and costly maintenance (Varshney, 1995).

In conventional system first seed bed is prepared thereafter 2 to 3 days, seeding is done in dry seed bed because by the time field residual moisture is lost which affect plant emergence. Therefore, in order to conserve the field-moisture time and energy in preparation of seed bed and seeding, these operations can be done simultaneously. Keeping above points in view, a power tiller operated, conservation till drill machine was planned to be designed and developed with suitable furrow openers.

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Table 1. Description of the developed machine.

S/No.	Name of components	Material used	Size, mm
1	Seed box	MS sheet	180 X 170 X 680
2	Fertilizer box	MS sheet	100 X 100 X 560
3	Tyne, (4 nos.)	Flat iron	40 x 8 x 340
4	Reversible shovel, (4 nos.)	Flat iron	30 x 5 x160
5	Tool bar, (1 no.)	Angle iron	35 x 35 x 5 x 720
6	Seed Metering fluted roller, (4 nos.)	Aluminum alloy	Standard
7	Braces, (8 nos.)	Flat iron 32x5	Variable size
8	Ground wheel, (1 no.)	Forged MS flat iron	Flat size 25 x 3 Dia. = 360
9	Seed metering shaft, (1 no.)	MS bar	Dia. = 15.88, L = 960
10	Fertilizer Shaft, (1 no.)	MS bar	Dia. = 15.88, L = 720
11	Sprockets, (3 nos.)	Cast iron	14 teeth, 19 teeth

MATERIALS AND METHODS

As per of aim of study, a desired type of seed cum fertilizer drill machine was designed and developed to suit with the *SHRACHI* power tiller, model: SF 15 DI. Engine S 1100 N, 4 -stroke Diesel Engine (Horizontal Type), manufactured /supplied by M/S Bengal Tools, Pvt. ltd. Calcutta.

Design considerations

(i) Easiness of seeding attachment.
(ii) To accommodate in available space between rotary tiller and riding seat (Varshney et al., 2004)
(iii) Details of major components of the machine are shown in Table 1 and detail-design is next described.

Seed and fertilizer box

The seed and fertilizer box of 2 mm MS sheet was designed for about 16 kg wheat seed and 14 kg paddy and for 10 kg DAP/ IFFCO granular fertilizer capacity. Considering density of seed and fertilizer and working capacity of power tiller, the size of box is about 0.021 m^3.

Tines

Four rigid tines, made of MS flat size 40 x 5 mm were mounted on a tool bar for seeding at a varying spacing of 18 to 22 cm suiting to wheat and paddy. Reversible narrow shovels mounted on each tine. Design methodology, materials and methods used for the study for individual components are next described.

Design of seed and fertilizer box

In literature, the box capacity for different type of manually, animal and tractor drawn seed drills are av**a**ilable but not for power tiller (Varshney et al., 2004). Therefore, as per design consideration of seed and fertilizer box, the dimentions were decided. The box was made from MS sheet rectangular in shape and shown in Figure 2. Horizontally, the seed cum fertilizer box was located between roto-tiller and riding seat behind the hood of rotary tiller. Vertically, the box height was limited by upper main transmission gear-lever, rotory transmission gear-lever and handles. Finally the size of seed box was determined as:

L x W x H = 680 x 180 x 170 mm^3
= 0.02081 cubic meter
The size of fertilizer box, L x W x H = 560 x 100 x 100 mm^3
= 0.0056 cum.
And the theoretical capacity of seed box = 0.2081 cum x 800 kg /cum
= 16.640 kg for wheat and for Paddy grain 12.5 kg.

Seeding capacity

The seeding capacity of the developed machine, with paddy and wheat seed is worked out based on actual observations as given below:

Theoretical capacity (ha/h), $\mathbf{C} = \frac{\mathbf{W\,x\,S}}{\mathbf{10}}$

Where, W = working width, m = 4 x 0.20 = 0.80 m**,** S = speed, kmph (1.45 - 3.0 km /h)

Thus, the designed box size for seed capacity is found satisfactory. Therefore, the net designed seed box capacity of 16 kg wheat would be sufficient for about 2 working hours.

Design of tool bar

A tool bar of square section, made by joining two angle iron was designed and fabricated for mounting of tractive tynes. The tool bar was made of square section of 40 x 40 x 5 mm joining two MS angle iron of size 35 x 35 x 5 mm and its length was kept 720 mm as shown in Figure 3. The short design calculation for forces and strength was calculated and the dimension of tool bar was determined using standard formulas.

Design calculation

In order to select the size of material requiring for tool bar, The following assumptions are made.
(i) Number of tines = 4
(ii) Maximum depth of operation, cm = 15
(iii) Width of furrow opener, cm = 3
(iv) Maximum ground clearance of tool bar and height of tines, cm = 34
(v) Center to center distance between two tines, cm = 20

Area of furrow cross section = width x depth = 3 x 15 = 45 cm^2

Therefore, the draft requirement for each tine = 45 cm^2 x 0.6 kg /cm^2 = 27 kg_f. (Assuming draftability of sandy clay soil in friable moisture condition = 0.6 kg_f /cm^2)
The tool bar is subjected to torision and bending moment due to induced draft.
The tool bar consist with four tines in one row.
Hence,

Total Draft = 27 x 4 = 108 kg_f = 108 x 9.8 = 1058.4 N

The design was calculated based on maximum load. Maximum load was calculated considering factor of safty equal to four for agricultural machines (Paul, 2003; Verma, 2005) as follows:

Total draft = 1058.4 x 4 = 4233.6 N

Torque on the tool bar by each tine = Draft x ground clearance
= 27 x 0.34 = 9.18 kg_f -m = 89.96 N **–**m

Total torque on the tool bar with 4- tines = 89.96 x 4 = 359.84 N -m
In addition to torque on the tool bar, bending moment would also be produce. The tool bar was considered as simple supported beam on the fram.The maximum bending moment**:**

$$BM_{max} = \frac{wl}{4} \quad (1)$$

Where, w = Total weight / force on the fram**,** l = Total length of tool bar, cm

$$BM_{max} = \frac{4233.6 \text{ x} .72}{4}$$

= 762.048 N -m
Equivalent torque ue to torision and bending moment was calculated as**:**

$$T_e = \sqrt{M^2 + T^2} \quad (2)$$

$$= \sqrt{762.048^2 + 359.84^2}$$

= 842.73 N -m

The maximum shear stress developed on the tool bar was obtained by using torsional formula as:

$$f_s / R = T / J \quad (3)$$

Where, f_s = Shear stress at any section**,** R = Distance of the section from nuetral axis = d / 2**,**T = Equivalent torque**,** J = Polar moment of inertia**.**
Considering each side of measured d mm and factor of safety 2 – 4 (we selected maximum safty of factor = 4) and ultimate stress of selected material, Fe = 360 N/mm^2 (Verma, 2005).

$$\text{Design stress} = \frac{\text{Ultimate stress}}{\text{Factor of safty}} \quad (4)$$

$$= \frac{360}{4}$$

= 90 N /mm^2

Maximum working stress of 360 N /mm^2 act at the center of toolbar. J is calculated by using formula as**:**

$$J = d^4 / 4 \quad (5)$$

Where, d = width of section

On substituting above values in the **Equation (3)**, we get**:**

$$\frac{90}{d/2} = \frac{842730}{d^4/4}$$

d = 35.5 mm ~36 mm

Therefore, equivalent size of tool bar of 40 mm , depending availability of material, was considered safe for the machine. The detailed diagram is shown in Figure 3.

Furrow openers

The design considerations for the furrow opener were that they should be of self cleaning nature, easily un-clogging type and narrow shape to minimize draft requirement.

Design procedure of the tine

The height of tine *ie* ground clearance was taken as 340 mm which was calculated as:

(1) Maximum working depth in tilled soil = 150 mm
(2) Free length (to avoid clogging by tool bar) = 190 mm

Width and thickness

The width and thickness of the tine was calculated as follows. A reversible shovel was fitted with tine as cutting tool. The tine was made of mild steel flate plate having carbon content from 0.15 to 0.25 per cent (Verma, 2005) of size 40 x 10 mm. Width of reversible shovel was 30 mm, with 5.0 mm thickness and was made of MS sheet.
The furrow cross sectional area = 150 x 30 = 4500 mm^2
The soil resistance = 0.0060 kg /mm^2
Soil resistance exerted at the tip of each furrow opener /tine = 264.6 N
Ground clearance of tine = 340 mm
The bending moment = draft x distance
= 264.6 x 340 = 89964 N /mm^2
Bending stress:

$$F = \frac{M\,C}{I} \quad (6)$$

Where, f = Bending stress, N /m^2**,** C = Distance from neutaral axis to the point at which strain is determined, m**.**
The sectional modulas from the neutral axis is computed by using formula:

$$Z = \frac{I}{C} \quad (7)$$

From the Equations **6** and **7**, we get**:**

$$Z = \frac{M}{f} \quad (8)$$

Taking bending stress equal to 49.05 N /mm^2 (Sachin, 2000; Verma, 2005).

$$Z = \frac{89964.0}{49.05}$$

= 1834.13 mm^2

Table 2. Summerize data on designed, developed and tested machine.

S/No.	Crop	Wheat *(Kanchan)*
1	Fuel consumption, l/h	1.04
2	Effective working width, m	0.80
3	Moisture content, %	18.0
4	Theoretical field capacity, ha/h	0.13
5	Effective field capacity, ha/h	0.11
6	Field efficiency, %	84.61
7	Wheel slip of power tiller, %	8.00
8	Operational speed, km/h	1.67
9	Cost of operation, Rs/ha	1413.00
10	Energy requirement. MJ/ha	657.94

Table 3. Comparative study of standard and design blade/tyne.

Type of blade/tyne	Field capacity (ha/h)	Fuel consumption (l/ha)	Field efficiency (%)	Mean mass diameter of clod (mm)	Earth work (ton/l fuel)
Standard blade, C	0.055	20.71	82	20.58	27.53
Standard blade, L	0.054	21.75	81	19.55	30.65
Design tyne	0.056	21.55	78	31.97	40.57
CD	0.150	0.91	2.00	3.22	8.34

Section modulas of the furrow openers, the ratio between the thickness to width (t : b) can be taken from 1 : 3 to 1 : 4. (Sharma and Mukesh, 2008)**:**

So, t : b = 1 : 4

$$Z = \frac{t \times b^2}{6} \quad (9)$$

$$1834.13 = \frac{t \times (4t)^2}{6} = \frac{16\,(t)^3}{6}$$

t = 8.82 mm

Considering the factor of safty, availability of material of standard size, the thickness of tine was taken 10 mm. Therefore, width of the tine = 4.0 x 10 = 40 mm

Therefore, the narrow reversible shovel types openers were selected as shown in Figure 4. In order to overcome the problem of trash and clod collection, between the adjacent tines, the furrow openers were placed behind the rotary blades on the frame. So, that a narrow shallow slot could be tilled by the rotary blades for placing seed in direct conservation drilling.

Seed metering mechanism

Simple fluted rollers were used for the metering of seeds and orifice types arrangement made for the fertilizer. The simple knob mechanism is used to meter the desired quantities of seed. The detailed diagram and figure of the fluted roller is shown in Figure 5.

Ground wheel and other parts

The ground wheel was made of MS flat iron of size 25 x 3 mm and the ring was made of 360 mm diameter, with steel pegs of length 70 mm. The pegs were made of 25 x 3 mm size. Total numbers of pegs were taken 12 on the periphery. The numbers of spokes were 6, made of iron rod of size 9.5 mm. The detailed diagram and figure of the ground wheel is shown in Figure 6. The diameter was designed for minimum rolling resistance and easy operation of the ground wheel. So, the clods and stubbles height should not be more than one third of its diameter. Considering 15 cm height of stubbles/ clods, the diameter of ground wheel was designed for 45 cm and thus the tip to tips of peg, the diameter was taken = 50 cm.

Working principle

The power is transmitted to ground wheel to metering shaft of seed and fertilizer without hindrance in the rotary tilling. During seeding, the tractive tines of seed cum fertilizer drill, place seeds and fertilizer behind rotary tiller instantaneously and perform tilling cum seeding operation in a single pass, conserving field moisture. The fabrication cost of the machine was found about Rs 6000.00. The machine was easily attached and detached and can be adjusted for different crops.

RESULTS AND DISCUSSION

The detailed view and design diagram of the developed machine is shown in Figure 1. As per design considerations the machine components were designed and fabricated successfully. During the field testing, the developed machine gave satisfactory results. Summarized data on designed, developed and tested machine are given in Table 2. The table revealed that the cost of sowing was worked to be Rs 1413.00 per ha and energy requirement was found to be 658 MJ/ha. Comparative study of standard blade and design tyne are given in Table 3. The maximum earth work was found in

Figure 1. View of developed machine.

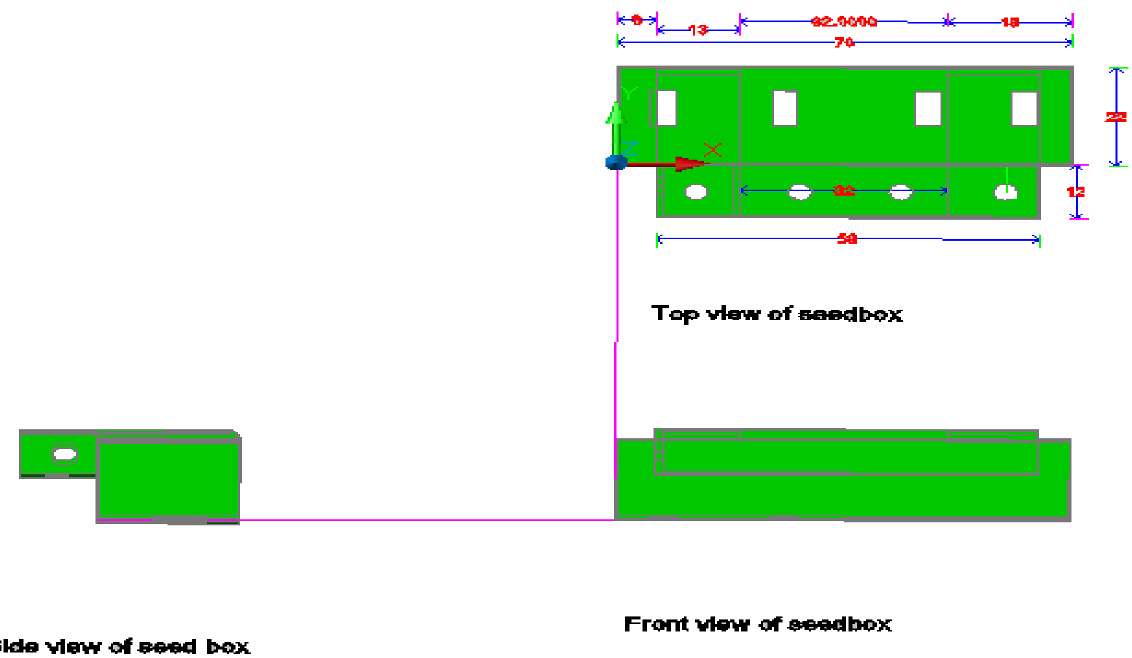

Figure 2. Views of seed and fertilizer box.

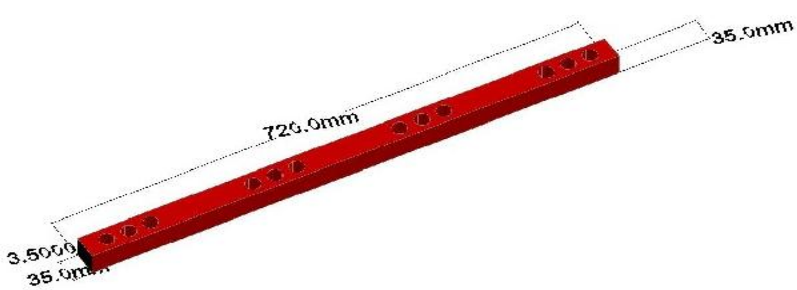

Figure 3. View of toolbar.

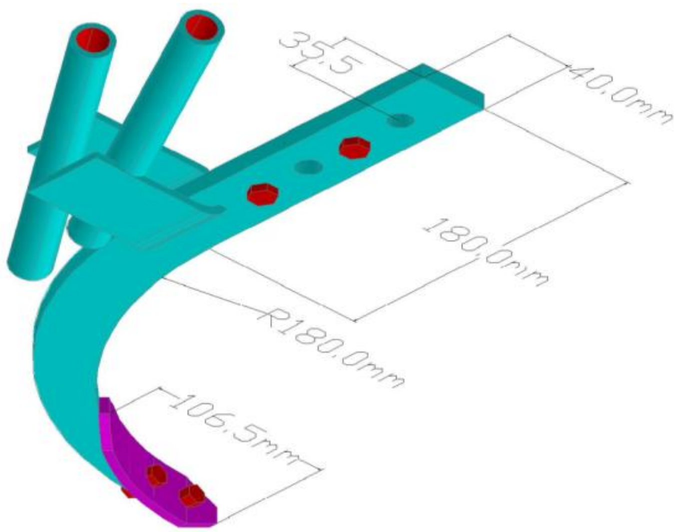

Figure 4. View of Tine with reversible shovel. dr =Diameter of the flute, d_f =Diameter of flute and A_f =Area of cross section of flute.

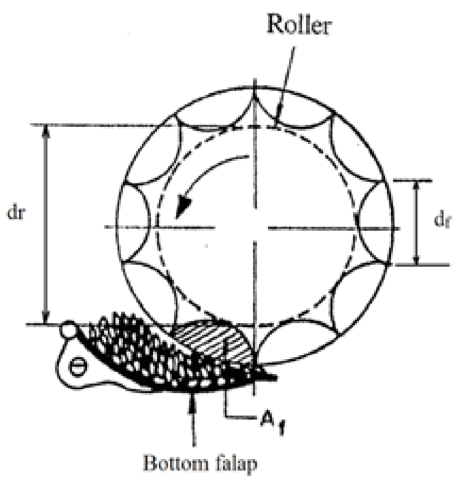

Figure 5. View of fluted roller. dr =Diameter of the flute, df =Diameter of flute and Af =Area of cross section of flute

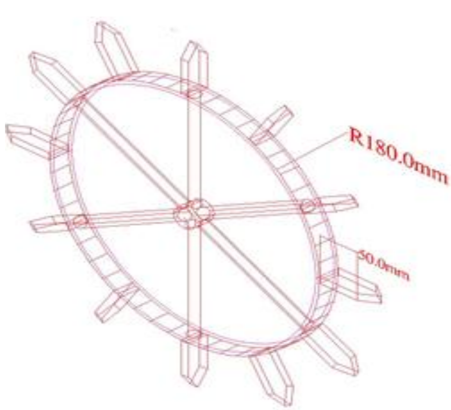

Figure 6. Ground wheel

design blade and it is significant with standard blade. However, fuel consumption was less than standard blade "L" (Kumar, 2012).

Conclusions

Field trials of developed machine have been conducted at the research field of faculty of Agricultural engineering, IGKV, Raipur. The developed machine work satisfactory.

Conflict of Interest

The authors have not declared any conflict of interest.

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