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African Journal of Agricultural Research

Table of Contents: Volume 9 Number 19 8 May, 2014

ARTICLES

Table of Contents: Volume 9 Number 19 8 May, 2014

ARTICLES

Table of Contents: Volume 9 Number 19 8 May, 2014

ARTICLES

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Full Length Research Paper

Enhance activity of stress related enzymes in rice (*Oryza sativa* L.) induced by plant growth promoting fungi under drought stress

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Water scarcity is one of the main consequences of changing climate which adversely affects the plant growth and productivity. The present study aimed to investigate the effect of plant growth promoting fungi (PGPF), *Trichoderma harzianum* strain-35 (T-35) and newly discovered *Fusarium pallidoroseum* strain-10 (FP-10) on total biomass production and activities of the stress related enzymes [superoxide dismutase (SOD), catalase (CAT) and peroxidase (POD)] in Swarna and Swarna sub-1 genotypes of rice under drought stress. PGPFs inoculated plants showed enhance shoot and root dry weight as compared to uninoculated plants under water stress. Quantitative analyses of antioxidant enzymes indicated that plants inoculated with PGPFs showed higher activity of SOD, CAT and POD enzymes as compared to uninoculated plants under severe drought condition (41.23% pot moisture content). Higher biomass and greater induction of antioxidant enzymes in plants may be the mechanism through which these PGPFs help plants to alleviate the consequences of drought stress and maintenance of plant homeostasis under severe drought.

Key words: *Trichoderma harzianum*, *Fusarium pallidoroseum,* rice, drought stress, antioxidant.

INTRODUCTION

Rice (*Oryza sativa* L.), is the leading food grain crop. Worldwide, more than 3.5 billion people depend on rice for more than 20% of their daily calorie intake (IRRI, AfricaRice and CIAT, 2010). More than 90% of rice is grown and consumed in Asia where 60% of the people on earth live (Rodrigues et al., 2008). The predominantly rice-growing areas in Asia are often threatened by severe abiotic stresses, of which the most common is drought (Wade et al., 1999). In many Asian rice areas, irrigation water is not available and rice relies almost completely on rainfall during growth under both lowland and upland conditions (Farooq et al., 2009). Among cereals, rice is the most drought-sensitive crop. Severe yield losses can occur in even a mild drought stress during reproductive stage (Verulkar et al., 2010). Water stress induces a number of physiological, biochemical and molecular manipulation within plants which governs growth and productivity (Daie et al., 1988). One of such biochemical

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mechanism includes antioxidant enzymatic system (viz. superoxide dismutase (SOD), catalase (CAT), peroxidase (POD) etc.), which protect plant cells against the detrimental effects of reactive oxygen species (ROS) generated under variety of environmental stresses (Noctor and Foyer, 1998).

Microbial communities can develop a range of activities that may be helpful in improving plant growth. Soil form an interface with the plant roots where symbiotic fungi can interact. Such interaction can manipulate the metabolic activity of plants which may help plants to tolerate the environmental stresses (Marulanda et al., 2007). *Trichoderma* beneficially interact with plant roots and can induced disease resistance, plant growth promotion and tolerance to abiotic stresses including drought (Harman et al., 2004). In limited water availability root size and architecture are the factor which determined yield performance of plants (Price et al., 2000). *Trichoderma* enhanced the growth of roots by colonizing it, thereby increasing plant productivity and the yields of reproductive organs (Bae et al., 2009). A study on *Trichoderma*-plant interaction characterized the possibility of *Trichoderma* species inducing tolerance to abiotic stress, possibly including drought, in cacao (Bailey et al., 2006).

The aim of this present study was to evaluate the effect of two plant growth promoting fungi (PGPF) *Trichoderma harzianum* strain-35 (T-35) and *Fusarium pallidoroseum* strain-10 (FP-10) on the growth enhancement, biomass production and antioxidant activity of two genotype, Swarna and Swarna sub-1 of rice.

MATERIALS AND METHODS

For the study, PGPF *F. pallidoroseum* strain-10 (Srivastava et al., 2011) and *T. harzianum* strain-35 (T-35) were obtained from Rhizosphere Biology Laboratory of Department of Biological Sciences of G. B. Pant university of Agriculture and Technology Pantnagar, and two rice genotype Swarna and Swarna sub-1 was obtained from the IRRI Office, NASC Complex, Pusa New Delhi, India.

Preparation of inoculants

For the preparation of fungal inocula 3-5 disk of fresh cultured fungus were inoculated in 100 ml of potato dextrose broth media and kept on shaker for 5 days at 28°C and colony forming unit (cfu) counted by dilution plate method.

Pot experiment

Rice growth promotion by these two strains under drought stress was performed in net house conditions. Rice seeds were surface disinfected by immersion in 70% ethanol and 3% (v/v) sodium hypochlorite for 1 and 5 min. Seeds were washed thoroughly three times with sterile distilled water then germinated on sterilized Petri dish. The soil used for experiment has the following: pH 8.31, organic carbon 1.2%, nitrogen 186.7 kg/h, phosphorus 34.91 kg/h, and potassium 145.6 kg/h. Before filling the pot the soil were autoclaved at 121 psi for 40 min thrice, every alternate day. The pots were filled with 300 g of soil and watered to field capacity before sowing the seeds. After 2 days the equally germinated seeds were selected for sowing. The fungal inocula were given to 1 ml/pot having 10^4 to 10^5 cfu level. Two seedlings per pot were maintained. After 30 days of sowing, 10 ml of phosphorus free nutrient solution (Hoagland and Arnon, 1950) were given, weekly to each of the pot. The experimental design used for the study was complete randomized design. There were six replicate of each isolates. After 55 days of sowing, the pots were irrigated up to water holding capacity of soil and left for drought stress by withholding the irrigation. First harvesting was done after 10 days of drought with three randomly selected replicate for the measurement of growth promoting trait (plant height, shoot fresh and dry weight of plants). Dry weight of sample was determined by placing the root and shoot samples separately into paper bags and drying them in an oven at 60°C for 48 h. Second harvesting was done after 12 days of drought for the measurement of antioxidant status of plants. Soil water content (SWC) was determined from the pot of second harvesting by the traditional gravimetric method. At the time of harvesting soil was sampled from the middle part of pots. After wet weight determination, soil was dried at 80°C for 48 h or till the complete drying of soil. The SWC were calculated as:

$$\text{SWC (\%)} = \frac{\text{(Weight of container with soil)} - \text{(Dry weight of soil with container)} \times 100}{\text{(Dry weight of soil with container)} - \text{(Weight of container)}}$$

Anti-oxidative enzyme analysis from plant sample

For evaluation of antioxidant status, drought plants were harvested, fresh weight were taken immediately and then placed in -20°C for further antioxidant activity. For assays of SOD, CAT, Guiacol POD, 0.5 g leaf samples (fresh weight) was homogenized with a pestle in an ice-cold mortar in 5 ml cold buffer containing: 50 mM potassium phosphate buffer (PH 7.0), 1 mM ethylene diamine tetra acetic acid (EDTA) and 1% (w/v) polyvinylpyrolidone (PVP). Whole extraction procedure was carried out at 4°C. The homogenate was centrifuged at 10,000 × g for 30 min at 4°C and the supernatant collected was used to assay enzyme activity. Protein concentration in the enzyme extract was determined by the method of Bradford (1976) using bovine serum albumin as a standard. SOD, POD and CAT activity were determined as described by Zhang and Kirkham (1996) with few modifications.

Statistical analysis was performed with the Statistical Package for Social Sciences (SPSS) software, and treatment means were compared in Turkey HSD, at 5% level of significance.

RESULTS AND DISCUSSION

Exposure to drought stress caused a droopy appearance of the shoots, and the leaves starting turning inwards from the outside edges. Plants were harvested after 10 and 12 days of drought. The moisture content of soil in pots was calculated as 41.23 ± 2.28% after 12 days of drought. After first harvesting at 10 days of drought both, *F. pallidoroseum* strain FP-10 and *T. harzianum* strain T-35, with 23.59 and 26.54% increase showed significant effect on plant height in Swarna, whereas in Swarna sub-1 only T-35 with 19.48% showed the significant effect as compare to control. Both the strains FP-10 and T-35 efficiently increased the root length in Swarna, while in Swarna sub-1 only T-35 showed increase in root length

Table 1. Rice growth promotion by selected fungal strains after 10 and 12 days of drought stress.

Days of drought	Varieties	Treatments	Length (cm) Shoot	Length (cm) Root	Fresh weight (g/pot) Shoot	Fresh weight (g/pot) Root	Dry weight (g/pot) Shoot	Dry weight (g/pot) Root
10 days	Swarna	Control	24.30[a]	13.85[a]	0.97[a]	0.42[a]	0.44[a]	0.22[a]
		FP-10	30.03[b]	15.47[a]	1.51[a]	0.67[a]	0.73[b]	0.37[b]
		T-35	30.75[b]	16.58[a]	1.36[a]	0.61[a]	0.62[ab]	0.29[ab]
	Swarna sub-1	Control	26.78[a]	16.73[a]	0.79[a]	0.33[a]	0.50[a]	0.18[a]
		FP-10	25.80[a]	14.72[a]	1.14[b]	0.44[a]	0.56[ab]	0.23[a]
		T-35	32.00[b]	17.40[a]	1.66[c]	0.91[b]	0.74[b]	0.55[b]
12 days	Swarna	Control	23.75[a]	14.43[a]	0.57[a]	0.26[a]		
		FP-10	29.85[ab]	15.52[ab]	1.14[b]	0.50[b]		
		T-35	32.82[b]	18.08[b]	1.19[b]	0.50[b]		
	Swarna sub-1	Control	29.33[a]	18.02[a]	0.69[a]	0.28[a]		
		FP-10	28.2[a]	14.23[a]	0.76[a]	0.40[b]		
		T-35	30.95[a]	16.58[a]	1.11[b]	0.39[b]		

Results are means of three replicate. Mean with different letters significantly different from each other ($P < 0.05$).

over control. After 12 days of drought, T-35 showed the significant effect on shoot (38.18%) and root (25.29%) length in Swarna over control, however, both the strains showed non-significant effect on shoot and root length in Swarna sub-1 over control. *F. pallidoroseum* strain-10 showed maximum increase on dry weight of shoot (66.50%) and root (56.05%) in Swarna after 10 days of drought, while in Swarna sub-1, strain T-35 with 47.11 and 205.55% increase showed maximum effect on shoot and root dry weight over control. After 12 days of drought both the strains showed significant effect on shoot and root fresh weight in Swarna, while in Swarna sub-1 only T-35 showed significant effect on both parameter as compare to control (Table 1).

Among several strategies used to improve crop yield under water stress, use of bio-agents such as *Trichoderma* is an effective and easily adaptive strategy (Bailey et al., 2006). In various plants, introduction of *Trichoderma* species is primarily being studied as biocontrol agent (Evans et al., 2003; Holmes et al., 2006), induce plant growth promotion and tolerance to abiotic stresses including drought (Harman et al., 2004). In present study, enhancement of root and shoot length was differ according to genotype of rice as well as the kind of treatments, however *T. harzianum* strain T-35 was found most effective in both the genotype of rice as compare to FP-10. Both the fungal strains markedly increased the root and shoot biomass in both the genotype of rice over control (Table 1). *Trichoderma* effects on plant growth promotion and root architecture are well known (Mastouri et al., 2012; Yedidia et al., 2001). Enhanced rooting system provides increased surface area for absorption of deep seated water and increase plant stand in drought (Malinowski and Belesky, 2000). The ability of *Trichoderma* isolates to enhance plant growth has been characterized in many cropping system, although the mechanisms involved have not been fully explained (Harman et al., 2004). In the present investigation, the enhanced shoot and root biomass of T-35 and FP-10 treated rice plants may be due to enhanced nutrient availability through solubilization and chelation of minerals and thus increased nutrient uptake efficiency, which is the proposed mechanism by which *Trichoderma* induces plants growth (Harman et al., 2004; Altomare et al., 1999; Yedidia et al., 2001). Similar to present study, increased shoot, root fresh and dry weight of *Trichoderma* inoculated plants under drought stress was observed (Bae et al., 2009). *F. pallidoroseum* as a bioinoculant, in previous study, have also been used as biofertilizer for the growth promotion of different crops like wheat, maize etc. (Srivastava et al., 2011).

The present study demonstrated that, after 12 days of severe drought, both fungal strains showed the greater activity of SOD, CAT and POD as compare to control. In Swarna, both the treatments showed higher SOD activity, however, the effect were non-significant, while in Swarna sub-1, both T-35 and FP-10 strains with 1.43 and 1.58-fold showed significant effect over control. Both the fungal strains T-35 and FP-10 significantly increased CAT activity (1.84 and 1.54-fold) in Swarna, while in Swarna sub-1 the effect were non-significant, however, both the strains showed increased CAT activity over control. In both the varieties of rice T-35 and FP-10, treated plants showed greater POD activity over control. In Swarna strain T-35 with 1.33-fold showed maximum POD activity, whereas in Swarna sub-1, strain FP-10

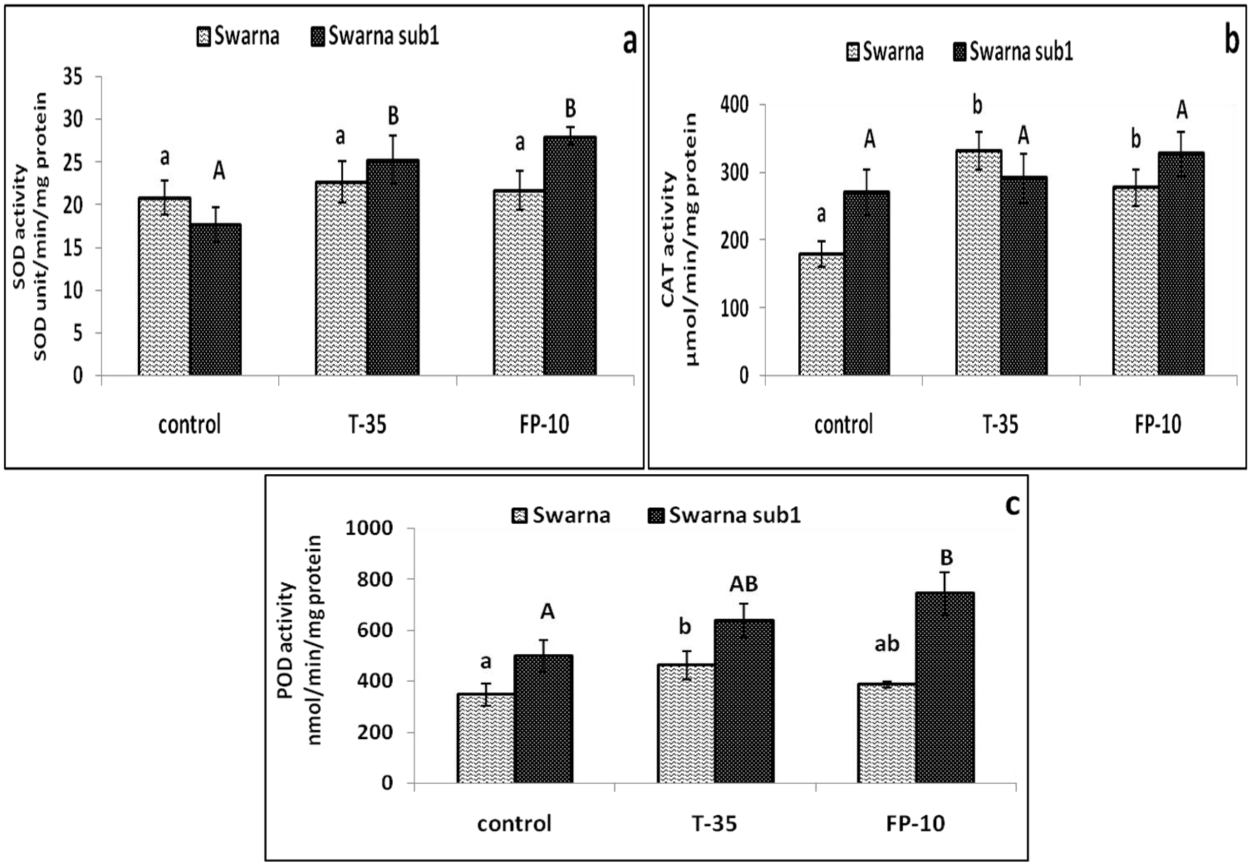

Figure 1. SOD (a), CAT (b) and POD (c) enzymatic activity of rice after 12 days of drought stress. Different letters denote significant differences (P<0.05) among treatments. Line above bars represents Mean ± standard deviation.

with 1.49-fold showed significant effect over control (Figure 1).

Plant response to drought differently that may involve the synthesis of a new set of proteins whose function is largely unknown. Under environmental stress ROS such as superoxide radical, hydrogen peroxide and hydroxyl radicals adversely affect the membranes and DNA of cells (Sharma and Dubey, 2005). Increased SOD activity has been correlated with induced resistance of plants to drought stress (Pastori and Trippi, 1992, 1993; Moran et al., 1994). SOD enzyme convert superoxide radical to hydrogen peroxide (H_2O_2) and oxygen, CAT enzyme convert toxic H_2O_2 to water and oxygen (Blokhina et al., 2003). In this respect under water stress only increased SOD activity cannot protect the plants from toxic effect of oxygen free radical and other antioxidant enzymes (CAT and POD) is necessary to remove toxicity of H_2O_2 (Arora et al., 2002). In present study, both the fungal strains increased the SOD, CAT and POD enzymes in both the genotype of rice as compare to control plants. When we compare both the genotype, irrespective of treatments, Swarna sub-1 showed higher activity of all enzymes as compare to Swarna. The result indicated that these fungal strains may help plants to tolerate stress under severe drought through the reduction of oxidative stress. Similarly, observation of enhanced activity of ROS-scavenging enzymes in *T. harzianum* colonized tomato plants in response to water stress have also been reported (Mastouri et al., 2012).

Conclusion

The result of the present study serve as base for the mediation of PGPF in enhancing water stress resistance in rice plants and need the evaluation of both the strains for growth promotion and productivity of rice under different environmental stress condition.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Effects of different rates of nitrogen (N) and phosphorus pentoxide (P_2O_5) on eggplant yield

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The balanced fertilization is crucial for obtaining a good plants growth and achieve good productivity indices. The aim of this study was to evaluate the performance of eggplant (*Solanum melongena* L.) under different doses of nitrogen (N) and Phosphorus pentoxide (P_2O_5) performed separately. The study was conducted in 5 liter-pots arranged in a completely randomized design, consisting of 5 doses (0, 50, 100, 150 and 200 kg ha^{-1}) of N and P_2O_5 with 5 replications in a greenhouse, located at latitude 22° 13' S and longitude 54° 48' W. The variables analyzed were: root fresh mass (RFM) and root dry mass (RDM), shoot fresh mass (SFM) and shoot dry mass (SDM), fruit weight (FW), number of fruits (FN) per plant, stem diameter (SD) and plant height (PH). Application of N had significant effects on all variables studied, except for SD. Application of P_2O_5 had significant effects on most variables, except for PH, SFM and FW. N applications affected yield more than P_2O_5 due to FN and FW. The dose of 100 to 150 kg ha^{-1} both for N and P_2O_5 provided the best results.

Key words: Soil fertility, plant nutrition, horticulture, Solanaceae.

INTRODUCTION

The eggplant (*Solanum melongena* L.) is an annual vegetable crop that belongs to the family Solanaceae and is native to India. It is an economically important crop in Africa, Asia, Central America and it is also cultivated in some warm temperate regions of the South America and Mediterranean (Aminifard et al., 2010).

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The eggplant has shown increasing importance among vegetables due to the wide popularization of its nutritional value (Zenia and Halina, 2008). This plant is well adapted to the tropical climate, and its development is influenced by the availability of several nutrients, especially nitrogen (N) and phosphorus (P) (Swiader and Morse, 1982).

Nitrogen deficiency in eggplant crop leads to stunted and chlorotic leaves caused by the formation of poor photosynthesizing that leads to early flowering and shortening of the growth cycle. The presence of N in excess promotes the development of organs above ground, with plenty of dark green tissue (high chlorophyll) of soft consistency and reduced root growth. With that it increases the risk of lodging and reduces plant resistance to adverse climatic conditions and foliar diseases (Bozorgi, 2012).

Nitrogen at appropriate levels is essential to plant growth due to its structural function in proteins and nucleic acids, which are the basic components of plasma and chlorophyll, both indispensable for the plant to perform photosynthesis (Taiz and Zeiger, 2004).

P deficiency induces abscission of flowers, consequently reducing the yield (Ribeiro et al., 1999). This nutrient plays an important role in energy transfer in cells, respiration and photosynthesis, and is a structural component of nucleic acids, as well as various coenzymes, phosphoproteins and phospholipids (Amiri et al., 2012).

Some authors studied the application of N eggplant as Kamili et al. (2002) studied the application of N in eggplants and observed that there was an increase in plant height (PH) with increased rates of N. Haag and Homa (1981) observed a significant decrease in the diameter of the eggplant stem when N was absent. Prabhu et al. (2006) studied the effect of different levels of nitrogen and phosphorus on culture of eggplant and found that the total yield per hectare was significantly increased with increasing doses of N and P. The highest yield was obtained from 200:100 kg NP ha^{-1}. In that sense, the doses of fertilizers applied to the soil by means of fertilization should foster the growth and yield, but excessive application of fertilizers can lead to toxicity or interfere with the absorption of other nutrients (Kehinde et al., 2011).

Knowledge of nutrient requirements of the plant is important in determining the amounts of nutrients to be applied. This is because the absorption of nutrients is differentiated according to plant phenology, being intensified with the flowering, fruit formation and growth. Thus, the study aimed to evaluate the performance of eggplant, fertilized with different doses of phosphorus and nitrogen applied separately.

MATERIALS AND METHODS

The work was installed in a protected environment at Faculdade Anhanguera in Dourados (FDO) in the year 2012. The city of Dourados is located at latitude 22° 13' S and longitude 54° 48' W and altitude of 430 m. The climate, according to Köppen (Mato Grosso Do Sul, 1990) is humid mesothermal type Cwa, with annual average temperatures and precipitation ranging from 20 to 24°C and rainfall of 1250 to 1500 mm, respectively.

The experiment consisted of nitrogen and phosphorus fertilization on an eggplant crop performed separately and arranged in a completely randomized design with 5 treatments and 5 replications. Doses were 0, 50, 100, 150, and 200 kg ha^{-1} of P_2O_5 and N. Each plot consisted of one plant per pot with capacity of 5 L, in which 3.5 kg of soil classified as clayey Haplorthox were placed, with the following chemical characteristics: pH 6.0 in water, 28.2 g dm^{-3} of organic matter, 26.0 mg $dm^{-3}$of P; and 6.4, 50.3, 18.0, mmol dm^{-3} of K, Ca, and Mg, respectively, being considered soil of good fertility, being nutrients at satisfactory levels.

The seedlings were grown in trays with 72 cells containing commercial substrate, by sowing one seed per cell of variety Embu (ISLA Sementes Ltda®). While driving the seedlings there was no fertilization. After 15 days of the emergence, the plants were transplanted to the pots, with one plant per pot, and the doses of N were applied as ammonium sulphate ($(NH_4)_2SO_4$) - 21% of N and P in the form of superphosphate (SS) - 18% P_2O_5 according to the treatment.

The variables analyzed were: root fresh mass (RFM) and root dry mass (RDM) (g), shoot fresh mass (SFM) and shoot dry mass (SDM), fruit weight (FW), number of fruits (FN) per plant, stem diameter (SD) and PH. Evaluations of PH and SD were performed at intervals of 10 days after transplantation and the number and weight of fruit was considered the first harvest after 120 days from the transplantation to the pots.

Seedling height was obtained with a graduated ruler (± 1 mm) measured from the ground level to the insertion of the last leaf. The SD was measured with the aid of a digital caliper (± 0.1 mm) obtained from the average of two orthogonal measurements. FW was determined using an analytical scale with precision of 0.0001 g.

For the evaluation of fresh and dry mass at the end of the experiment, the plants were separated into root, and above-ground organs (stems and leaves), and then dried at 65°C with forced air circulation for a period 48 h, until constant weight.

Data were subjected to analysis of variance (ANOVA; $P < 0.05$) to determine the significant effect of treatments. Regression analyses were conducted to test the effects of doses on the evaluated characteristics. The statistical software SISVAR 5.1 was used (Ferreira, 2007).

RESULTS AND DISCUSSION

The results of the ANOVA showed significant effects for most variables analyzed ($p < 0.05$) for doses N, except for the variable DC. The results were similar for the doses of P_2O_5 levels for most variables, except for PH, SFM and FW.

Nitrogen

PH presented an increasing linear response to the increase of nitrogen doses (Figure 1), in which the maximum dose applied promoted an estimated maximum value of 68 cm. Oliveira et al. (2012) studied the initial growth of eggplant using biomass of *Tefhrosia cândida* to cover the soil with and without nitrogen fertilization and found greater PH with nitrogen fertilization regardless of the doses.

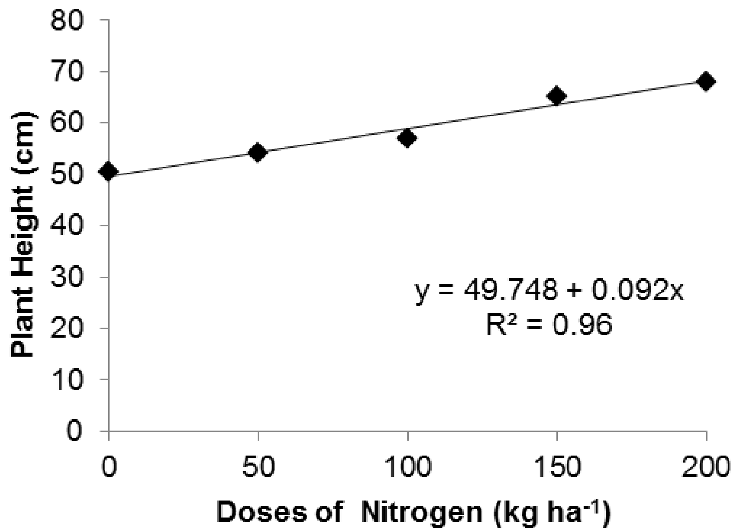

Figure 1. Plant height (PH) according to the doses of N in the eggplant crop.

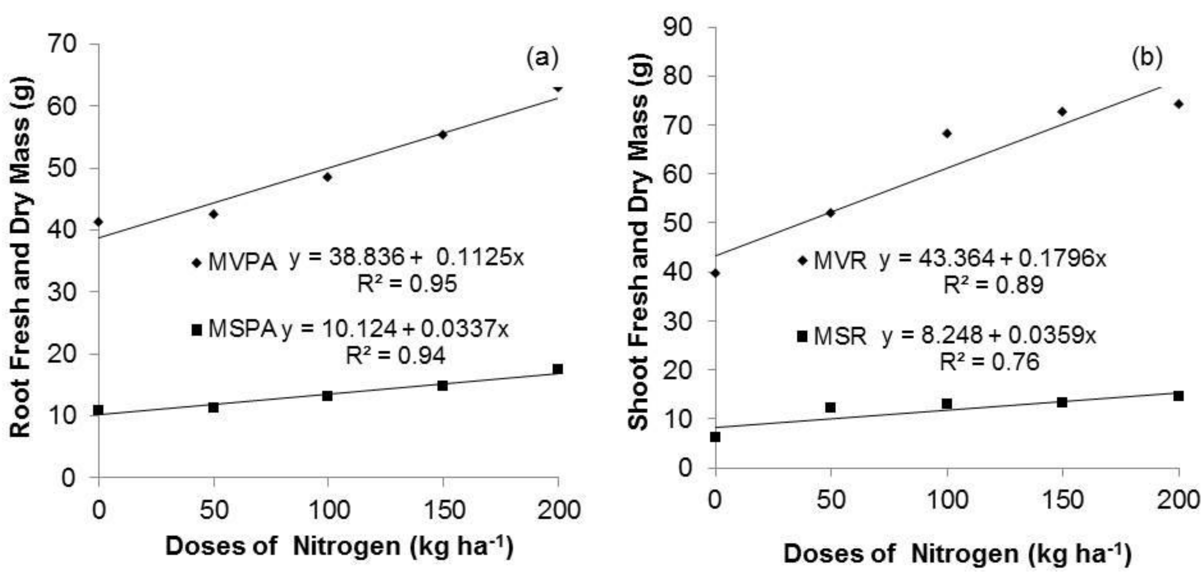

Figure 2. Shoot fresh and dry mass (a) and root fresh and dry mass (b), according to the doses of N in the eggplant crop.

When evaluating components of eggplant production in Iran, Bozorgi (2012) measured a height of 111.5 cm for 90 kg ha^{-1} of nitrogen, such height is almost twice that found in this work. One of the factors that probably contributed to that difference is the time of measuring. Bozorgi (2012) reported that in his study the measurement was made at the peak of fruiting, while in this test it was performed at the beginning of fruiting, and the climatic condition of northern Iran (Bwk) is also different from that of the place in which this study took place (Cwa).

SFM and SDM increased linearly with increasing doses of nitrogen (Figure 2a), in which the maximum dose promoted a maximum value of 59 and 15 g, respectively. Cardoso et al. (2008) studied the application of cattle manure (CM) and magnesium termophosphate (MT) in the fertilization of eggplant and found a value of 50.28 g $plant^{-1}$ for the SDM by the combination of higher doses of N and P supplied by the fertilizers, respectively. Largest increase in the dry mass of the eggplant was also verified by Oliveira et al. (2012) with nitrogen and ground cover with *T. cândida*. Coutinho Neto et al. (2010) also

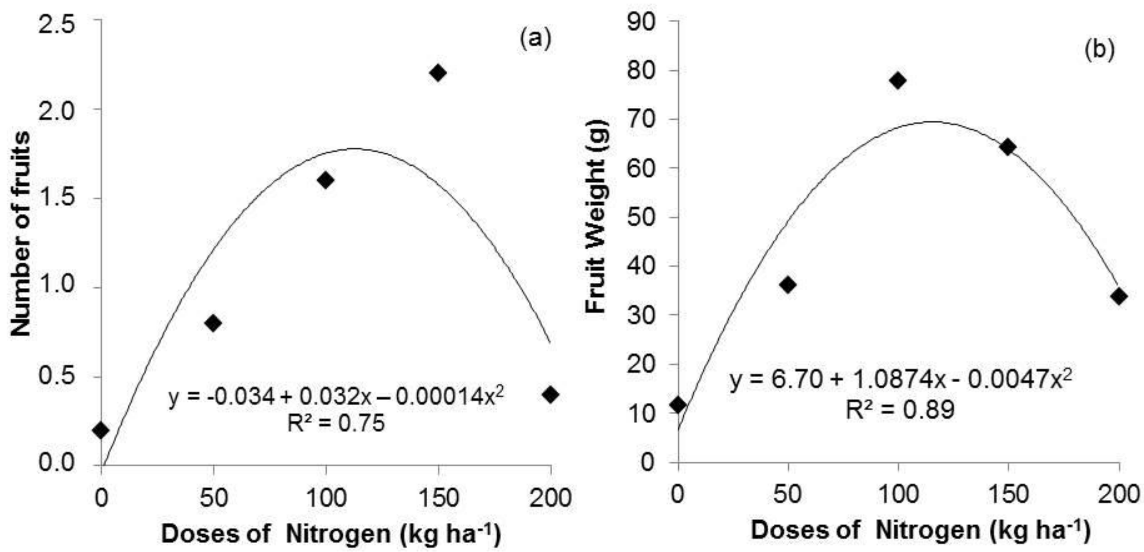

Figure 3. Fruit weight (a) and number of fruits (b), according to the doses of N applied to the eggplant crop.

observed it when studying doses of N and K in a radish crop.

Silva et al. (2001), on a study on red pepper, found that the application of ammonium sulfate increased SDM. According to these authors, the result was due to the accumulation of nutrients, which results in increased biomass, stimulating vegetative growth. Pedrinho et al. (2007) evaluated the effect of nitrogen fertilization on biomass and cardioactive glycosides content of *Nerium oleander* L. and observed increasing linear effect parameters for fresh and dry mass, according to the amount of N applied.

The fresh and dry mass of both roots and shoots also showed increasing linear responses with increasing doses of N (Figure 2b), in which the maximum dose promoted a maximum value of 74.24 and 14.68 g, respectively. Cardoso et al. (2008) found a higher value for eggplant RDM (16.74 g plant^{-1}) with a combination of the maximum doses of CM and MT with quadratic and linear adjusts, respectively.

Silva et al. (2001), in a study on red pepper, reported that N fertilization did not increase RDM due to the effect of salinity with potassium chloride (KCl), and possibly also by the antagonism between the ammonium sulfate (NH_4SO_2) and chloride used as sources of nutrients. For the culture of radish, Coutinho Neto et al. (2010) found no significant effect on RDM under the effect of N doses.

FW (Figure 3a) showed a significant response to the quadratic model with the initial increase up to the dose of 100 kg ha^{-1} in which an average of 77.84 g fruit was promoted, followed by a decline curve for doses of 150 and 200 kg ha^{-1} of N. This effect occurred in accordance with the FN per plant (Figure 3b), probably caused by a toxic effect of ammonium sulfate.

According to Foloni et al. (2006), cover fertilization with ammonium sulfate, when not done to correct soil acidity in their study on cotton considerably impaired the accumulation of Ca, Mg and K in the shoots. According to these authors even fertilization with ammonium sulfate causes rapid drop in soil pH, and the acidity inhibits the production of NO_3^- in soils receiving application of NH_4^+. Ferreira et al. (2010) found a linear effect for the average mass of tomato fruit, due to the increase of nitrogen rates.

In a study on red, pepper Campos et al. (2008) evaluated different doses of nitrogen and found a quadratic effect for N. The largest FN per plant was (44) at a dose of 250 kg ha^{-1} of N. The increasing FN per plant with increasing levels of N is probably due to the fact that nitrogen is the element to be absorbed in larger quantities by plants of the family Solanaceae. N is fundamental to the growth and development of plants (Oliveira et al., 1999). In this sense, the same authors observed an increase in fruit yield per pepper plant, depending on the supply of N by means of fertigation.

According to Carnicelli et al. (2000), the reduction in the FN per plant at doses above that responsible for the maximum value for this characteristic may be related to the toxic effect of ammonium and low nitrification rate, reducing the absorption of other cations (K^+, Ca^{2+}, Mg^{2+}) by the plant. According to Filgueira (2000), some cultures resent excess of nitrogen, such as root or tuberous plants; nitrogen excess can cause excessive vegetative growth at the expense of the production of tubers or roots.

Ferreira et al. (2010) observed a linear effect for the FN per tomato plant according to the nitrogen doses. These responses in different surveys are possibly related to the hormone balance in the plant canopy. The increase in the availability of nitrogen to plants increases the synthesis of

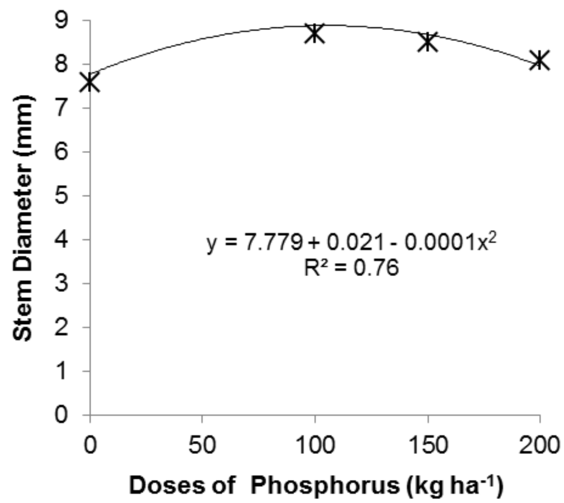

Figure 4. Stem diameter according to P_2O_5 levels in eggplants.

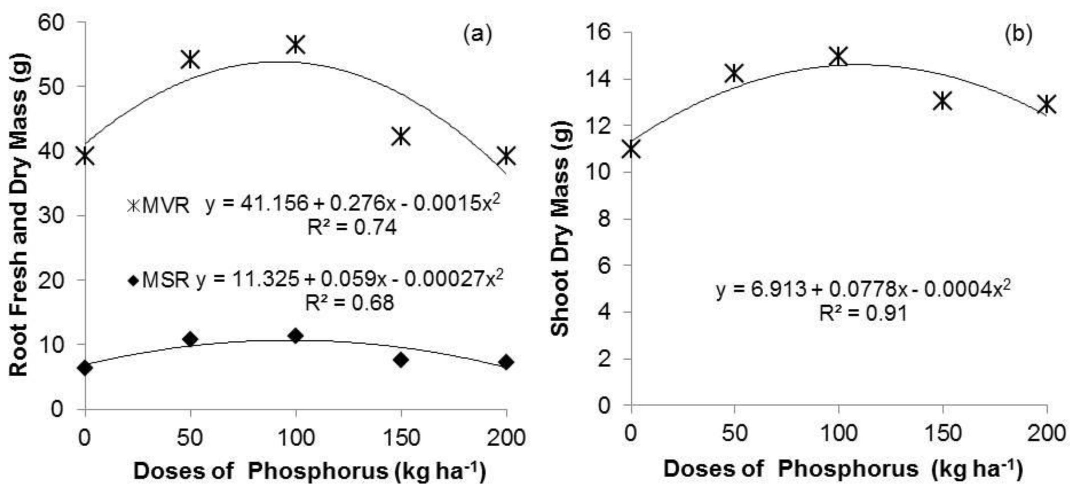

Figure 5. Root fresh and dry mass (a) and shoot dry mass (b), according to the doses of P_2O_5 in an eggplant crop.

hormone gibberellin at the apex of the shoots and leaves in expansion, being responsible for increasing fruitfulness.

The increase in the supply of nitrogen to plants may result in increased photosynthetic potential, what may lead to a greater production of carbon skeletons leaves, increasing the potential of the source and hence the supply to the drain (Ferreira et al., 2010).

With the results of this experiment it is possible to observe that N can increase eggplant production, what is not only due to the increase in average FW, but also to larger FN.

Phosphorus

In the evaluation of SD it was possible to observe a quadratic effect, with positive responses at doses of 50 and 100 kg ha^{-1} of P_2O_5 (Figure 4), the latter being the dose that best represents the results. Doses above 100 kg ha^{-1} did not correspond positively with a decrease in the SD. Zonta et al. (2010) verified a positive linear correlation with increasing doses of P_2O_5, in which the maximum dose used (3,000 kg ha^{-1}) of superphosphate promoted a maximum value of 25.73 mm SD. Filgueira (2003b) also claims that there is an increase in neck diameter; according to the author, the improvement in this feature can provide greater sustainability for the plant as well as higher sap flow, favoring the development of the plant and its fruits, what can lead to greater productivity, hence higher profitability to the producer.

The maximum weight of the RDM and RFM (Figure 5a) was obtained with 100 kg ha^{-1} at 120 days; higher doses obtained decrease in levels. Peryea (1990) reported that

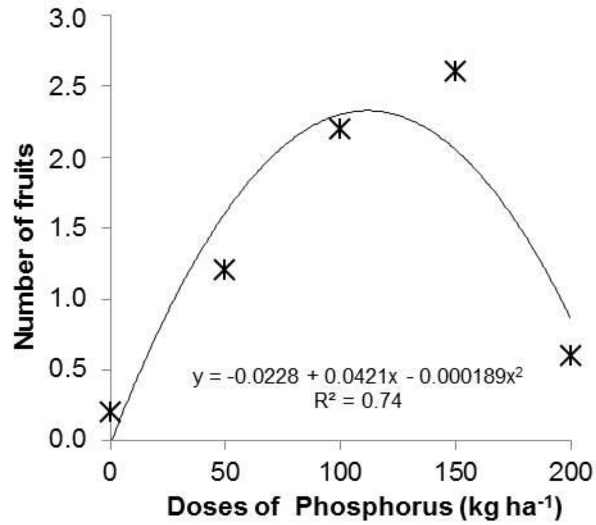

Figure 6. Number of fruits, according to the doses of P_2O_5 in the eggplant crop.

high doses of phosphorus can lead to toxicity, reducing root growth, which can account for a reduction in the RFM and RDM with increasing doses of phosphorus. Cardoso et al. (2008) found that the combination of higher doses of cattle manure and magnesium thermophosphate provided linear and quadratic adjusts, respectively, for the RDM of the eggplant (16.74 g plant^{-1}).

The SDM showed significant results, with little difference among the levels of phosphorus (Figure 5b); the dose of 100 kg ha^{-1} provided 14.98 g of eggplant SDM. Possibly from this dose, with the increased availability of P_2O_5 in the soil, absorption grew in proportions greater than the increase in SDM production, resulting in a reduction of the amount of dry mass. High concentrations of P_2O_5 in the tissues may reduce photosynthesis, due to the excessive export of trioses-P from the cytosol to the chloroplast, also reducing the intermediates of the calvin cycle and consequently the production of photoassimilates (Taiz and Zeiger, 2004).

Cardoso et al. (2008) found a higher value of SDM (50.28 g plant^{-1}) by a combination of higher doses supplied by fertilizers; P deficiency is detrimental to the growth of shoots. Moura et al. (2001) studied red pepper with different levels of phosphorus as fertilizer, and verified answers that fit the quadratic model. According to these authors, SDM increased with the supply of P_2O_5 up to near 250 mg of P_2O_5 kg^{-1} of soil, in which the result is attributed to the efficiency in the use of phosphorus in shoot growth, and to the greater intensity of phosphorus redistribution from the older and inactive tissues to the younger under development.

The ratio of root/shoot decreased with the increase in P_2O_5 in the soil due to larger increases in SDM production than in RDM, according to Martinez et al. (1993) this behavior should not be generalized for all kinds of plants. When some nutrients limit plant growth, roots become drains relatively stronger for carbohydrates in comparison to the shoot, what leads to a reduction that affects the roots (Taiz and Zeiger, 2004). Other authors, such as Castro et al. (2012) report that the reduction in shoot growth in conditions of deficiency of P can be related to the decreased production of cytokinin in the roots, and the translocation of this reduction to the shoot, since this hormone is involved in leaf senescence and indirectly on stomatal closure.

The FN per plant (Figure 6) showed a significant response to the quadratic regression model, with the initial increase up to the dose of 150 kg ha^{-1}, with an average production of 2.6 fruits per plant, followed by the decline curve for the dose of 200 kg ha^{-1} of phosphorus. The dose of 150 kg ha^{-1} caused a reduction in the FN per plant, which may indicate that increasing phosphorus may have caused changes in the availability of other nutrients that are essential to crop development.

The fact that high doses of P_2O_5 reduce the FN is reported by Instituto da Potassa and Fosfato (1998). In that study the authors observed that soils with high phosphorus content may cause a zinc deficiency, because high levels of phosphorus may reduce the absorption of zinc by the plant. The increase of salinity, the toxicity and zinc deficiency induced by high concentrations of phosphorus are some of the causes of the reduction in the FN according to Peryea (1990) and Seno et al. (1996), respectively. However, Filgueira (2003b) states that Zn may present the phenomenon of "hidden hunger", which is not detected visually. Zonta et al. (2010) found a highly significant effect (p <0.01) with the application of superphosphate at the eggplant sowing to the FN, having a quadratic response to increased phosphorus fertilization. Doses above 2054 kg ha^{-1} of superphosphate provided an estimated value of more than 26 fruits $plant^{-1}$. Manfio (2007) observed that the FN per plant was 65% higher when compared to the absence of P_2O_5, which indicates that phosphorus was effective in raising the FN in the eggplant.

Conclusion

The eggplant crop presented higher performance for most of the variables in relation to nitrogen, for which the dose with 100 to 150 kg ha^{-1} for the N source used in this work showed the best results. Doses which were higher than that led to lower yields in addition to increasing the cost of production.

The performance of the eggplant according to the levels of phosphorus applied was not different from that obtained with the application of nitrogen; however, the results obtained by the application of nitrogen were most satisfactory, since it showed differences for the variables number and weight of fruits.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Performance of groundnut (*Arachis hypogaea* L) varieties in two agro-ecologies in Sierra Leone

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Nine groundnut trials were conducted in the Southern Province of Sierra Leone in 2012 and 2013. The objectives of the trials were to evaluate the performance of two improved/groundnut varieties (Samnuts 22 and 23) and one improved local variety in the transitional rain forest and the savanna grassland agro-ecologies in the Southern Province of Sierra Leone, and to evaluate the responses of the varieties to phosphorous fertilizer. The experiments were laid out in a randomized complete block design with three replications. Grain yield by the treatment combination was significantly higher in the transitional rain forest than in the savanna grassland. The variety Samnut 23 performed significantly higher in terms of grain yield than the varieties Samnut 22 and Slinut 1, while the variety Samnut 22 produced more stover yield than Samnut 23 and the improved local variety in the two agro-ecologies considered in both years, an indication that Samnut 23 could be recommended for grain production while Samnut 22 recommended for fodder production in both agro-ecologies. Addition of single super phosphate (SSP) fertilizer enhanced the performance of all the varieties and also increased the formation of nodules by the varieties and had significant effect on biomass production. The improved local variety was an early maturing variety; Samnut 23 was a medium maturing variety, while Samnut 22 was a late maturing variety.

Key words: Forest transitional, savanna woodland, Samnut, *Arachis hypogaea*, agro-ecologies, haulm, stover, biomass, fodder.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.), also known as peanut, is an important food and cash crop across West Africa. The crop is cultivated mainly by small-household and resource-poor farmers (including women). Cultivated groundnut (*A. hypogaea* L.) belongs to genus *Arachis* in subtribe Stylosanthinae of tribe Aeschynomenea of family Leguminosae. It is a self-pollinated, tropical annual legume (Ntare et al., 2008). It is a legume that ranks 4th among the oilseed crops and 13th among the food crops of the world. It provides high quality edible oil (48 to 50%), (used in cooking, margarines, salads), easily digestible protein (26 to 28%), and about half of the 13 essential vitamins and more than a 3rd (7) of the 20 essential minerals necessary for normal human growth and maintenance. In addition it produces high quality fodder for livestock (Taru et al., 2008; Multipurpose Groundnut Feb, 2009)

Groundnut is by far the most important grain legume grown in Sierra Leone. It is predominantly grown in the Northern Province of Sierra Leone (IDRC, 1982). Planting

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is done at the onset of the rains (1st Season in most areas in Sierra Leone) between April and June and harvesting is done in August and September. Production in Sierra Leone is completely by hand using hoes as a tool and no input of fertilizer or pesticides using predominantly disease susceptible local varieties.

According to Food and Agriculture Organization (FAO), groundnut production data (FAO STAT, 2008) yields of groundnut in Africa are much lower than the average world yields, and yields in Sierra Leone are very low (0.6 to 0.7 tons/ha.). Researchers attribute this low yield to biotic, abiotic and socio-economic factors (Caliskan et al., 2008; Pande et al., 2003; Upadhyaya et al., 2006) including soil nutrient deficiencies (especially calcium and phosphorous) moisture stress, pest (especially rodents) and disease problems, low plant population poor weed control and unavailability and lack of access to quality seed of improved varieties.

Some of the most crucial characteristic differences between agro-ecologies are climatic - the rainfall distribution pattern and average temperatures. The average rainfall in the growing period of the crop was different both in the quantity, and pattern of distribution in the 2 years of growth in the two agro-ecologies. Kamara et al. (2011) indicated the influence of agro-ecology on groundnut pod yield in the Sudan and Northern Guinea savannah in North Eastern Nigeria.

The importance of phosphorous for legume production has been recognized for a long time. Franco and Avillio (1976) suggested that legumes may require more phosphorous than non-legume because of their higher requirement of phosphorous for symbiotic nitrogen fixation. Anil et al. (2008) stated that among the essential plant nutrients phosphorous is most important for seed production, helping to form a healthy and sound root system which is essential for nutrient uptake from the soil. Further, phosphorous is a component of adenosine diphosphate (ADP) and adenosine triphosphate (ATP). Phosphorous plays a role in cell division, flowering, crop maturation, root development and nodulation

Phosphorus (P) deficiency is the most frequent nutrient stress for growth and development of grain legumes including groundnut (Kamara et al., 2008). One of the most important soil nutrients for crop production is phosphorous. Phosphorus plays an important role in the maturity of the crop, root development, photosynthesis, nitrogen fixation and other vital physiological processes. In the order of importance to crop performance, phosphorus is rated second to nitrogen (Gervey, 1987). Sharma and Yaday (1997) reported that phosphorus plays a beneficial role in legume growth by promoting extensive root development and thereby ensuring a good yield. Balasubramanian et al. (1980) observed in a fertility study that phosphorus application results in better nodulation and seed yield. Rhodes (1983) reported that phosphorus application improved nodulation and seed yield of cowpea. El-Dsouky and Attia (1999) also attributed increased number and weight of nodules, nitrogen activity and groundnut yield to phosphorus fertilization. Kwari reported that, low phosphorus content of the soil may restrict *rhizobia* population and legume root development, which in turn can affect their N_2 fixing potential (Kwari, 2005). Studies conducted by researchers in Savanna regions of Nigeria showed that application of P at the rate 20 to 40 $kgha^{-1}$ significantly improved the performances of the grain legumes, groundnut (Balasubramanian and Nnadi, 1980); and soybean (Kamara et al., 2007).

Crop species and varieties, differ in their tolerance to low soil P and in their ability to utilise soluble P sources under different climatic, soil, and management conditions.

The N_2 Africa project introduced the present work through a grant through International Institute of Tropical Agriculture (IITA) from Wageningen University (Prime Sponsor) to assess performance of two varieties of groundnut at different locations in two agro-ecologies in Sierra Leone. Specifically, these experiments considered two (2) improved/exotic groundnut varieties (Samnuts 22 and 23) for evaluation of their performances and their responses to phosphorous fertilizer in the transitional rain forest and savanna woodland agro-ecologies in Southern Sierra Leone.

MATERIALS AND METHODS

The experimental set up was a randomized block design, with groundnut variety and P rate arranged in a factorial combination, replicated three times.

Two P rates were used; No SSP (-P) application and application of 270 g SSP per 12 m^2 plot (+P). Three varieties were used in these trials; Samnut 22, Samnut 23 and Slinut 1 (local control released by SLARI). Planting was done in six randomized plots, making one block in a randomized complete block design with three replications. Each plot consisted of six (6) rows with twenty (20) plants per row. The intra row distance was 20 cm, and the inter row distance was 50 cm. No P was added to the -P plots and 270 g SSP was added to 12 m^2 plot for the +P plots by banding at planting. One seed of groundnut was planted per hill for all the varieties. Each of the trials was weeded three times before harvest.

Data collection and analysis

Data was collected on % germination, Above ground biomass in subsample area of 2 m^2, oven dry weight of biomass subsample, mean nodule per treatment (sub sample of 10 plants per plot), total fresh weight of all pods in central 2 × 2 m plot, total fresh weight of all haulms in 2 × 2 m plot, oven dry weight of subsample of haulms, 100 seed weight, grain yield, and stover (haulm + husk/empty pods yield).

Data analysis was with Genstat discovery edition 3. The combined analysis was analyzed as a split - split plot design with year as the main plot factor, ecology as the sub plot factor and treatment combination (variety + or -P) as the sub-sub plot. Means were compared with least significant difference (LSD) at 5% probability.

Experimental sites

The experiment in both years was conducted at different sites

Table 1. Seed yield of treatment combination per ecology.

Treatment combination	Ecology	
	Transitional rainforest	Savanna woodland
	Seed yield (kg/ha)	Seed yield (kg/ha)
Samnut 22 (- P)	651	497
Samnut 22 (+ P)	832	631
Samnut 23 (- P)	898	620
Samnut 23 (+ P)	1167	839
Slinut 1 (- P)	277	227
Slinut 1 (+ P)	372	352

$LSD_{5\%}$ = 84.6.

within the same vicinity to eliminate any residual effect of fertilizer application and as a precautionary disease control mechanism. The agro-ecologies targeted in the study were the transitional rain forest and the savannah woodland in the Southern Province of Sierra Leone.

RESULTS AND DISCUSSION

Seed grain yield

The mean grain yields for both ecologies for the crop in 2012 at 846 kg/ha was significantly higher than the mean grain yield in 2013 at 363 kg/ha at the 5% level of probability. This may be due to rainfall distribution pattern. Rainfall in 2013 was heavy at 2710 mm but came in heavy downpours for a shorter period, while rainfall in 2012 was less heavy at 2420 mm but was more evenly distributed. The transitional rain forest ecology produced more grain yield in both years than the savanna woodland ecology, confirming report by Kamara et al. (2011) of the influence of agro-ecology on groundnut seed yield in Northern Nigeria. The seed yield of the different varieties including their interaction effect with ecology and the treatment combinations (+ and - P) were significantly different at the 5% level of probability, as shown in Table 1. The variety Samnut 23 had the highest mean grain yield in both 2012 and 2013 in both ecologies followed by Samnut 22 as is similarly reported by Bala et al. (2011) for the same varieties at the IAR experimental farm in Samaru in Nigeria. There is a consideration (Bala et al., 2011) that variety Samnut 23 is inherently higher-yielding than Samnut 22 which implies that the variety is more efficient in the manufacture of assimilate and partitioning of same to the reproductive sink. This may explain the superiority in seed yield production of Samnut 23 over variety Samnut 22. The superior performance of Samnut 23 over Samnut 22 in all agro-ecologies tried within 2 years is also reported by Kamara et al. (2011) who worked in two locations within 2 years (2005 and 2006) in the tropical savannas in Northeast Nigeria.

Phosphorous treated plots produced significantly higher seed grain yield that plots without phosphorous. Similar results are reported by Tran Thi (2003) and Anil et al. (2008) who report increase grain yield with phosphorous application. Das (2008) observe an increase in seed yield of chickpea with incremental doses of phosphorous up to 60 kg P_2O_5 /ha^{-1}. Thu Hha (2003) observe that in poor alluvial soil, yield was significantly higher than the control with 60 kg P_2O_5/ha, while the sandy soil required 90 kg P_2O_5/ha to produce a significantly higher yield. It was also observed that agronomic efficiency for P show a similar trend and is maximized at 60 and 90 kg P_2O_5/ha, in the poor alluvial and sandy soils, respectively. Rajkishore (2005) reported that the number of filled pods per plant, total number of pods per plant at harvest and pod yield per hectare and consequently yield in groundnut were influenced by different levels of phosphorus application.

Haulm yield

Significantly more haulm was produced by the crop in 2012 = 2334 kg/ha than the crop in 2013 = 1106 kg/ha (p =.001, $LSD_{5\%}$ = 354.1). The crops in the transitional rain forest agro-ecology produced a significantly higher average haulm yield = 1808 kg/ha than those grown in the savanna woodland agro-ecology =1650 (p = <0.001, $LSD_{5\%}$ = 227.9). The varietal responses to phosphorous treatment and their interaction with environment were also significant (Table 2). However, the local variety produced more haulm yield in the savanna woodland ecology than in the forest transition ecology, rendering this variety more adaptable for haulm production in this ecology. The variety Samnut 22 produced more haulm than the varieties Samnut 23 and the local variety/check Slinut 1. All the varieties showed increased haulm yield (increased dry matter production) with the application of phosphorous in both ecologies. Das et al. (2008), Ranjit (2005), Kamara et al. (2010) and Kausale et al. (2007) also report increase in haulm production with addition of phosphorous. Singh and Ahuja (1985) reported that applied phosphorous increase the leaf area and increase accumulation of dry matter.

Patel et al. (1990) and Deshmukh et al. (1995) reported

Table 2. Haulm production of treatment combinations per ecology.

Treatment combination	Ecology	
	Transitional rainforest (kg/ha)	Savanna woodland (kg/ha)
Samnut 22 (- P)	2237	1969
Samnut 22 (+ P)	2966	2433
Samnut 23 (- P)	1323	1401
Samnut 23 (+ P)	2311	1434
Slinut 1 (- P)	867	1321
Slinut 1 (+ P)	1144	1278

$LSD_{5\%}$ = 266.7.

Table 3. Mean husk production of treatment combination per ecology.

Treatment combination	Ecology	
	Transitional rain forest (kg/ha)	Savanna woodland (kg/ha)
Samnut 22 (- P)	389	410
Samnut 22 (+ P)	615	439
Samnut 23 (- P)	455	393
Samnut 23 (+ P)	646	516
Slinut 1 (- P)	206	237
Slinut 1 (+ P)	296	343
Mean	434.5	389.7

$LSD_{5\%}$ = 132.6.

that dry matter accumulation in groundnut is as a result of leaf and stems growth during the vegetative phase and a combination of pod and kernel growth concurrent with shifts in leaf and stem mass during reproductive phase. Dry matter accumulation due to 40 and 80 kg ha^{-1} P levels was 10.0 and 9.8%, respectively; moreover no P. The increase in dry matter due to P could be mainly due to active involvement of P in carbohydrate metabolism which helps in putting more vegetative growth

Husk yield

The husk produced by the varieties was significantly affected by the treatment combination (variety + or - P), ecology and their interactions at the 5% level of probability (Table 3). The varieties produced significantly more husk in 2012 than in 2013 (p <.004); this may be due to the superior performance of the crop in 2012 than in 2013. The ecology had significant effect on husk production (p = 0.321) with the transitional rain forest producing on the average more husk yield than the savanna woodland ecology probably due to more pod production in the transitional rainforest. The variety Samnut 22 produced significantly more husk in the transition rainforest ecology than in the savanna woodland ecology. All of the varieties showed increased production of husk with the addition of phosphorous. Phosphorous addition increased the dry matter production in the varieties as stated also by Ranjit (2005) and Kamara et al. (2010).

The mean husk production was not significantly different between the varieties Samnut 22 and Samnut 23; however, the husk weight produced by both varieties was significantly different from the husk weight produced by Slinut 1 (P < 0.001).

The husk produced by Slinut 1 is thin/light weight with a smooth reticulation, while husk produced by Samnut 22 and Samnut 23 are robust with rough reticulation.

Stover yield

The varieties (treatment combinations) and their interaction effect with year and ecology were very significant for mean stover production. Year had a significant effect on stover production by the different treatment combinations, with more stover being produced in 2012 than in 2013 (p = 0 .002). This is due to the superior performance of the crop in 2012 than in 2013. The agro-ecology also had a significant effect on stover production (p = 0.036). More stover was produced in the transitional rainforest than in the savanna agro-ecology.

The treatment combinations had significant difference

Table 4. Mean Stover production of treatment combination/ecology.

Treatment combination	Ecology	
	Transitional rain forest (kg/ha)	Savanna woodland (kg/ha)
Samnut 22 (- P)	2625	2440
Samnut 22 (+ P)	3581	2872
Samnut 23 (- P)	1778	1794
Samnut 23 (+ P)	2957	1950
Slinut 1 (- P)	1073	1558
Slinut 1 (+ P)	1440	1621
Mean	2242.33	2039.17

$LSD_{5\%}$ = 182.4.

Table 5. Mean Nodule production by the treatment combination per ecology.

Treatment combination	Ecology	
	Transitional rainforest (kg/ha)	Savanna woodland (kg/ha)
Samnut 22 (- P)	100.4	191.1
Samnut 22 (+ P)	169.4	178.4
Samnut 23 (- P)	88.7	58.8
Samnut 23 (+ P)	130.2	70.0
Slinut 1 (- P)	83.8	155.1
Slinut 1 (+ P)	154.0	183.8
Mean	121.08	139.53

$LSD_{5\%}$ = 10.10.

in their response to stover production in the different ecologies (Table 4). Phosphorous addition had a significantly higher effect on stover production of Samnut 22 and Samnut 23. The response to phosphorous addition in Slinut 1 though numerically higher was not statistically significant at the 5% level. The response to phosphorous addition was highest in the variety Samnut 22 which produced more stover than the varieties Samnut 23 and Slinut 1

Nodule formation

The treatment combinations (variety -/+ phosphorous) and their various interaction with ecology and year were very significant and had significant effect on the mean number of nodules produced by the varieties at the 5% level of significance. There was no significant difference between the nodules produced by the varieties in 2012. There was however, a significant difference between nodules produced by the varieties in 2013 in the two agro-ecologies with varieties in the savanna woodland producing more nodules than varieties in the transitional rainforest. The variety Samnut 22 produced the most nodules followed by the local variety, Slinut 1 and then Samnut 23. Agro-ecologies had significant effect on nodule production. There was a significant effect of the addition of phosphorous on nodule production (Table 5). Addition of phosphorous increased nodule production as is reported also by Kausale et al. (2007), Yakubu et al. (2010) and Anil et al. (2008). High response of the varieties to phosphorous with respect to nodule formation may be due to low native phosphorous content in Sierra Leonean soils in addition to the role of phosphorous in groundnut production - root formation, nodule initiation, nodule growth and functioning in nitrogen fixation.

Biomass production

The above ground biomass produced was significantly affected by the year ($p = 0.008$), ecology ($p = 0.004$) and by the varieties ($p = <0.001$) and their various interactions (p = all less than 0.005). Significantly more biomass was produced in 2012 = 3174 kg/ha than in 2013 = 1964 ($p = 0.008$). Significantly more biomass was produced by the varieties grown in the savanna woodland than in the transitional rainforest agro-ecology (Table 6).

The variety Samnut 22 produced more biomass than Samnut 23 and Slinut 1. This variety is of a long duration to maturity. The local variety Slinut 1 produced more biomass than Samnut 23. All the varieties responded to phosphorous addition for biomass production. The plots having addition of phosphorous produced more biomass

Table 6. Mean biomass production by the treatment combinations per ecology.

Treatment combination	Ecology	
	Transitional rain forest (kg/ha)	Savanna woodland (kg/ha)
Samnut 22 (- P)	1972	3132
Samnut 22 (+ P)	3199	3371
Samnut 23 (- P)	1818	2473
Samnut 23 (+ P)	2198	2285
Slinut 1 (- P)	1619	2932
Slinut 1 (+ P)	2645	2794
Mean	2241.8	2831.2

$LSD_{5\%}$ = 396.9

than plots with no addition of phosphorous. Application of phosphorus fertilizer generally increased total dry weight in both years and in both agro-ecologies. The increases in dry weight due to phosphorus application may be due to the fact that phosphorus is known to help in the development of more extensive root system (Sharma and Yaday, 1997; Gobarah et al., 2006; Kamara et al., 2011) and thus enables plants absorb more water and nutrients from depth of the soil. This in turn could enhance the plant's ability to produce more assimilates which are reflected in the high biomass production.

The response of Samnut 23 was not statistically significant within the variety at the rate of application of phosphorous in the experiment. The most pronounced effect of phosphorous addition on biomass production was in Samnut 22 which showed a very significant increase in biomass production. The effect of phosphorous on biomass production was variously reported by Kamara et al. (2010), Kausale et al. (2007) and Anil et al. (2008)

Conclusions

This study found that agro-ecology of cultivation had significant effect on groundnut seed yield, haulm production and stover yield; and that the response of groundnut to phosphorous application was steady in the two agro-ecologies, which validates the importance of P for production of groundnut in Sierra Leone. It was also found that the effect of phosphorous was influenced by the variety with some varieties showing higher response either in terms of grain yield, haulm production, and nodulation or biomass production. The variety 'Samnut 23' which is early to medium maturing produced higher grain yields than the other varieties Samnut 22 and Slinut 1. The late maturing Samnut 22, however, produced higher fodder yields than 'Samnut 23'. Both varieties (Samnut 23 and Samnut 22) are less susceptible to the prevalent *Cercospora* leaf spot disease. The variety 'Samnut 23' which is of a similar duration to maturity as most of the local varieties but is higher yielding in terms of seed yield and relatively disease resistant is recommended for farmers in Sierra Leone. However, for farmers interested in fodder for their livestock in addition to grain, the variety Samnut 22' is recommended. The transitional rainforest ecology is found more productive for groundnut production than the savanna woodland ecology especially for seed yield.

Conflict of Interests

The authors have not declared any conflict of interests.

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Competitiveness of flaxseed with weeds under different row spacings

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The aim of this study was to evaluate the effect of the weed competition with different spacings in the culture of flaxseed (*Linum usitatissimum* L.). The experiment was conducted at the Campus of Unioeste - Cascavel, Paraná State, using the split-plot design in which the plots consisted of presence and absence of weeds and subplots consisted of row spacings (0.15, 0.30, and 0.45 m) with six replications. Plant height, number of capsules, stems and seeds per plant and yield ($kg.ha^{-1}$) were determined. The increase of spacings between rows and the coexistence with the weed community were detrimental to production components of flaxseed.

Key words: *Linunm usitatissimu* L., competition, spatial arrangement of plants.

INTRODUCTION

Flaxseed (*Linum usitatissimum* L.) is a herbaceous plant that belongs to the Linaceae family, with more than 200 recognized species (Cui, 1998). The energy use of flax seeds can give a new direction to this culture, since its seed is rich in oil. The seeds contain about 38% oil, that once extracted can be used to produce biofuels (Rabetafika et al., 2011).

Spacing and spatial arrangement are the main factors related to the degree of interference between crops and weeds, as they act on the precocity and intensity of shading of the crop over weeds (Dias et al., 2009; Tharp and Kells, 2001; Norris et al., 2001; Knezevic et al., 2003). Balbinot and Fleck (2005) emphasize that the competitiveness of crops is dependent on factors such as: cultivated species, morphological and physiological characteristics of the genotypes, weed species present in the area and time of their emergence, and also environmental conditions, especially temperature, solar radiation and rainfall.

Barreyro and Vallduvi (2002) determined the critical period of interference for the culture of flaxseed between 30 and 80 days of sowing, observing significant losses when the culture was subjected to infestation throughout the cycle. The authors emphasize that it is a tool to reduce damage by weeds and use different alternatives for management and control. Several studies have been developed to analyze the behavior of the infestation in the spatial distribution of crops between rows of soybean (Melo et al., 2001), beans (Burnside et al., 1998) and corn (Ramos and Pitelli, 1994) and peanut (Pitelli et al.

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Tablel 1. Chemical attributes of an oxisol before the establishment of the experiment.

Layer	pH	M.O.	P	Al	H+Al	Ca+Mg	K	S	CTC	V
cm	$CaCl_2$	g dm^{-3}	mg dm^{-3}		------------------$cmol_c dm^{-3}$------------------					%
0-20	5.37	50.29	19	0.25	6.93	17.6	0.22	17.82	24.75	72.00

2002). However, studies on flax are practically nonexistent.

One way to increase the competitiveness of the crop is by reducing the spacing, so that the crop canopy closes between rows faster and shades the weeds. In that sense, the purpose of this experiment is to investigate the potential development of golden flaxseed (*Linum usitatissimum* L.), with and without weed infestation in different row spacings.

MATERIALS AND METHODS

The experiment was conducted under field conditions in the agricultural year of 2012, during the period from April to August 2012 at UNIOESTE (State University of Western Paraná), located in the city of Cascavel, Paraná, Brazil, latitude 24°53'47" S and longitude 53°32'09"W. The region presents mesothermal and super humid temperate climate, Cfa climate type (Koeppen) (Caviglione et al., 2000). The average annual temperature in the region is 19.6°C, annual rainfall of 1971 mm and 2462 h of sunshine per year (IAPAR, 2011). Monthly averages of temperature and precipitation are shown in Figure 1 and Table 1.

The experimental setup used was the split plot scheme, in which the plots consisted of the presence and absence of weeds and subplots consisted of row spacings (0.15, 0.30, and 0.45 m) with six replications. The subplots consisted of six rows (5 m long), with a useful area of four central lines. The sowing of flaxseed was held manually on April 14th, 2012 in the lines starting with a manual furrowing. As for the sowing operation, a final population of 333,000 plants.ha^{-1} was obtained to all spacings. Base fertilization rate was 200 Kg ha^{-1} of formula 02-20-18. Weed control in the area with no competition was carried out manually. No agrochemical was applied during the experiment. The following characteristics were evaluated: plant height, number of stems, seeds and capsules per plant and yield (Kg ha^{-1}). In order to determine the parameters of production ten plants in each plot were sampled. Grain yield was obtained by manual harvesting of central lines in each experimental unit. Subsequently, the tracking and weighing of grains took place. The yield was corrected to 13% moisture, and results were expressed in Kg ha^{-1}.

In order to characterize the weed community in treatments where the crop was under interference, two frames of 0.25 m^2 were sampled. Weeds were collected, identified and counted. The results were submitted to analysis of variance and the interaction between factors and their means were compared by Tukey's test at 1 and 5% probability, using the statistical package Assistat ® version 7.5 beta (Silva and Azevedo, 2002). Data unfolding was performed when the interaction infestation x spacing was significant.

RESULTS AND DISCUSSION

The weed community consisted of the following species: *Raphanus sativus* (8.19%), *Lolium multiflorum* (16.78%), *Sonchus asper* (1.12%), *Galinsoga parviflora* (0.29%), *Bidens pilosa* (0.14%), *Ambrosia elatior* (5.05%), *Mollugo verticillata* (24.53%), *Taraxacum officinale* (23.20%), *Facelis apiculata* (3.68%), *Croton glandulosus* (2.35%), *Eupotarium pauciflorum* (3.04%), *Fumaria officinalis* (2.74%), *Diodia teres* (0.98%), *Richardia brasiliensis* (4.90%), *Bromus catharticus* (2.06%), *Emilia fosbergii* (0.44%), *Sida rhombifolia* (0.44%).

The rainfall at the experimental site (Figure 1) was considered good for the development of the culture, despite the uneven distribution, it can be said that the production performance was not influenced by soil water deficit. According to Hocking et al. (1997) and House et al. (1999), factors such as low rainfall and high temperatures during the anthesis and grain filling stage have a significant effect on flaxseed yield.

The performance of the analysis of variance is presented in Table 2. One can observe a significant difference for all production components analyzed in relation to infestation. The spacings did not influence in plant height. The interaction between infestation x spacing did not affect the number of capsules per plant.

Plant height was influenced by infestation (Table 2) and by the interaction Infestation x Spacing. Regarding the level of infestation, it can be seen that when flaxseed was grown in larger spacings (0.45 m) interaction between the weed and the culture had no effect on plant height (Table 2). Melo et al. (2001), when determining the period previous to the interference in a soybean crop with row spacings of 30 and 60 cm found no influence of the presence of weeds in plant height as well as in the first pod insertion and 100 seed weight. Balbinot and Fleck (2005) found no significant effect of row spacing on plant height on a corn crop.

As for the number of capsules, one may note the significance of the infestation and spacing in relation to the component (Table 3). Interaction between factors did not influence the number of capsules per plant. The coexistence of culture with the infestation resulted in a reduction of 56% capsules per plant. Andrade et al. (1999) observed a reduction in the number of pods/plant in beans with greater spacing with coexistence due to the competition with weeds. According to the authors with greater spacing there is proper closing of the culture, providing greater infestation and better conditions for their development. According to Teasdale (1995), the adoption of smaller spacings increases the competitiveness of the crop with weeds due to the greater amount of light that is intercepted by the crop

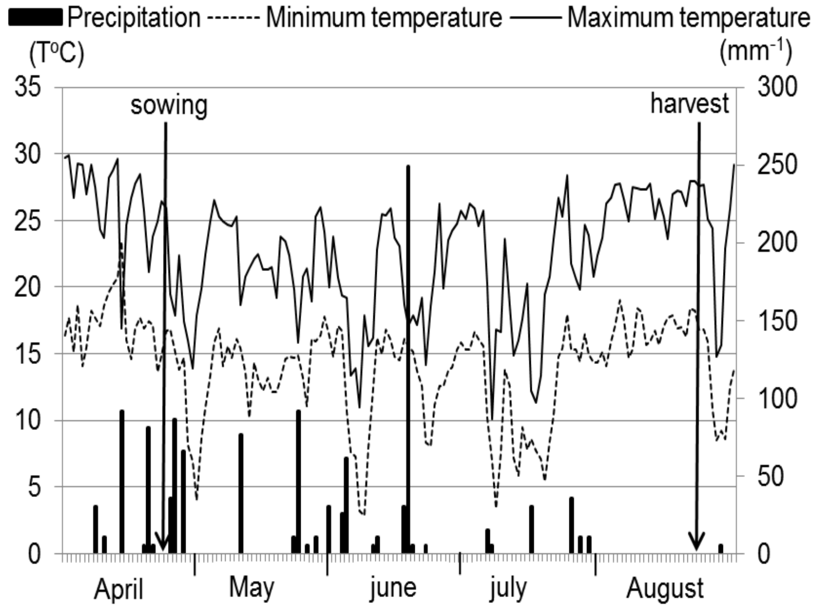

Figure 1. Precipitation (mm^{-1}) and temperature (T°C) recorded during the experiment.

Table 2. Height, number of stems, number of capsules, number of seeds and yield.

Treatments	Plant height	Capsules	Stems	Seeds	Yield
Infestation (I)	**---cm---**	**------------ number/plant----------**			**---Kg.ha^{-1}---**
Without	76.61^{b}	32.16^{a}	2.05^{a}	237.50^{a}	1228.03^{a}
With	84.50^{a}	13.44^{b}	1.38^{b}	105.45^{b}	606.81^{b}
C.V.(%)	6.34	30.89	49.35	32.65	31.72
Spacing (S)					
0.15	79.08	17.83^{b}	1.33^{b}	111.94^{b}	1107.29^{a}
0.30	83.08	28.83^{a}	1.41^{b}	230.68^{a}	1130.71^{a}
0.45	79.50	21.75^{ab}	2.41^{a}	171.80^{ab}	514.25^{b}
C.V. (%)	6.29	36.83	41.29	39.29	36.19
I	**	**	*	**	**
S	n.s.	*	**	**	**
IxS	*	n.s.	*	**	**

n.s. = Not significant, * = significant at the 5% probability level, ** = significant at 1% probability.

Table 3. Deployment of interaction infestation x spacing for plant height.

Infestation	**Spacing**		
	0.15	**0.30**	**0.45**
Plant height			
without	71.83^{bA}	79.00^{bA}	79.00^{aA}
With	86.33^{aA}	87.16^{aA}	80.00^{aA}

Columns = lowercase; Lines = uppercase; Means followed by the same letter do not differ statistically among themselves. ns = not significant, * = significant at the 5% probability; ** = significant at 1% probability.

Table 4. Deployment of interaction infestation x spacing for number of stems, number of seeds and yield.

Infestation	Spacing		
	0.15	0.30	0.45
Number of stems			
Without	1.16^{aB}	1.83^{aB}	3.16^{aA}
With	1.50^{aA}	1.00^{aA}	1.66^{bA}
Number of seeds			
Without	135.20^{aB}	357.97^{aA}	219.32^{aB}
With	88.68^{aA}	103.40^{bA}	124.28^{bA}
Yield			
Without	1317.18^{aA}	1731.65^{aA}	635.26^{aB}
With	897.41^{bA}	529.76^{bAB}	393.25^{aB}

Columns = lowercase; Lines = uppercase; Means followed by the same letter do not differ statistically among themselves. ns = not significant, * = significant at the 5% probability; ** = significant at 1% probability.

canopy. The number of stems, seeds and yield were affected by the infestation and spacing, as well as the interaction between Infestation x Spacing. Due to the interaction between factors, the unfolding was analyzed in Table 4.

One can verify in what concerns to the number of rods that when the culture was subjected to living with weeds spaced 0.45 m between rows there was a reduction from 3.16 to 1.66 stems per plant. Note that when the culture was kept free from weeds the spacing of 0.45 m between rows provided a greater number of stems per plant.

When observing the differences in the unfolding of interaction infestation x spacing (Table 4) for the component number of seeds per plant, one can notice a negative influence of the coexistence of the crop with the infestation, resulting in the decrease of seeds per plant, matching what was stated by Barreyro and Vallduvi (2002); VallduvI et al. (1997) and Gruenhagen and Nalewaja (1969). When the crop was under infestation there was no difference between the spacings in the production component, however with the spacing of 0.15 m between rows, the infestation did not harm the crop. The highest number of seeds per plant was observed with the spacing of 0.30 m, with no infestation.

For two corn genotypes with presence of weeds, Balbinot and Fleck (2005) observed reduced stem diameter, plant height and all components of grain yield with 11% reduction in the number of grains per ear due to infestation. The yield was influenced by the interaction between infestation x spacing (Table 4). The competition did not affect the productivity with spacing of 0.45 m between rows, but there was an increase of 32 and 70% in the spacings of 0.15 and 0.30 m, respectively, in relation to infestation. Row spacing did not affect productivity when culture competed with weeds. Balbinot and Fleck (2005) obtained better results in grain yield of maize with reduced spacing and no competition.

Barreyro and Vallduvi (2002) found loss of 63, 54 and 79% in 1993, 1994 and 1995 respectively, in the yield of flaxseed when submitted to the competition throughout the cycle. Dias et al. (2009) observed a reduction in productivity from 2,054 to 341 Kg.ha^{-1} in a peanut crop with spacings of 0.8 m between rows due to the interference of weeds, what represents 83% loss of productivity. For the distance of 0.9 m, the coexistence of 140 days between weeds and crop resulted in a production decrease from 1,820 to 82 Kg.ha^{-1},which is equivalent to 95%.

Conclusion

There is an influence of the interaction of factors infestation and spacings on flaxseed development. The lowest row spacing did not affect crop productivity when it was subjected to infestation.

Conflict of Interests

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

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Agriculture information needs of farm women: A study in State of north India

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Access to accurate, timely and reliable information plays a crucial role in the adoption of appropriate agriculture technology. Although, women contribute significantly in the farming operations, their contribution is not yet fully recognised and acknowledged. In order to improve agriculture productivity and production efficiency, there is an urgent need to identify their agriculture information needs. The present study was undertaken to find out the agriculture information needs of farm women in a Himalayan State of North India. The study adopted a descriptive research design and the study sample included 120 farm women selected from eight randomly selected villages using PPS method. The findings indicate that farm women expressed the need for information regarding disease control/management, weed control/management, high yielding variety crops, fertilizer requirement, use of improved farm implements, and information related to marketing. An appropriate information dissemination strategy can be developed on the basis of their information seeking and information sharing behaviour. The study has policy and programming implications for devising appropriate extension strategies for fulfilling the information needs of farm women for enhancing agriculture productivity and production efficiency.

Key words: Information needs, farm women, information seeking behavior.

INTRODUCTION

Agriculture has been and continues to be the principal engine of economic growth in India as well as in most of the developing countries. It is the one of the critical sector of national development planning as it employs about 60% of the workforce and contributes almost 18% to the national gross domestic product (Government of India, 2011). Besides, it also contributes significantly towards India's export earnings and provides raw material for many industries. Hence, continued and sustained growth of agriculture sector is critical to meet the food requirements of a growing billion-plus population of the country besides providing livelihood opportunities and income generation activities in rural areas.

Farm women have traditionally been an important work force in agriculture. They play a significant and crucial role in all the stages of crop production from seed

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selection to post harvest activities and in other allied enterprises such as dairy, cattle management, fish and poultry farming, sheep rearing etc., besides fulfilling their responsibilities of home making and child rearing. In recent years, there has been an increasing recognition of the need to integrate women into mainstream development efforts. Despite rural women's active involvement in farming, they do not have access to scientific and technological knowledge. Therefore, for consistent growth in agricultural production, it is very important to equip the women farmers with relevant and timely information to improve their production techniques and increase their income (Shailaja and Reddy, 2003). Due to the lack of agricultural extension services support, farm women have no agricultural information sources related to crops and livestock production, inadequate technical competency and exposure to outer world (Olowu and Yahaya, 1998). It is important to disseminate information about new technologies so that farm women are able to make use of latest agricultural developments.

Theoretical framework

Information asymmetry at farm level has been identified as one of the main reasons for low agriculture productivity and production efficiency. Access to accurate, timely and reliable information plays an important role in the adoption of appropriate agriculture technology. Although, women contribute substantially in farming operations, their contribution is not yet fully recognised and acknowledged. Although, rural women are actively involved in the process of food production, processing and marketing, social and economic constraints have placed barriers around their access to scientific and technological information (Daman, 1997). The women folk do not have needed technical knowledge to enable them derive productive use of farm input for optimum yield. In India, it is a known fact that male farmers have more access to agriculture extension services than women. In fact, the whole agriculture extension system is organised to serve men farmers, and women farmers are often neglected whether they have access to information and training opportunities.

Consequently, farm women's knowledge and skills remain low and unsuitable for modern farming techniques. Protz (1997) posited that due to the multiple roles women play in the rural household (including caretakers of children and the elderly), they do not fully benefit from extension services, particularly, when the time of delivery (of extension service) conflicts with their other household responsibilities. According to FAO (1998), rural women are burdened by their domestic tasks and family obligations and controlled by social restraints such that they are constrained time-wise to be away from home to attend to extension training programmes.

Information need can be conceptualised as the data or set of data specially required to perform a task or make an appropriate decision about a problem related to farming at a particular time. Research on information needs and information seeking behaviour concurs that information is tailored to individuals' job or task. Hence, we need to assess the information needs of farm women so that they can perform their farming operations efficiently and contribute in increasing agriculture productivity.

Uttarakhand: A North Himalayan state of India

The locale of the present study was a north Himalayan State (Uttarakhand) which was created on 9th November, 2000 as 27th State of India. It borders China on the North, Nepal on the East, and Indian States of Himachal Pradesh (H.P.) and Uttar Pradesh (U.P.) on North-East and South, respectively. The State is divided into two main divisions – Garhwal and Kumaon – with a total of thirteen districts. It has a total area of 53,484 km^2 of which 93% is mountainous and 65% is covered by forests. Most of the northern part of the state is covered by high Himalayan peaks and glaciers. The total population (Census, 2011) is 10.116 million with almost 70% population living in rural areas.

The state's economy is primarily based on tourism, especially religious tourism in Garhwal region. The agriculture is basically subsistence type with little or no marketable surplus. The land holdings are small and scattered, much of which is unfit for farming. However, as we know, the mountainous farming is primarily a family farming system due to its small scale character, diversification of crops grown, integration of forest and animal husbandry activities. The life and lifestyle of the people living in these areas have evolved over the centuries and inspired them to seek sustenance from the land besides conserving natural resource base and ecosystems.

Besides tourism, Agriculture sector is the employers of the largest work force which is the backbone of Uttarakhand's economy. Most of the farming in hills is subsistence level and there is very little marketable surplus. A woman in Uttarakhand is earning Rs.18.13/day (less than half-a-dollar per day) and this is less than the per capita income of India (Sharma, 2012). And, for them to play a more active role in food security, sustainable farming and rural development, there is an urgent need to provide rural women with more latest, reliable and convenient information continuously and on timely basis (Kazilastan, 2007). In order to enhance agriculture production, and ensure continuous flow of appropriate agriculture technologies to women farmers, there is an urgent need to determine their information needs, find out their preferred information sources and their access to training and capacity building opportunities. One of the

Table 1. Distribution of respondents according to their socio-personal characteristics (N = 120).

Characteristic	Categories	Frequency	Percentage
Age	Young (up to 31)	16	13.33
	Middle (32-57)	69	57.50
	Old (more than 57)	35	29.17
Land holding	Marginal (<1 ha)	120	100.00
	Small (1-2 ha)	0	0
	Medium (2-4 ha)	0	0
	Large (>4 ha)	0	0
Education	Illiterate	32	26.67
	Primary	42	35.00
	Junior	33	27.50
	High school	13	10.83
Type of family	Nuclear	86	71.67
	Joint	34	28.33
Size of family	Small (up to 5)	86	71.67
	Medium (6-10)	34	28.33
Media exposure	Radio	13	10.83
	Television	117	97.50
	Mobile Phone	120	100.00
Extension agency contact	Formal	0	0.0
	Informal	120	100.00

ha = hectare.

remedial measures that needs to be undertaken is to induct a sizeable number of well trained women personnel in training and extension programmes at all levels and more so at the grass-root level. An appropriate information delivery mechanism needs to be developed to take care of it.

Against this backdrop, the present study was conducted with the following objectives: (1) to find out the socio-personal, communication characteristics of the farm women; (2) to study their information seeking and information sharing behaviour; and (3) to determine their agriculture information needs.

METHODOLOGY

(i) Study locale: The study was carried out in Kumaon region of Uttarakhand State. Out of the six districts of the Kumaon region, one district (Pithoragarh) was selected randomly. Out of eight development blocks, two blocks (Gangolihat and Berinag) were selected randomly. For documenting the information needs of farm women, two villages from each of the selected blocks were selected randomly. Members of those households whose main occupation had been agriculture were considered as the respondents for the study.

(ii) Sampling procedure: The respondents (that is, farm women) were selected purposively as the study was focused on farm women. From each village, a list of all the farm women engaged in agriculture was made using census method. And by using probability proportionate to size (PPS) method, 25% of total farm women from each of the selected villages were selected randomly. Thus, a sample of 120 respondents, that is, farm women who actually performed the farming activities were included in the study. The sample is representative of hill farm women of Kumaon division of Uttarakhand state.

(iii) Data collection and analysis: The data were collected (in March - April 2013) with the help of a semi structured interview and analysed using the SPSS. In order to validate the data collected through quantitative technique, some qualitative technique like observation was also used.

RESULTS AND DISCUSSION

Socio-personal characteristics of farm women

Presented below are the demographic attributes of the respondents. The results in Table 1 reveal that majority of the respondents (57.5%) belonged to middle age group followed by old (29.17%) and young (13.33%) age group.

Table 2. Distribution of respondents according to information seeking and information sharing behaviour of farm women (N = 120)*.

S/N	Communication behaviour	Always		Sometimes		Never	
		F	%	F	%	F	%
(a)	**Information seeking behaviour**						
1.	Friends and Relatives	106	88.33	10	8.3	4	3.33
2.	Progressive Farmers	0	0	0	0	120	100
3.	Elderly person	99	82.5	9	6.91	12	10
4.	Extension functionaries	0	0	0	0	120	100
(b)	**Information sharing behaviour**						
1.	Friends and relatives	119	99.16	1	0.83	0	0
2.	Progressive farmers	0	0	0	0	120	100
3.	Neighbours	118	98.33	2	1.66	0	0
4.	Needy person	119	99.16	1	0.83	0	0

F = Frequency.

The findings reveal that all the respondents (100%) were marginal farmers having land holding of less than one hectare and there were no respondents found in small, medium and large category. Dwivedi (2011) reported that majority of farm women in the category of small farmers (less than 2 ha) were 64%, followed by 28% marginal (2 to 10 ha) and 8% large (more than 10 ha).

Further, 35% of the respondents were educated up to primary level followed by Junior (27.5%) whereas 26.67% of the respondents were illiterate, and only 10.83% had education up to High school. Traditionally, the state of Uttarakhand has been rated as a high literacy rate (about 72.28% as per census 2011), and the results of the present study also emphasize that most of the respondents were literate. As regards the type of family, majority of respondents, that is, (71.67%) had nuclear families while only 28.33% respondents belonged to joint families. It is generally believed that people in rural areas/village live in large/ joint families. But the study found that nuclear family was predominant which may be due the reason that the younger generation in the these villages (and elsewhere as well) has migrated to nearby urban areas/cities in search of employment and higher educational opportunities; but the elderly people still preferred to stay in the villages for social, emotional and age factor. These findings are supported by Kumar and Bhardwaj (2005) who reported that nuclear family system was predominant in the villages as 55.36% of the respondents belonged to nuclear family, and the rest (that is, 44.64%) were living in joint families. Regarding family size, majority of the respondents (71.67%) belonged to small family followed by medium family (34%); and no respondent figured in large family due to the fact that most of the families were ‘nuclear type’. As regards media exposure of farm women, only 13% of them had access to Radio whereas 97% had watched television, and all of them (100%) had access to a mobile phone. The findings of the study are in line with that of Papnai (2011) who also reported that a positive change was visible in the hills owing to mobile phones being ranked first in media ownership as well as its use. Television and radio are still considered supreme by many of the respondents because of low cost and easy availability to farmers in rural areas whereas computer has yet not reached in the hill regions.

Further, as regards extension agency contact with farm women, the study found that public sector extension agents did not visit the farm women in villages of hills as all the respondents reported ‘no’ when asked about their level/frequency of contact with formal sources of extension advisory services. However, all the respondents reported to have had contact with informal sources which included fellow farm women, friends and relatives living in the same village/nearby village. Further, there could be several reasons for their unavailability as they rarely visit the villages. Besides, selective approach towards meeting only male farmers may also have contributed to this trend as observed in the study findings. Thus, we can conclude that there is an urgent need to streamline the formal extension mechanism and sensitize it to serve the farm women.

Information seeking and information sharing behaviour of farm women

As we have already noted, timely access to and availability of information plays an important role in technology adoption thereby improving the agriculture productivity. The study sought to find out the information seeking and information sharing behaviour of farm women. The results obtained are given below.

It can be inferred from Table 2 that majority of farm

Table 3. Information needs as expressed by farm women (N = 120)*.

S/N	Areas of information need	Most needed		Needed		Not needed	
		F	%	F	%	F	%
(a)	**Pre-sowing phase**						
1.	Decision about crops to be grown	93	77.50	27	22.50	0	0
2.	Land/area allocation	94	78.33	26	21.67	0	0
3.	Crops Varieties: HYV	120	100.00	0	0	0	0
4.	Land preparation methods	78	65.00	42	35.00	0	0
5.	Farm implements	120	100.00	0	0	0	0
(b)	**Sowing phase**						
1.	Right time of sowing	71	59.16	49	40.83	0	0
2.	Sowing method	66	55.00	54	45.00	0	0
3.	Spacing	67	55.83	53	44.16	0	0
4.	Use of farm implements	120	100.0	0	0	0	0
(c)	**Post-sowing phase**						
1.	Weed control/management	120	100.0	0	0	0	0
2.	Irrigation/water requirement	74	61.66	46	38.33	0	0
3.	Fertilizer requirement & Application	106	88.33	14	11.66	0	0
4.	Disease control/Management	120	100.00	0	0	0	0
(d)	**Harvesting phase**						
1.	Time of Harvesting	82	68.33	38	31.66	0	**0**
2.	Method of Harvesting	85	70.83	35	29.17	0	**0**
(e)	**Post-harvest phase**						
1.	Processing Techniques	86	71.67	34	28.33	0	**0**
2.	Storage	73	60.83	47	39.17	0	**0**

F = Frequency in each cell; HYV refers to high yielding varieties of crops.

women (88.33%) always sought information about farming from friends and relatives; however, elderly persons were 'always' a good source of information for sizable number of farm women (82.5%). The farm women did not contact progressive farmers, local leaders and extension functionaries for any kind of information. Lack of visits by extension functionaries in the village and low exposure to the different social and media organizations might be the reasons behind this tendency of seeking information from cosmopolite sources. Saleh (2011) also observed that information used by rural women was mainly informal. They align more to information received from friends, relatives, husbands, sons and daughters.

Further, as regards informing sharing behaviour of farm women, almost all of them (99.16%) always shared the information with friends and relatives and needy persons followed by neighbours (98.33%). They never shared the information with progressive farmers which could be due to less frequency of interaction with them as male members of their family usually held discussion/consultations with them. Singh and Bishnoi (2009) reported that majority (80%) of the respondents shared their information with family members only, followed by neighbours (70%), friends (68%) and relatives (30%).

Agriculture information needs of farm women

Agriculture information needs of farm women were analyzed and prioritized. The information need was identified by two methods, that is, information collected through semi-structured interview schedule and followed with a focus group discussion in each of the selected village. The types of information needed was organized into five categories so that each aspect of crop cycle was covered adequately. The categories of information needs were: Pre-sowing, sowing, post-sowing, harvesting and post-harvest and marketing. The intensity of information need was determined on three point continuum-Most needed, needed and not needed. The results obtained are given in Table 3.

The respondents as explained above have expressed a variety of information needs related to different areas of agriculture. An attempt was made to rank-order these needs and they were analysed using mean score/weighted mean. The results obtained are given in Table 4.

Table 4 shows that information about three areas, viz. disease control/management and weed control/management and use of farm implements were accorded 'first rank', which means that all the

Table 4. Ranking of information needs related to agriculture.

S/N	Areas	Weighted mean	Rank
1.	1. Weed control/management 2. Disease control/management 3. Use of farm implements	3.00	I
2.	Seed treatment and seed rate	2.92	II
3.	Fertilizer requirement and application	2.88	III
4.	Land/area allocation	2.78	IV
5.	Decision about crops to be grown	2.77	V
6.	Processing	2.71	VI
7.	Method of harvesting	2.70	VII
8.	Time of harvesting	2.68	VIII
9.	Land preparation methods	2.65	IX
10.	Irrigation/water requirement	2.61	X
11.	Storing	2.60	XI
12.	Right time of sowing	2.59	XII
13.	Sowing method and spacing	2.55	XIII

respondents essentially need the information about these areas equally. Further, seed treatment and rate was ranked second followed by fertilizer requirement and application (third rank), land area and allocation (fourth rank), decision about crops to be grown (fifth rank), processing (sixth rank), method of harvesting (seventh rank), time of harvesting (eighth rank), land preparation methods (ninth rank), irrigation/water requirement (tenth rank), storing (eleventh rank), right time of sowing (twelfth rank). Sowing method and spacing occupy the last rank with weighted mean score 2.55. Thus, we can conclude that information most needed by farm women in the study area are information about disease control/management, weed control/management and farm implements/use of farm implements.

Conclusion

On the basis of the study findings, it can be safely concluded that farm women had moderate to high need for information about the areas as specified above. The fact that three areas, viz. disease control/management, weed control/ management, and high yielding variety of crops were given top rank by a large majority of farm women indicate that our extension advisory services should make intensive efforts to educate the farm women. The information seeking and sharing behaviour of the farm women gives an indication to the communication strategy to be followed in information dissemination.

Further, farm women had expressed that they had little knowledge about modern farming practices which can be provided through regular visits of extension functionaries.Specific trainings need to be organized targeting farm women. Besides, proper demonstration in training along with theoretical knowledge, use of proper farm implements, deployment of required field staff and adequate supporting facilities and services, frequent field visits, required marketing information and awareness about governmental schemes should be given top priority in public communication campaigns.

Findings of the study would be useful for the extension personnel for conducting need based and well focused training programmes and generate mass awareness using accessible media to farm women. The study may also serve as a reference point to suggest and implement various development plans and extension strategies to bridge the information gap between the research stations, the farm women, and may lead to upscale the knowledge and skills of farm women leading improved agriculture productivity.

Conflict of Interests

The authors have not declared any conflict of interests.

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Phosphorus and potassium fertilization in culture of soybean plants in the Oxisol

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It is recommended to use phosphorus and potassium fertilization on soybean; however it has been common to verify the absence of effect on crop productivity, especially in no-tillage system. Thus, the study aimed to evaluate the effect of doses of superphosphate and potassium chloride in the leaf tissue nutrient content and yield of soybean growing in Oxisol. The experiment was installed in October 2011 in a randomized block design in split-bands with two factors (4x4), with four replications, totaling 64 plots, being Factor 1 with doses of superphosphate (0, 136, 331 and 700 kg ha^{-1}) at sowing and Factor 2 with doses of potassium chloride (0, 160, 320 and 800 kg ha^{-1}) released with cultivar Vmax RR (SYN 7059RR). In the experiment, the variables evaluated were Ca, Mg, K, P, S, Cu, Zn, Mn and Fe in leaf tissue and grain yield. The fertilization with superphosphate and potassium chloride do not interfere in leaf nutrient content and yield of soybean cultivar Vmax RR (SYN 7059RR) grown on an Oxisol of clayey with levels of P and K classified as high. In these cases, it is advisable to keep only the maintenance fertilization according to the values of P and K exported by grain.

Key words: Chemical fertilizer, tillage systems, organic mineral fertilizer, superphosphate, potassium chloride.

INTRODUCTION

The soybean (*Glycine max* L.) constitutes the most important oilseed grown as protein source in the world (AGRIANUAL, 2009). On the world stage, Brazil is the second largest producer and a major exporter of grains

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Table 1. Chemical and texture attributes of the Oxisol collected in the 0-0.2 m depth layer Guaira – PR, 2011.

pH[1]	C	P[4]	Ca^{2+}[2]	Mg^{2+}[2]	K^{+}[4]	Al^{3+}[2]	H+Al[3]	SB	CTC
	$g\ dm^{-3}$	$mg\ dm^{-3}$	--------------------- $cmol_c\ dm^{-3}$ -----------------------						
5.50	19.09	11.50	8.14	1.58	0.82	0.00	4.28	10.54	14.82
Cu[4]	**Zn[4]**	**Fe[4]**	**Mn[4]**	**S[5]**	**V**	**Clay [6]**	**Silt[6]**	**Sand[6]**	
----------------- $mg\ dm^{-3}$ -----------------					%	------------- $g\ kg^{-1}$ -------------			
11.50	4.40	22.00	254	9.50	71.12	660	200	140	

[1] pH in $CaCl_2$, the ratio 1:2.5, [2] Extractor KCl 1 mol L^{-1}, [3] Extractor calcium acetate 0.5 mol L^{-1} pH 7.0, [4] puller Mehlich-1 , [5] Extractor Ca (H_2PO_4) 2 500 mg L^{-1} P in (HOAc) 2 mol L^{-1}, [6] the hydrometer method (EMBRAPA, 2009).

(USDA, 2013; IBGE, 2013). Among the cultural practices, increased amounts of fertilizer especially potassium and phosphate have been used to achieve increases in productivity (Malavolta, 2006). These elements have a very important role for increasing soybean yield since the phosphorus (P) acts as a constituent of stores high energy compounds such as adenosine triphosphate (ATP) and potassium (K) acts as an activator of enzymes and osmotic regulation (Taiz and Zeiger, 2013).

For the phosphorus, the mobility in the soil is minimal causing accumulation of P over a few years of cultivation through the residual effect or left of the preceding year not used by the plant as well as because due to dry matter accumulation on the surface of soil and organic matter in the topsoil (Novais et al., 2007; Rosolem and Merlin, 2011). According to Galvani et al. (2008) and Olibone and Rosolem (2010), the dynamics of soil P can be modified on systems with no-tillage, in the case of P applied to the soil surface to optimize the operation of machines, detecting elevation of P bound to calcium and organic carbon. Fontana et al. (2008) observed decreased adsorption and precipitation of P in Red Hapludox managed under no-tillage soybean/oats succession. The adoption of management systems that provide an increase in the content of soil organic matter may decrease the adsorption P, the formation of complexes that block adsorption sites on the surface of iron oxides and aluminum (Tirloni et al., 2009). The use of cover crops can cause an increase in no-tillage, the levels of total organic carbon and thereby decreasing the adsorption of phosphate and foster the levels of Prem (Pereira et al., 2010).

On the other hand, potassium fertilization on soybean has been performed at sowing (Bernardi et al., 2009). However, due to the salt effect and high solubility of potassium salts commonly used, this practice has led to often reduce plant growth because salinity near the roots to the point that it has been used to haul the application especially in high doses (EMBRAPA, 2010).

According to Marschner (2012), K is the second mineral nutrient required by plants in terms of quantity but is not incorporated into the soil organic matter with a straw and significant reservoir of K in the short-term tillage system (SPD) (Rosolem et al., 2003).

It is an opportunity to check the response of potassium and phosphorus fertilization as the yield potential of soybeans increases especially in no-till which has gradual recovery of organic matter in addition to improving the physical, chemical and biological soil system detecting whether to perform the correction fertilization to increase soil fertility or its relevant only perform maintenance fertilization.

Thus, the study aimed to evaluate the effect of doses of superphosphate and potassium chloride in the leaf tissue nutrient content and yield of soybean cultivar Vmax RR (SYN 7059RR) grown on an Oxisol.

MATERIALS AND METHODS

This research was performed in Guaira western Paraná with the following coordinates 24° 21'S and 54° 10'W with an altitude of 259 m. The farm uses no tillage for 25 years in succession of crops using soy in summer and wheat /corn in the winter. The soil in the area is classified as Oxisol very clayey (EMBRAPA, 2013) and the particle size characteristics of the soil and the result of the chemical analysis of the property are shown in Table 1.

According to the Climate Division of the State of Paraná, the region is under the influence of the climate Cfa (humid tropical zone) well distributed rainfall during the year and hot summers with maximum average annual temperature of 28.5ºC and average minimum of 16.6°C (Caviglione et al., 2000). The rainfall recorded during the conduct of the experiment between October 2011 and February 2012 was 997 mm (Figure 1).

The experiment was conducted under direct seeding system and the area was previously occupied by wheat crop during the winter. Soybean cultivation was performed 20 days after wheat harvest with sowing in seven October 2011 in six lines with five feet long spaced 0.45 m. The plots were evaluated total area of 13.50 m^2 and floor area of 5.40 m^2 for the soybean crop excluding 0.5 m of edging and a line on each side.

The installation of the experiment was performed in October 2011 in randomized block design on track with two factors (4×4) with four replications totaling 64 experimental plots. Factor 1 corresponds to the phosphorus fertilizer in the form of single superphosphate (SFS: 18% P_2O_5): 0, 136, 331 and 700 kg ha^{-1} of chemical fertilizer applied at sowing. For Factor 2, four doses of potassium chloride (KCl: 60% K_2O) were used 0, 160, 320 and

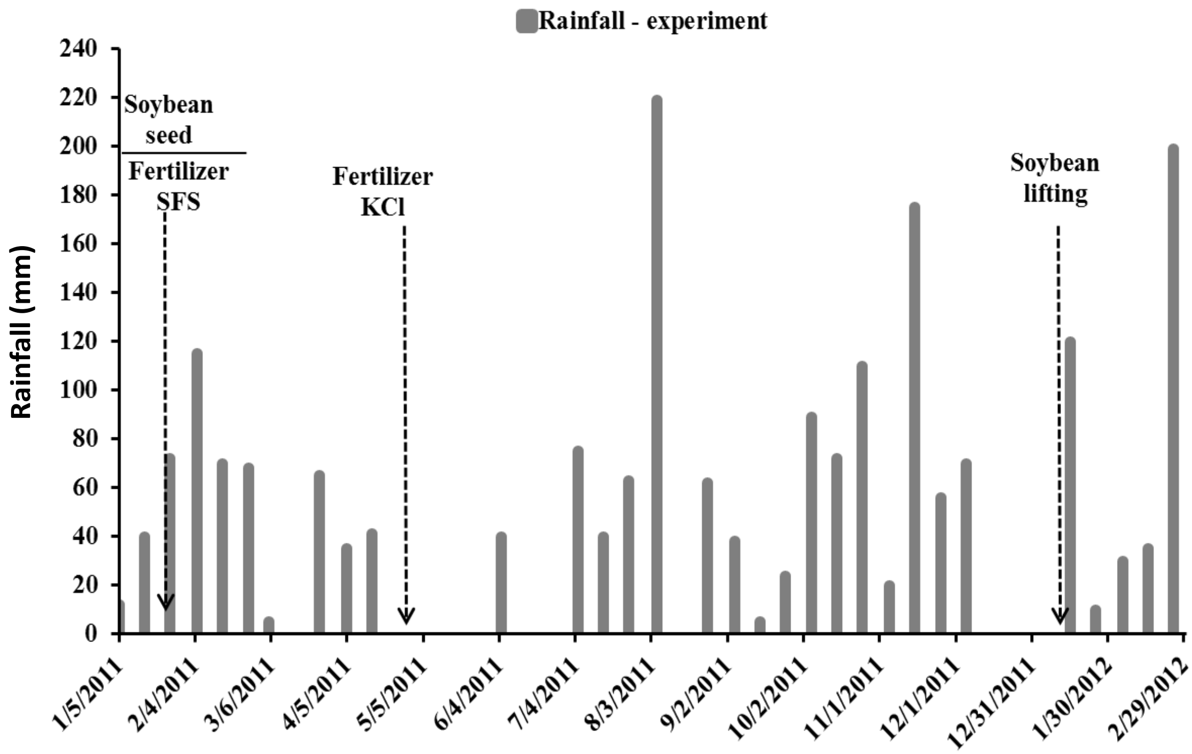

Figure 1. Rainfall (mm) in the experimental area during the conduct of soybean between 10/01/2011 to 03/01/2012.

800 kg ha^{-1} of fertilizer being applied to haul on November 11, 2011 during Stage V4 vegetative soybean crop.

In conducting the experiment carried out in the summer of 2011/12 which made soybean seeding more appropriate for the region transgenic variety Vmax RR (SYN 7059RR) as agroclimatic zoning of Paraná (MAPA, 2011). For seed treatment fungicide Maxim XL (25 g l^{-1} with fludioxonil and 10 g l^{-1} with metalaxyl-M) at a dose of 100 mL per 100 kg of soybean used and the monitoring of pests diseases and weeds was performed according to the recommendations for soybean (EMBRAPA, 2010).

Soybean leaf samples was collected in full bloom as recommended procedures regarding the time and leaves sample according to Malavolta et al. (1997) for the determination of Ca, Mg, K, P, S, Cu, Zn, Mn and Fe (EMBRAPA, 2009) and total nitrogen (Tedesco et al., 1995). At the point of collection, the aerial part of soybean collected on February 15, 2012 was held on the threshing thrashing Winner B-150 to obtain the grain. Grain samples were measured in mass in order to determine productivity with subsequent standardization of the moisture content of the grain samples to 14%.

Statistical analysis of results was performed with the aid of SAEG 8.0 software (SAEG, 1999), data were subjected to analysis of variance, significant doses of SFS and KCl affect analysis were conducted using regression. Models were tested based on the F test significance considering the levels of 5 and 1% probability.

RESULTS AND DISCUSSION

The highest volume of precipitation concentrated in the month of November at the vegetative stage of soybean and in late February after harvest and lower values in the months of December 2011 and January 2012 (Figure 1). At the time of flowering, grain filling decreased soil water due to the occurrence of periods with no rain. The average yield obtained in the experimental area was 2,689.76 kg ha^{-1} closed to the national average (IBGE, 2013), that is the situation of culture in Brazil and assessment opportunity of the effect of fertilizers.

When analyzing the results, the absence of response to application of superphosphate (SFS) and potassium chloride (KCl) both as foliar nutrient concentrations in grain yield was verified (Tables 2 and 3). The levels found in leaves are suitable within the sufficiency range for soybeans for all nutrients (EMBRAPA, 2003) including the control treatment, except magnesium which was observed in the range of low level averaging 2.08 (sufficiency range: 2.60 to 10.00 g kg^{-1}).

Lack of action of fertilization with phosphorus (P) and potassium (K) are probably due to the experimental areas that have soil with high nutrient content (Malavolta, 2006) as shown in Table 1. These results corroborate with other authors as Fontoura et al. (2010) in soybean who found no activity of phosphate fertilizers on yield of annual crops in crop rotation on soil with high P content (8.7 mg dm^{-3}) system.

When analyzing data of Table 3, it was verified interaction with respect to the application of KCl and SFS, comprising the use of a multiple linear equation for foliar Ca content, but there was no significant effect on any of the possible equations to represent the effect doses of SFS and KCl in Ca content of the use of higher doses of

Table 2. F values, coefficient of variation (CV%) and phosphorus (P), potassium (K), sulfur (S), calcium (Ca) and magnesium (Mg) in the leaf tissue of soybean, arising from the application of increasing doses superphosphate (SFS) and potassium chloride (KCl) in soybeans in crop year 2011/2012 Guaira - PR 2012.

Source of variation	P	K	S	Ca	Mg
	---------------------------------- g kg^{-1} ----------------------------				
Factor SFS					
--- kg ha^{-1} P_2O_5 ---					
0	4.87	22.16	3.29	7.47	2.03
136	4.88	20.44	3.31	7.56	2.00
331	4.66	21.52	3.33	7.98	2.16
770	4.95	20.76	3.67	8.26	2.15
Factor KCl					
--- kg ha^{-1} K_2O ---					
0	4.79	21.42	3.49	7.97	2.32
80	4.81	21.39	3.05	8.01	1.97
160	4.85	21.01	3.45	7.75	1.99
320	4.87	21.04	3.58	7.52	2.04
			Mean		
	4.83	21.21	3.39	7.81	2.08
		F Test			
Fator SFS	1.13^{ns}	0.83^{ns}	1.26^{ns}	1.03^{ns}	1.00^{ns}
Fator KCl	0.06^{ns}	0.05^{ns}	0.58^{ns}	0.08^{ns}	1.12^{ns}
SFS x KCl	0.52^{ns}	0.91^{ns}	0.52^{ns}	2.78*	1.66^{ns}
$C.V._{SFS}$ (%)	11.54	14.93	20.32	19.02	17.78
$C.V._{KCl}$ (%)	19.69	17.98	29.86	32.00	32.16
$C.V._{SFS\ x\ KCl}$ (%)	14.01	11.02	22.64	17.04	27.44

* And **: significant at 5% and 1%, respectively, by F test ns not significant at the 5% level by F test.

SFS provided greater amount of Ca in the leaf tissue of soybean, probably by the roots have absorbed Ca soluble fertilizer (Ferdandes, 2006).

However, with increasing doses of KCl and tended to reduce the levels of Ca, a fact that can be directly related to competition for absorption of cations by roots of soybean (Novais et al., 2007). At elevated K occur in the soil, derived KCl, may have been competition between K and Ca cations to be absorbed, so that the increasing levels of KCl does not reflect in a significant increase in Ca content (Table 2).

The magnesium content may have the same explanation given to calcium since these nutrients have similarities to the soil behavior and potassium suffers from competition with the soil (Novais et al., 2007) (Table 1). The Mg content contained in soybean leaves in the control was approximately 15% higher than those who received doses of potassium (Table 2). This result corroborates with the findings from Scherer (1998) who observed an increase of the Mg content in soybean leaves with the decrease in K availability in the soil.

In several recent works, no effect has been observed with the use of phosphate and potassium fertilization on soybean in areas with tillage (Sfredo, 2008; Guareschi et al., 2008; Pauletti et al., 2010; Vieira et al., 2013). For example, in the State of Paraná, Sfredo (2008) states that for the system of succession soybean / wheat-oats-barley-corn double-cropping system was suppressed with P and K fertilization for soybean in SPD in soil with phosphorus above 18.0, 14 and 9 mg dm^{-3} in soils with less than 20% clay, 20% to 40% and more than 40%, respectively, and potassium when content was above 0.30 $cmol_c$ dm^{-3}. Vieira et al. (2013) that analyzed 15 experiments, also concluded that if the content of P in the soil is equal to or greater than 6 mg dm^{-3} and K less than 0.30 $cmol_c$ dm^{-3}, it was possible to establish relative income above 90% for the soybean crop in Oxisol with over 15 years of tillage.

Likewise, Guareschi et al. (2008) observed that the yield of soybean under Dystroferric Red Latosol was also similar in the presence or absence of fertilization with P and K. In Oxisol cultivated with soybean for seven years (Pauletti et al., 2010), the productivity of the soybean crop was not affected by phosphorus and potassium fertilization in situations in which the content of P and K were considered high and medium in ground,

Table 3. F values, coefficient of variation (CV%) and-copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe) in leaf tissue of soybean and grain yield, arising from the application of increasing doses of superphosphate (SFS) and potassium chloride (KCl) in soybeans in crop year 2011/2012 Guaira - PR 2012.

Fonte de Variação	Cu	Zn	Mn	Fe	Yield
	-------------------- mg kg^{-1} --------------------				--- kg ha^{-1} ---
Factor SFS					
--- kg ha^{-1} P_2O_5 ---					
0	16.47	44.69	74.31	160.13	2,712.03
136	15.77	42.83	74.71	161.03	2,485.18
331	15.71	37.66	74.23	177.12	2,811.11
770	14.73	41.08	63.11	158.13	2,711.11
Factor KCl					
--- kg ha^{-1} K_2O ---					
0	14.93	36.25	66.66	154.22	2,808.64
80	14.89	47.17	77.16	162.79	2,519.38
160	16.30	39.58	69.98	163.96	2,649.38
320	16.56	43.27	72.56	175.45	2,741.97
			Mean		
	15.67	43.27	72.56	164.45	2,689.76
			F test		
Fator SFS	1.48^{ns}	0.96^{ns}	3.12^{ns}	0.67^{ns}	1.46^{ns}
Fator KCl	0.87^{ns}	0.79^{ns}	1.05^{ns}	0.36^{ns}	1.99^{ns}
SFS x KCl	1.17^{ns}	0.71^{ns}	1.53^{ns}	1.78^{ns}	0.39^{ns}
C.V.$_{SFS}$ (%)	16.69	29.34	17.89	26.11	17.02
C.V.$_{KCl}$ (%)	25.81	51.07	24.14	35.44	13.26
C.V.$_{SFS\ x\ KCl}$ (%)	20.77	34.07	35.14	29.33	13.86

* and **: significant at 5% and 1%, respectively, by F test ns not significant at the 5% level by F test.

respectively. These results demonstrate the importance of the role of organic matter cycling and accumulation of nutrients in surface-tillage system, and make them available in the organic plant uptake forms (Rosolem and Merlin, 2011), providing sustainability in soybean. This situation demonstrates lack of response of fertilization in soils with high fertility allowing omission of maintenance fertilization during cultivation, reaching situations that allow seven years of cultivation in the absence of fertilization (Pauletti et al., 2010). However, it should be noted that the nutrients extracted by crops are not fully supplied by the existing cycling in sustainable farming systems such as no-tillage, with fertilization being essentially maintained.

The neutrality of the content of most nutrients in leaf tissue and soybean yield before the doses of P and K (Tables 2 and 3) also show that the demand of nutrients required by the cultivar used which was supplied is extremely important as it can be diagnosed with cultivar, had nutritional condition to express their potential especially at conditions in which the work was grown. Recently, Alcantara-Neto et al. (2010) detected quadratic response of grain yield to P levels in Oxisol cultivated for only two years with annual culture in area of degraded pasture with maximum yield at a dose of 94.8 kg ha^{-1} of P_2O_5.

It is noteworthy still, that the absence of interference in productivity with the use of phosphorus and potassium fertilization is also related to the ability of the roots of soybean plants act in depth, a fact that provides culture, explore the soil volume in which lets meet demand nutritional (Castro and Kluge, 1999), even with high horizontal variability for chemical P and K existing in agricultural soils due to fertilization in the seed (Schlindwein and Anghinoni, 2000) online, especially in cultivated soils in tillage (Rosolem et al., 2003; Olibone and Rosolem, 2010).

In general, crops in areas with incorporated fertility and tillage performed with crop rotation, fertilization maintenance shall be the focus in fertilization correction. Excessive use of fertilizers on the basis of P and K may reduce the absorption of other nutrients as observed in this study with Ca and Mg. However, in the case of the state of Paraná, there are few sources of reference to guide practitioners as to maintain doses that should be applied based on soil nutrient uptake by soybean.

Conclusions

The fertilization with superphosphate and potassium chloride do not interfere in leaf nutrient content and yield of soybean cultivar Vmax RR (SYN 7059RR) grown on an Oxisol of clayey with levels of P and K classified as high. In these cases, it is advisable to keep only the maintenance fertilization according to the values of P and K exported by grain.

Conflict of Interests

The authors have not declared any conflict of interests.

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Evaluation of the biodiversity and stabilization of the soil after the fixating of the dunes by *Retama retam* Webb., *Tamarix gallica* L. and *Tamarix aphylla* (L.) Karst in the dunes cordon of El-Mesrane (W. Djelfa) in Algeria

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Our study of the biodiversity of the vegetation and the stability of the soil surface at the levels of the dunes fixed by *Retama retam* Webb., *Tamarix gallica* L., *Tamarix aphylla* (L.) Karst and the natural fixation in the two experimental projects of the dunes fixation in Zahrez Gharbi of El-Mesrane region (W. Djelfa) shows that the dunes fixed by *T. gallica* and *T. aphylla* represent an important diversity with 57 species, 36 species in the dunes fixed by *R. retam* Webb. and *T. aphylla* (L.) Karst and a significant diversity of 24 species at the levels of the dunes naturally fixed. The Shannon weaver –index (H') registered on the vegetation of the dunes fixed by *T. gallica* L. and *T. aphylla* (L.). Karst is of H ' = 3.12; it is 2.61 at the levels of dunes fixed by *R. retam* Webb. and *T. aphylla* (L.). Karst, It achieved a 2.18 on the vegetation of the natural regeneration of *R. retam* Webb and sandy plants. On the qualitative plan, the distribution of the biologic types is marked by the dominance of the therophytes of the flora. The multidimensional treatment demonstrated that the moisture, the fertility and the soil stability are the ecological factors responsible for the composition and the repartition of the vegetation in the several studied dunes which demonstrates that there is noticeable dunes stability through the mechanical and biological treatment realized on these dunes.

Key words: Zahrez Gharbi, desertification, El-Mesrane, fixation, dunes, cordon.

INTRODUCTION

The dune cordon of Djelfa –Boussaâda is considered as a major topographical element at the level of the Zahrez basin (Gharbi and chergui W Djelfa) and constitutes a permanent menace for the surrounding ecosystems. Under the wind dynamic, the free sands colonize the neighboring zones (farm land, tracks and infrastructures) considered as the most visible phenomenon of desertification, the dunes mobility cause significant economical and social repercussions.

The different fixation works on dunes led by the National Institute of the Forest Researches (NIFR) since 1982, in the two experimental projects on the dune

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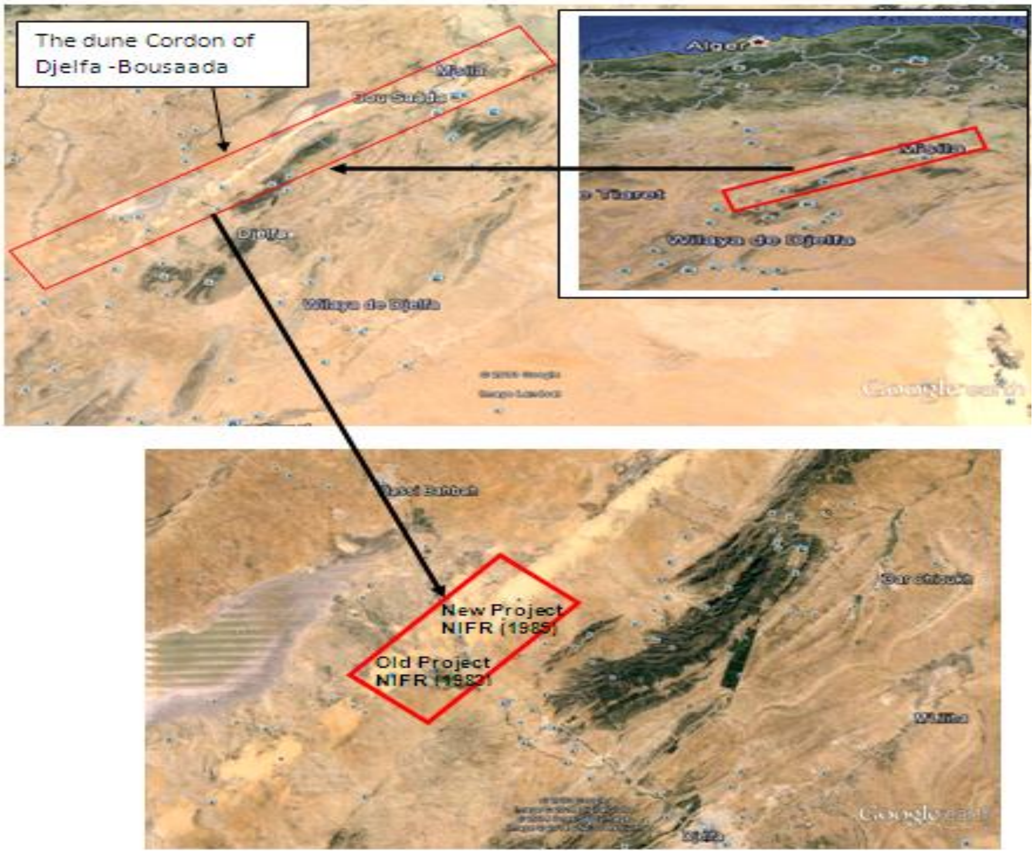

Figure 1. Location of the fixation projects experimental of the dunes on the dune cordon of Djelfa Bousaada.

cordon of Zahrez Gharbi at the area called El-Mesrane (W. Djelfa) consist in testing the different mechanical and biological dunes fixation technically and in comparing their resistance to the environment conditions, as well as their efficiency to reach a stabilization model that is secure and economical. However, consequently to these dunes fixation studies, the current necessity is to establish a qualitative and quantitative evaluation of the different experienced operations. Many studies to have been achieved in the dune cordon of El Mesrane (W. Djelfa) in order to know and inquire of the reaction and efficiency of the different alive and inert materials, introduced at an experimental level on the lively dunes. We cite as an example, the Makhlouf works 1992 on the sedimentologic studies of the sands of the dunes cordon in the Zahrez Gharbi basin (Djelfa) Chouial et al. (2000) which have proved the Algerian experience in the area of mechanical and biological fixation of the windmill formations such as the case of the experimental project of Elmesrane.

The objective of our current research is to achieve a quantitative and qualitative (phytoecologic) of the vegetation and an evaluation of the stabilization of the soil's surface of the dunes fixed by *Retama retam* Webb., *Tamarix gallica* L. and *T. aphylla* (L.) Karst in the experimented spots at the level of the dune cordon of Elmesrane.

Description of the studied area

Geographic situation

The studied area is situated in the dune cordon level according to Pouget (1980); this area is part of the Zahrez Gharbi basin in the high south plain of Algeria. Our studied area called El-Mesrane at 35 km of the north of Djelfa Town; it represents a middle altitude of 860 m which its geographic coordinates are: Longitude: 3° 00 and 3°03 E and Latitude: 34°34' and 34° 36 N.

The specific studied area includes the different fixed dunes in 1983 by the NIFR in the fixation experimental projects of the dunes (Figure 1).

Geology and geomorphology

The dune cordon is a recent geological formation which

Figure 2. Micro-dune fixed by *Aristida pungens* Photo taken by Guerrache, March 2013.

Figure 3. Nebkas formed by *Saccocalyx satureioides* Photo taken by Guerrache, March 2013).

appears at the end of the tertiary and the beginning of the quaternary, coming from the soft rocks (marlstone and red clay) which have been extracted by the erosion of the mountain as well as the presence of salt Limestone Gypsum and soluble salts) that have many effects on the composition of waters either underground or superficial ones (Figures 2 and 3).

Pedology

According to Pouget (1980), the color of the sands varies from the red (5 YR 5/6-6/6) to the white (IO YR 8/1) while passing through the yellow (7, 5 YR 6/6 à 6/4). As for most windmill formation of this kind, the granulometric fractions inferior to 50 µ (clays and thin Silt) are practically absent (Figure 4a, b, c, d).

Vegetation

The dune cordon is characterized by sandy vegetation and phreatophyte (Figure 5a, b) (*Tamarix sp, Imperata cylindrica, Phragmites communis*). We can distinguish several groups: To the north: the principal Nebkas are colonized by the following groups: *Tamarix* and *salicornes, sparte* (*Lygeum spartum*, *Artemisia campestris*, Drinn *(Aristida pungens)*, *Saccocalyx satureioides*. Between the Zahrez; the crassulescentes steppes to *salicornia arabica* and *Suaeda mollis* are dominant to the south –west of the dune cordon on the alluvial soils: Steppes at white Artemisia (*Artemisia herba alba*), sparte (*L. spartum*), *A. campestris*, as well as cereal cultures between these different formations. The species used for the biological fixation at the level of El-Mesrane dunes are: *Atriplex halimus*, *Atriplex canescens, Atriplex nummularia, Acacia cyanophylla, Acacia cyclops, Elaeagnus angustifolia*, *Gleditsia triacanthos L.*, *Lycium arabicum*, *Medicago arborea, Opuntia ficus indica*, *Pistacia atlantica Desf*, *Prosopis juliflora*, *R. retam*, *T. aphylla*, *T. gallica.*

Bioclimate

Our studied area presents an accentuated arid tendency of a semi arid inferior type with a fresh winter characterized by a long dried season going of May to October undergoes the geographic situation between the influence of the south and those of the Mediterranean to the north (Kaabeche, 1997). The climate is rigorous, extreme and uncertain with an annual rainfall range feeble and irregular; it is evaluated at 326.91 mm/year. And the average temperature records the maximum in July 26.83°C and the minimum in January 4.76°C. Moreover, the winds are always violent consequently the vegetation cannot install without an adequate protection system.

METHODOLOGY

The sampling

We achieved two studies, quantitative and qualitative (phytoecological) the sampling took place during the 2008, 2009 and 2012 spring period, a period in which all the spring species are represented.

Quantitative inventory (linear Statement)

The linear statement is considered as an efficient means to study the evolution of the vegetation cover when it involves a permanent

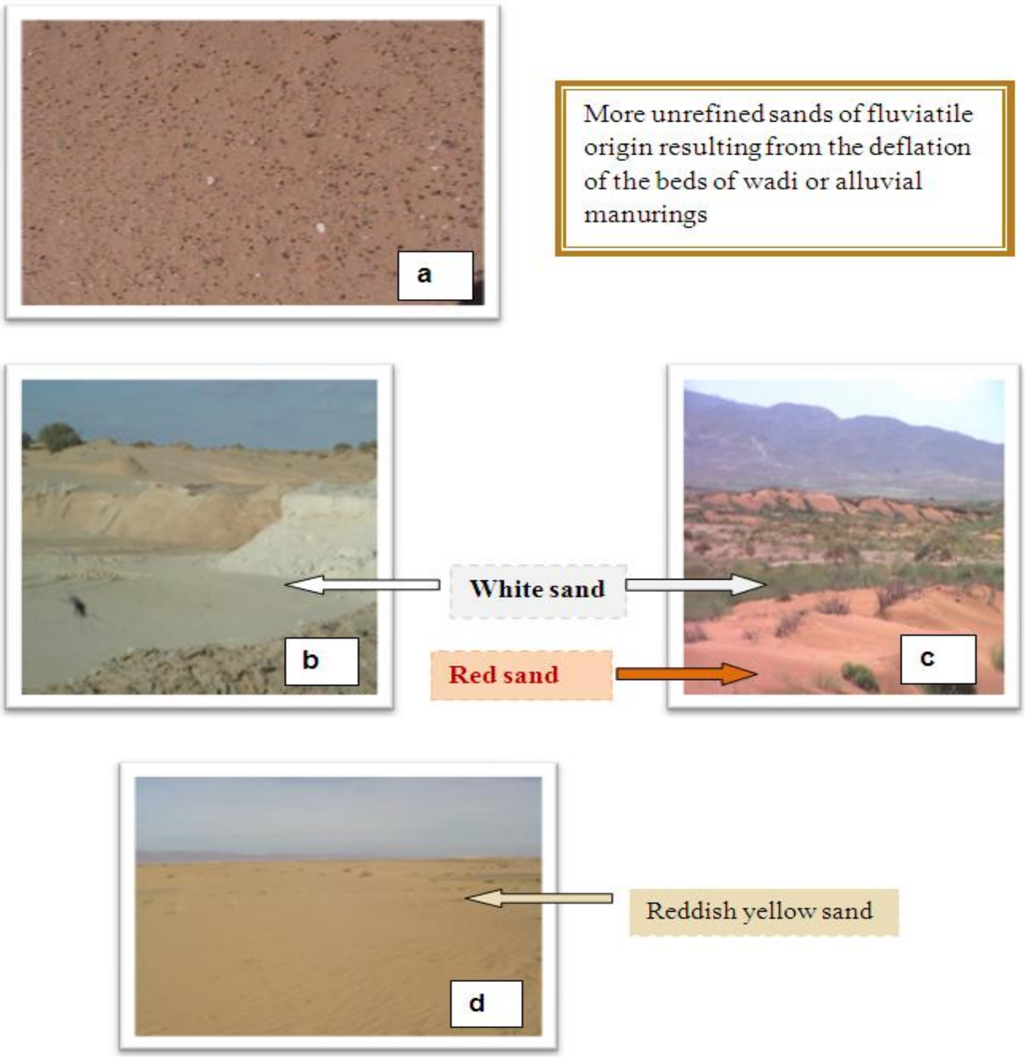

Figure 4 (a, b, c, d). Texture and color of the sand of the wind formations Photo taken by Guerrache, March 2013).

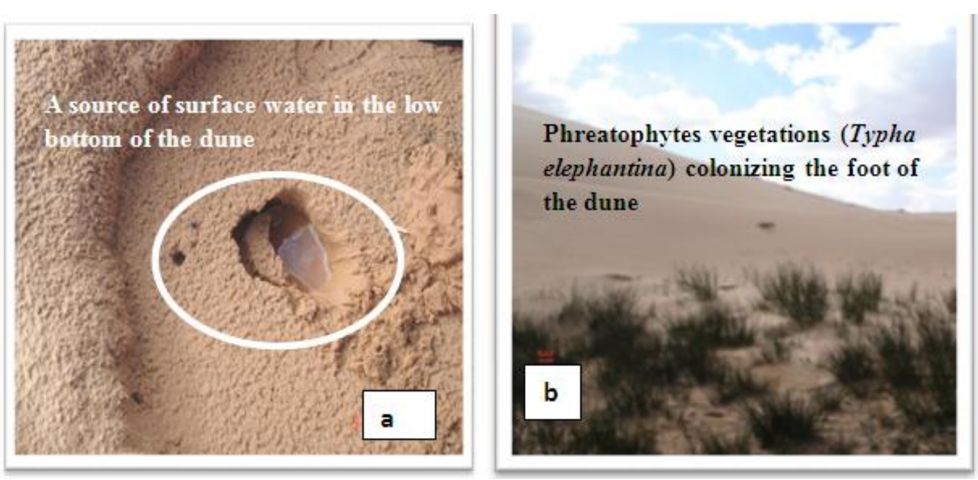

Figure 5 (a, b). Photos showing the importance of groundwater of the dune cordon of Zahrez Photo taken by Guerrache, March 2013).

line Gounot (1969), Aidoud (1983), a reading can be done every 10 cm long and 10 m line and materialized by a graduated ribbon extended above the vegetation. This linear method permits to provide specific data related to the vegetation and the characteristics of the surface that allow evaluating:

(a) The global recovery of the vegetation (GR): Expressed in percentage is calculated as follow:

$$GR\ \% = 100 \times \frac{Nv}{N} = 100 \times \frac{N - Nwv}{N}$$

Nv = number of points of vegetation; N = Number of points of reading (100 points); Nwv = number of points without vegetation.
(b) The specific frequency (SF) of a species: Allows to appreciate the place of the species "i" in the occupation of the total space of the vegetation:

$$SFi = ni / N$$

ni = number of the species "i"; N = the sampled surface.
(c) The specific contribution (SC): Allows to estimate the contribution of the species "i" in the whole of the studied species:

$$Csi = SFi / \sum SFi$$

The specific frequency (SF) of the species "i".

Qualitative inventory (phytoecological)

On the different picked dunes, we have delimited the area by 32 m^2. It is the most adequate surface for the study of those dunes ecosystems dominated by the therophytes. 86 statements were achieved and every statement contains floristic and ecological data. The floristic data are represented through a list on which are mentioned all the identified species in the sampling area. Every species has abundance –dominances coefficient according to Braun-Blanquet scale 1959 and vegetal formation type characterized according to Ionesco and Sauvage (1962).

Analysis and data processing

Analysis statistic

According to the number of data, 86 statements and 68 species were used to estimate multivariate analysis; factorial analysis of correspondence (FAC) and the ascendant hierarchic classification (AHC) whereas for the treatment of the floristic data, the software was utilized of version 5 statistica.

Qualitative and quantitative evaluation of the biodiversity

Biological diversity consequently made it possible for us to study the biological comeback after the dune stability. The taxons composing the different groups of the individualized vegetation were characterized by:

a) Their taxonomic diversity: This was realized from the flora of Algeria Quezel and Santa (1962-1963), the flora of Sahara (Ozenda, 1977), the flora and the vegetation of Sahara (Ozenda, 1991).
b) Biologically raw and real: The biological types listed in the database Raunkiaer (1934) Amended by Ellenberg and Muller-Dombois (1967) were used.
c) The specific diversity, index of Shannon H': This was calculated from the (SC) generally measured by means of lines:
$H' = - \Sigma (ni / N) \times \log_2 (ni / N)$
Ni: Number of individuals of a species, i going of 1 in S (total number of species).
N: Total number of individuals.
This index values was between 0 and 5 bits per individuals (Frontier, 1983).
d) Equitability (E): Represents the report between the specific diversity of theoretical maximal Shannon and the logarithm of specific wealth of the sample (Frontier, 1983):
$E = H' / H'_{max}$ avec $H'_{max} = \log_2 S$,
S: Specific wealth.
(d) The frequencies rows diagrams: Frontier and Pichod-Viale (1998) presented a detailed overview of the diversity because their speeds vary according to the specific diversity.

RESULTS AND DISCUSSION

Identification of the vegetal groups and their floristic and ecological characteristics

The examination of the projection of the points statements of the AFC statements-species (Figures 6, 7 and 8) allowed us to identify the lots of the similar statements, this means the principal vegetal groups. The dendrogram analysis obtained permitted the division of the whole statements into two principal classes (Figure 6):

Class A: It includes the achieved statements in the dunes already fixed by *R. retam* Webb., *T. gallica* L., *T. aphylla* (L.) Karst. This class is subdivided into two groups:

Group 1: It is formed by the achieved statements already fixed essentially by *T. gallica* L., *T. aphylla* (L.) Karst.

Group 2: It is formed by the achieved statements already fixed by *R. retam* Webb. and *T. aphylla* (L.) Karst that is localized in the depression.

Class B: Represented by one unique Group (3) formed by the achieved statements in the dunes recently fixed with the natural regeneration of *R. retam* Webb. and sandy plants.

Ecological signification of the factorial axes

Factorial maps of the statements-species

The factorial plans (1-2) Figures 7 and 8 illustrate three distinct and well individualized groups:

Group 1: It is characterized by the statements of the dunes fixed by *T. gallica* L., *T. aphylla* (L.) Karst with a dominant exposition (North) at different toposequences with a middle recovering of the vegetation of 35%. This group represents vegetal species relatively demanding

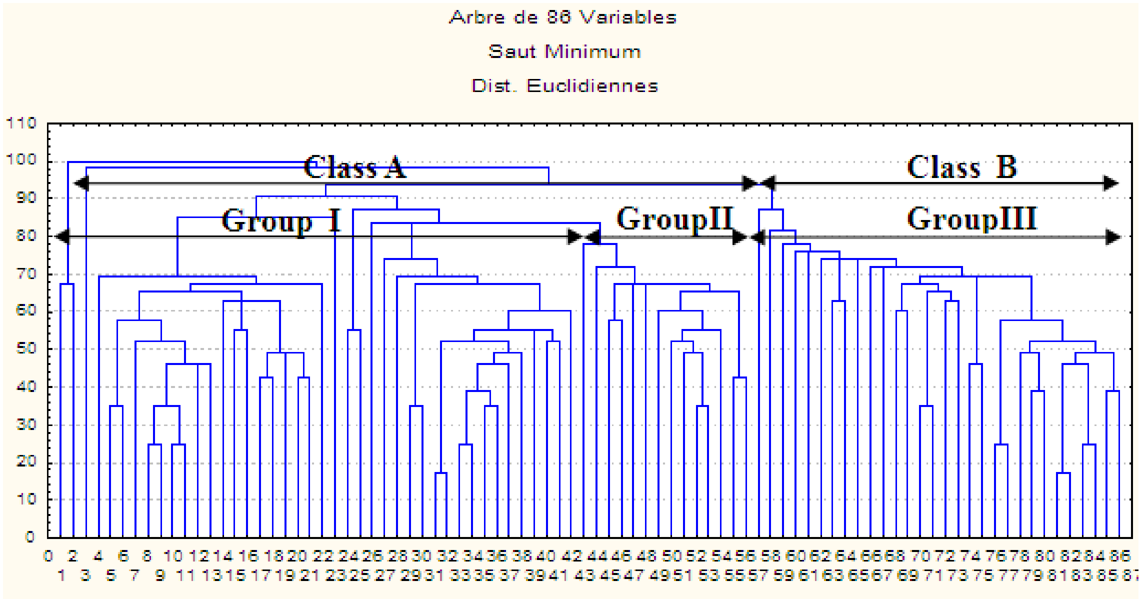

Figure 6. Ascending hierarchical classification of 86 statements.

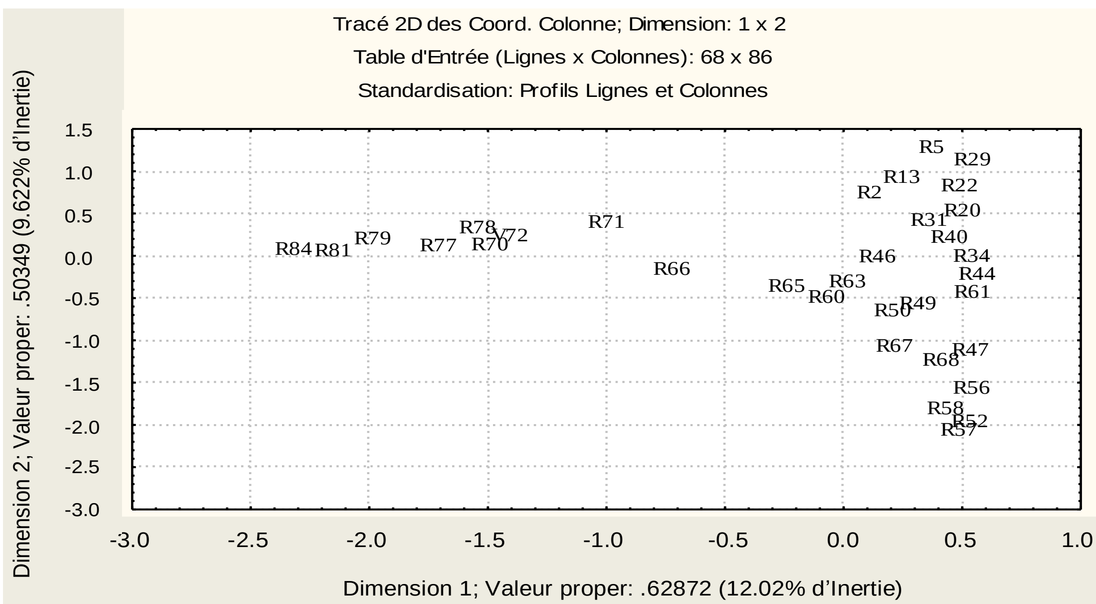

Figure 7. Factorial statements of the distribution along the axes 1 and 2.

such as a species of the families of the compounds and grasses for example *Paronychia argentea*, *Rumex bucephalophorus* L. colonize the dry sandy areas, *Atractylis carduus*, *Ifloga spicata* (Sandy), *Bassia muricata*, *Hordeum murinum*, *Galactites tomentosa*, *Lolium rigidum*, *Herniaria fontanesii*, *T. gallica*, *Schismus barbatus*, *Bromus sterilis*, those species colonize the dunes already fixed in time. According to Ozenda (1982) *L. rigidum, B. sterilis*, *H. murinum, S. barbatus* G. *tomentosa*, *B. muricata, T. gallica* and *T. aphylla* characterized well the sandy area.

Group 2: Includes the dunes statements fixed by *R. retam* Webb. and *T. aphylla* (L.) Karst with a south dominant exposure where all the toposequences are presented except for the statement of *T. aphylla* (L.) Karst which is just in the depression that has a middle recovering of vegetation of 55%. This group is marked by

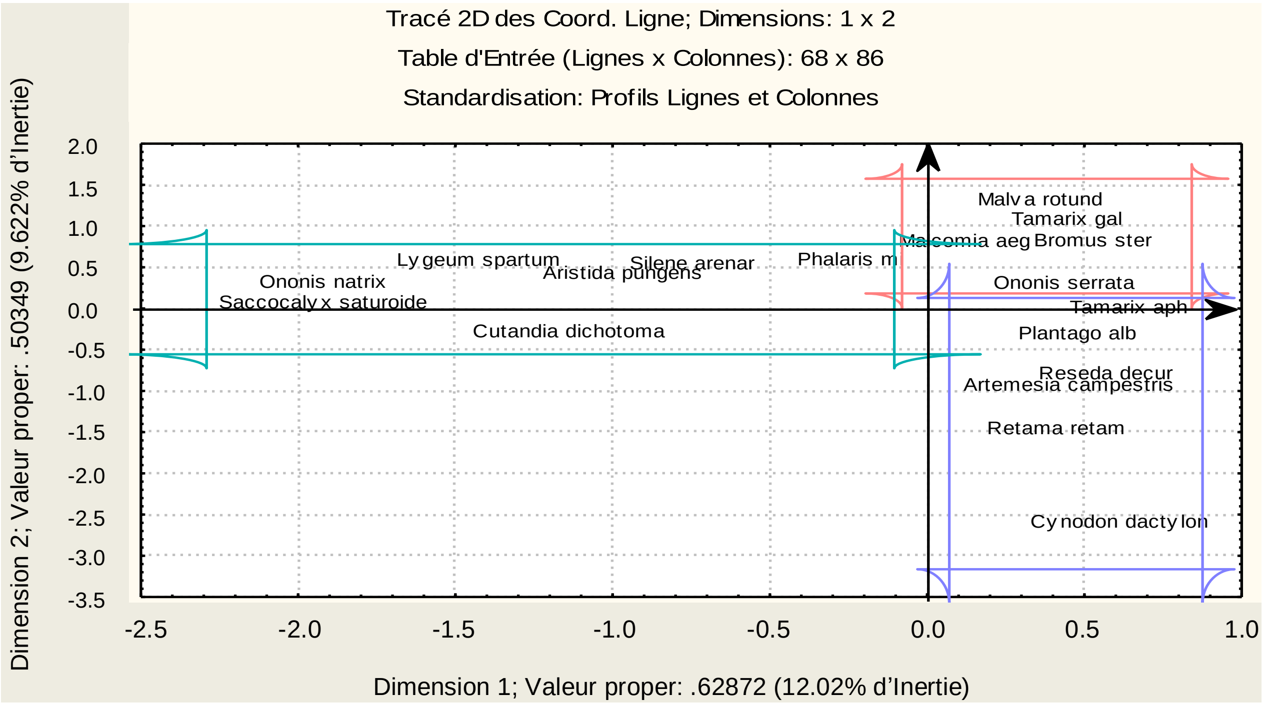

Figure 8. Factorial species of the distribution along axes 1 and 2.

the presence of the following species *R. retam*, *Plantago albicans Artemesia campestris, M. aegyptiaca* and *Launaea resedifolia*. *Eruca vesicaria, Scabiosa arenaria, T. aphylla, Reseda decursiva, P. albicans, R. retam.*

According to Ozenda (1982) *P. albicans* is a frequent species in the consolidated sandy area, but Pouget (1980) characterizes it as a species consisting of a simple sandy veil at a surface of an underlying soil of any nature but Djebaili (1984) evokes this species in the alliance of *A. herba alba* and *P. albicans* colonizing the non salty depression and the soils are generally muddy. According to killian (1948), *T. aphylla* developed in the bed of the wadi where the layer of sand keeps humidity in the depth.

Group 3: Includes the statements of the dune recently fixed by the natural regeneration of *R. retam* and those which are not fixed yet and submitting the influence of the fixation with a south dominate exposure according to the different toposequences with a very weak recovering of the vegetation. There is a noticeable abundance of vegetal species well adapted to these areas: sandy species such as *A. pungens*, *Euphorbia guyoniana, S. satureioides Ononis natrix*, *Pseuderucaria teretifolia* Pouget (1979), Ozenda (1982). *A. pungens, Cutandia dichotoma, Pseuderucarea teritifolea*, *Cynodo dactylon and Euphorbia* colonize the dunes recently or not yet fixed.

According to Maire (1926), the sandy grounds of the highlands of the Sahara are occupied by the association to Drinn (*A. pungens*) in addition to these plants, we can find some nano-phanerophytes as *R. retam*, *Saccocalyx satureoides*, *E. guyoniana*, *Thymelaea micrphylla*, *A. campestris* and some are *Hemicryptophytes* such as *Launea reseifolia, Onopordon arenarium* and *M. aegyptiaca.*

The ecological significance of factorial axes will consequently be like this:

i. Axis 1 illustrates the evolution of the stability of the dune field: A fixed sandy soil, consolidated and frequented by relatively demanding species (positive part of Axis 1) is opposed to soil not yet stabilized, more or less mobile and colonized by sandy plants (negative part of Axis 1).
ii. Axis 2 denotes the dampness of the sandy soil and the fertility of the field in north exposure where we have the presence of species relatively water demanding such as *B. sterilis*, *L. rigidum, T. gallica* and *T. aphylla* (positive part of Axis 2) instead of other species enough resistant to the drought, well adapted to the arid conditions of those types of biotope and frequenting the south exposure such as *Retam retam and A. campestris.*

Evaluation of the biodiversity

Systematic diversity

At the level of the dunes fixed by *T. gallica* (L.) and *T.*

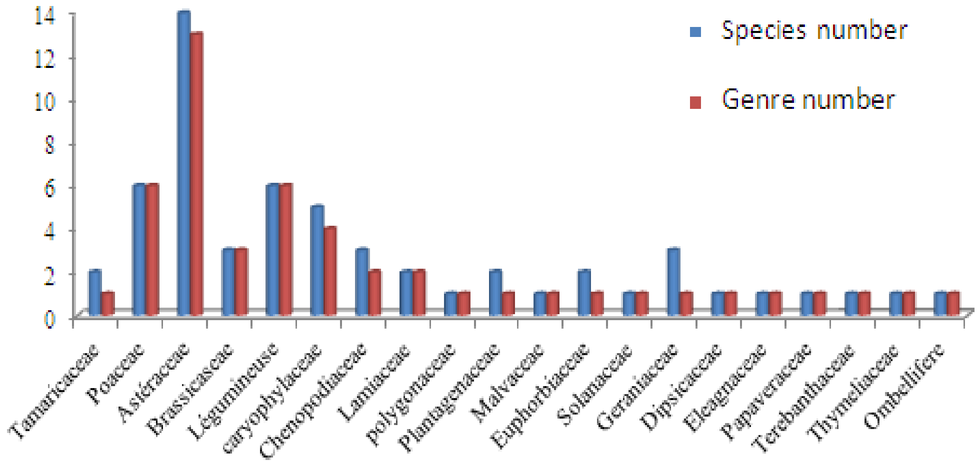

Figure 9. The diversity taxonomic of the group1 (Number of family and genre).

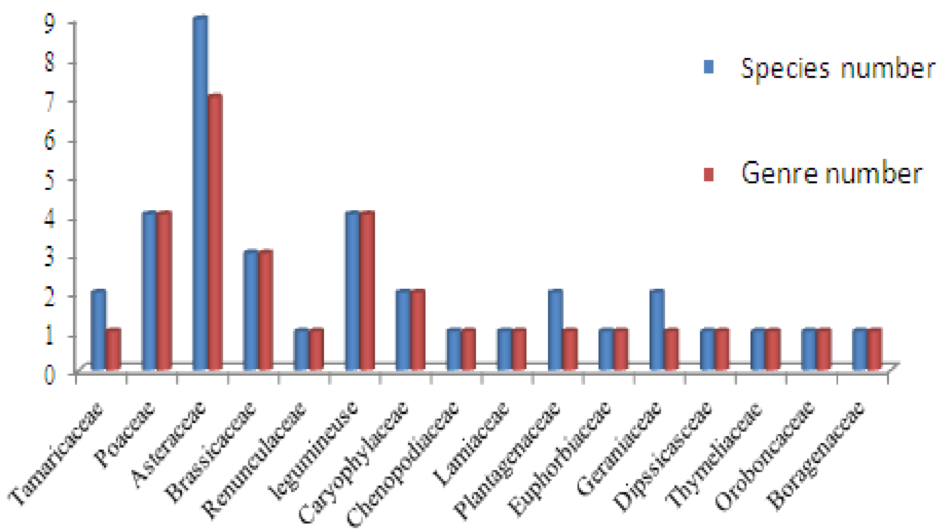

Figure 10. The diversity taxonomic of the group 2 (Number of family and genre).

aphylla (L.) Karst (Group 1*),* we counted 20 families, 49 genres and 57 species. Figure 9 shows the best families represented on the specific and generic plan which are the asteraceae (13 genres and 14 species) followed by the fabaceae (leguminous) and the poaceae (6 genres and 6 species), a feeble participation of the brassicaceae, chenopodiaceae and geraniacea (3 genres for each and 3, 2 and 1 species, respectively).

The tamaricaceae, lamiaceae, plantagenaceae and euphorbiacea are represented just by 2 species in which majority is monogenetic, exceptionally for the lamiaceae, the other families are monogeneric and monospecific.

In Group 2, the analysis of the floristic composition of the fixed dunes by *Retam retam* Webb *and T. aphylla* (L.) Karst permitted the identification of 16 families, 30 genres and 36 species. The dominant families are the asteraceae (4 genres and 9 species), the fabaceae and the poaceae (4 genres, 4 species) then the brassicaseae (3 species and a monogeneric) followed by the tamaricaceae, caryophylaceae, plantagenaceae and geraniaceae present 2 species and only one genre, 9 families are monogeneric (Figure 10) group of natural fixation and the dune submitting the influence.

In Group 3, we counted just 9 families divided into 23 genres and 24 species. The best represented families on the generic and specific plan are always the asteraceae (8 genres and 8 species) followed by the fabaceae (3 genres, 3 species) then, the poaceae and the cayophylaceae (3 genres and 3 species), next, the plantagenaceae (2 genres and a monospecific). This

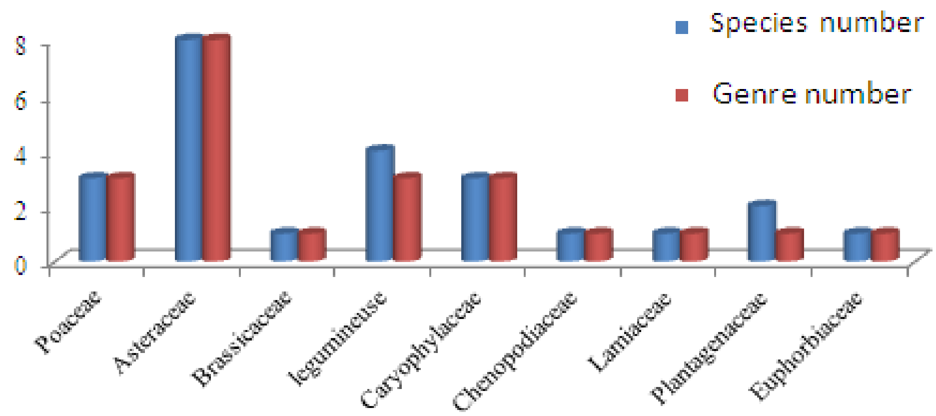

Figure 11. The diversity taxonomic of the group 3 (Number of family and genre).

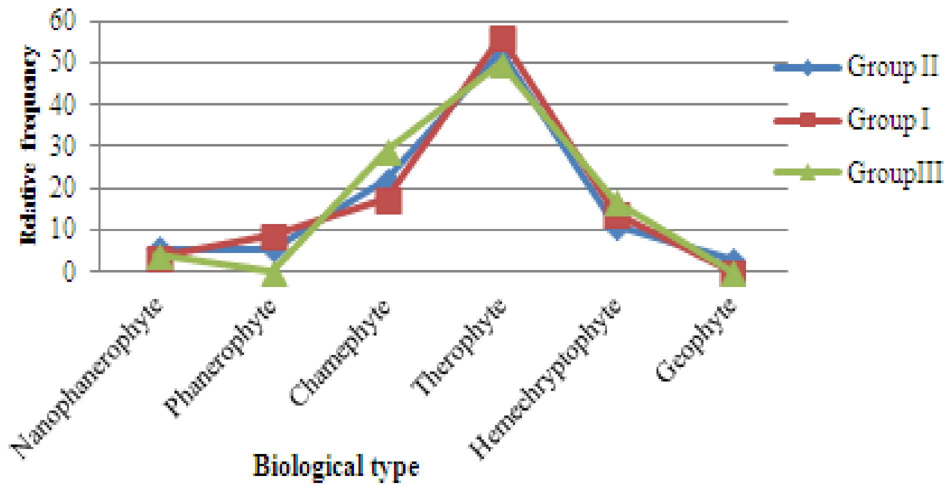

Figure 12. Raw biological spectrum of three groups.

group is also characterized by the presence of 4 monogeneric and monospecific families (Figure 11).

The flora analysis of three vegetal groups defined in the dunes cordon (Figures 5, 6 and 7) shows that these group have richness in families, genre and varied species, the group of the dunes fixed by *T. gallica and T. aphylla* (*L.*) Karst is the richest whereas Group 3 of the naturally fixed dunes and submitting the fixation influence is the poorest. The best represented families on the generic and specific plan in the three groups are: the Asteraceae, the fabaceae and the poaceae.

Biological type

Raw spectrum

The analysis of the distribution of the biological types (Figure 12) reveals the neat dominance of the therophytes 56.14% in Group 1, 52.77% and 50%. In Groups 2 and 3, respectively followed by the chameaphytes that is important in Group 3 with 29.16%, 22.22% in Group 1 and 17, 54% in Group 2 then the hemicryptophytes that represents as well as relatively significant rate of 16.66, 14.03 and 11.11% in Groups 3, 2 and 1, respectively.

Whereas for phanerophytes that occupy the fourth positions of 8.66% in the dunes fixed by *T. gallica* and *T. aphylla* (L.) Karst (Group 1). Followed by the nanophanerophytes with 3.50% and share the position with the nanophanerophytes 5.55% for each one in the dunes fixed by *T. aphylla* (L.) Karst *and Retam retam* Webb. (Group 2) followed by the geophytes that come in the last position with a very feeble presence 2.77% with an exception of the dunes fixed by the natural regeneration and the dunes submitting the fixation influence where this spot is owned by the nanophanerophytes.

The percentage of the phanerophytes, nanophanerophytes, hemicryptophytes and geophytes decreases with xeric and openness of the environment whereas the percentage of the therophytes and the chameaphytes increases.

The numerical abundance of the therophytes indicates the openness of the vegetal rug many authors present the therophytisation as a form of resistance to the climate rigors (Negre, 1966; Barbero, 1990). We notice that the more the conditions of the environment are rigors, the more the therophytes increase whereas the phanerophytes decrease and that is what we observed during the period in which the studied area received an average rain quantity very feeble during the quarters of the first months of the year 2008. This rainfall has privileged the development of the therophytes. Consequently, we remark the deflation of the soil and silting at some spots, this silting on the self mulching permits the development of the therophytes.

Therefore in a particular mesoclimate, the rate therophytes is linked to the type of the vegetal formation and particularly to its openness degree and consequently (Daget, 1980). Indeed, the high commission of the development of the steppe (HCDS) rends the planted perimeters a month per year to farmers on basis of the state of the vegetation and the climatic condition in to enrich the soil with nitrates and permit the development of ruderals.

Real spectrum

The contribution of the biological types to the vegetal rug follows the following schema: Phanerophytes > Therophytes > Hemicryptophytes > Chameaphytes > Nanophanerophyte in the dunes fixed by *T. gallica and T. aphylla* (L.) Karst (Group 1). In the group of the dunes fixed by *Retam retam* Webb and *T. aphylla* (L.) Karst (Group 2) the plan becomes Phanerophytes > Nanophanerophytes > Therophytes > Chameaphytes > Hemicryptophytes > Geophytes.

In the group belonging to the dunes of the natural regeneration and the dunes submitting to the influence of the fixation (Group 3): Phanerophytes > Chameaphytes > Therophytes > Hemicryptophytes. The phanerophytes are well represented with a very high rate of 69.83% in Group 1 and we also notice a high rate on 47% in Group 2. This dominance is explained by the plantation of *T. gallica* L. and *T. aphylla* (L.) Karst that represents important coverings.

The nanophanerophytes are well represented in Group 3 too with the rate of 34.99% whereas they are in codominance with the hemicryptophytes in Group 2 with a rate of 3.72 and 4.2%, respectively in Group 1 with a rate of 13.95 and 3.84% for each one.

Le Houerou (1992) focus on the important of chameaphytes in the grasses formations and this is due to the fact that they are not grazed by the herds that prefer hemicryptophytes and therophytes. Indeed, Hemicryptophytes generally prefer the damp environment rich in organic matter (Barbero et al., 1989) which represent a feeble content in the groups and explains their weakness in the space covering.

Relative significant rates of the therophytes: 21.72% in Group 1, 12.8 % in Group 3 and 8.09% in Group 2 was also noticed. This therophytes dominance can be explained by the presence of the productive and disrupted housing habitat were the therophytes behaved as redurals according to Grime (1977).

Finally, the geophytes of insignificant value (< 1 %) in Group 2, whereas they do not exist in Groups 1 and 3, what goes back to the forest meadow formations formed by the plantation of *R. retam* Webb. that represent recovering with a rate of more than 50% on the downs and down depth of the dunes.

Quantitative evaluation of the floral diversity of different groups

The quantitative results obtained with three plants groups are presented in Table 1. If we consider only the floristic composition, we remark that the obtained results are logic; this means that the dunes anciently fixed are richer in taxons than the recently fixed and anthropised stations.

This richness was explained by self mulching effect, the highest value of Shannon weaver –index (H’) was obtained in Group 1; H’ = 3.12 which is the richest specifically with 57 species, followed by Group 3; H’ = 2.61 less rich specifically with 24 species but mostly found with important abundance indexes dominance. Finally, with Group 2 H’ = 2.18 which is relatively inferior to that already obtained.

The diversity index (H’) can now be seen to vary with specific richness (Ramade, 1981; Lacoste and Salanon, 1999). Whereas if we consider the equitability (E) we notice that recently fixed dunes and which are under the fixation influence present relatively superior values, E = 0.56 than those anciently fixed by *T. gallica* L., *T. aphylla* (L.) Karst and *R. retam* Webb. E = 0.53 and E = 0.41, respectively this means that recently fixed dunes which are under the fixation present a diversity relatively less important than the fixed dunes which was explained by the fact that the silting up diminishes the floristic richness notably the number of species.

Raw frequency diagrams

The row frequency diagrams (Figure 13) obtained for the three groups show curves that generally present the same look indicating consequently a middle diversity and

Table 1. Quantitative results of the biodiversity of three groups

Quantitative	Groups		
	I	II	III
Specific diversity	57	37	24
Shannon weaver –index (H')	3.12	2.18	2.61
Equitability- index (E):	0.53	0.41	0.56

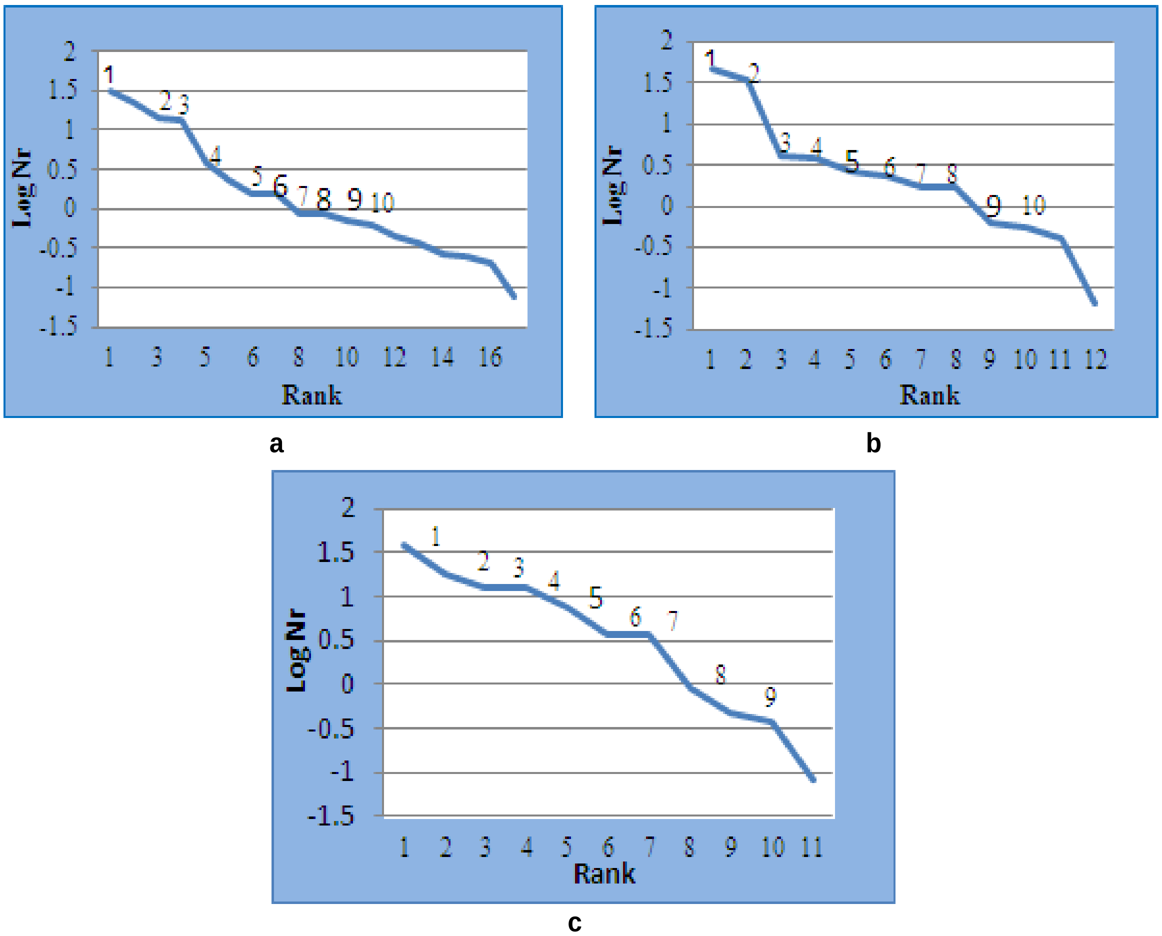

Figure 13. Real biological spectrum of three groups a. Diagram rank-frequency -Group I b. Diagram rank-frequency -Group II c. Diagram rank-frequency -Group III.

equitability (Frontier and Pichod-Viale, 1998) with a right extremity, a contingent of rare species.

On the dunes fixed by *T. gallica* L. and *T. aphylla* (L.) Karst (Figure 13a), the floral cortege is marked by the abundance of the fixating species *T. aphylla* (L.) Karst (1), *T. gallica* L. (2), *L. arabicum* (4), *P. atlantica* (5) as well as a remounted biologic marked by the dominance of *L. rigidum* (3) H. *murinum* (6), *Loeflingia hispanica* (7), *helichrysum stoechas* (8), *P. albicans* (9) and *Astragalus cruciatus* (10) indicate the fertility of the soil after its fixation.

In group of the dunes fixed by *R. retam* Webb. and *T. aphylla* (L.) Karst (Figure 13b) the physionomicall dominant species are principally the essence fixating *T. aphylla* (L.) Karst (1) and *R. retam,* floristic diversity formed of *Plantago ovata* (3) *Phalaris minor* (4), *A. campestris* (5), *O. arenarium* (6), *P. albicans* (7), *Leontodon mulleri* (8), *helichrysum stoechas* (9) and *Leontodon hispanicus* indicating a significant remounted biologic through this type of fixation.

Finally, at the level of dunes which are influenced by the fixation and regeneration of *R. retam* Webb.

(Figure 13c), the floristic cortege is marked by the abundance of sandy plants such as *R. retam* Webb. (1), *S. satureioides* (2), *E. guyoniana* (3), *A. pungens* (4), *Malcolmia aegyptiaca* (5) *P. teretifolia* (6), *O. natrix* (7), *Silene arenarioides* (8) and *Lotus pusillus* (9).

Conclusion

The results obtained show the success of plantations through resumption of the natural vegetation and come-back biological significant. There is a lively change of the current situation of intervention by the installation of very varied vegetation modifying the surface of the ground on all the fixed dunes. The analysis of the flora of three plant groups shows that these groups have a wealth in families, genres and varied species. The group of the dunes fixed by *T. gallica* L. and *T. aphylla* (L.) Karst is the richest with 57 species followed by the dunes fixed with *R. retam* Webb and *T. aphylla* (L.) Karst with 36 species against 24 species in the dunes of recent natural fixation; characterized by the presence of sandy plants. The most represented families on the generic and specific plan were Astéraceae, Fabaceae and Poaceae.

On the quantitative level, the indexes diversity vary according to the specific richness were remarked. The Shannon index registered on the vegetation of the dunes fixed by *T. gallica and T. aphylla* (L.) Karst that is H' = 3.12, it is of 2.61 at the levels of dunes fixed by *R. retam* Webb. and *T. aphylla* (L.). Karst and 2.61 in the levels of dunes fixed by *R. retam* Webb. and sandy plants, consequently, this leads to quantitative and qualitative floristic richness of the palatable species notably of the therophytes which explains the augmentation of the Shannon index in the fixed and consolidated dunes.

This analysis also proved that dampness and soil stability are the ecological factors responsible of the composition and the repartition of the vegetation in the different studied dunes. The condition of the development of these species, in addition to the installation of the species show that there exists a noticeable stability of the dunes, and this is due to the mechanical and biological treatments achieved on these dunes.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Alkalinity induced changes in some of the enzymes of nitrogen metabolism during germination and early seedling growth of rice genotypes

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Seeds of three rice (*Oryza sativa* L.) genotypes Viz. IR-42 (intolerant), USAR-1 and NDR-501(Tolerant) were germinated in Petri-dishes containing aqueous solution of $NaHCO_3$ at pH of 8.5, 8.8, and 9.2 at 30+1°C in seed germinator. Seed kept for germination on distilled water served as control. Nitrate reductase (NR), Nitrite reductase (NiR) and Glutamine synthetase (GS) activities were assayed in embryonic axis after 72, 96 and 120 h, respectively after soaking. Nitrate reductase (NR) and nitrite reductase were higher in USAR-1 fallowed by NDR-501 and IR-24 respectively under normal condition. Glutamine synthetase activity on the other hand, was maximum in NDR-501 and minimum in IR-24. Activities of the entire enzyme increased with growth stage but decreased progressively with increasing level of alkalinity, though the magnitude of reduction was more in intolerant genotype IR-24. Enzymes activity in the tolerant genotype under normal as well as alkaline condition was higher and might be due to their better equipped salt tolerant mechanism. Glutamine synthetase being one of the key regulatory enzymes of nitrogen metabolism. It linked with the molecular basis of salt tolerance in rice genotypes and providing certain degree of protection against hostile environment.

Key words: Alkalinity, glutamine synthetase, nitrate reductase, nitrite reductase, and rice.

INTRODUCTION

Soil alkalinity is one of the major problems in part of India as well as world for rice production. About 434 m.ha rice area of world is affected by soil alkalinity (Wang et al., 2012). Soil alkalinity and salinity are the complex and two different abiotic stresses which is caused by high amount of Na_2CO_3 or $NaHCO_3$ and NaCl or $NaSO_4$ respectively.

Alkaline soil is more destructive for plant growth and development due to high pH and hard physical structure in comparison to saline soil. Alkali stress precipitates many minerals and restricts the absorption of Cl^-, NO_3^- and H_2PO_4 and disturbs the ionic balance of the cells (Yang et al., 2008; Wang et al., 2012).

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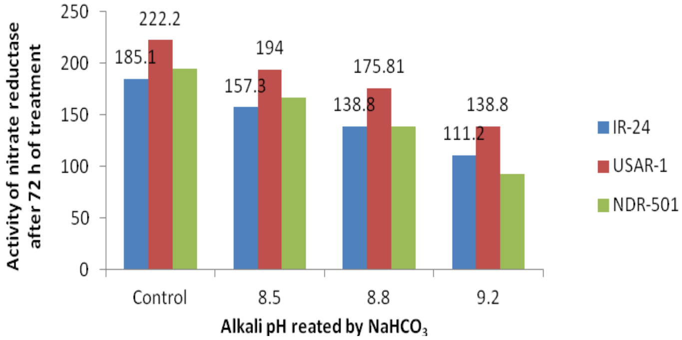

Figure 1. Effect of alkalinity on nitrate reductase activity (µ moles of nitrite produced h-[1] mg-[1] protein) in germinating embryonic axis of rice genotypes after 72 h.

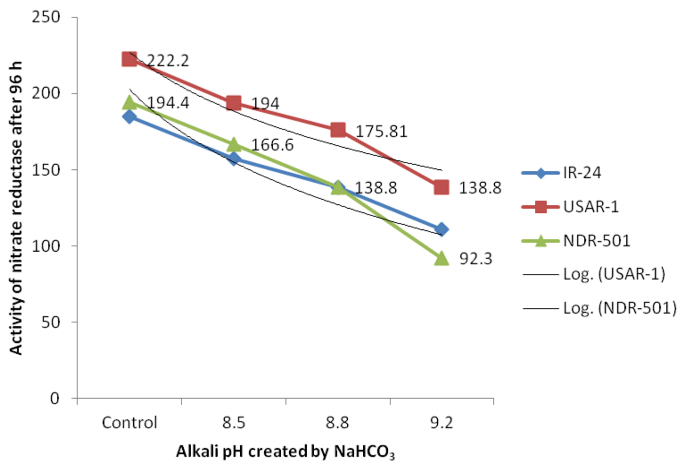

Figure 2. Effect of alkalinity on nitrate reductase activity (µ moles of nitrite produced h-[1] mg-[1] protein) in germinating embryonic axis of rice genotypes after 96 h.

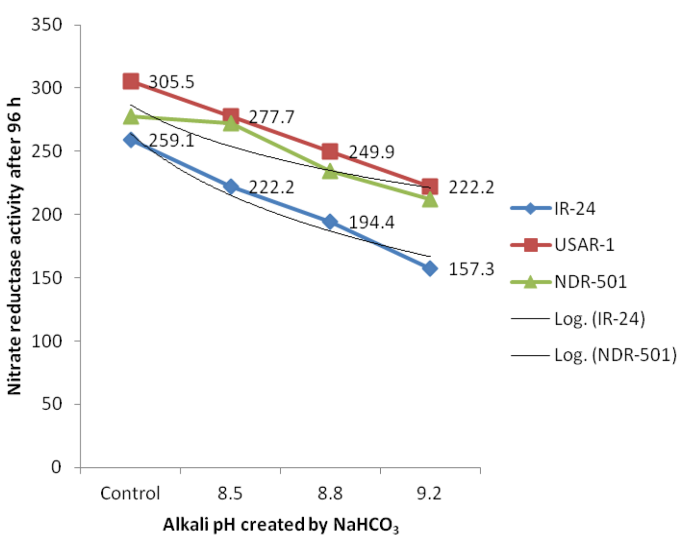

Figure 3. Effect of alkalinity on nitrate reductase activity (µ moles of nitrite produced h-[1] mg-[1] protein) in germinating embryonic axis of rice genotypes after 120 h.

Plant growth under alkaline condition is affected primarily by restricted root development. Plant survival and growth in such condition is the result of adaptive process such as ion transport and accumulation of compatible solutes (Yang et al., 2007). Many of these compatible solutes are nitrogenous compounds like amino acids, betaines, proline etc. Thus, proper and efficient nitrogen metabolism is crucial for salt tolerance (Munns and Tester, 2008).

Nitrogen metabolism disturb owing to high pH of the substrate and poor soil physical condition. Nitrogen metabolism being one of the key processes in the growth and development of plant needs particular attention especially at the enzymatic level. Enzymes like nitrate reductase and glutamine synthetase are the key rate limiting steps in nitrogen metabolism (Wang et al., 2012). Variability in nitrate and nitrite reductase, glutamine synthetase and glutamate dehydrogenase activity (Rakova et al., 1978) has been reported under saline condition in a number of crops. However, studies pertaining to the activity of these enzyme under alkaline condition are very few and inconclusive. The present study was, therefore undertaken using three rice cultivars differing in salt tolerance for assessing the enzymatic behavior in endosperm and embryonic–axis of germinating seeds under alkaline conditions.

MATERIALS AND METHODS

An experiment was conducted with three rice genotypes namely IR-24 (intolerant) USAR-1 and NDR-501(tolerant) under growth cabinet. The solutions of different levels of alkalinity viz. 8.5, 8.8 and 9.2 were prepared by 50 mM amount of $NaHCO_3$ in distilled water. Ten seeds were placed in each petri dish containing 10 ml solution of desired alkalinity level. Control treatment contained 10 ml distilled water. The petri dishes were placed in seed germinator in darkness for germination at 30+1°C. Enzyme analysis was done at 72, 96 and 120 h, respectively after sowing. Nitrate reductase (NR) and Nitrite reductase (NiR) activities were assayed according to the method of Jaworski (1971) and Ferari and Verner (1971) respectively. Glutamine synthetase (GS) was assayed by the modified r-glutamyl transferase method of Elliot (1955).

RESULTS AND DISCUSSION

A sharp progressive decrease in nitrate reductase (NR) activity in embryo-axis of all the three rice genotypes were apparent due to increasing levels of alkalinity (Figures 1, 2 and 3). NR activity in embryo-axis decreased sharply under salt stress condition at 72 h showing 79.2% reduction at pH 9.2 in salt intolerant genotype IR-24 while 62.8 and 52.8% in NDR-501 and USAR-1 respectively.

Nitrate reductase activity under alkaline medium greatly reduced due to unavailability of substrate for enzymatic reaction. Absorbed sodium disturbs the cells homeostasis of Na^+/K^+ ratio and cell environment for nitrate reductase activity (Wang et al., 2012). Decreased NR activity in rice

Table 1. Effect of alkalinity on nitrite reductase activity (μ moles of nitrite reduced min^{-1} mg^{-1} protein) in germinating embryonic axis of rice genotypes.

Genotypes	Control	pH			Mean
		8.5	8.8	9.2	
		72 h			
IR-24	88.9	74.0	51.8	44.4	64.8
USAR-1	111.1	88.9	74.0	59.2	83.3
NDR-501	103.7	811.4	59.2	51.8	74.0
Mean	101.2	81.4	61.7	51.8	
	Genotypes	**Alkalinity**	**Interaction**		
CD at 5%	8.2	9.4	16.3		
		96 h			
IR-24	133.3	118.5	103.7	74.1	107.4
USAR-1	162.9	133.3	111.1	96.3	125.9
NDR-501	140.7	133.3	88.9	66.7	107.4
Mean	145.7	128.1	101.2	79.0	
	Genotypes	**Alkalinity**	**Interaction**		
CD at 5%	7.8	9.0	16.0		
		120 h			
IR-24	177.8	163.0	133.3	111.1	146.3
USAR-1	214.8	200.0	177.8	155.6	187.0
NDR-501	192.6	148.1	133.3	118.5	148.1
Mean	195.1	170.4	148.1	128.4	
	Genotypes	**Alkalinity**	**Interaction**		
CD at 5%	7.1	8.2	14.2		

varieties under sodic conditions has also been reported by Dwivedi et al. (1982). Pandey and Lal (2003) also reported decreased activity of nitrate reductase in wheat. Lower NR activity under alkaline condition could possibly be due to reduced uptake of nitrate by the tissues under alkali condition and leading to lower induction of enzyme activity (Wang et al., 2012).

Like nitrate reductase, nitrite reductase (NiR) activity in salt sensitive genotype IR-24 was also lower than that of salt tolerant genotypes USAR-1 and NDR-501, which maintained the same trend even under alkaline condition at all the stages of seedling growth (Table 1). Nitrite reductase activity increased with time period in embryo axis in all the treatment irrespective of genotypes. Once again the salt sensitive genotypes IR-24 showed greater reduction in (NIR) activity than salt tolerant genotypes USAR-1 and NDR-501.

NiR activity is affected due to poor activity of NR under alkaline environment. High Na^+ content in and outside the cell environment changes ion balance and reduces the activity of enzyme involves in nitrogen metabolisms (Munns and Tester, 2008). Decrease in NiR activity under salinity condition has also been reported by Wang et al. (2012).

Glutamine synthetase activity in the embryo axis decreased significantly due to increase in alkalinity levels in three rice genotypes (Figures 4, 5 and 6) although the magnitude of reduction was higher in salt susceptible genotype IR-24 (46%) at pH 9.2 against 30 and 32% in USAR-1 and NDR-501 respectively. Enzyme activity in embryo axis was lower at 72 h but increased gradually at 96 and 120 h period in all the treatment.

In nitrogen metabolism, nitrate is reduced to nitrite by nitrate reductase and nitrite to ammonium by nitrite reductase. Ammonium compound from this reduction and other sources is converted into organic compound by glutamine synthetase (GS) or alternate glutamate dehydrogenase (GDH) pathway (Shi et al., 2010). But the decrease in glutamine synthetase, nitrate reductase and nitrite reductase activities under alkaline condition is an indication of disturbed nitrogen metabolism in rice due to high sodium and bicarbonate ions (Kusano et al., 2011; Rakova et.al., 1978). Lower GS activity under alkaline condition is an accumulation of ammonia and amino acid especially glutamate which was toxic in higher concentration. Accumulation of glutamate, alanine, asparagines, and cysteins under salt stress was shown by Strogonov (1973).

Differential behavior of nitrate reductase, nitrite conferring salt tolerance to rice. Glutamine synthetase

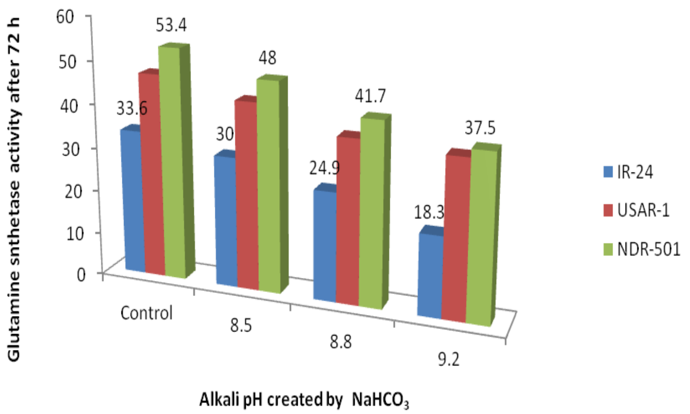

Figure 4. Effect of alkalinity on glutamine synthetase activity (μ moles glutamyl hydroxamate produced g^{-1} fresh weight h^{-1}) in germinating embryonic axis of rice genotypes after 72 h.

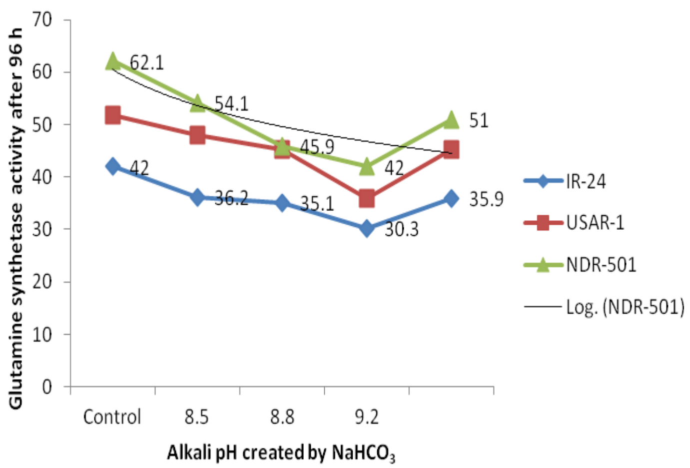

Figure 5. Effect of alkalinity on glutamine synthetase activity (μ moles glutamyl hydroxamate produced g^{-1} fresh weight h^{-1}) in germinating embryonic axis of rice genotypes after 96 h.

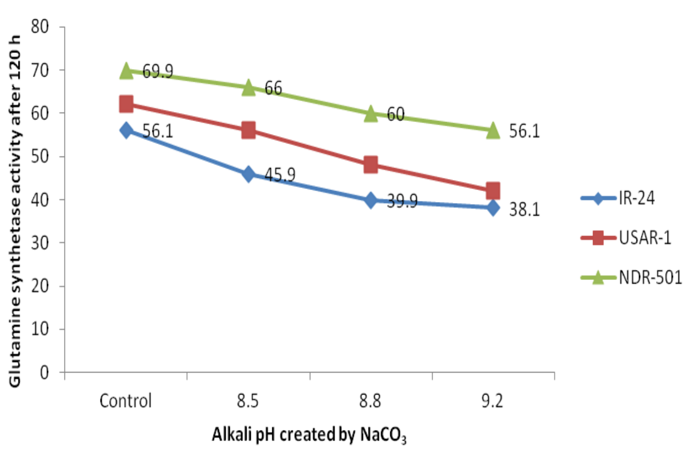

Figure 6. Effect of alkalinity on glutamine synthetase activity (μ moles glutamyl hydroxamate produced g^{-1} fresh weight h^{-1}) in germinating embryonic axis of rice genotypes after 120 h.

reductase and Glutamine synthetase in rice genotype differing in salt tolerance indicates their possible roles in being key regulatory enzyme of nitrogen metabolism might be playing some useful roles in inducing salt tolerance to USAR-1 and NDR-501 genotypes which maintained relatively higher GS activity even under alkaline condition (Figures 4, 5 and 5). In conclusion, it appears that genotypic differences do exist in different enzyme activities but their measurement at two or three stages during early seedling stage alone may not correlate with the growth and yield of plant.

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Full Length Research Paper

Growth and physiological response of tomato to various irrigation regimes and integrated nutrient management practices

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The experiment was conducted by combining two factors namely; irrigation scheduling with three levels and nutrient management with five levels. The two factors were crossed factorially; irrigation treatments were arranged in vertical strips and integrated nutrient management arranged in horizontal–strip with strip plot design replicated three times. Field soil was sampled for physical and chemical property determinations. Equal amount of irrigation water were applied before the initiation of irrigation treatments. Once the drip system was installed, irrigation was done on the basis of daily evapotranspiration (ETo) value of the previous day. Growth and canopy characteristics such as plant height, stem diameter, lateral branch length, canopy width and canopy depth were measured and canopy cover was estimated. Additionally yield and yield components at harvest were measured from sample fruits. Physiological data such as chlorophyll content, quantum yield, and Ft were assessed. Data were subjected to analysis of variance as per the design using the SAS Software. Among irrigation levels tested, highest total yield 82.14 t ha^{-1}, was recorded from full irrigation treatment followed by 57.30 t ha^{-1} from 80% ETc irrigation levels and lowest total yield 49.30 t ha^{-1} from 60% of full irrigation depth. This finding indicated that tomato should be irrigated at full water requirement to get maximum fruit yield. From this investigation, the total fruit yield was recorded from N 185 kg ha^{-1} P 60 kg ha^{-1} combination and N 75 kg ha^{-1} P 50 kg ha^{-1} treatment combination with 67.483 and 67.31 t ha^{-1} respectively. Application of N 185 kg ha^{-1} P 60 kg ha^{-1} combination (grower's check) did not contribute to much yield difference but would encourage luxury consumption and environmental pollution. Thus combinations of full irrigation treatment with N 75 kg ha^{-1} P 50 kg ha $^{-1}$ nutrient application would be recommended for verification for tomato production around Melkassa.

Key words: Drip irrigation, N and P nutrient, evapotranspiration (ETo), ETc, tomato.

INTRODUCTION

Food security is a major concern in many parts of the world including East Africa, Rift Valley of Ethiopia where rainfall is unpredictable and unreliable (Tesfaye, 2008). The prospects for significant expansion of crop cultivation or irrigation area are limited (Edossa, 2014). To meet the rising food demand that will occur as a result of increasing population the government planned to ensure sustainable land and water productivity improvements, through integrated nutrient management over the coming decades.

The basic concept underlying the principles of integrated nutrient management is the maintenance, and possible improvement, of soil fertility for sustaining crop productivity on a long-term basis (Hegde and Srinivas, 1989). Sustained productivity may be achieved through the combined use of various sources of nutrients, and by managing these scientifically along with the growth cycle for optimum growth, yield and quality of crops, in a way adapted to local agro-ecological conditions.

Fertilizer- and water-management programs in vegetable crops production are linked; optimal management of one program requires proper management of the other; the ideal outcome should be visualized as keeping both water and nutrients in the plant root zone (Hochmuth and Hanlon, 2010). Although existing knowledge on the effects of irrigation, nutrients and other growth factors on fruit yield of field-grown tomato is appreciable (Scholberg et al., 2000) detailed studies of crop and canopy characteristics in the CRV area appear to be lacking. The detailed studies of crop and canopy characteristics are required to define crop management in the CRV areas to support field managements. Among irrigation systems, many loses encounter surface irrigation, like surface leaking conveyance canals, surface run off or deep percolation etc….from limited volumes of water compared with crop water requirements, it is economically necessary to get even more from the water. This may be done in many cases by adopting efficient irrigation methods, which can apply the scarce water more accurately; minimizing losses through different ways. Improved benefits of such systems can be derived by using efficient water application methods such as drip irrigation. The water then can be used much more efficiently for supplemental irrigation for much larger areas, or for longer seasons. The experience from many countries show that farmers who changed from furrow system to drip systems can cut their water use by 30 to 60% and crop yields often increase at the same time (Sijali, 2001). The use of such drip irrigation system permits reduction of water loss up to 50% (Hochmuth and Hanlon, 2010) and can increase the yield per unit of land by up to 100% compared with surface irrigation systems (Cowater, 2003).

In many places in Ethiopia, there are an extensive campaign of water harvesting, tapping ground water and using appropriate technologies- like treadle pump, rope and washer pumps with the realization that in many places existing water resources cannot meet the needs of the expanding population (Moges, 2006). Thus this study was conducted with the objectives to evaluate combined application of nitrogen, phosphorous, Farm Yard manure (FYM) and irrigation scheduling on growth and yield of tomato and to determine the optimal irrigation levels for maximum tomato fruit yield.

MATERIALS AND METHODS

The experiment was conducted at Melkassa, combining two factors namely; irrigation scheduling with three levels and nutrient management with five levels. Irrigation treatments were arranged randomly in vertical strips in order to adjust irrigation depth uniformly along the strips. Integrated nutrient were randomly arranged in horizontal–strip plots. These two factors were crossed factorially and replicated three times. The irrigation scheduling treatments were 1) full potential evapotranspiration (ETc) [IIRI], 2) 80% ETc (= 0.80 ETc) [IRII] and 3) 60% ETc [IR III] with *Melkashola* tomato variety. The first treatment entailed optimal watering without any stress throughout the growth period; the amount of irrigation water applied to the highest irrigation water treatment was limited to the tomato consumptive use demand. In the remaining two treatments, various levels of stresses mentioned as treatment were applied starting from the start of developmental stages through mid- and late- growth stages up to harvesting stages. The second factor was five nutrient management levels with 1) NP rates obtained from field survey (smallholder farmers' rate) (N_FP_F) (N 185 kg ha^{-1} P 60 kg ha^{-1} combination) [designated as INM-I]. Based on the survey result (Edossa et al., 2013b, 2014) and information gathered from different bodies, the average amount of nitrogen and phosphorus fertilizers used by tomato growers, viz; UREA 289.51 kg ha^{-1} and DAP 286.66 kg ha^{-1} were identified and used for this field experiment as indicated as INM-I treatment, thus combined Urea and DAP were used for this treatment. The total nitrogen 133.17 kg form Urea plus 57.33 kg N from DAP summed to 190.5 N kg ha^{-1}. 2) Averages of best N and P rates found from two seasons on station experiment (N_RP_R) (N 75 kg ha^{-1} P 50 kg ha^{-1}) [INM-II] (Edossa et al., 2013a), 3) On station best N and P rates (N_RP_R) (N 75 kg ha^{-1} P 50 kg ha^{-1}) +15 tone ha^{-1} (FYM) [designated as INM- III]; 4) Use of 15 tone ha^{-1} FYM only [INM-IV] and 5) Check, no nitrogen, phosphorus and manure application [INM-V]. Both DAP and TSP fertilizers were used for the combined N and P rate treatment ($N_{75}P_{50}$), averages of findings from on station furrow and rainfed experiments [INM-II].

The low-cost gravitational drip structures were used for the experiment. A separate water meter (litter) were used to measure the amount of water quantities directly applied to each strip plots by each four separate tankers with volumes of 2000 L that installed (placed) for each irrigation regime at the head of strip plot. Four tankers were placed in the field at the height of 1.0 m frame above the field so that water is at the height necessary to provide the water pressure required for operating the system.

The laterals are 16 mm in diameter and fitted with integral drip emitters (drip emitters are welded to the inner wall of the tube and come as continuous rolls with outlets at 0.3 cm). Each plot consisted of three lateral drip lines with 5.5 m length. The emitters were prefabricated to discharge at a constant rate of 1.3 L per hour discharge rate under pressure-compensation emitters. The emitters on laterals were spaced at 0.3 m corresponding distance Of tomato plant spacing with in a row. The lateral line was laid out along each tomato row at 1.0 m spacing. The total area for each subplot was 16.50 m^2. In order to improve non-uniform-flow rate along the strip lines, 1) clean water were used directly from irrigation canal in order

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to minimize the chance of clogging the filtration system and each emitter were inspected regularly to identify clogged emitters if there was; they were unblocked by pressing with fingers because it can cause non-uniform application of waters, 4) one meter head might provide good pressure. Each tomato plants were planted under emitter so that they would benefit from the water supplied by the emitters. The field was furrow irrigated before imposing drought stress treatments, once the seedlings were well established, the irrigation treatment was commenced, at predetermined daily crop water use (ETc). Three and half meter distance buffer strip separate each plots or side flows were precluded to avoid lateral run-on and run-off (side flows) from other irrigation treatment plots.

Three sample pits were opened from each three replications for determination soil physic-chemical physical properties. Three soils samples were composted from 0 to 20, 20 to 40 and 40 to 60 cm depth accordingly from each replication. Similarly soil samples were taken for the determination of chemical properties at different depths (0 to 20, 20 to 40 and 40 to 60). All procedures and analytical methods used were a routine soil test of the sample and includes the following parameters: Textural class, soil pH, ECe, CEC, Organic Carbon, Total N, Available P, Exchangeable K, Zn, and Mn which were analyzed;

1) Soil texture: Hydrometer method was used;
2) pH measurement was made in water and in 1: 2.5 soils: water or solution suspension using a digital pH meter;
3) Electrical conductivity was measured from 1: 2.5 soils: water suspension using digital electrical conductivity meter;
4) Organic carbon was determined using Walkley-Black's method (Walkley and Black, 1934);
5) Organic matter,
6) Available phosphorus;
7) Total N,
8) C: N Ratio;
9) Exchangeable Cations; and
10) Cation Exchange Capacity.

The following general procedures and methods of analysis of the soil physico-chemical properties for experimental field was made at Deber Ziet Agricultural Research Centre Soil Laboratory. These are soil reaction, pH (1:2.5) H_2O (Water with 1:2.5), Texture (Bouycous Hydrometer Method), ECe (dS m^{-1}) (1:2.5) H_2O (Saturation Paste Extract Method), Exchangeable Cations (Neutral Ammonium Acetate methods), [CEC ($cmol_c$ Kg^{-1} soil)], organic carbon (%) (Walklay and Black, 1934), total nitrogen (%) (Micro Kjeldshl Method, 1982), available P using Olson et al. (1982); additionally, bulk density, 2) field capacity, 3) permanent wilting point of the field soils were estimated. Soil samples were tested and analyzed at Deber Ziet Agricultural Research Center.

Field plots were prepared with forty-five plots and with drip irrigation systems and independent gate valve for each strips. Seedlings were transplanted in field at 0.30 m* 1.0 m spacing. Before initiating treatments, seedlings after transplant were irrigated to the field capacity for three weeks in order to improve root development (Kirnak *et al*., 2001).

Fertilizers were applied manually; all phosphorus fertilizer quantities were added at once at the time of transplanting and Urea applied in three equal splits, 1/3 of Urea was applied at transplanting and second application 1/3 after 20 days and final third application of Urea was applied after 40 days after transplanting. Manure was mixed with 30 cm top soil and applied a month before transplanting. FYM were analyzed for available macro- and micro-nutrient elements similar to previous experiment. The pre-determined rates of FYM were estimated on air-dry weight basis where samples of FYM were taken from moisten manure heap.

The initial soil water content for top soil at time of transplanting is assumed to be close to field capacity as a result of continuous pre-furrow irrigation events. This assumption is dictated by the fact that small vegetable seedlings are extremely very sensitive to moisture stress. Then the proper amount of daily irrigation for a crop is the amount of daily ET taking place minus any daily effective rainfall (Allen et al., 1998).

Equal amount of irrigation water were applied to each treatment before the initiation of irrigation treatments (sum of daily ETc). Once the drip system is installed, the drip irrigation was done on the basis of ETo value of the previous day. The amount of irrigation water applied, ETm, was determined from the calculated water requirement for tomato as determined from the crop coefficient (Kc) and the daily reference evapotranspiration (ETo) using ETc = ETo * Kc. Irrigation scheduling was based on check book of soil water balance budget method (ETc = ETo*Kc) where simple accounting approach for estimating how much soil-water remains in the effective root zone based on water inputs and outputs. Irrigation was scheduled when the soil-water content in the effective root zone is near the predetermined allowable depletion volume through keeping track of rainfall, evapotranspiration and irrigation amounts. Daily irrigation treatments were applied until the estimated required volume of water is completely gone from the tanker.

Tomato average Kc would be taken after many adjustments have been made for initial, mid and late season stages to be 0.6, 1.15 and 0.8, respectively (Allen et al., 1998). The drip irrigation efficiency was assumed to be 0.85 for lesser quality of laterals and gravity pressure head that are available in the local markets. The daily ETo data used in this research were calculated with the software program EToCalc developed by Raes (2006) on basis of the FAO Penman Monteith equation with standard coefficients for the Angstrom formula and a standard albedo value of 0.23 from Melkassa Weather Station were used. The net irrigation, that is, the amount of irrigation water required to bring the soil moisture level in the effective root zone to field capacity (Michael, 2008) is calculated as net irrigation requirement. Daily net irrigation water applied at each growth stages were determined by the following field water balance equation, [Net irrigation, ETc = Kc *ETo].

The daily effective rainfalls were calculated based on the procedures developed by USDA (1997). However, rainfall event occurring during harvesting would be excluded since it is not useful for the yield formation (*Anon*.). The estimated effective rainfalls were summed over the tomato growing period. The total amount of irrigation water applied to each treatment was calculated as the sum of water applied during the crop establishment period and the ETc of the remaining period and finally the total water supplied to the crop equals to the amount of irrigations and total effective rainy precipitations recorded along the crop growth period.

Daily irrigation amount were adjusted according to existing reference *ET* and *Kc*. The irrigation treatments were differentiated by their two meters arrangement for strip, irrigation events would be controlled manually by using valve and water meter at the water tanker. The valve was put on and off after calculating net irrigation and adding losses (gross depending on amount of water to be applied at desired level for each strip separately). Records of daily applied water were kept from the start of treatment application up to final harvest date for each treatment and was summed up for each treatment. Soil moisture was monitored periodically using gravimetrically in order to apply estimated amount of water for replenishing the root zone to field capacity.

Soil samples were collected regularly for soil moisture estimation using gravimetric method (Home et al., 2002). Helical auger was used to collect soil samples. Before irrigation water application, the profile water content was determined. Irrigations were adjusted and initiated at predetermined depletion of available soil water. Samples were taken to the office work room, weighed (wet weight), oven dried, and weighed again (dry weight). Cares were taken to protect soil samples from drying before they were weighed. An electric oven takes 24 h at 105°C to adequately remove soil water (USDA, 1997). Percentage of total soil-water content on a dry weight basis was then computed.

The values of Kc of tomato used (0.6, 1.15 and 0.80 respectively, in the initial, mid and late season stages) is represented with 25 days for the initial, 34 days for the development, 20 days for mid and 41 days for late growing stage; making a total of 120 days as recommended by Allen et al. (1998). The daily Kc development coefficient for tomato for any day in the growing season were adjusted by considering that during the initial and mid-season stages Kc is constant and equal to the Kc value of the growth stage under consideration (Allen et al., 1998). During the crop development and late season stage, Kc varies linearly between the Kc at the end of the previous stage (Kc prev) and the Kc at the beginning of the next stage (Kc next), which is Kc end in the case of the late season stage. The partial wetting for wetting patterns of the drip emitters was measured from sample drippers and adjusted to 0.3 ratios.

Some of growth and canopy characteristics data such as plant height- measured using rulers; stem diameter- measured using digital calipers just at above the surface (≈5 cm), lateral branch length-measured using rulers. Canopy cover (CC) was estimated by multiplying mean canopy width with mean canopy depth and dividing the products by the area covered by the plant (spacing between rows multiplied with spacing between plants). Additionally yield and yield components at harvest, fruit size, average fruit length (longitudinal) and equatorial diameter at harvest using digital calipers and average fruit mass at harvest, total yield (includes both marketable and unmarketable fruit yield) were measured.

Finally the following physiological data such as chlorophyll content, quantum yield, and Ft were assessed from sample plants and leaves. The leaf chlorophyll content was estimated non-destructively using a portable hand held Chlorophyll Meter (Minolta SPAD-502, Konica Minolta Sensing, Inc. Japan). An average of one leaf per plant and five leaves per plot were measured. The SPAD readings were measured at 90 DAT on fully expanded leaves from 5 plants per plot. The quantum yield: [expressed as number of molecules of CO_2 fixed or O_2 evolved per photon absorbed. The quantum yield measurements were taken using same SPAD readings similar to leaf chlorophyll content measurement from 9:00 to 11:00 at 90 DAT on fully expanded leaves from 5 plants per plot. The leaf chlorophyll fluorescence (Ft) was also taken at same time as quantum yield using hand held SPAD readings instrument. Samples of five matured top leaves from many branches were taken from compound leaf, from third to fourth compound leaf single leaf plot were composited. Additionally, leaf stomatal conductance was measured at 70 DAT using Porometer (Model Sc-1; Steady State Diffusion Porometer, Decagon Devices) (mmol/m^2s) were used. Leaf stomatal conductance was measured from five sample leaves per plot and the measurement was taken before noon 9:00 to 11:00 pm (Taiz and Zeiger, 2003). Daily rainfall data were also used for the manipulation of growing season daily weather conditions. EToCal (Raes, 2009) was used for the estimation of daily reference evapotranspiration to identify each day into either dry or wet days. Data from this experiment were subjected to analysis of variance as strip plot design using the SAS Analytical Software (2003). When the F-value was significant, a multiple means comparisons were performed using DMRT at $P < 0.05$ probability level.

RESULTS AND DISCUSSION

Soil analysis

The results of soil textural analysis showed that sand, silt and clay has relatively similar proportions. The soil textural analysis at this site has indicated that it is predominantly clay loam throughout its profile. The bulk density of top soil 0 to 20 cm depth range from 1.015 to 1.035 g·cm^{-3}, and range from 0.957 to 1.069 g·cm^{-3} for the sub surface 30 to 40 cm soil depth and finally range from 1.001 to 1.055 g·cm^{-3} for the lowest depth (40 to 60 cm depth). The analysis of all soil samples indicated that the soil has same pH values of an average 7.61 at all layers which are mildly alkaline rating. The average field capacity (FC) was found to be 0.335 m^3 m^{-3}, and average wilting point (WP) of the soil sample were found to be 0.205 m^3 m^{-3}.

The field plot has higher OC in the surface soil 2.76% (g/100 g) (high rating - good structural condition with high structural stability) and 2.03% (g/100 g) in the middle (20 to 40 cm depth) (high rating - good structural condition with high structural stability) and the bottom (40 to 60 cm) with 1.26% (g/100 g) content rated as moderate with both average structural condition and average structural stability. The analysis indicate that the OM of the top soil (0 to 20 cm depth) found to be 4.73% (g/100 g) rated as high described as good structural condition with high structural stability. In the second layer (20 to 40 cm depth) the OM was found to be 3.50% and rated as high and described as good structural condition with high structural stability. However, the bottom layer (40 to 60 cm), the OM was found to be 2.20% indicating the layer has moderate rating, average structural condition with average structural stability. Both the top soil layer (0 to 20 cm) and following layer (20 to 40) cm depth has similar total N 0.139%, rated as low status (Hazelton and Murphy, 2007). While the last layer (40 to 60 cm depth) has 0.086% total N again rated as low N status. The C: N ratio of the top soil was found to be 16.91 while 14.89 for the bottom soil layer. The available P content of top soil (0 to 20 cm depth) is found to be 36.50 ppm which is rated as very high P status; while 26.76 ppm P content in the second layer (20 to 40 cm depth), still rated as very high P level. However 11.62 ppm P content was measured in the bottom layer (40 to 60 cm depth), and rated as moderate.

Results of soil analysis indicated that the Ca content of all soil layers have greater than 40.32 cmol (+) kg^{-1}, rated as very high rating values while Mg content analysis indicated that the overall soil layers have higher than 4.67 cmol (+) kg^{-1}, rated as high. The K^+ content of the top soil layer (0 to 20 cm depth) was found to be 4.20 cmol (+) kg^{-1}, and rated as very high, while 3.32 cmol (+) kg^{-1} were recorded from the second soil layer (20 to 40 cm depth), and still rated as very high. Finally 2.82 cmol (+) kg^{-1} were recorded from bottom soil layer (40 to 60 cm depth) which is rated as very high. The results of high K^+ contents of various soil samples of the experimental plots including previous experimental fields have high K^+ content. These high K^+ content is in line with the recent findings of Murphy (1959), who reported that most Ethiopian soils in the 1950th had high K^+ content. The Ca: Mg cationic balance of soil samples derived from sample soil analysis and range from 7.404 to 9.146 (low Mg rating) for the upper soil (0 to 20 cm depth) and 6.316 to 10.033 (low

Table 1. Analysis of variance table showing mean square values of vegetative growth yield and yield components parameters of tomato as influenced by integrated nutrient managements and application of various moisture regimes.

Source of variations	df	Mean square values								
		Plant height (cm)	Canopy diameter (cm)	Canopy width (cm)	Stem diameter (mm)	Leaf Ft	Leaf quantum yield	Leaf chlorophyll content	Stomatal conductance	Total yield (t/ha)
Replication	2	13.726	65.4847	41.0891	6.26460	1049.76	0.00221	216.895	1231.1	1695.8
INM	4	28.651**	51.7305*	45.2294**	3.97776	2008.72	0.00801	56.367	396.5	2060.9*
Error (a)	8	12.810	5.3407	8.4087	1.30895	1165.02	0.00138	26.384	1814.1	991.3
Irrigation Levels (IR)	2	204.644**	7.2842	66.8408**	6.31708	2025.41	0.00153	466.172**	22349.2**	43979.1**
Error (b)	4	12.803	9.0678	3.4260	4.00823	1367.90	0.00783	3.216	403.4	315.0
NM x IR	8	12.713*	14.5756	5.9727	1.47473	857.51	0.00395	26.387	1427.2	2434.7*
Error (c)	16	4.816	7.6629	6.8035	1.82010	1818.15	0.00471	47.024	699.3	637.5
Total	44									
Grand Mean		59.426	34.967	47.745	14.763	229.24	0.5340	51.737	132.80	62.916
CV (%)		3.693	7.91653	5.463031	9.138399	18.60080	12.85726	13.25450	19.91227	12.69
R^2		0.912	0.817187	0.828409	0.731594	0.551956	0.600687	0.729260	0.872104	0.926333
Root RME		2.194	7.91653	2.608343	1.349112	42.63974	0.068658	6.857437	26.4435	79.84406

Figures without asterisk indicates non significant at $P > 0.05$; * and significant at $0.05 < P \geq 0.01$ and ** significant at $P < 0.01$ probability levels, respectively.

Mg rating) for the sub surface 20 to 40 cm depth and 7.379 to 11.196 (low to Mg deficit rating) for the last bottom 40 to 60 cm soil depth indicating that the experimental field has low Mg content. There is an overall trend that the Ca: Mg cation balance ratio increases depth-wise; the estimated values indicates more Mg deficit in the last depth. Similarly Mg^{2+} content is higher in the upper and tends to decreases in the lower.

Mean square, main and interaction effect of growth, physiological responses and yield components of tomato as influenced by irrigation regimes and integrated nutrient management (INM) practices

Analysis of variance indicated that application of various irrigation regimes combined with integrated nutrient management showed significant interaction effect on some of the variables and variable effects on some other measurements recorded from tomato plant (Table 1). Application of various irrigation regimes combined with INM did not show interaction effect on any one of tomato growth and development characteristics with this experiment.

However interactions of irrigation regimes and integrated nutrient management were observed on total fruit yield and WUE of *Melkashola* variety. Highest yield of 82.1 t ha^{-1} fresh fruit was obtained from full irrigation and lowest yield of 49.3 t ha^{-1} obtained from 60% irrigation water with saving 40% of irrigation water (Table 2).

As irrigation depths decrease there is direct relationship with total fruit yield reduction in tomato. This supports the statement by Muchovej et al. (2008) that vegetables are nothing but nicely packaged water; it is quite profound and points to the fact that high quality and yield are directly associated with proper water management. Similar findings were reported by Kirnak et al. (2001) where egg plants grown under high water stress had less fruit yield and quality than those in the control treatment. Reviewing the yield obtained from various N and P study, Jones (2008) explained that referring report of FAO, a good commercial yield of tomato under irrigation ranges between 450 q and 65.0 t ha^{-1}. Similar findings were obtained by Sezen et al. (2010) and Tuzel et al. (1994) where increasing irrigation, full irrigation increased total tomato fruit yield. Kirnak et al. (2001) generalized that the decrease in fruit yield and plant growth induced by water deficit in egg plants was a consequence of a reduction in transpiration.

Similar results were found by Birhanu and

Table 2. Mean values of various irrigation regimes and integrated nutrient management on vegetative growth, fruit yield and yield components of tomato grown under drip irrigated condition.

Irrigation regimes	Plant height (cm)	Canopy diameter (cm)	Canopy width (cm)	Stem diameter (mm)	Leaf Ft	Leaf quantum yield
IR I	63.55^A	35.75	49.678^A	15.50^A	215.89	0.52267
IR II	58.27^B	34.85	48.065^A	14.46^B	234.73	0.53733
IR III	56.44^C	34.33	45.492^B	14.32^B	237.09	0.54200
Mean	59.426	34.69	47.5218	14.76	229.23	0.534
LSD (0.05)	3.6275	NS	1.8765	3.6275	NS	NS
Integrated NM						
[$N_{185}P_{60}$] [INM-I]	62.51^A	38.79	51.27^A	15.63^A	237.26	0.54333^AB
[N_RP_R] ($N_{75}P_{50}$) [INM-II]	59.40^B	35.56	48.21^B	15.16^AB	247.18	0.57667^A
[INM- III]	58.62^B	33.91	46.92^BC	14.68^AB	233.44	0.52556^AB
[INM-IV]	58.38^B	34.06	47.09^BC	13.91^B	218.22	0.49444^B
[INM-V]	58.38^B	32.50	45.23^C	14.42^AB	210.07	0.5300^AB
Mean	59.45	34.96	47.744	14.76	229.23	0.534
LSD (0.05)	3.890	NS	3.152	1.2437	NS	0.040

Irrigation regimes	Leaf chlorophyll content	Stomatal conductance	Marketable fruit (t ha^{-1})	Unmarketable yield (t ha^{-1})	Total fruit yield (t ha^{-1})	WUE[1] (kg fruit yield ha^{-1} m^{-3})
IR I	55.02^A	176.74^A	63.63^A	18.267	81.902^A	28.96^A
IR II	54.88^A	117.29^B	33.83^B	22.413	56.250^B	24.23^B
IR III	45.30^B	104.36^B	27.82^B	23.062	50.868^C	28.95^A
Mean	51.737	132.80	41.765	20.813	62.916	27.72
LSD (0.05)	1.818	20.362	9.712	NS	5.689	2.311
Integrated nutrient management						
[$N_{185}P_{60}$] [INM-I]	54.12	130.41	41.765	26.223	67.988^A	29.57
[N_RP_R] ($N_{75}P_{50}$) [INM-II]	52.64	133.87	43.27	22.772	66.050^A	29.57
[INM- III]	50.07	130.00	38.048	21.705	59.752^AB	28.52
[INM-IV]	53.61	143.61	38.746	19.384	58.130^AB	26.72
[INM-V]	48.24	126.11	46.990	16.154	63.144^B	24.78
Mean	51.733	132.80	41.765	21.713	62.916	27.720
LSD (0.05)	NS	NS	NS	NS	4.98	NS

*= Average of three replications. Means within each column with different letters are significantly different at LSD at *P* = 0.05 level of significance. [1] = WUE was estimated by dividing the total fruit yield production per ha per m^3 of water used by the plant.

Tilahun (2010) that their irrigation was positively influenced tomato productivity; the result was due both to the increase in number of berries per plant and the fruit average weight as irrigation increased. Their study concluded that the total yield and marketable tomato yields were

Table 3. Total fruit yield (t ha^{-1}) of tomato as affected by interaction of application of various irrigation regimes and integrated nutrient management (INM) under drip irrigated growing condition.

Irrigation level	INM*					Mean (t ha^{-1})
	INM I	INM II	INM III	INM IV	INM V	
IRR I	99.886	89.195	75.290	74.446	71.880	82.1394^{A}
IRR II	57.498	60.940	61.101	47.328	59.683	57.309^{B}
IRR III	45.069	51.815	54.650	56.302	38.660	49.300^{C}
Mean	67.483^{A}	67.317^{A}	63.681^{AB}	59.359^{AB}	56.741^{B}	62.9162

* Mean of three replications.

Table 4. Average plant height (cm) of tomato as affected by interaction of application of various irrigation regimes and integrated nutrient management under drip irrigated growing condition.

Irrigation level	Integrated nutrient management (INM)*					Mean
	INM I	INM II	INM III	INM IV	INM V	
IRR I	67.613	65.120	60.360	61.203	63.493	63.558^{A}
IRR II	61.136	55.203	58.553	57.370	59.113	58.275^{B}
IRR III	58.7866	57.880	55.726	56.570	53.260	56.444^{C}
Mean	62.512^{A}	59.401^{B}	58.213^{B}	58.381^{B}	58.622^{B}	***59.426***

* Mean of three replications.

significantly decreasing as the deficit level was increased. At the same time, they found that the marketable yield decreased with stress levels. The reduction of total yield of tomato with an increased amount of water stress level of this test was consistent

with previous work conducted on tomato and other crops such as cotton (Candido et al., 2001; and Yaza et al., 2002).

Among integrated nutrient tested, INM I and INM II gave similar fruit yield 67.48 t ha^{-1} and 67.31 t ha^{-1} and lowest fruit yield was obtained from check plot (INM V) 56.74 t ha^{-1} (Table 3). This indicates that the experimental field is relatively fertile probably due to residual P available from previous year's applications in the soil.

The grand mean plant height measured was 59.42 cm, with the highest values measured from IRR-I with 63.55 cm and the last values was measured from IRR III 56.44 cm (Table 4). It is observed from correlation analysis that plant height was significantly, strongly and positively correlated with fresh fruit yield of tomato with r^2 = 0.691. Thus the higher plant height, the more flowers and fruits would be produced from the plants that contribute to yield.

Irrigation levels brought highly significant effect on plant height, canopy width, leaf chlorophyll content, stomatal conductance and total yield at $P < 0.01$ levels (Table 1). As irrigation depth decreased, plant height decreased, highest for full irrigation was 63.558 cm, and lowest for lowest irrigation depth (60% ETo) with 56.44 cm in height (Table 2). Irregular and inadequate water supply reduced growth, yield, and quality of different tomato cultivars (Tan, 1990). Kirnak et al. (2001) found that severe water stress reduced plant height by 46%, stem diameter of egg plant by 51%. Similarly as irrigation depth increased the canopy width increased, measuring highest 49.6780 cm and lowest 45.4927 cm (Table 3). Similar to plant height and canopy width, highest irrigation level increased leaf chlorophyll content 55.02 unit and lowest irrigation depth reduced leaf chlorophyll content to 45.30 unit. Similarly, stomatal conductance of tomato was highest 176.74 for highest irrigation depth, while, lowest 104.36 for lowest irrigation depths (Table 3). This indicates that under low moisture conditions, tomato leaves has low stomatal conductance that contributed to low CO_2 assimilation and further low dry matter production and corresponding fruit yield.

Management of INM practices brought highly significant effect on plant height and canopy width at $P < 0.01$ probability levels; whereas significant effect on canopy diameter, total yield and water use efficiency at 0.05< P > 0.01 probability level (Table 1).

Table 2 shows some of the growth and vegetative response of tomato to integrated nutrient management; there are increments of most growth parameters towards integrated nutrient managements (INM-I), while there is reduction of these growth parameters towards the check. Highest plant height was recorded from INM-I, with 62.51 cm, while similar heights were recorded from all other integrated nutrient managements (Table 2). Similarly highest canopy width, 51.277 cm was recorded from INM-I while last 45.234 cm was recorded from check. Highest canopy diameters with 38.793 cm from INM I and

Table 5. Estimation of Pearson correlations coefficients (r^2) between growth characteristics of tomato as influenced by fertility management practices and irrigation regimes under drip irrigated condition.

Growth characteristics	PH	CD	CW	SD	Stomatal conductance	QuaYield	LeChloFluo	LeChloCon
CD	0.294*							
CW	0.555**	0.796**						
SD	0.336*	0.562**	0.594**					
Stomatal conductance	0.498**	0.084	0.350*	0.234				
QuaYield	0.219	0.302*	0.235	0.233	-0.203			
LeChloFluo	0.029	-0.005	0.046	0.038	-0.215	0.692		
LeChloCon	-0.247	-0.223	-0.346*	-0.3789*	-0.434	-0.048	0.200	
Total fruit yield	0.691**	0.464	0.697**	0.534**	0.587**	0.133	0.003	-0.556**

** indicates significant correlation at $P < 0.01$, * significant correlation at $P < 0.05$. The decimal numbers without any asterisk are non-significant at $P < 0.05$ level of significance. PH: Plant height, CD: Canopy diameter, CW: Canopy width, SD: Stem diameter, QuaYield: Quantum yield, LeChloCon: Chlorophyll content, LeChloFluo: Chlorophyll Fluorescence.

lowest 32.50 cm from check were recorded. Similar highest total fruit yield , 67.483 t ha^{-1}, was obtained from INM-I and INM-II, while lowest total fruit yield was recorded from check with 56.741 t ha^{-1} (Table 2); this most probably due to the fact that water deficit also inhibited the uptake of nitrogen, phosphorus and other nutrients within the plant. Although there is no much yield variations, as application of FYM would improve soil physical properties and would sustain the soil fertility and plant productivity eco-friendly.

Correlations among and within growth and yield characteristics of tomato under various irrigation regimes and INM practices

Some plant growth characteristics have very strong positive and significant associations with total fruit yield such as total fruit yield with plant height (r^2 = 0.69), total fruit yield with canopy width (r^2 = 0.69), total fruit yield with stem diameter (r^2 = 0.53), total fruit yield with stomatal conductance of tomato under various irrigation depths and integrated nutrient applications (r^2 = 0.58) (Table 5). While the analysis indicated that the associations between total fruit yield with leaf chlorophyll has extremes negative and strong significant association (r^2 =-0.55). The analysis further showed that there is no significant association or direct relationships between total fruit yield with canopy diameter, total fruit yield with quantum yield, total fruit yield with ChloFt of tomato under this experiment.

Regression analyses of growth and yield characteristics of tomato under application of various irrigation regimes and INM practices

Regressions analyses were used to relate growth parameter with irrigation depth, with the equation representing the relationship between the two parameters, among plant height and stem diameter has equations and coefficient of determination (R^2) were put on each figure. As irrigation depth decrease there is direct plant height and stem diameter reduction with R^2= 0.92, and R^2 = 0.839 (Figure 1).

The results of chlorophyll fluorescence measurement indicated that as irrigation depth increased the chlorophyll fluorescence yield was reduced (Figure 2). Based on the review of Maxwell and Johnson (2000), light energy absorbed by chlorophyll molecules in a leaf can undergo one of three fates: it can be used to drive photosynthesis (photochemistry), excess energy can be dissipated as heat or it can be re-emitted as light—chlorophyll fluorescence. These three processes occur in competition, such that any increase in the efficiency of one will result in a decrease in the yield of the other two. Hence, by measuring the yield of chlorophyll fluorescence, information about changes in the efficiency of photochemistry and heat dissipation can be gained. The results from the experiment showed that as irrigation depth increased, the portion of light energy absorbed by chlorophyll molecules in a leaf can undergo to drive photosynthesis (photochemistry) performance would be increased so that yield of the tomato plant increased. On the other hand, deficit irrigation increased leaf chlorophyll fluorescence of tomato probably suggesting much light is not used in the photosynthesis performance.

Figure 2 indicates that at higher irrigation regimes, there would be higher stomatal conductance with R^2 = 90%, relationship. Low stomatal conductance indicates significant stomatal closure associated with reduced transpiration (Taiz and Zeiger, 2003). Low stomatal conductance is related to low water supply to the tomato plant, which implies relatively dried conditions in the rizospher.

The regression function analysis indicated that as irrigation depth increases, the leaf chlorophylls fluoresce linearly decreased at R^2= 83%. As irrigation depth

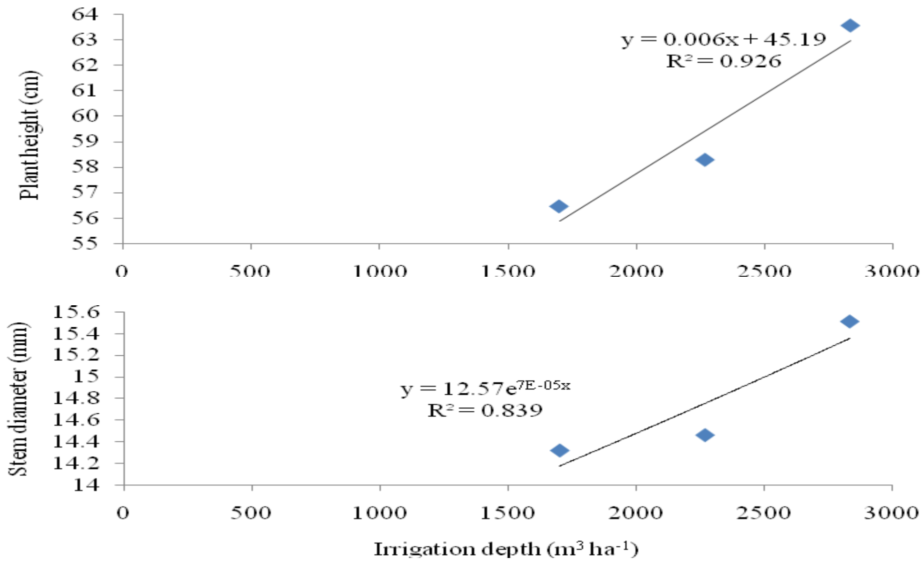

Figure 1. Graphical relationship of regression of growth characteristics, yield and yield component responses of tomato as a function of irrigation water use.

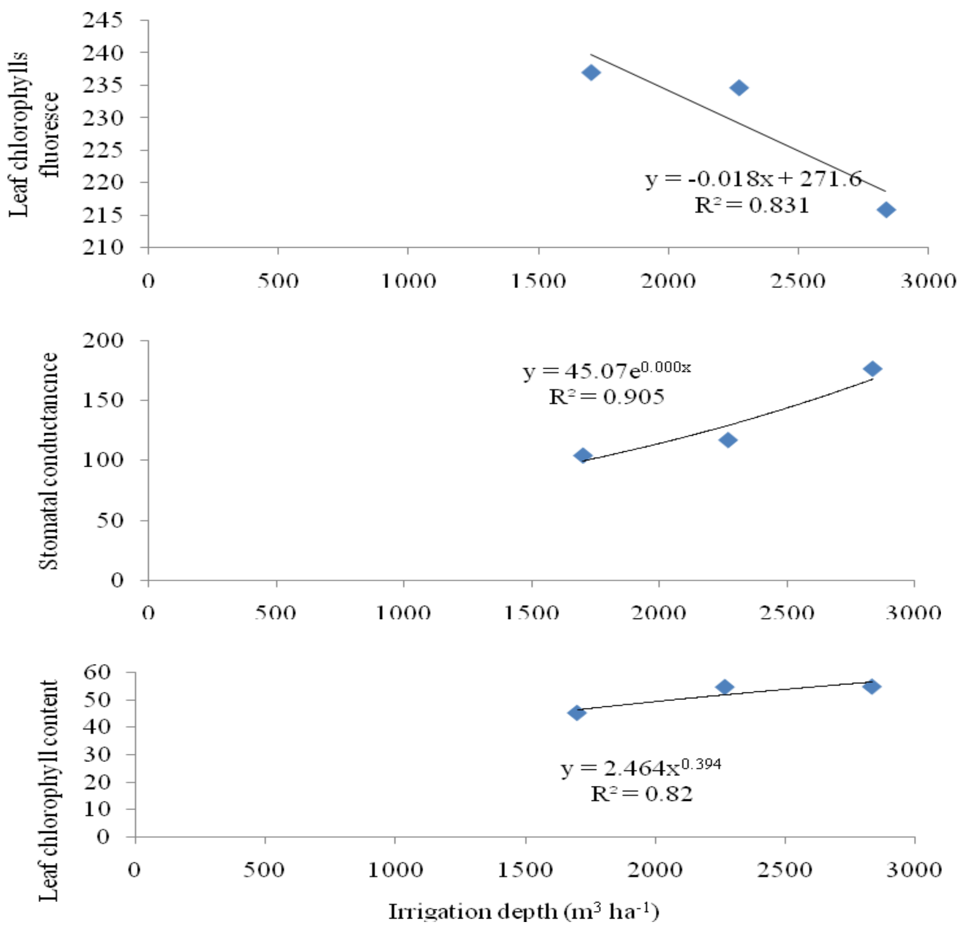

Figure 2. Graphical relationship of regression of leaf chlorophyll content, stomatal conductance and leaf chlorophylls fluorescence responses of tomato as a function of irrigation regimes.

increases, the leaf chlorophyll content was found to be increasing in power function R^2 = 82%. Similar findings were reported by Kirnak et al. (2001) where water stress resulted in significant decreases in chlorophyll content of egg plants

It also showed positive relationship with yield at R^2 = 0.587 with fresh fruit yield. The stomatal conductance is much more closely related to soil water status, and the only plant part that can be directly affected by soil water status is the root system. Mild water stress does usually affect both leaf photosynthesis and stomatal conductance (Taiz and Zeiger, 2003).

Conclusions

Among irrigation levels tested for tomato, highest total yield 82.140 t ha^{-1}, was recorded from full irrigation treatment and followed by 57.30 t ha^{-1} from 80% ETc irrigation levels and lowest total yield 49.30 t ha^{-1} from 60% of full irrigation depth, this finding indicated that tomato crop should be irrigated at full water requirement to get maximum fruit yield. The highest mean plant height was measured from IRR-I (full) and the last value was measured from IRR III (60% of full irrigation). The correlation analysis indicated that plant height was significantly, strongly and positively correlated with fresh fruit yield of tomato. Thus the higher the plant height, the more flowers and fruits would be produced from the plants that contribute to yield. Similarly, highest irrigation level increased leaf chlorophyll content and lowest irrigation depth reduced leaf chlorophyll content; stomatal conductance of tomato was also highest for highest irrigation depth, while lowest for lowest irrigation depths indicating that under low moisture conditions tomato leaves have low stomatal conductance that contributed to low CO_2 assimilation and further low dry matter production and corresponding fruit yield. Water deficit probably inhibited the uptake of nitrogen, phosphorus and other nutrients within the plant. This study showed that there is increments of most tomato vegetative growth parameters towards integrated nutrient managements (INM-I), while there is reduction of these growth parameters towards the check.

This investigation showed that high tomato fruit yield was recorded from INM-I and NM-II treatments with 67.483 and 67.317 t ha^{-1} respectively. However use of high dose of N from treatment INM-I (farmer's N application rate) did not increase tomato fruit yield higher than INM-II indicating application of extra N by growers, did not contribute to yield but may be to various N losses. Although, the exact nutrient (N and P) requirements depend on fertility status of the soil including the cation balances in which the crop is being taken; from this experiment combination of full irrigation treatment with INM-II N and P nutrient application would be recommended for verification. However, addition of fully decomposed farmyard manure did not contribute to yield and requires further research, but might help for the maintenance of good soil conditions.

The results of chlorophyll fluorescence measurement indicated that as irrigation depth increased the chlorophyll fluorescence yield was reduced. The results from this experiment showed that as irrigation depth increased, the portion of light energy absorbed by chlorophyll molecules in a leaf can undergo to drive photosynthesis (photochemistry) performance would be increased so that yield of the tomato plant increased. On the other hand, deficit irrigation increased leaf chlorophyll fluorescence of tomato probably suggesting much light is not used in the photosynthesis performance. From this experiment, it is observed that at higher irrigation regimes, there would be higher stomatal. Low stomatal conductance indicates significant stomatal closure associated with reduced transpiration; low stomatal conductance is related to low water supply to the tomato plant, which implies relatively dried conditions in the rizosphere. As irrigation depth increased the leaf chlorophyll fluorescence linearly decreased; however the leaf chlorophyll content found to be increased.

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Full Length Research Paper

Tropical grass fertilized with wood ash in Cerrado Oxisol: Concentrations of calcium, magnesium and sulphur

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While nutrients such as calcium, magnesium and sulphur are required by plants in lower amounts than the amounts required of nitrogen, phosphorus, and potassium, these nutrients are as important as those required for the growth and development of plants. Varying concentrations of calcium and magnesium can be found in wood ash as residue, which may have a high percentage of these nutrients. This study aims to evaluate the concentration of calcium, magnesium and sulphur in *Brachiaria brizantha*, a genus of tropical grasses, as a function of the levels of wood ash. The experiment was conducted in a greenhouse. The experimental design was completely randomized in a factorial of 6 × 2, corresponding to 6 doses of wood ash (0, 3, 6, 9, 12 and 15 g dm^{-3}) and 2 cultivars of *B. brizantha* (Marandu and Xaraes), and was completed with 6 replicates. Experimental characteristics included the concentrations of calcium, magnesium and sulphur in the dry mass of the shoots and roots of Marandu and Xaraes. The variance of the results was analyzed using an F test at a 5% probability. For wood ash, we performed a regression analysis, and for tropical grasses, we performed a Tukey test at a 5% probability. In the three sections, the highest concentrations of calcium, magnesium and sulphur in the shoots and roots of Marandu and Xaraes are between the wood ash doses of 7.72 and 11.79 g dm^{-3}, respectively. The wood ash influences the nutritional characteristics of the grasses by increasing the concentrations of calcium and magnesium in the shoots of Marandu and Xaraes, respectively, in excess of 42 to 29% and greater than 77 and 39% increments for the roots. The average concentrations of magnesium in shoots of Marandu and Xaraes were 0.87 and 0.94 g kg^{-1}, respectively, while the roots had concentrations of 0.94 and 0.95 g kg^{-1}, respectively. Wood ash as a fertilizer promotes significant changes in the nutritional characteristics of the grasses Marandu and Xaraes when planted in Cerrado Oxisol.

Key words: *Brachiaria brizantha*, mineral nutrition, solid residue.

INTRODUCTION

In agricultural activities, fertilizer application is paramount for the correction or maintenance of soil fertility. The replenishment of soil nutrients in a proper range generally improves the nutritional status of the plants, thus

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increasing crop productivity. Soils of the Brazilian Cerrado, which have low natural fertility (Lopes and Guimaraes, 1994) and commonly dystrophic in nature, should be improved chemically by fertilization.

Fertilization practices, such as the use of wood ash as solid waste, have been used to fertilize and improve soil fertility. Wood ash is a residue capable of generating changes in the chemical properties of soils (Ferreira et al., 2012) because it is rich in calcium and magnesium (Mello, 1930). Chirenje and Ma (2002) reported that the solubility of carbonates in predominant ash follows the potassium sodium >> order >>> calcium > magnesium.

Park et al. (2012) used this waste (wood ash) as a nutrient for ryegrass (*Lolium perenne* L.) and oats (*Avena sativa*), and Pita (2009) applied wood ash on the dry matter production of maize (*Zea mays*). In these studies, the vegetal ash significantly increased the biomass production of these crops.

In this context, this study aimed to evaluate the concentrations of calcium, magnesium and sulphur in the shoots and roots of tropical grasses in 2 cultivars of *Brachiaria Brizantha* (Marandu and Xaraes) as a function of fertilizing Cerrado Oxisol soil with wood ash.

MATERIALS AND METHODS

The testing period of the experiment was from August to December, 2011 in a greenhouse (16°27'46" S; 54°34'49" W). The average temperature recorded during this period was 34°C. The soil was an Oxisol (Embrapa, 1999), which was collected in the 0.0 to 0.20 m layer in the Cerrado. The chemical characteristics of the soil at the beginning of the experiment were as follows: pH of $CaCl_2$ = 4.0, MO = 24.8 g dm^{-3}, P = 1.2 mg dm^{-3}, K = 40.0 mg dm^{-3}, Ca = 0.2 cmolc dm^{-3}, Mg = 0.1 cmolc dm^{-3}; Al = 1.3 cmolc dm^{-3}, V = 6.5%. The physical characteristics of soil were as follows: sand = 476 g kg^{-1}, clay = 441 g kg^{-1}, silt = 83 g kg^{-1}.

The wood ash used in the study was obtained from the boiler food industry, having the following characteristics: $CaCl_2$ pH = 10.90, N = 0.56%, P_2O_5 (Neutral Ammonium Citrate + Water) = 1.7%, K_2O = 2.72%, Zn = 0.01%, Cu = 0.01%, Mn (CNA + water) = 0.00, B = 0.02%, Ca = 2.7%, S = 1.49%.

The design of the experiment was completely randomized, consisting of a factorial of 6 × 2 (6 doses of wood ash: 0, 3, 6, 9, 12 and 15 g dm^{-3} and 2 tropical grasses of the genus *Brachiaria*, (Marandu and Xaraes cultivars) with 6 replicates. Each plot consisted of plastic pots with a capacity of 7 dm^3 of soil. The wood ash was incorporated into the soil and incubated for 30 days. Irrigation was performed using a gravimetric method, maintaining soil moisture at a maximum of 60% of its water holding capacity throughout the experimental period.

After the incubation period, the grasses were sowed at a depth of 2.5 cm and were planted using approximately 20 seeds per pot. When the plants reached 10 cm, they were thinned based on size, uniformity and arrangement within the vessels, resulting in five plants per pot.

All plots received nitrogen fertilization at a dose of 200 mg dm^{-3} using urea as the nitrogen source. This fertilization was repeated for every cut, in which the first fertilization occurred during the plant thinning, while the second and third occurred after each cut. During the first plant growth after thinning, fertilization was held with micronutrients boron, copper, zinc and molybdenum, with sources of boric acid, copper chloride, zinc chloride and sodium molybdate at doses of 1, 39, 2.61, 2.03 and 0.36 mg dm^{-3}, respectively (Bonfim-Silva et al., 2007).

Three cuts were made in the shoots at intervals of 30 days. The first cut was made 30 days after the emergence of forage grasses. The first and second cuttings of the shoots of the fodder was cut to 5 cm from the stem of each plant, while the third cutting was cut close to the stem of each plant.

After each cut, the plant material was collected to obtain a mass and were packed in paper bags to be properly identified and submitted for drying in a forced air oven at 65°C for 72 h until reaching a constant weight (Silva and Queiroz, 2002). The same procedure was repeated on the second and third sections of the plant.

For the third plant sections, the dry weight of each shoot was combined with the gathered plant roots. The roots were separated from the shoots by sieving (mesh sieve of 1.00 and 0.25 mm). The shoots and roots were placed in labelled, dry paper bags under glass using the same methodology of the shoot. After obtaining the mass of the dry material, the material was ground using the Wiley mill.

The concentrations of calcium, magnesium and potassium in the dry mass of the shoots and roots of tropical grasses were determined according to the methodology proposed by Malavolta et al. (1997).

The results were subjected to analysis of variance at 5% probability and significant when applied to regression test doses of wood ash and Tukey test for cultivars of *B.brizantha* using the statistical software Sisvar (Ferreira, 2008).

RESULTS AND DISCUSSION

The concentrations of calcium, magnesium and sulphur in the shoots Marandu and Xaraes were significant with interaction effect between tropical grasses and the dose of wood ash only to the calcium concentration. In the roots, an interaction between these factors occurred only regarding the calcium concentration, with isolated effect for the magnesium concentration and no significant effect was observed in the sulphur concentration (Table 1).

In the three sections of tropical grasses, the calcium concentrations in the shoots of Marandu and Xaraes were fitted to linear and quadratic regression models. In the first section, the highest concentration of calcium in the Marandu shoots was observed at the wood ash dose of 11.79 g dm^{-3}, with increments of 43.76 and 51.05% for Marandu and Xaraes, respectively, when treated with ash compared to plants with no application to this residue (Figure 1A).

In the second section, the calcium concentration was adjusted using a linear regression model. An increase of 42.54 % in the calcium concentration in the shoots of the tropical grasses was observed when comparing results observed from using the highest dose of wood ash of 15 g dm^{-3} to without treatment of wood ash residue (Figure 1B).

In the third section, an isolated effect for tropical grasses and a dose of wood ash was seen. The results were analyzed using a linear regression model. In the grass shoots, an increase of 69.44% in the calcium concentration was observed when compared with the

Table 1. Concentration of calcium, magnesium and sulphur in the shoots and roots of grasses Marandu and Xaraes a function of doses wood ash.

Nutrient	Source of variation			Cuts	Coefficient of variation (%)
	Grasses forage	Doses of wood ash	Interaction		
	0.2840^{ns}	0.0000***	0.0043*	1º	15.59
Calcium shoot	0.0011**	0.0001**	0.8109^{ns}	2º	28.04
	0.3053^{ns}	0.0000***	0.3716^{ns}	3º	15.31
Root	0.0000***	0.0000***	0.0000***	3º	21.49
	0.1324^{ns}	0.0008*	0.8691^{ns}	1º	18.76
Magnesium shoot	0.8525^{ns}	0.0014*	0.2154^{ns}	2º	18.38
	0.0000***	0.0000***	0.6199^{ns}	3º	15.73
Root	0.0001**	0.0000***	0.6598^{ns}	3º	15.15
	0.0815^{ns}	0.1313^{ns}	0.0713^{ns}	1º	6.83
Sulphur shoot	0.0000***	0.3727^{ns}	0.9083^{ns}	2º	7.06
	0.1818^{ns}	0.0095**	0.0980^{ns}	3º	5.95
Root	0.0644^{ns}	0.5822^{ns}	0.2754^{ns}	3º	4.14

ns, Not significant by F test at 0.05 probability. ***, ** and *; Significant at 0.1, 1 and 5% probability level by F test, respectively.

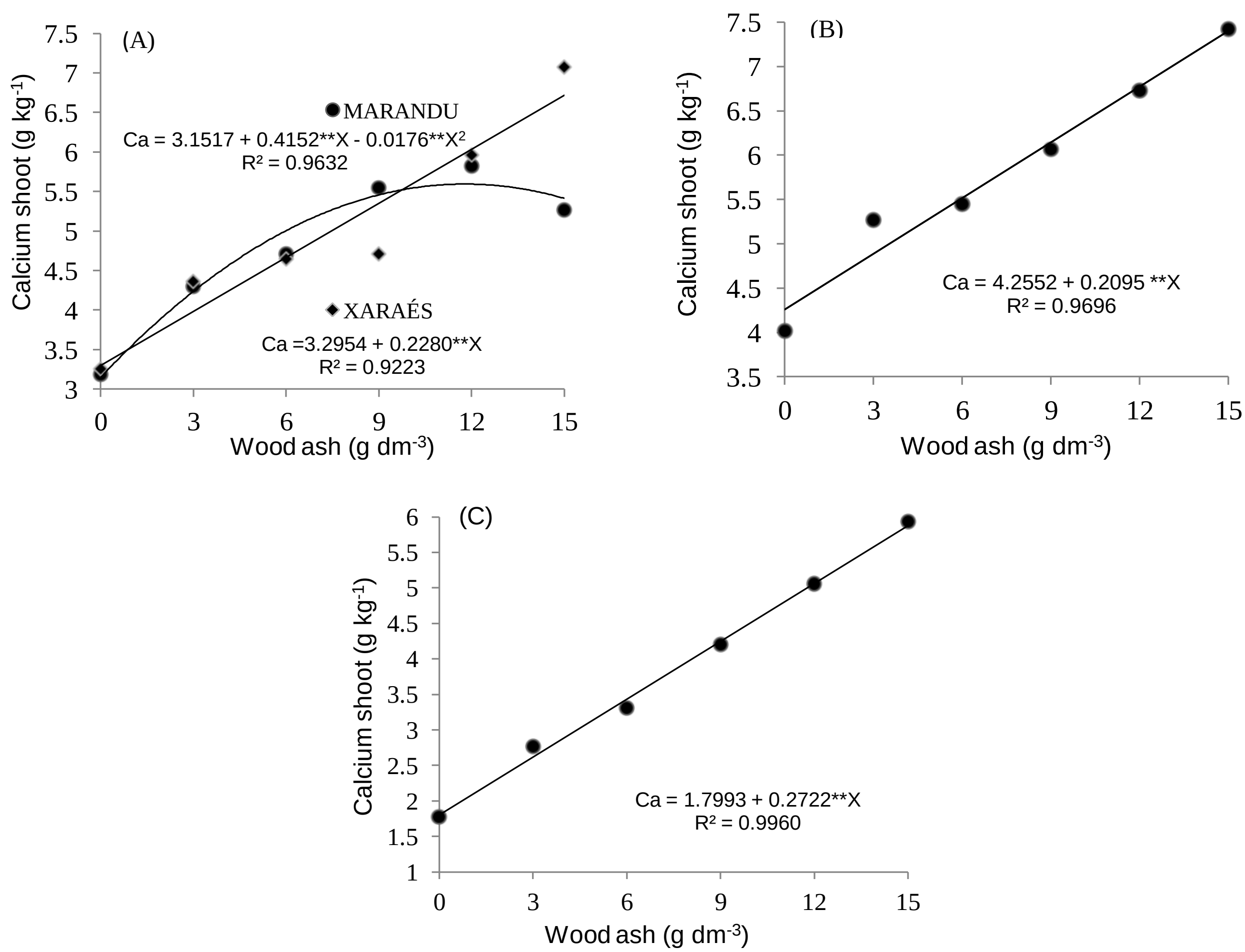

Figure 1. Concentration of calcium (Ca) in shoots of grasses Marandu and Xaraes a function of doses wood ash, on the first (A), second (B) and third (C) cuts. *****. **** and *: Significant at 0.1, 1 and 5% probability level, respectively.

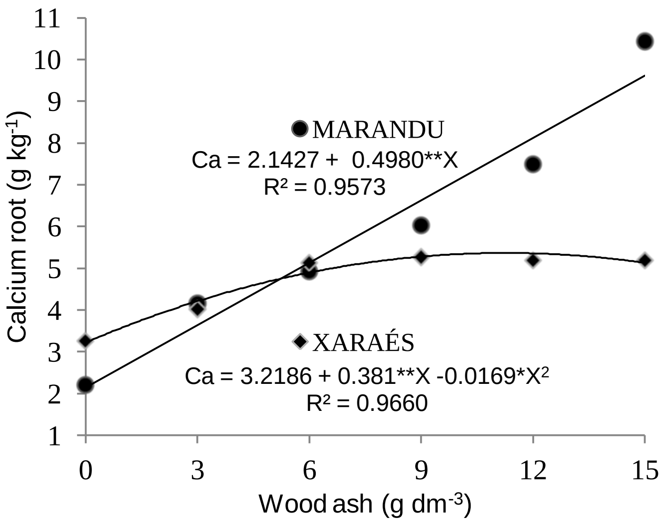

Figure 2. Concentration of calcium (Ca) in roots of grasses Marandu and Xaraes in function of the doses wood ash in third cut. ****** and *: Significant at 1 and 5% probability level, respectively.

maximum dose of vegetal ash without fertilization of wood ash residue (Figure 1C).

In Gallo et al. (1974), normal concentrations of calcium in plants may vary from 2 to 4 g kg^{-1}. In *B. brizantha*, calcium concentration varies between 3 and 6 g kg^{-1} (Werner et al., 1996). Monteiro et al. (1995), who studied the Marandu grass with and without nutrients, found that calcium concentrations observed in the aerial part of the grass were 0.9 g kg^{-1} for the treatment without calcium and 8.5 g kg^{-1} for the complete treatment.

Souza Filho et al. (2000) evaluated Marandu's ability to absorb nutrients as a function of pH and observed calcium concentrations in shoots of 5.22 g kg^{-1}. In Xaraes grass, Costa et al. (2006) observed calcium concentrations of 4.82 and 4.27 g kg^{-1} at 30 and 60 days of growth, respectively.

In the present study, the calcium concentrations observed in shoots of Marandu and Xaraes were 5.88 and 7.40 g kg^{-1}, respectively, for both the second and third cuts. Thus, it is believed that fertilization with wood ash has increased the pH of the soil, providing nutrients and calcium assimilation for the plants, resulting in similar calcium concentrations as those found by Galo et al. (1974) and Werner et al. (1996) but returning higher concentrations than those reported by Costa et al. (2006) and Souza Filho et al. (2000).

At the roots of Marandu and Xaraes, there was a significant relation between tropical grasses and the dose of wood ash in regard to calcium concentration, as observed using linear and quadratic regression models. For Marandu, calcium concentrations increased by 77.73%; for Xaraes grass, the maximum concentration of calcium was observed at the dose of 11.27 g dm^{-3} for wood ash, increasing the concentration of calcium by 39.93% (Figure 2).

Monteiro et al. (1995), who subjected Marandu to treatments both with nutrients and without nutrients, observed calcium concentrations in the grass roots of 0.8 g kg^{-1} in treatments without calcium and 4.6 g kg^{-1} for the treatment with calcium.

In this study, the concentrations of calcium in the Marandu and Xaraes roots were 9.61 and 5.36 g kg^{-1}, respectively. While results show that the concentration of calcium supplied by fertilization exhibit no differences after treatment with wood ash for the aerial part of both the second and third cuts, the absorption of this nutrient is distinct in the roots of these grasses. Thus, the wood ash influences the calcium concentration in the roots of grasses Xaraes and Marandu, possibly contributing to the regulation of metabolism for these plants.

In plants, calcium is very important for the growth of meristematic tissues and proper functioning of the root apex; thus, indirect influences of this nutrient in crops may alter conditions for root growth. Calcium deficiency, an absence or disability of calcium, may lead to a decrease in the growth of roots, becoming darker and eventually dying (Dechen and Nachtigall, 2007).

In the present study, these symptoms of calcium deficiency were not observed because an adequate supply of calcium was provided by the plant fertilizer via the wood ash. Therefore, the concentration of calcium contained in the residue was satisfactory, noting that concentrations are above levels observed by Monteiro et al. (1995). The knowledge of these concentrations suggests that appropriate fertilizer management with wood ash allows for greater mass production of these crops.

For the magnesium concentration in the Marandu and Xaraes shoots, a significant isolated effect was observed between tropical grasses and the dose of wood ash based on linear and quadratic regression models. In the first cut of grass, the maximum concentration of magnesium in the shoots for both forages was observed at a dose of 11.23 g kg^{-1} at increments of 29.07%.

In the second section of the plants, the dose of wood ash of 7.72 g dm^{-3} provided the highest concentration of magnesium with an increase in the concentration of this nutrient in the grass shoots by 47.24% (Figure 3A and B). In the third section of the plants, the magnesium concentration in the Marandu and Xaraes shoots increased by 49.88% when comparing the treatment with the highest dose of wood ash (15 g dm^{-3}) with the treatment without the application with the wood ash residue. For the third section, the magnesium concentration in the grass shoots responded linearly with the dose of wood ash, ranging between 1.09 and 2.23 g kg^{-1} (Figure 3C).

In the present study, the magnesium concentration in the shoots of tropical grasses was 1.06 and 3.10 g kg^{-1} for the first and second cuts, respectively. Monteiro et al. (1995) observed a magnesium concentration of 4.9 g kg^{-1} in Marandu. Batista and Monteiro (2010), who evaluated

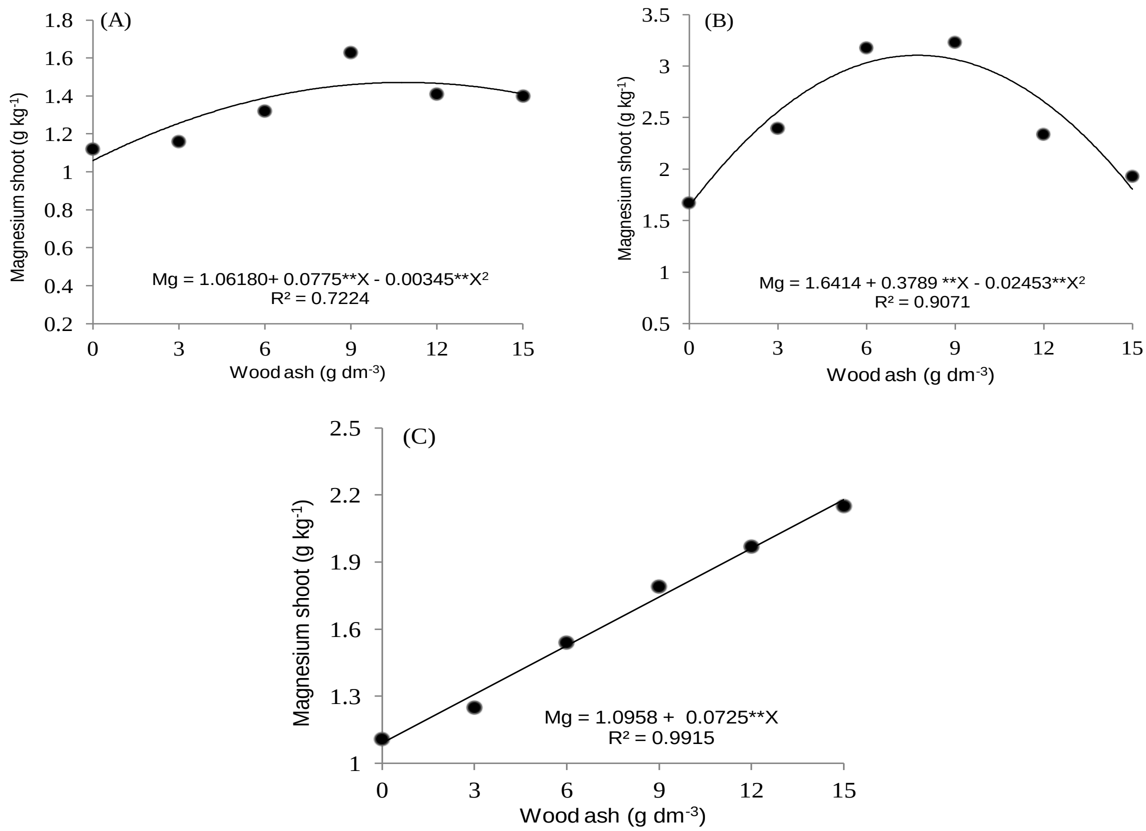

Figure 3. Concentration of magnesium (Mg) in shoots of grasses Marandu and Xaraes a function of doses wood ash, on the first (A), second (B) and third (C) cuts. ***. ** and *: Significant at 1% probability.

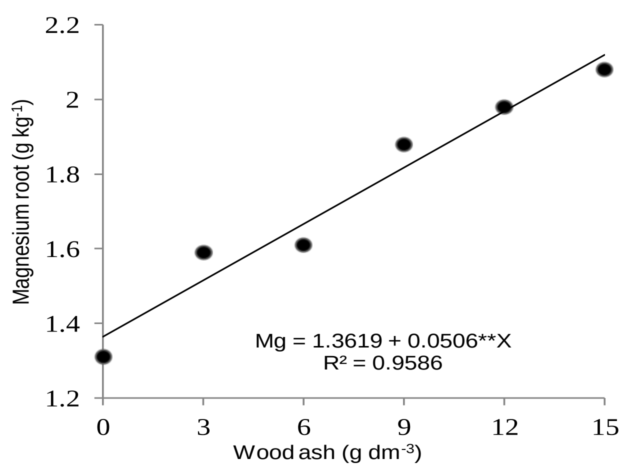

Figure 4. Concentration of magnesium (Mg) in roots of grasses Marandu and Xaraes in function of the doses wood.

concentrations of potassium, calcium and magnesium in Marandu grass that had been fertilized with nitrogen and sulphur, found magnesium concentrations in the leaves of the grasses to be 8.40 and 3.52 g kg^{-1} for the first and second harvests, respectively.

Costa et al. (2007) observed magnesium concentrations in shoots of Xaraes grass of 3.10 and 3.22 g kg^{-1} at 30 and 60 days of growth, respectively. Costa et al. (2010) found that Marandu grass exposed to rates and sources of nitrogen for a period of 3 years had a magnesium concentration of 2.83 g kg^{-1} at the highest nitrogen dose of 300 kg ha^{-1} $year^{-1}$.

The optimal magnesium concentrations for *B. brizantha* Marandu are between 1.5 and 4.0 g kg^{-1} (Werner et al., 1997). In this study, the concentration of magnesium in shoots of tropical grasses meets the range considered to be ideal by these authors.

For the magnesium concentration in the roots of grasses Marandu and Xaraes, a significant isolated effect between the tropical grasses and the dose of wood ash was observed using a linear regression model. Considering the experimental range, the magnesium concentration in the roots of tropical grasses ranged from 1.36 to 2.12 g kg^{-1}, resulting in an increase of 35.89% magnesium concentration in the roots of these grasses (Figure 4).

In studies of mineral nutrition, the required magnesium concentrations in the roots of Marandu grass were of 3.5 g kg^{-1} (Monteiro et al., 1995). For Van Raij (1991), the

Table 2. Sulphur (g kg^{-1}) in the shoot of the grasses Marandu and Xaraes, in second cut.

Cut	Sulphur (g kg^{-1})	
	Marandu	**Xaraes**
Second cut	0.87^b	0.94^a
CV%	7.06	

Means followed by lower case online differ by Tukey test at 5% probability. CV% = coefficient of variation.

requirements of magnesium by crops are relatively modest. Thereby the sulphur and magnesium in plant leaves generally varies between species, for which the magnesium concentration may range from 0.2 to 0.4%.

For the sulphur concentration in Marandu and Xaraes shoots and roots, there was no interactions effect in the levels of wood ash; significant differences only were observed with isolated effect for the tropical grasses in the second cut (Table 2). The mean magnesium concentrations observed in the shoots Marandu and Xaraes were 0.91 and 0.94 g kg^{-1}, respectively, for the first cut and were 0.91 and 0.93 g kg^{-1}, respectively, for the third section. At the root, the concentration of sulphur was 0.94 g kg^{-1} for Marandu and 0.95 g kg^{-1} for Xaraes.

The concentrations of sulphur deemed appropriate for *B. brizantha* Marandu grass are between 1.5 and 3.0 g kg^{-1}. Thus, in this study the concentration of sulphur in the Marandu and Xaraes shoots for three cuts were lower than the values referenced by previous authors.

In general, many organic sulphur compounds in parts of plants have vegetable proteins containing sulphur and nitrogen, and these nutrients are related in a range of proportions, indicating a proper nutrition for each culture.

Generally, the N:S ratio can range from 13:1 to 14:1. In the present study, the dose of nitrogen (urea) of 200 mg dm^{-3} increased by 0.56% from using wood ash and the sulphur content provided by manure with wood ash increased by 1.49% (not considering the organic matter ground), which may indicate that the nitrogen and sulphur contents are below the relative proportion observed by Werner and Monteiro (1988). This low ratio may be explained by the concentration of sulphur being outside of the range considered adequate for these crops.

Cultures generally rely proportionally on more sulphur in soil, with an ideal of 5% organic matter in the soil, that is, 50 g dm^{-3}, and these levels in tropical soils are generally low.

Conclusions

The concentrations of calcium and magnesium in the tropical grasses Marandu and Xaraes were measured in relation to the levels of wood ash. Marandu and Xaraes were planted in Cerrado Oxisol soil and the levels were consistent with concentrations considered suitable for these grasses.

To obtain an adequate concentration of sulphur in tropical grasses, the use of wood ash as a source of fertilizer requires more research but can act as a supplement when combined with mineral fertilizer.

Wood ash as a fertilizer promotes significant changes in the nutritional characteristics of the grasses Marandu and Xaraes when planted in Cerrado Oxisol.

Conflict of Interests

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

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Full Length Research Paper

Physical fractionation of soil organic matter under different land use systems

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A sustainable management of soil organic matter is fundamental for the maintenance of the soil productivity. The objective of this study was to evaluate changes in the contents and storage of the fractions of the soil organic matter under different management systems compared to the native vegetation as reference in a Red-yellow Latosol in the southern region of the State of Espírito Santo, Brazil. The applied treatments consisted of four land use systems: native forest, annual crop, perennial crop and pasture. Samples were taken from 0 to 10 cm layer for the physical fractionation of soil organic matter, analyzing the amount of total organic carbon and carbon in the light and heavy fraction determining the storage of carbon in the light and heavy fraction. In the native forest, the amounts and storage of carbon were the highest, both in the light and heavy fraction showing stability in the soil carbon reserve. The light fractions of the soil organic matter are more sensitive to the management of the land use systems than the heavy fraction and total organic carbon.

Key words: Soil tillage, agroecosystems, organic carbon.

INTRODUCTION

The different cultivation systems adopted in farming areas after the removal of the native vegetation, induce alterations in the chemical, physical and biological properties of the soil, depending on the type of crop and adopted cultivation practices, establish a new equilibrium in the soil system. In Brazil historically, many management practices were imported from countries with temperate climate where the tilling of the soil surface layer is a practice that is often fundamental for the success of the farming activity. These practices however, increase the oxygen entry into the soil, favoring decomposition processes of soil organic matter (SOM). In Brazilian, soils which are highly weathered with low fertility and marked acidity; organic matter improves the soil fertility because it is the main soil load matrix and also acts as nutrient reservoir. On the other hand, it is known that in tropical soils, the decomposition of organic matter is five times higher than in temperate regions,

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reinforcing the importance of management practices to maintain or increase the SOM contents (Silva and Machado, 2000).

Research addressing the diverse compartments of the organic matter, as well as their relations with farm management, contributes to the development of strategies for the sustainable use of soils with the aim of reducing the impact of farming activities on the environment (Pinheiro et al., 2004; Rangel et al., 2007). The physical fractionation of SOM has proved promising in the distinction of carbon compartments of the soil subject to the influence of various management systems and in the identification of the mechanisms that physically protect organic matter (Collins et al., 1997), besides characterizing the relations between organic matter and soil aggregation (Guegan et al., 1997; Freixo et al., 2002).

Physical fractionation separates SOM in two main compartments based on the specific densities of the organic fractions: i) light fraction (LF), with density lower than 1.7 g cm^{-3} which is a transitory compartment between plant residues and the stabilized and humified organic matter with a higher C/N relation than that of the soil and representing mostly the smallest fraction of the dead compartment of SOM which encompasses, normally from 2 to 18% of total C and from 1 to 12% of total N of the soil and, ii) heavy fraction (HF) composed of organic matter fixed to the colloids or retained on the soil aggregates which can contain more than 90% of the total soil C (Janzen et al., 1992; Vincent et al., 1996; Rangel et al., 2007).

The LF has proved to be an early indicator of the changes in SOM caused by different uses and management systems. Several solutions are used in its separation but little is known about their effects on the quantity and quality of the extracted fraction. Also, little is known about the possible effects of the separation solution on the posterior qualification of OC (Demolinari et al., 2008). The HF consisted of organic matter in advanced decomposition stages not visually distinguishable, strongly connected to the mineral fraction of the soil constituting primary mineral-organic complexes and containing organic composts of high recalcitrance (Christensen, 2000; Roscoe and Machado, 2002). The HF corresponds to SOM in advanced decomposition stage being more stable and with a longer residence time in soil than the LF (Chistensen, 2000; Souza et al., 2006). The purpose of this study was to evaluate the effects of different land use systems on contents, stocks and fractions of organic carbon of a Yellow Red Latosol in the southern region of the State of Espírito Santo, Brazil.

MATERIALS AND METHODS

This study analyzed samples of a Red-Yellow Latosol from the Federal Institute of Education, Science and Technology of Espírito Santo, campus Alegre, Espírito Santo, Brazil (20º 45’ 51” S; 41º 27’ 24” W; 131.4 m).

For the evaluation of different land use systems, four neighboring areas were selected and distributed in a homogenous soil strip. The evaluated land use systems were: native forest (NF), annual crop (AC), perennial crop (PC) and pasture (PT). These land use systems were chosen based on the use history and the characteristics of the adopted management systems. The history of the evaluated systems is shown in Table 1.

Soil samples were collected in September in 2012, selecting four 300 m^2 plots per system (15 × 20 m). Fifteen simple samples per land use and plot were collected from the 0 to 10 cm layer, and blended to a composite sample, thus resulting in four composite samples per use system, each one constituting a replication. For the evaluation of soil bulk density, an undisturbed sample per plot was collected from the same layer (0 to 10 cm) with a volumetric ring of 89.53 cm^3, calculating the bulk density of the soil of each system from the average of four replications. In all use systems, before collecting the soil samples, the plant residues on the soil surface were removed.

The composite samples (replications) were packed in plastic bags and sent to the laboratory. For the analysis of organic carbon contents (OC) the samples were air-dried, loosened, ground in a mortar and sieved through a 0.210 mm mesh. The samples for the physical fractionation were air-dried, loosened and sieved through a 2 mm mesh to obtain air-dried soil.

The OC was determined by the method described by Yeomans and Bremner (1988). The light and heavy fractions of the SOM were obtained as described by Anderson and Ingram (1989). The OC content in the light fraction (C-LF) was determined according to the methodology described by Yeomans and Bremner (1988). The OC content in the heavy fraction (C-HF) was obtained by the difference: C-HF = OC - C-LF. Based on the data of the contents of C-LF and OC, the proportion C-LF/OC was calculated by the following formula: (C-LF/OC) x 100. The storage of C-LF and C-HF in the different land use systems was calculated by the following formula: storage of C-LF or C-HF (t ha^{-1}) = content of C-LF or C-HF (g kg^{-1}) x Ds x E/10 in which Ds = soil density (kg dm^{-3}) (average of four replications) and; E = thickness of the soil layer (cm).

The data of the contents of OC, C-LF and C-HF of the relation C-LF/OC and of the storages of C-LF and C-HF were subjected to analysis of variance to test the effects of the land use systems. The means were compared by the Tukey test at 5% using the statistical package SAEG.

RESULTS

The content total of organic carbon (TOC) was altered significantly by the land use systems (Table 2). The highest contents were observed in the NF system and the lowest in AC and PC with TOC contents varying from 14.42 to 8.10 g kg^{-1} in NF and PC, respectively.

In comparison to the NF area, all other management systems reduced the TOC contents indicating an increase in the oxidation rate of the soil TOC under cultivation. In relation to the NF system, the reductions in TOC contents were respectively, 26.7, 43.8 and 9.7%, for the use systems AC, PC, PT.

The results of this work indicate that the higher contribution of crop residues to the PT systems (mainly from the root system) and AC (crop residues of weeds that invade the area in the fallow period) can lead to over time to a higher storage of soil TOC, exceeding the

Table 1. Use History/Record of the systems installed in Red-Yellow Latosol in the State of Espírito Santo, Brazil.

Use system	Symbol	Use History/Record
Native forest	NF	Remnant of native forest located about 500 m away from the other use systems with the same soil class. The state of soil equilibrium was used as reference.
Annual crop (Sorghum)	AC	Area previously cultivated with vegetables for 11 years; in 1994 planting of forage sorghum (*Sorghum bicolor*) for animal feeding. The field was re-planted every year in conventional tillage system using crop-specific cultural practices. The area was left fallow in the second growing season.
Perennial crop (Coffee)	PC	Area previously used as orange orchard for 23 years, where in 2006 conilon coffee farming was implanted (*Coffea canephora*). Crop-specific cultural practices were used including pruning (once a year), leaving the crop residues between the crop rows.
Pasture	PT	Pasture consisting initially of Pernambuco grass, a native species of the region. After 64 years in 1994, *Brachiaria decumbens* was planted and continuously grazed by cattle in semi-intensive regime and without soil fertility management.

Table 2. Total organic carbon contents (OC), light fraction carbon (C-LF), organic carbon percentage in the light fraction in relation to the organic carbon (C-LF/CO) and organic carbon in the heavy fraction (C-HF), in the 0 - 10 cm layer of a Red-Yellow Latosol under different use systems in the State of Espírito Santo, Brazil.

Use system	TOC	C-LF	C-LF/OC	C-HF
	---------- $g\ kg^{-1}$ ----------		%	$g\ kg^{-1}$
NF	14.42 a	3.50 a	24.10 a	10.92 ab
AC	10.57 bc	0.37 b	3.70 b	10.20 b
PC	8.10 c	0.50 b	6.55 b	7.60 c
PT	13.02 b	0.37 b	2.95 b	12.65 a

Averages followed by the same letter in the column do not differ statistically by the Tukey test to the level of 5% of probability. NF= Native forest, AC = annual crop, PC = Perennial crop and PT = pasture.

contents found in the PC system where there is less plant residue input.

Among the cultivation systems, the absence of or the reduction in soil tillage in the PT area resulted in an increase of 60.7 and 23.3%, respectively, in the soil TOC content in this system, in relation to the PC and AC systems. The higher value of OC in AC, similar to the PT system can be explained by the management history of this land with soil tillage and incorporation of residues, lime and fertilizer.

Table 2 shows the TOC contents in the light fraction (C-LF), the relation C-LF/CO and the TOC content of the heavy fraction (C-HF) of SOM in the different land use systems. In the different land use systems, C in the light fraction (C-LF) had highest contents in NF. This indicated that the physical protection of the light fraction of SOM is better in this system. The C-LF contents were greatly reduced in the cultivated areas. In relation to the NF system, where C-LF was 3.5 g kg^{-1}, the contents of this fraction in the systems AC, PC, and PT decreased by 85.71, 89.43 and 89.43%, respectively.

The C in the heavy fraction (C-HF) corresponded, on average, to 90.7% of the soil TOC (Figure 1), increasing the proportion in the following order: NF > PC > AC > PT, with values above 93% in AC, PC and PT. The most labile fraction of SOM (C-LF) represented a small percentage of soil TOC (Table 3). In the evaluated systems, C-LF represented from 2.95 (PT) to 24.1% (NF) of soil TOC. In the forest area, the percentage of C-LF was 3.7 to 8.2 times higher than that in the PC and PT systems.

Carbon storage in the light and heavy fractions of SOM is shown in Table 3. The storage of C-LF varied from 0.44 a 3.85 t ha^{-1} with the highest value in the NF system.

The increase and percentage reductions in carbon contents and storage in samples collected from the different land use systems are shown in Figure 2. The values obtained in the soil of native forest were used as

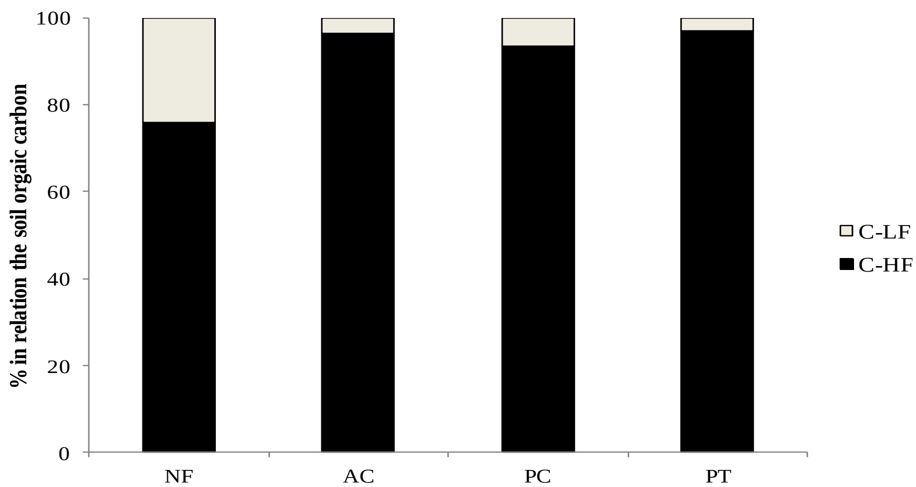

Figure 1. Proportion of carbon contents in the light fraction (C-LF) and carbon in the heavy fraction (C-HF) in relation to the total organic carbon (TOC) of the soil. NF = Native forest, AC = annual crop, PC = perennial crop and PT = pasture. Espírito Santo, Brazil.

Table 3. Bulk density (Bd), storage of organic carbon light fraction and storage of organic carbon heavy fraction in the 0 - 10 cm layer of a Red-Yellow Latosol under different use systems in the State of Espírito Santo, Brazil.

Use system	Bd	Storage C-LF	Storage C-HF
	kg dm^{-3}	------------------- t ha^{-1}	--------------------
NF	1.09 a	3.85 a	11.95ab
AC	1.19 a	0.44b	12.17ab
PC	1.27 a	0.68b	10.18b
PT	1.29 a	0.44b	15.21a

Averages followed by the same letter in the column do not differ statistically by the Tukey test to the level of 5% in probability. NF = Native forest, AC = annual crop, PC = perennial crop and PT = pasture.

reference. Highest variations among the analyzed carbon fractions were detected in the C-HF contents. In the PT system, an average increase in C-HF contents of 15.8% in relation to the forest soil was observed.

DISCUSSION

According to Stevenson (1994), the reduction in the organic matter content of the cultivated soils is due to the reduction in the quantity of residue soil input and to the increase of microbial activity and, consequently, the rate of organic matter decomposition, due to better aeration, increase in soil temperature and the more frequent alternation of wetting and drying cycles of the soil. The increase in C quantities lost by erosion and leaching explains, similarly, the decrease in organic matter in cultivated areas (Ramani et al., 1997) as shown by the contents of OC in the systems with annual and perennial crops (Table 2).

In a study with a Latosol under two types of plant cover [natural vegetation of the Cerrado (Brazilian savannah) and corn cultivation for 30 years]. Passos et al. (2007) concluded that the type of plant cover and soil management influenced the OC contents of the soil. According to Leal et al. (2010), the highest contents of OC in systems without soil tillage can be explained by the factors associated to the protection mechanisms of SOM: recalcitrance, physical protection and chemical molecular interaction.

According to Longo and Espíndola (2000), these reductions in the OC contents in cultivated soils are explained by the fact that organic matter is concentrated in the uppermost soil layers, and is for this reason, more susceptible to microclimatic alterations caused by the use and management systems. These results (Table 2) are in agreement with those of Tiessen et al. (1994) and Mielniczuk et al. (2003). According to these authors, in cultivated areas of the tropics, the high rates of SOM loss result in a reduction of 50% in the original SOM content in relation to the same soil under natural vegetation, in less than 10 years of cultivation, mainly in the systems with

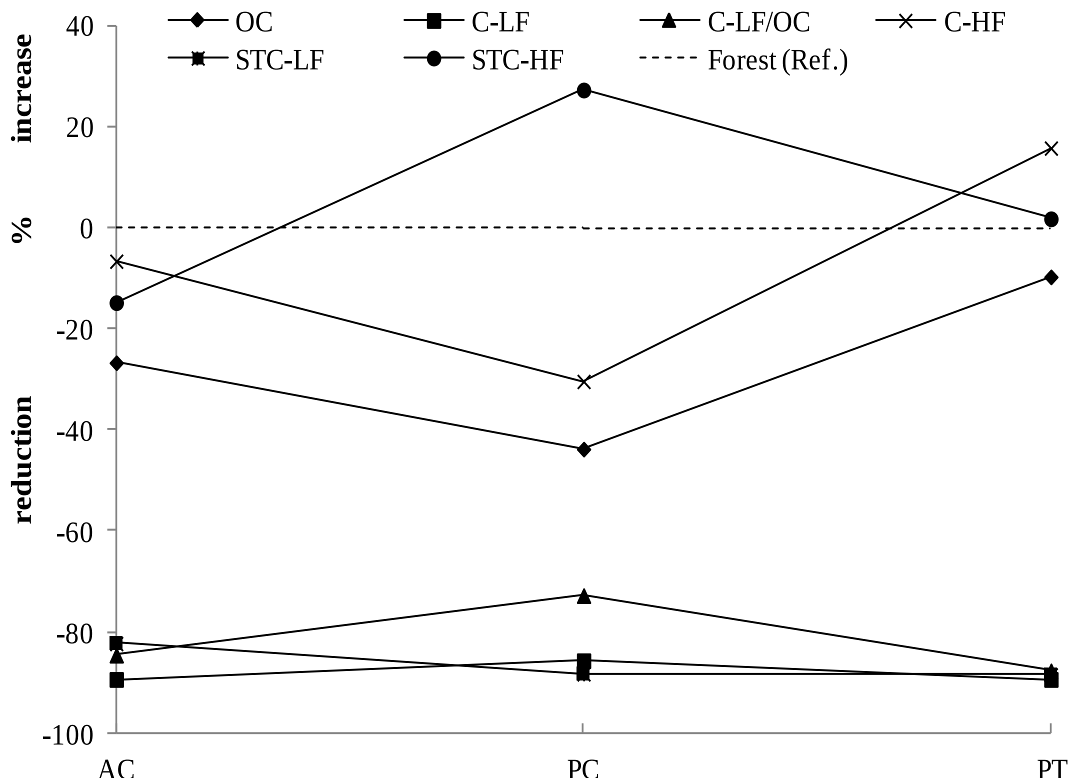

Figure 2. Percentage increase and reduction of the carbon fractions in Red-Yellow Latosol in the systems of annual crop (AC), perennial crop (PC) and pasture (PT) in relation to the native forest (NF-reference). TOC = total organic carbon of the soil; C-LF = carbon in light fraction; C-LF/OC = relation between C-LF and TOC; C-HF = carbon in heavy fraction; STC-LF = storage of carbon in light fraction and; STC-HP = storage of carbon in heavy fraction. Espírito Santo, Brazil.

low input of plant residues.

Doran (1980) reported that soil tillage, as it occurs in some PC systems (hoe-weeding) and periodically in the AC system, causes disturbance inducing stress in the microbial populations and, once the C additions in these systems are lower, there is a higher consume of soil TOC by microorganisms resulting in SOM reduction.

The increase in TOC contents observed in the PT system can be associated to grazing of the grasses, which may have led to the increase in soil TOC contents due to the high deposition of organic matter, the high allocation of photosynthates to the root system, the high root contents of lignin and the higher humification coefficient of the carbon added to the soil (Boddey et al., 2001; Pillon et al., 2001).

Considering the run time of the PC systems (5 years), the absence of soil tillage and the input of residues from cultural practices on the field, higher TOC contents would be expected in this system of soil use. In the AC system, the observed reduction in the TOC contents indicates that: i) the residue contribution and/or conversion to SOM were less efficient than in the forest area (NF); ii) that these systems are more favorable for the decomposition of organic matter in (Silva et al., 2004); iii) or that a longer period is required until the TOC contents in this system come close to those observed in the forest soil. Another factor to be considered is the quality of the residues added to the soil in the evaluated use systems. Silva et al. (2004) reported that plants or younger tissues are richer in proteins, minerals and the water-soluble fraction, whereas the tissues of older plants contain higher proportions of recalcitrant compounds, e.g., cellulose, hemicellulose, lignin, and polyphenols.

These results (Table 3) are in line with Freixo et al. (2002) and Rangel et al. (2007), who reported an average reduction in the C-LF contents of 85 and 89%, respectively, in Latosol under different use systems, in relation to the same soil under native scrubland (study reference).

In non-anthropized systems, such as NF, the source of organic substances is mainly associated to the natural deposition of plant residues that find their way into the soil in the form of leaves, branches and other organic fragments, as well as to organic substances derived from root decomposition (Pohlman and Mccoll, 1988). Rovira and Vallejo (2002) reported that the resistance to acid hydrolysis is higher for the recalcitrant organic polymers (lignins, suberins, resins, and wax). Therefore, the highest C-LF contents found in the NF soil can also be associated to the quality of crop residues applied to the soil, which probably contain higher proportions of carbon that is more recalcitrant from the chemical point of view.

The small contribution of C-LF to the TOC of the soil (C-LF/TOC), mainly in the crop systems, is probably associated to lower residue contribution and to the higher decomposition rate of this fraction in soils that are less structured, more oxygenated, with high temperatures, and plentiful supply of water liming and fertilization (Christensen, 2000). Another explanation for the small participation of the C-LF in the OC of the soil is that the only protection mechanism of this fraction is the recalcitrance of its constituent materials, making the C-LF more available to the microbiota than the HF of SOM (Roscoe and Machado, 2002).

For clay soils of temperate regions, Parfitt et al. (1997) reported a percentage of C-LF varying from 16 to 39% of the soil TOC. However, for clay Latosols of tropical regions under different management systems (forest, scrubland and pasture), Golchin et al. (1995) and Freixo et al. (2002) found that the relation C-LF/OC varied from 1 to 4% of the soil TOC. In a study about the densimetric physical fractionation of SOM in a Latosol under different management systems (forest, eucalyptus, pinus, pasture, and corn), Rangel et al. (2007) reported a variation of 2.3 to 12% of TOC in the relation C-LF/TOC which values similar are to those listed in Table 2 with the exception of the NF system.

The C-HF contents varied from 7.60 to 12.65 g kg^{-1}, with no difference in the contents in the NF from the PT system, as similarly reported by Potes et al. (2010). The storage of C-HF was little influenced by the management systems of the soil, very likely due to the short period of cultivation and the constant tillage of the soil in the AC system, once the following groups of protection mechanisms of SOM act in this fraction: molecular recalcitrance, physical protection and chemical interaction, extending the carbon cycling time in these in relation to the light carbon fraction, where only the molecular recalcitrance mechanism acts (Leal et al., 2010).

The highest storage of C-LF observed in the NF system was probably due to the higher contribution of plant material in relation to the other management systems. According to Six et al. (2002), the C-LF is strongly influenced by the quantity of the dry matter added to the soil, being the storage of C-LF directly proportional to this input.

This behavior differed from that of the C-LF, which decreased in all evaluated systems. For the properties of TOC, C-LF, C-LF/TOC and STC-LF, there was a reduction in relation to the reference system (NF), indicating the susceptibility of organic matter to oxidation in environments with low input of plant residues and management with less emphasis on conservation. Considering the different land use systems, the highest reductions in carbon contents were noted in the C-LF, making this property very useful as an indicator of changes in soil organic matter in different agroecosystems.

Conclusions

The clearing of native forest (NF) and the adoption of different land use systems caused some significant alterations in the contents and storage of the fractions of the evaluated organic matter. In relation to the reference system (NF), there was a reduction in the contents of TOC, C-LF, of the relation C-LF/TOC and in the storage of C-LF in all evaluated use systems. The mean reductions in the evaluated properties were highest in the soil in the area of annual crop (AC) compared to the NF system decreasing 89.4% in the C-LF content. The land use systems showed the following decreasing order of SOM preservation: NF >PT > PC > AC. Carbon in the light fraction (C-LF) was the most sensitive property and reflected the main changes in the OC of the soil and was induced by the different land use systems.

Conflict of Interests

The authors have not declared any conflict of interests.

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Review

The epidemiology of *Pectobacterium* and *Dickeya* species and the role of calcium in postharvest soft rot infection of potato (*Solanum tuberosum*) caused by the pathogens: A review

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Contamination of potato with soft rotting enterobacteria belonging to the *Pectobacterium* and *Dickeya* genera is one of the biggest problems in potato production. Calcium plays an important role in minimising the severity and incidence of potato tuber soft rot in storage. This review gives a detailed assessment of the epidemiology of the pathogens and how calcium affects potato tuber soft rot in storage.

Key words: Potato, soft rot, calcium, *Pectobacterium*, *Dickeya*.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is grown worldwide and is the fourth most important crop in the world (Krauss, 2008; Kandil et al., 2011). To meet the food and nutritional needs of an ever-increasing population, predicted to reach 6.3 billion in 2020, there is need to manage and control pests and diseases (Krauss, 2001). Bacterial soft rot causes losses of up to 60%, in the field, in transit and during storage (Abo-Elyousr et al., 2010; Toth et al., 2011; Ngadze et al., 2012). Potato tuber soft rot is caused by pectinolytic *Pectobacterium* and *Dickeya* bacterium species (Czajkowski et al., 2011). Postharvest soft rots can occur as a result of injuries during harvesting and handling (Conway, 1989; Bhat et al., 2010) and the prevailing weather conditions during the growing season can also affect disease occurrence on stored tubers (Cwalina-Ambroziak et al., 2009).

Calcium is an important nutrient for plant growth and is normally present in adequate amounts in calcareous alkaline soils and in irrigation water (Stark et al., 2004). Tuber internal defects can be reduced by improving tuber calcium, and an increase in tuber calcium improves storability (Conway, 1989; Ozgen and Palta, 2005) whilst localized tissue calcium deficiency initiates cell death and tissue necrosis (Kleinhenz et al., 1999). Calcium is a determining factor in the resistance and susceptibility of potato tubers to bacterial soft rot (Miles et al., 2009) and thus, effective postharvest control of bacterial soft rot in potato can be achieved by increasing tuber calcium through fertilization and postharvest vacuum infiltration with calcium sulphate or calcium nitrate (Conway et al., 1992). Other cultural practices that work hand-in-hand with nutrient management include tillage, irrigation management, crop sequence and soil pH adjustment (Huber and Haneklaus, 2007). There is no existing practical or effective chemical control for bacterial tuber soft rot. However, yield losses can be

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reduced by good crop husbandry, use of non-contaminated planting material and cultivation of resistant or tolerant varieties (Conway et al., 1992; Toth et al., 2003; Abo-Elyousr et al., 2010).

SOFT ROT BACTERIA

The main enterobacteria that cause tuber soft rot are *Pectobacterium carotovora* subspecies *carotovora* (*Pcc*), *Pectobacterium atrosepticum* (*Pa*), *Pectobacterium carotovora* subspecies *brasiliense* (*Pcb*) and *Dickeya* species (Lojkowska and Kelman, 1994; Ngadze et al., 2012).Tubers can be contaminated by more than one bacterial pathogen and contamination is unavoidable (Perombelon, 2000). The soft rot bacteria are rod shaped, gram negative, non-sporing, facultative anaerobes. They are mobile and have peritrichous flagella (Samson et al., 2005; Czajkowski et al., 2011). *Pectobacterium* species occur singly, in pairs and at times in small chains.

On nutrient agar, bacterial colonies incubated for 48 h at 28°C are round convex shaped and cream coloured (Mahmoudi et al., 2007). Soft rot bacteria are opportunistic pathogens which produce cell wall degrading enzymes in large amounts thereby out-competing other pathogens. They are pectinolytic and produce a wide range of enzymes which include proteases, cellulases, pectinases and xylanases (Perombelon, 2002). The susceptibility of tubers to rotting differs with varieties and also with the rate of wound healing (Murant and Wood, 1957) as well as tuber calcium content (Locascio et al., 1992; Czajkowski et al., 2011)

SOFT ROT BACTERIA HOST RANGE

Bacteria belonging to the *Dickeya* and *Pectobacterium* genera have a wide range of plant hosts and the host range overlaps but not completely (Ma et al., 2007). The *Dickeya* species are dominant worldwide and infect maize, *Chrysanthemum* species, banana, potato, *Dianthus* species and tomato (Samson et al., 2005) among other hosts. *Pectobacterium carotovora* subspecies *carotovora* (*Pcc*) has a wide host range which includes onions, carrots, potatoes, lettuce, tomatoes, cucumbers, ornamentals and others (Rashid et al., 2012). *Pectobacterium atroseptica* (*Pa*) is almost exclusive to potato (Ma et al., 2007). *Pectobacterium carotovora* subspecies *brasiliense* and *Pcc* are more aggressive than *Pa* in causing potato tuber and stem rot (Marquez-villavicencio et al., 2011). However, *Pa* has a wider host range compared to *Pcc* and *Pcb* (Czajkowski et al., 2011). *Pectobacterium carotovora* subspecies *carotovora* and *Pa* are virulent at 28 to 32°C but *Pcc* is more pathogenic at higher temperatures than *Pa* (Schober and Zadoks, 1999; Rashid et al., 2012). Studies by Ngadze et al. (2012) showed that *Dickeya dadantii* is more virulent than *Pa* and *Pcb* under Zimbabwean climatic conditions.

THE GEOGRAPHICAL DISTRIBUTION OF SOFT ROT BACTERIA

Potato tuber losses during storage and in transit due to bacterial soft rot caused by *Pa* and *Pcc* are of worldwide occurrence and importance (McGuire and Kelman, 1983; Bain and Pérombelon, 1988; Snijder and van Tuyl, 2003) and the species of *Pectobacterium* that cause soft rots vary with climatic conditions and geographical location (Peltzer and Sivasithamparam, 1985). The *Pectobacterium carotovora* subspecies *carotovora* occurs both in temperate and warm climates (Abo-Elyousr et al., 2010) while *P. atroseptica* is restricted to temperate climates (Perombelon, 2000). The *P. carotovora* subspecies *brasiliense* was first reported in Brazil in 2004 and later in South Africa, United States, Israel (Marquez-Villavicencio et al., 2011) and Zimbabwe (Ngadze et al., 2012). The first *Dickeya* species report on potato was in the Netherlands in the 1970s (Toth et al., 2011). *Dickeya* species occur in temperate, subtropical and tropical regions (Czajkowski et al., 2011). In storage, the extent of potato decay depends on the cultivar, storage conditions, inoculum concentration (Bain and Perombelon, 1988) and tuber characteristics like calcium content.

EPIDEMIOLOGY AND AETIOLOGY

Host-pathogen relationships determine the ability of a host plant or plant organ to avoid infection or invasion by the pathogen. Avoidance or resistance/tolerance is achieved through inherent tolerance/resistance mechanisms of the host plant or plant organ related to its ability to reduce or limit pathogen penetration, development and its ability to reproduce (Graham and Webb, 1991; Toth et al., 2003). The major source of field inoculum is the mother tuber. Bacteria can contaminate progeny tubers when they are transmitted by soil water through the roots and via the vascular system. When contaminated progeny tubers in storage are exposed to conditions favourable for bacterial growth, tissue maceration occurs (Perombelon, 2002; Abo-Elyousr et al., 2010; Czajkowski et al., 2011). Tissue maceration is the separation of cells from each other in a tissue system (Bateman, 1968). Soft rot bacteria can survive for several months, from season to season (Perombelon, 2002) and tubers can be contaminated through wounds created during harvesting and handling. Survival of soft rot bacteria in the soil depends on soil pH, temperature and moisture. Bacteria can survive for up to 6 months in the soil even in the absence of plant debris (Czajkowski et al., 2011). Airborne insects can carry soft rot bacteria from one plant to another. Bacteria can also be present in aerosols especially on rainy days and are viable for up to

10 min. Contaminants of bacteria can also be found in surface and irrigation water (Czajkowski et al., 2011).

The susceptibility of tubers to bacterial soft rot is influenced by tuber water potential, membrane permeability, intercellular concentration of reducing sugars, polyphenol oxidase, oxygen level and other factors. Low oxygen concentration increases susceptibility to tuber soft rot resulting in extensive tissue degradation (McGuire and Kelman, 1983). Studies by Schober and Zadoks (1999) on chicory heads showed that the highest growth rate of *Pcc* occurred at 10°C while that of *Pa* was at 15°C and at water potential ranging from -0.12 to -0.8 MPa. The lag phase of the growth curve increased with decreasing water potential (Schober and Zadoks, 1999). Depletion of oxygen in tubers due to tissue respiration impairs host resistance. It negatively affects cell wall lignification and suberization, thereby resulting in tuber degradation by pectinolytic enzymes (Perombelon, 2002). Growth of *Pa* is inhibited by the antibacterial phytoalexin rishitin. Lyon et al. (1992) found no correlation between cultivars and their resistance to soft rot due to rishitin accumulation. *Pectobacterium* lack enzymes capable of degrading both lignin and suberin. The external suberized periderm provides the first line of defence against pathogen invasion and moderates the exchange of oxygen, carbon dioxide and water (McGuire and Kelman, 1983; Lyon et al., 1992). Low oxygen concentrations and high carbon dioxide concentrations inhibit suberin and periderm formation (Lyon et al., 1992). Contrarily, studies by Murant and Wood (1957) showed that the rate of suberization differed among varieties but was not directly related to disease resistance or susceptibility to rotting.

The availability of water results in the proliferation of lenticels and swelling of cortical cells, making it easy for bacteria to penetrate due to cell membrane permeability and leakage of cell contents (Perombelon, 2002). Increasing tuber water content affects susceptibility to attack by bacteria and storage in humid atmosphere increases rotting (Murant and Wood, 1957).

Pectobacterium species produce pectolytic enzymes (polygalacturonase and pectin lyase) which macerate tuber tissue and induce electrolyte leakage and cell death (McGuire and Kelman, 1986). The ability of *Pectobacterium* species to macerate the plant tissue depends on the amounts of plant cell wall degrading enzymes secreted (Flego et al., 1997). Pectins are made up of chains of polygalacturonic acid residues with rhaminose insertions. The chain allows spaces for insertion of cations (Conway et al., 1992). In the potato medullary tissue, galacturonic acid precipitates calcium to form calcium pectate (McGuire and Kelman, 1986).

Studies by Marquez-Villavicencio et al. (2011) showed that potato soft rot was affected by physiological characteristics such as tuber size and maturity. Smaller tubers were more resistant to soft rot than larger ones.Mature tubers were more resistant due to a better developed periderm and presence of antibacterial substances as well as less water content. Early harvested tubers had higher water content and less toxic substances (e.g. phytoalexins and phenolic compounds) and thus exhibited a higher incidence of tuber soft rot than mature ones (Abo-Elyousr et al., 2010). Abo-Elyousr et al. (2010) concluded that increasing the storage period to up to 4 months increased susceptibility of potato tubers to soft rot.

SYMPTOMS OF TUBER DISEASE

Symptoms of potato tuber diseases may be influenced by conditions such as soil and tuber mineral content, soil moisture, temperature, physical factors, chemical factors and genetics (Miles et al., 2009). When seed tubers are infected by *Pectobacterium* and *Dickeya* species, field symptoms will include reduced emergence, wilting, chlorosis, tuber and stem rot, blackleg, haulm desiccation and plant death (de Haan et al., 2008). Tuber soft rot begins at the stolon end and lenticels. It also infects tuber wounds under moist conditions, causing lesions (Czajkowski et al., 2011). Symptoms of tuber soft rot range from a slight vascular discolouration to complete tuber decay. Infected tuber tissues have a cream to tan colour and a brown to black colour at the margins. At higher temperatures (27°C), rots caused by *Dickeya* species produce a creamier, cheesy rot than that by *P. atrosepticum* (Toth et al., 2011). Bacterial ooze from infected tubers onto healthy tubers results in the rotting of healthy tubers (Czajkowski et al., 2011).

PLANT NUTRITION AND DISEASES

The resistance and susceptibility of a plant to diseases can be determined by the plant's nutrition. The plant's nutrition determines the morphological structure of the host and the ability of pathogens to survive. It is a defence mechanism and an important potential cultural control practice. Inorganic fertilizers such as calcium, magnesium, nitrogen and potassium alter pathogenicity and improve plant resistance to diseases (Huber and Haneklaus, 2007; Huber and Jones, 2012). The mineral nutrition, such as calcium, nitrogen, magnesium, potassium and phosphorus, during the growth period of a potato plant can influence the occurrence of tuber soft rot in storage (Mcguire and Kelman, 1983). It is believed that there is increased susceptibility of plants to diseases due to the lack or deficiency of essential elements such as calcium and magnesium (Czajkowski et al., 2011). The use of plant nutrients to control diseases is an environmentally friendly practice and there is need to provide a balanced nutrition so as to effectively control diseases (Dordas, 2008). Increasing nitrogen results in increased disease severity, potassium increases host plant resistance and silicon creates a physical barrier against fungal hyphae.

FACTORS AFFECTING CALCIUM UPTAKE

The above-ground vegetative part of the potato plant is higher in calcium than in the tubers due to the tubers' low rate of transpiration as calcium moves passively throughout the plant in the xylem as a result of the transpiration pull (Ozgen et al., 2002; McGuire and Kelman, 1983). Foliage calcium is increased by low humidity and high air temperature both of which result in increased transpiration.

Sandy soils normally have a low cation exchange capacity and potato tubers harvested from them are low in calcium and therefore susceptible to soft rot compared to those high in calcium (McGuire and Kelman, 1983, 1986). Calcium application in general potato production is recommended when soil exchangeable calcium is below 300 mg/kg but this amount is generally considered sufficient. Testing soil for exchangeable calcium, however, does not predict the calcium required by tubers (Gunter and Palta, 2008). Studies by Gunter and Palta (2008) showed that tuber calcium varies with variety and season but had no relationship to soil calcium. Increasing tuber calcium can be achieved by improving calcium uptake by placing calcium in the tuber and stolon area. Calcium fertilizer should be placed on the hill where tubers develop (Kratzke and Palta, 1986; Conway et al., 1992; Palta, 1996; Stark et al., 2004). Application of calcium to the main root system does not increase tuber calcium since water and nutrients will be transported to the leaves (Ozgen et al., 2006). Tubers have less transpiration rates than the leaves and hence cannot compete effectively for calcium applied to the main root system. Gunter and Palta (1998) showed that the accumulation of calcium in tubers varied among cultivars and seasons, and concluded that different cultivars have different calcium uptake thresholds due to their genetic makeup implying that improvement of tuber calcium can be done through plant breeding.

Uptake also depends on the general health of the plant, availability of nutrients, such as nitrogen, calcium, potassium, phosphorus and magnesium in the soil, time of application, the stage of growth and the source of calcium (Westermann, 1993; Palta, 1996). Calcium can be absorbed by tubers directly from the soil solution though the deposition and diffusion of calcium in the tubers is affected by cultivar, maturity, soil type, fertilizer practices and weather. This is confirmed partly by the observation that early harvested tubers have less calcium content than late harvested tubers (Conway et al., 1992).
Further, cations such as magnesium compete with calcium thereby impeding calcium uptake by plants (Conway et al., 1992; McGuire and Kelman, 1983), while increasing potassium reduces calcium uptake (Bangerth, 1979; White et al., 2009). Calcium fertilizers increase potassium, sulphur and phosphorus concentrations in the soil but reduce magnesium concentration (White et al., 2009). A pH of 5 and below resulted in calcium deficiency and the maximum availability of soil calcium was at pH 6.5 to 8.5 (Westermann, 1993). Therefore, there is need to balance soil nutrients and soil pH.Calcium is transported together with water in the xylem. Therefore to effectively increase tuber calcium supplemental calcium should be added during the tuber bulking stage because the tubers develop later in the season. Tubers have their own roots which take up water and calcium (Palta, 2010) and applications must be within reach of these tuber roots. An effective way of applying calcium is through fertigation (Westermann, 1993; Palta, 1996) while less soluble fertilizers can be applied by side dressing before the last hilling (Ozgen et al., 2006). Injection of fertilizer into irrigation water requires careful irrigation management so as to achieve uniformity of fertilizer application while avoiding leaching and runoff (Westermann, 1993).

Calcium can be applied as calcium chloride, calcium nitrate, gypsum (calcium sulphate), lime and calcium-ammonium-nitrate and normally, application is effective when split (Ozgen et al., 2002; 2006). Lime and gypsum have low water solubility whereas calcium nitrate is highly soluble (Palta, 1996; Kleinhenz et al., 1999). Studies by McGuire and Kelman (1983) showed that calcium nitrate was more effective in increasing calcium concentration of peel and medullary tissue than calcium chloride and calcium sulphate. However, liming and fertilization does not guarantee an increase in calcium content in storage organs by the required amounts due to inefficient distribution of calcium in the storage organs. Research by Ozgen et al., (2006) showed that the application of gypsum was not effective in increasing the calcium concentration in tuber tissue, even when gypsum was applied in combination with other soluble calcium fertilizers due to low amounts of gypsum fertilizer they applied during their study. In some cases (in stored tubers for instance), calcium can be added directly on storage organs or by dipping in calcium chloride solutions for longer periods as a direct calcium treatment to increase calcium. Other methods include vacuum or pressure infiltration, which have been used to increase calcium levels in apples so as to improve storage quality (Conway, 1989). Tuber tissue maceration is reduced by calcium chloride and calcium propionate salts but their effectiveness depends on the method of application, organism and concentration (Hajhamed et al., 2007).

EFFECT OF CALCIUM ON PLANT RESISTANCE TO SOFT ROT

Increasing calcium concentration in the potato tubers helps reduce the incidence of tuber soft rot during storage, thereby increasing shelf life (Kratze and Palta, 1986; Palta, 2010). Abo-Elyousr et al. (2010) reported a correlation between tuber cell wall, calcium content and the level of resistance to soft rot while McGuire and Kelman (1983) found tuber calcium concentration to be high in the cortex and periderm. Calcium, which is a secondary messenger in plant cells, contributes to maintenance of cell membrane stability and cell wall structure (Ozgen et al., 2002). McGuire and Kelman (1983) showed that soft rot severity caused by *Pa* was inversely related to tuber calcium concentration just as application of calcium effectively reduced decay caused by *P. carotovora.* The surface area decay of potato tubers by *Pa* reduced from 93 to 15% and medullary calcium concentration increased from 0.022 to 0.063% after being held in a mist chamber for 60 h (Conway et al., 1992). Studies conducted by Locascio et al. (1992) showed that the in-season application of calcium fertilizer reduced bacterial soft rot incidence from 43 to 4% in 3 years. As calcium increased, disease severity decreased because an increase in tuber calcium most likely led to an increase in the cross-linkages of pectate chains, thereby reduced susceptibility to tuber soft rot. Calcium phosphite is used as a nutritional compound and it has an antimicrobial action against pathogens. When tubers were artificially infected with *P. carotovora*, it reduced the lesion area (Lobato et al., 2008, 2010).

MECHANISMS OF CALCIUM INDUCED RESISTANCE TO SOFT ROT

Calcium in the middle lamella is responsible for promoting gelling in a pectin solution (Conway, 1989) and provides stable reversible inter-molecular linkages between pectin molecules by making the cell wall rigid (Gunter and Palta, 1998). McGuire and Kelman (1983) showed that, at the highest levels of calcium fertilization, tuber surface area decay was reduced by almost half and Abo-Elyousr et al. (2010) reported that varieties with the highest amount of pectin substances and calcium content recorded the lowest weight of rotting tissue. Presumably, calcium bridging of the plasma membrane components reduced electrolyte leakage and maceration by pectolytic enzymes (McGuire and Kelman, 1986) since extracellular calcium is thought to help in maintaining the selective permeability of plasma membranes because of the bridging of calcium ions on phosphate and carboxylate groups of phospholipid head groups at the membrane surface (Gunter and Palta, 2008; Geary et al., 2010).

Tubers with high calcium have an improved structural integrity of both the plasmalemma and cell wall materials as compared to tubers with low calcium content. This is thought to inhibit the multiplication and spread of the bacterial pathogen throughout the tissue (McGuire and Kelman, 1986). The activity of Polygalacturonase (PG), a cell-wall-degrading enzyme produced by bacterial and fungal pathogens, is inhibited by calcium and hence cannot breakdown the pectin in the plant tissue cell walls.

Calcium prevents PGs from interacting with the pectin polymer and blocks the diffusion of PGs through the cell wall (Goodwin et al., 1997; Huber and Jones, 2012). Goodwin et al. (1997) reported that the level of calcium in canola leaf extracts was significantly correlated to disease resistance and to inhibition of PG activity by *Leptosphaeria maculans*. Increasing calcium content of beans decreased the activity of PG and pectate transeliminase thereby increasing resistance to Pcc (Krauss, 1999) while Benson et al. (2009) showed that pink soft rot disease infection and severity decreased with an increase in the available calcium between 3 and 343 mg/L.

CONCLUSION AND PERSPECTIVES

Although host plant resistance and cultural methods have been shown fairly conclusively that they play an important role in the control of soft rots, their deliberate and coordinated use has not been widespread and loss caused by soft rots remain high. These losses will continue to haunt farmers until resistant varieties become ubiquitous on farms. In the meantime, avoidance of infection through use of certified seed remains a cornerstone in safeguarding losses in potato production caused by soft rot pathogens. The occurrence of even more virulent subspecies of soft rots makes host plant resistance in this area very important.

Conflict of Interests

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

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Full Length Research Paper

Sources and rates of nitrogen in summer corn under no-tillage on winter cover crops

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Cover crops occupy and protect the soil during winter and also provide nutrients to tropical soils. The aim of this study was to evaluate the effect of sources and levels of nitrogen applied to a summer corn crop cover in succession to cover cropsunder no-tillage. The experimental design consisted of randomized blocks with four replications in a scheme with subdivided plots. The main plot was composed of two crops that preceded corn; common oat (*Avena strigosa Schreb.*) and forage turnip (*Raphanus sativus*), and a winter fallow area (weed). The subplot consisted of two nitrogen sources (urea and ammonium sulphate), and the splits of each subplot were constituted by four rates of nitrogen (0, 30, 60 and 120 kg ha^{-1}). The following production components were analyzed: ear diameter, kernel rows per ear, mass of 1000 grains and grain yield. Corn grown after oat presented responses to nitrogen fertilization for mass of 100 grains and hence to grain yield.

Key words: *Zea mays*, nitrogen fertilization, urea, ammonium sulphate

INTRODUCTION

Corn is a crop of major economic importance for the state of Paraná, representing 26% of the Brazilian production, with about 12.61 million tonnes (Demarchi, 2010). First crop corn in the state has been increasing in yield potential due to the technology used by producers. Nitrogen is one of the most important nutrients for plant growth (Fageria and Moreira, 2011), especially corn. The recommendation of nitrogen fertilization on summer corn coincides with different species that occupy the soil during winter, what may affect the stocks of nitrogen (N) in the soil and nutrient utilization by the plant. According to Fernandes and Libardi (2012), the advancement and consolidation of the direct drilling system in tropical soils with soil re-covering increment N in the soil, what leads to new agricultural recommendations for crops.

Another aspect to be considered in what concerns to the nitrogen fertilization of corn is the source of mineral nitrogen. Ammonium sulphate and urea are the two most

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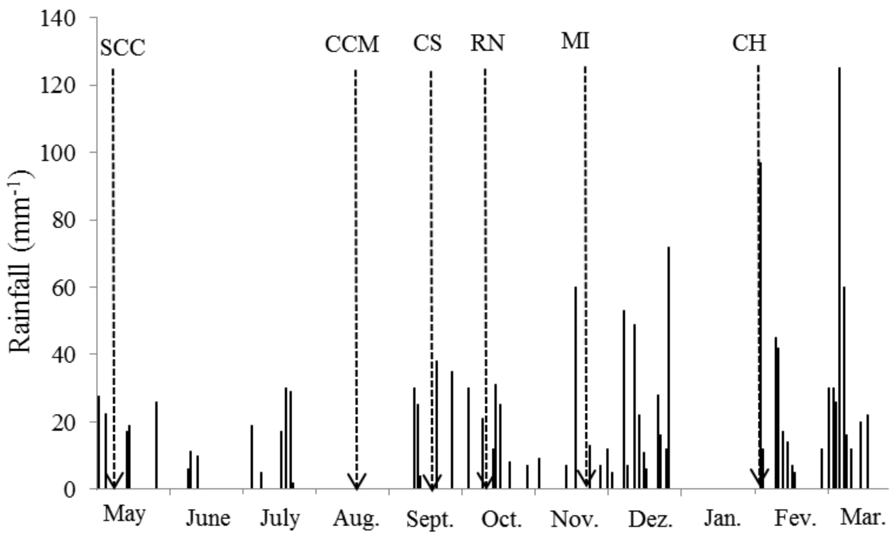

Figure 1. Rainfall recorded during the experiment. Seeding cover crops (SCC), cover crop management (CCM), corn seeding (CS), male inflorescence (MI), rates of nitrogen (RN), corn harvest (CH).

used N sources in Brazilian agriculture, possibly for being less expensive and more readily available on the market (Barbosa Filho et al., 2005). Losses by volatilization when using ammonium sulphate are not large, however, such source typically has a cost per unit of N far superior to urea (Lara Cabezas et al., 2008). Soil cover crops have capability to provide nutrients for subsequent crops and increase organic N in the soil (Sainju et al. 2005). Such practice is gaining more and more space in the agricultural areas of southern Brazil, where there has been a search to optimize the direct drilling system with crop rotation (Doneda et al., 2012).

Legume species are an important source of nitrogen to the soil through biological fixation (Silva et al., 2006), and are also a great alternative for soil decompression, resulting in benefits for plants in succession (Rosa et al., 2012). Grasses increase the permanence of straw on the soil surface by the higher C/N ratio, and thus, cause lower decomposition rates with greater persistence (Torres et al., 2008). Silva et al. (2006) observed maximum technical efficiency of nitrogen on corn with rates of 205 and 175 kg ha^{-1} in succession to black oats and forage turnip, respectively. Lourente et al. (2007) found maximum corn yield under no-tillage, when sown in succession to wheat and common oat at rates of 140 and 137 kg ha^{-1}of nitrogen. According to Roselem et al. (2004), graminoids have elevated ratio C/N and dry matter production, however, when corn is being cultivated in succession in tropical areas, it is necessary to perform nitrogen supplementation. The aim of this study was to evaluate the effect of preceding winter crops, sources and rates of nitrogen applied to the summer corn crop cover on crop yield components, consolidated under no-tillage.

MATERIALS AND METHODS

The work was conducted under field conditions in the agricultural year 2012 to 2013, in an agricultural area in the municipality of Medianeira-Pr, which presents as its geographic coordinates longitude 54° 04'16'' W, latitude 25° 20'09''S and altitude of 286 m. The climate is humid subtropical with hot summers, with an annual average of 21°C (Iapar, 2013). The average monthly rainfall are shown in (Figure 1).

The soil used in the experiment was collected on the same property, at a depth of 0 to 20 cm and classified as eutroferricOxisol (LVe) (EMBRAPA, 2006). Prior to the experiment, soil sampling was conducted to determine its chemical characteristics at a depth of 0 to 20 cm, the results were: 16.53 g dm^{-3} organic carbon; pH ($CaCl_2$) 5.30; 19.90 mg dm^{-3} of P, 0.51 cmol$_c$ dm^{-3} of K^+; 6.56 cmol$_c$ dm^{-3} of Ca^{2+}; 2.75 cmol$_c$ dm^{-3} of Mg^{2+}; 4.61 cmol$_c$ dm^{-3} of H^+ Al; CTC 14.43 cmol$_c$ dm^{-3} and 68.05% of base saturation.

The experimental design consisted of randomized blocks with treatments arranged in a scheme with subdivided plots, with four replications. The plots, measuring 100.8 × 4.20 m, were established by winter cover crops: common oat (*Avena strigosa* Schieb.), forage turnip (*Raphanus sativus*) and a control treatment (witness), without growing cover crops (fallow). Subplots measuring 33.6 × 4.20 m, with two sources of nitrogen(urea 46%, ammonium sulphate 21%), and subsubplots 16.8 × 4.20 m four rates under cover fertilization in the corn crop (0, 30, 60 and 120 kg ha^{-1}). The cover species were mechanically sown in winter, 5th May 2012, in succession to a soybean crop, with its sowing density following the technical recommendation for each crop. Plant desiccation was performed on 16thAugust 2012 by using herbicide glyphosate (2.275 g i.a. ha^{-1}) and subsequent mechanical handling through a crusher model Triton©.

Corn was sown mechanically, on 16th September 2012, with basic fertilization in all plots of 210 kg ha^{-1} of NPK formulation 13-06-9. The corn used was the hybrid Pioneer 30F53, considered as medium cycle, recommended for normal season planting (summer). Density of 4.1 seeds per meter was used, with distance of 0.70 m between lines, totalizing 58,000 plants ha^{-1}. The seeds were treated with Thiamethoxam in a rate of 210 i.ag/100 kg seeds. For the control of weed in post-emergence, 1650 g of atrazine i.a. ha^{-1} +

Table 1. Diameter of ear, rows per ear, 1000-grain weight and grain productivity of maizeabout cover crops and rates of nitrogen.

Cover crops	Diameter of ear	Rows per ear	1000-grain weight	Yield (kg ha^{-1})
Black oat	51.15	16.42	315.06	9543.53
Oilseedradish	54.70	16.70	316.57	10140.99
Fallow	52.18	16.50	315.05	10259.13
CV (%)	19.59	2.43	3.42	11.12
Source (S)				
Urea	53.59	16.53	318.46	9949.12
Amm.Sulphate	51.76	16.55	312.66	9884.75
CV (%)	18.27	2.58	6.12	6.72
Teste F			**Values of F**	
Cover crops (C)	1.004n.s.	4.092n.s.	0.209n.s.	3.822n.s.
Source (S)	0.865n.s.	0.036n.s.	2.166n.s.	0.220n.s.
Rate (R)				
CV (%)	18.58	4.07	4.84	9.97
Linear reg.	0.003n.s.	2.090n.s.	36.077 **	8.381 **
Quadratic reg.	1.331n.s.	7.319 **	0.716n.s.	3.818n.s.
Interaction (CxS)	1.100n.s.	5.094 *	0.133n.s.	3.270n.s.
Interaction (CxR)	0.907n.s.	0.654n.s.	0.926n.s.	1.591n.s.
Interaction (SxR)	0.951n.s.	1.591n.s.	2.079n.s.	0.180n.s.
Interaction (CxSxR)	0.889n.s.	2.273 *	1.311n.s.	0.587n.s.

Means with different small letters in the columns are statistically different at (**) 1% and (*) 5% of probability or no significant (n.s.) Tukey test.

148 g of mesotrionei.a. ha^{-1}, were applied, when corn plants presented six fully expanded leaves. The application of nitrogen rates to the cover in the subplots was performed manually beside the plants when they were in V6 (six fully expanded leaves).

During corn harvest, the two central rows of each plot were sampled, discarding 0.50 m from each end. Five ears of each line were collected and separated to determine the following yield components: number of grain rows per ear (by counting the grain rows of each ear, individually); ear diameter (with the aid of a caliper); mass of 100 grains (average mass of five subsamples of 100 grains corrected to 13% moisture) and productivity (mass of grains produced in the two central lines of each plot corrected to 13% moisture by estimating the productivity kg ha^{-1}). The results were subjected to analysis of variance, by using the F test at 5% for comparing cover crops and sources of nitrogen, and polynomial regression analysis, for studies of N rates on coverage, using the statistical package Assistat® version 7.5 beta (Silva and Azevedo, 2002).

RESULTS AND DISCUSSION

There was adequate rainfall distribution in the early stage of crop development with good rainfall until close to the male flowering, even after the application of N in the cover (Table 1). Ear diameter suffered no influence (p <0.05) of the studied factors and the interaction between them (Table 1), what disagrees with Ohland et al. (2005) who observed an increase in ear diameter in the succession hairy vetch/corn regardless of the rate of N applied. Lourente et al. (2007) found a significant effect only in function of N rates for ear diameter.

The number of kernel rows in the ear was not significant for the preceding crop and nitrogen source, but significant for the interaction (Figure 2), as well as for rates of N applied to the cover when corn was sown on fallow. Souza et al. (2011) found results that support this work, in which N sources had no effect on variable kernel rows per ear in two years of cultivation in Selvíria (MS). Meira et al. (2009) and Casagrande and Fornasieri Filho (2002) also found no differences between sources in the component number of kernel rows per ear.

There were significant effects (p<0.05) in the interaction between cover crops and nitrogen sources on the number of kernel rows in the ear (1). Because of the interaction, the deploymentwill be analyzed in Table 2. One can notice in the interaction that the succession forage turnip/corn resulted in 19.90 kernel rows with ammonium sulphate being used as nitrogen source. The number of kernel rows in the ear was significantly influenced by N rates when corn was sown in the fallow area. The quadratic model was the one that best fit to the data, with maximum response obtained by the derivative of the equation, with 17.20 kernel rows per ear, at a rate of 67 kg ha^{-1} of ammonium sulphate (Figure 2D). When

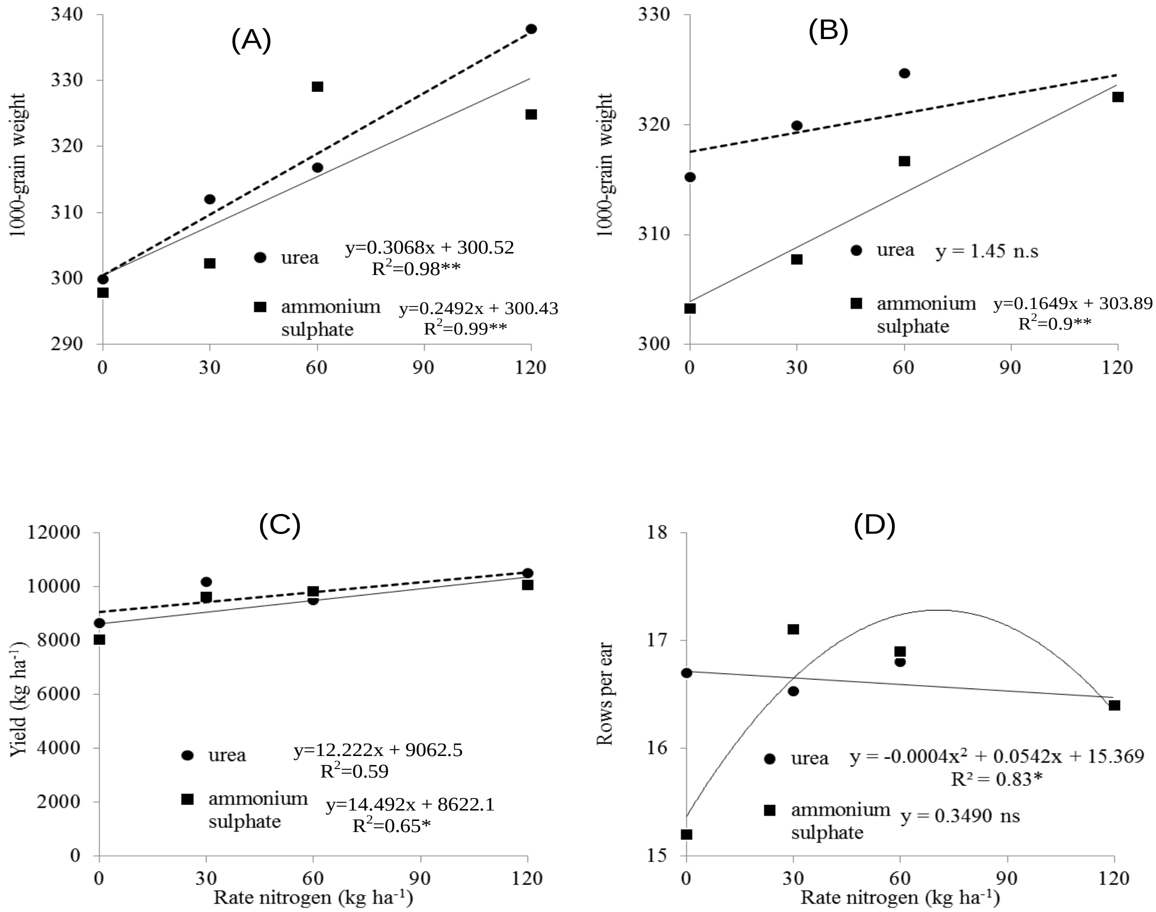

Figure 2. 1000-grain weight, Black oat (A); Oilseed radish (B); Grain productivity, Black oat (C); Diameter of, Fallow (D); the relative rates of nitrogen.** = significant at 1% probability; n.s. = not significant.

Table 2. Unfolding of the interaction cover crops/sources.

Cover crops	Source	
	Urea	**Amm.sulphate**
Black oat	16.50^{aA}	16.35^{bA}
Oilseed radish	16.50^{aB}	16.90^{aA}
Fallow	16.60^{aA}	16.40^{bA}

Means followed by the same letter (lowercase in the columns for comparison between cover crops. Capital letters in the lines comparing sources show no difference (Tukey, 5%).

the preceding crop was common oat and forage turnip, there was no response to nitrogen fertilization. Casagrande and Fornasieri Filho (2002) found no effect of N rates (0, 30, 60 and 90 kg N ha^{-1}), in the form of urea in the number of kernel rows per ear.

The mass of 1000 grains was significantly influenced by nitrogen fertilization applied to the coverage in an increasing way with linear adjust when corn was cultivated in the succession common oat/corn with maximum values of 338 g with a rate of 120 kg ha^{-1} of urea (Figure 2A), supporting what was stated by Lourente et al. (2007) who studied the effect of sources and rates of N in the soil and observed a linear increase of mass of 1000 grains up to the maximum rate of 200 kg ha^{-1}. Oliveira and Caires (2003) also found a linear increase of the mass of 100 grains in succession to common oat, and pointed out that such yield component was crucial to increase grain yield, using rates of 0, 30, 60, 90 and 120 kg $ha^{-1}$of N. In the succession forage turnip/corn only ammonium sulphate provided response on the mass of 1000 grains (Figure 2B), and in the succession fallow/corn there was no influence of nitrogen fertilization.

Soratto et al. (2011) found no effect of sources and levels of nitrogen applied to the coverage of winter corn crops cultivated in succession to millet. Lourente et al. (2007) observed maximum mass of 1000 grains for corn in succession to wheat, with values of 291 g by applying 168 kg N ha^{-1}. Ohland et al. (2005) found that corn seeding after hairy vetch showed higher mass of 1000 grains compared to corn sown after forage turnip, regardless of nitrogen levels,with average values of 353 g.

For grain yield, the results were significant ($p<0.05$) for nitrogen rates, and not significant for the previous crop and N source, as well as for interaction. Although there were no significant differences for interaction, regardless of the previous crop and N sources, corn fertilized with urea produced 10,490 kg ha^{-1}, and with ammonium sulphate, 10,054 kg ha^{-1}, showing no evidence of the maximum technical efficiency rate (Figure 2C). Possibly the lack of response of the sources happens due to the fact that soon after the application of N there were rains, reducing losses by volatilization, especially urea.

Corn grain yield was not influenced by N rates in coverage when sown in succession to forage turnip and fallow area. Lourente et al. (2007) found higher corn yields when the grain was sown in succession to fallow and forage turnip in the absence of nitrogen fertilization. Silva et al. (2006) observed maximum productivity for the succession common oat/corn with 8,280 kg ha^{-1}, with the application of 205 kg ha^{-1} of N. When corn was sown after forage turnip, the maximum productivity level was 8,020 kg ha^{-1}obtained at a rate of 175 kg $ha^{-1}$of N.

Soratto et al. (2010) when working with four N sources (urea, ammonium sulphate, starea and entec) in succession to soybean in the region of Chapadão do Céu (GO), found that ammonium sulphate provided the highest corn grain yield in relation to starea, however, it did not differ from other sources. Kappes et al. (2009) observed a significant increase in grain yield with the application of 70 kg $ha^{-1}$of N, regardless of the source used (sulphate and ammonium, urea and entec). Roselem et al. (2004) observed higher corn productivity in succession to millet with nitrogen fertilization applied to the coverage; however, such fertilization of 120 kg $ha^{-1}$was not enough to supplement the needs of the crop after common oat. Silva et al. (2012), in a study in western Paraná, verified yields of 3.928 kg ha^{-1} of summer corn with rates of 7 tonnes per ha^{-1} of poultry litter being used as nitrogen source.

Conclusion

Corn grown after common oat showed responses to nitrogen fertilization for mass of 1000 grains and hence for grain yield.

Conflict of Interests

The authors have not declared any conflict of interests.

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Review

The potential use of cover crops for building soil quality and as trap crops for stinkbugs in sub-tropical fruit orchards: Knowledge gaps and research needs

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There is a renewed interest in cover crops and the role they can play in the pursuit of sustainability in agroecosystems. These versatile crops have not only demonstrated the ability to improve soil but numerous species have also shown the potential to act as trap crops for insect pests. We suggest that cover crops may concurrently serve both these purposes in sub-tropical fruit orchards, depending on the choice and application thereof. We recommend that cover crops should be investigated for this dual purpose and propose a selection of soil health indicators for measuring the resulting changes in the soil. We suggest that cover crops will be more effective if the biodiversity within and adjacent to the main crop can be increased through habitat manipulation to enhance natural enemies of pest insects. A selection of cover crops that have the added potential as trap crops for stink bugs have also been identified for investigation.

Key words: Cover crops, soil quality, soil health indicators, trap crops, sub-tropical fruit orchards, diversification, natural enemies, pentatomid, stink bugs.

INTRODUCTION

Agroecological conversions aim to provide sustainable solutions for agricultural endeavours and food security. Two of the important focus areas in these conversion processes include crop nutrition and crop protection. Sustainable organic solutions for crop nutrition are based on the foundation of high quality soils which may provide healthy growing media for plants. Nicholls and Altieri (2004) postulate that ecosystems become productive when a balance of rich growing conditions prevail that allow crops to become strong and healthy, which in turn render them resilient to stress and adversity. Soil organic matter influences almost all characteristics related to healthy soils. Practices that promote good soil organic matter management are thus the very foundation for high quality, healthy soils and consequentially result in more sustainable and thriving agricultural ecosystems (Magdoff and van Es, 2009).

Sustainable organic solutions for crop protection are based on an array of cultural and biological management strategies. These have to cater for pests, diseases and

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adverse environmental conditions which may affect plant survival and quality. Fruit trees are susceptible to attacks by a wide spectrum of insects at all stages of their growth just like all other annual and perennial crops. Virtually all herbivore insect pests, however, show distinct preferences for certain plant species, cultivars, or certain crop stages (Hokkanen, 1991). Attractive alternative host plants can, therefore, potentially be used to lure pests away from the main crop to the more attractive host plants, commonly called trap crops. Cover crops could serve both the purposes of promoting soil organic improvement and of trap crops for pest insects depending on the choice and application thereof. Schipanski et al. (2013) estimated that cover crops could increase 8 of the 11 ecosystem services they investigated without negatively influencing crop yields.

AGROECOLOGICAL CONVERSIONS

What is a sustainable agroecosystem? It is one that maintains the resource base upon which it depends, relies on a minimum of artificial inputs from outside the farm system, manages pests and diseases through internal regulating mechanisms, and is able to recover from the disturbances caused by cultivation and harvest (Altieri, 1989; Buchs, 2003; Dalsgaard et al., 1994; Edwards et al., 1990; Gliessman, 2007). A number of processes fundamental to the sustainable functioning of ecosystems have been identified. These include the flow of energy, cycling of nutrients, population regulating mechanisms and a state of dynamic environmental equilibrium where succession approaches a condition of stability within a particular ecosystem (Altieri, 1989; Gliessman, 2007; Moonen and Barberi, 2008). It is important to understand these processes in order to apply them successfully in agroecosystems (Malézieux, 2012; Ratnadass et al., 2012). The main strategy of the agroecological approach to achieve sustainability is to apply these ecological processes and components to the design and management of agroecosystems. Pure organic conversions may solve all or most of the problems associated with conventional farming practices, but will not necessarily prevent problems from arising in the first place (Gliessman, 2007). When agroecosystems are redesigned to achieve natural ecosystem-like characteristics by incorporating ecological processes, the most important causes of many of these problems are addressed and ecological sustainability may be achieved. Studies have shown that conversion of agroecosystems improves the overall sustainability of most of these cropping systems (Benayas and Bullock, 2012; Caporali and Campiglia, 2001; Evenari et al., 1961; Fernandez et al., 2008; Gliessman et al., 1996; Letourneau et al., 2011; Pywell et al., 2011; Reeve et al., 2011; Swezey et al., 1994, 1998). Although there is still a long way to go to achieve sustainability, these conversions have increased the components of sustainability. Farmers have also achieved organic certification and promoted awareness of alternative food systems, which have proved not only popular, but also profitable.

SOIL QUALITY

Enhancing soil quality in intensive agricultural systems is important to sustaining productivity and improving environmental quality (Subbian et al., 2000). High quality soils *per se* are therefore worth quantifying because soils and their biota provide valuable ecosystem services like storing and releasing water, decomposing plant and animal matter, transforming and recycling nutrients, sequestering and detoxifying toxicants, and promoting plant health by suppressing plant-pathogenic microbes and phytophagous fauna (Doran and Zeiss, 2000). Soil quality, as such, deals with the integration and optimization of the physical, chemical and biological properties of soil for improved productivity and environmental quality (Karlen et al., 2001). Doran (1994) defines soil quality as ‘the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health. Kremer and Hezel (2012) describes soil quality assessment as the indication of the ability of management systems to optimize soil productivity and to maintain its structural and biological integrity.

SOIL ORGANIC MATTER

Some of the most significant ecological processes in crop production are those occurring within the soil, such as interactions between soil, nutrients and micro-organisms. The functioning of these processes is essential for healthy crop growth and sustainable production. Good soil organic matter management is the foundation for creating a favourable environment for the proper functioning of these ecological processes in the soil. Anything that adds large amounts of organic residues to a soil may increase organic matter (Joseph et al., 2008). One of the oldest practices in agriculture has been to apply manures or other organic residues generated off the field. A typical agricultural soil has 1 to 6 percent organic matter which consists of three distinctly different parts: living organisms, fresh residues like compost and well-decomposed residues called humus (Magdoff and van Es, 2009). The availability of nutrients is influenced either directly or indirectly, by the presence of organic matter. The intimate contact of humus with the other soil components allows many reactions, such as the release of available nutrients into the soil solution, to occur rapidly (Seiter and Horwath, 2004). Most of the nutrients in soil organic matter cannot be used by plants as long as they exist as part of large organic molecules. Soil organisms are positively correlated with organic matter content (Nair and Ngouajio, 2012). As soil organisms decompose organic matter, nutrients are converted into simpler inorganic or mineral forms that plants can easily use. This process, called mineralization, provides much of the nitrogen that plants need. Soil organisms are therefore essential for keeping plants well supplied with nutrients because they make nutrients available by freeing them from organic molecules (Anderson, 2003; Doran and Zeiss, 2000; Hulugalle et al., 1999). For example, proteins are converted to ammonium (NH_4^+) and then to nitrate (NO_3^-). The mineralization of organic matter is also an important mechanism for supplying plants with such nutrients as phosphorus and sulphur, and most of the micronutrients they need (Magdoff and van Es, 2009). The organisms referred to are highly dependent on soil organic matter as source of food.

If soil organisms are absent or inactive, more fertilizers will be needed to supply plant nutrients. Organic matter, as residue on the soil surface or as a binding agent for aggregates near the surface, also plays an important role in decreasing soil erosion. Organic matter is also the single most important soil property that reduces pesticide leaching since it can change the chemical structure of some pesticides, and other potentially toxic chemicals, rendering them harmless. It is therefore clear that the supply of active organic matter must be maintained so that humus can continually accumulate to assist in the eventual mineralization (Magdoff and van Es, 2009).

COVER CROPS

The use of cover crops have the potential not only to act as an aid in maintaining diversity below ground but also to return residues to the soil when they are mulched or green manured. Some cover crops may produce as much as 1900 to 2900 kilograms biomass per hectare (Clark, 2007; Hulugalle et al., 1999; Jokela et al., 2009) and are considered as strategic in sequestering carbon in soils of agro-ecosystems (Lal, 2011). De Lima et al. (2012) found the use of cover crops to affect the support capacity of soil and least limiting water range to crop growth positively. Cover crops also supply nutrients to the follow-up crops, suppress weeds (Mennan and Ngouajio, 2012), and break pest cycles (Sullivan, 2003). McDaniel et al. (2014) consider cover crops to sustain soil quality and productivity by enhancing soil C, N, and microbial biomass, making them a cornerstone for sustainable agroecosystems. Bugg et al. (2009) found understory cover crops in pecan orchards to enhance some arthropods that may aid the biological control of pecan pests. Cover crops are not only important for improving soil quality by adding organic matter to the soil (Nascente et al., 2013), but can also serve a second important purpose in protecting crops against certain pests. They may act as 'trap crops' to lure pests away from the main crop or create a favourable environment for more diverse insect populations which may harbour beneficial insects such as pollinators and predators. Silva et al. (2010) found significantly higher numbers of beneficial arthropods in orchards with ground cover vegetation in comparison with bare soil. Cover crops also help maintain high populations of mycorrhizal fungal spores which improve inoculation of the next crop. Their pollen and nectar are also important food sources for predatory mites and parasitic wasps, which are both important for the biological control of insect pests. A cover crop also provides a good habitat for spiders which in turn assist in decreasing pest populations (Magdoff and van Es, 2009; Ramos et al., 2010).

SOIL HEALTH INDICATORS

Many authors have attempted to develop soil health indicators by measuring various soil characteristics (Arshad and Martin, 2002; Doran and Zeiss, 2000; Glover et al., 2000; Gugino et al., 2009; Karlen et al., 2003, 2008; Knoepp et al., 2000; van Antwerpen, 2009; van Bruggen and Semenov, 2000; Werner, 1997). Indicators of soil quality for agroecosystems are described by many different variables that include mainly chemical, physical and biological parameters (Mele and Crowley, 2008). These indicators refer to measurable soil attributes that influence the capacity of soil to perform crop production or environmental functions (Arshad and Martin, 2002). The choice of a standard set of specific properties as indicators of soil quality can be complex and will vary among agroecosystems and management objectives (Schoenholtz et al., 2000. The concept of soil quality seems to be clear, but measuring it still remains difficult (Zornoza et al., 2007).

As modern agriculture is forced towards low input systems where soil biological processes primarily account for soil fertility, nutrient cycling, and disease control, key indicators of soil quality must include biological measures. Biological indicators have consequently become increasingly important in the assessment of quality in soils that are managed mainly to enhance their ecological functioning (Nielsen and Winding, 2002). Soil quality must be inferred from easily measurable soil properties and these soil quality indicators must be comprehensible and useful to land managers, who are the ultimate stewards of soil quality and soil health (Acton and Padbury, 1993; Doran and Zeis, 2000). Magdoff and Weil (2004) point out that researchers have found soil organic matter (SOM) related properties to be important indicators of soil quality and Dumansky (1994) concluded that soil organic matter is emerging as a key indicator for assessing sustainability of land management systems. Soil organic matter (SOM) management is the key for not only converting degraded or low quality soils into high quality ones, but also for maintaining or improving already healthy soils (Magdoff and van Es, 2009).

When confronted with the question of which soil quality indicators are most likely to be affected by the use of cover crops, soil quality indices and indicators should be selected according to the soil functions of interest and the defined management goals for the system (Andrews et al., 2002). Indicators for any study should, therefore, firstly, be selected to best reflect the achievement of the goals identified and secondly to meet the criteria proposed by Doran and Zeiss (2000), that is, sensitivity to variations in management and good correlation with beneficial soil functions; usefulness for elucidating ecosystem processes; comprehensibility and usefulness to land managers and whether easy and inexpensive to measure. Gugino et al. (2009) developed a protocol for assessing the health status of soils. They evaluated 39 potential indicators for their use in rapidly assessing soil health based on:

- Sensitivity to changes in the soil
- Management practices
- Relevance to soil processes and functions
- Consistency and reproducibility
- Ease and cost of sampling
- Cost of analysis

This protocol (also known as the Cornell soil health assessment protocol) emphasizes the integration of soil biological measurements with soil physical and chemical measurements. A total of four physical and four biological indicators with a standard chemical soil test analysis were selected for the protocol. This protocol conforms well to the criteria proposed by Doran and Zeiss (2000) and we therefore propose soil health indicators which are based mainly on the Cornell soil health assessment protocol. The following indicators are proposed for measuring soil quality changes in sub-tropical fruit orchards with cover crops:

1. Soil Physical Properties
- Aggregate stability
- Available water capacity
- Surface and subsurface hardness (penetrability)
- Bulk density

2. Soil Biological Properties
- Organic matter content
- Active carbon content
- Potentially mineralizable nitrogen
- Earthworm abundance and biomass
- Meso-arthropod assessment (*Collembola* count)
- Nematode community profiling

3. Soil Chemical Measurements
- Exchangeable macronutrients
- Micronutrient concentrations
- pH
- Electrical conductivity
- Cation exchange capacity and cation ratios

TRAP CROPS

Habitat and vegetation management can be used effectively as the basis of ecologically-based pest management tactics in sustainable agriculture (Andow, 1991; Altieri and Letourneau, 1984; Bukovinsky and van Lenteren, 2007; Gurr et al., 2003; Hendrickx et al., 2007; Letourneau et al., 2011; Pickett and Bugg, 1998; Proveda et al., 2008; Schoeman, 2007; Schoeman and Mohlala, 2007). The concept of trap cropping fits into the ecological framework of habitat manipulation of an agroecosystem for the purpose of pest management (Altieri and Nicholls, 2004). Phytophagous hemipterans are, in general, polyphagous, but they may show feeding preferences for certain taxa (Panizzi, 2000). Plants that are highly attractive to these insects, therefore, have the potential to be used as trap crops. The potential success of a trap cropping system depends on the interaction of the characteristics and deployment of the trap crop with the ecology and behaviour of the targeted insect pest (Shelton and Badenes-Perez, 2006). In general, the attractiveness of the trap crop and the presentation of trap crops in the field are important factors in attracting the insect and in the success of the trap cropping system (Velasco and Walter, 1992). Various trap crops have been recorded to attract pentatomid stink bugs (Knight and Gurr, 2006; Lockwood and Story, 1986; Mizell et al., 2008; Shelton and Badenes-Perez, 2006; Velasco et al., 1995; Velasco and Walter, 1992; Velasco et al., 1995). Shelton and Badenes-Perez (2006) are of the opinion that the potential of trap cropping significance would be greater if farmers, scientists and extension educators could expand their concepts of trap cropping to include more diverse modalities in their research. These should include modalities based on the trap crop plant *per se*, modalities based on the deployment of the trap crop and others such as biological control-assisted trap cropping and semiochemically assisted trap cropping.

TRAP CROPS AND BIODIVERSITY

Various researchers have demonstrated the potential of increased biodiversity to enhance biological control of insect pests in agroecosystems. Diversified crops exhibit better plant pest suppression, natural enemy enhancement and less crop damage +than monocultures (Altieri and Letourneau, 1984; Andow, 1991, Gurr et al., 2003; Bianchi et al., 2006; Poveda et al., 2008; Letourneau et al., 2011). Landis et al. (2000) however caution that to selectively enhance natural enemies, the important elements of diversity should be identified and provided rather than simply increasing diversity *per se* which can exacerbate some pest problems. This can be achieved by enhancing the natural resources needed by natural enemies by providing suitable habitat with adequate shelter, more suitable microclimates as well as alternative food sources such as pollen and nectar. The challenge is to integrate these resources into the landscape in a way that is spatially and temporally favourable for natural enemies and practical for producers to implement. Habitat manipulation for the inclusion of cover crops may be particularly effective by simultaneously increasing biodiversity within and adjacent to the main crops. Altieri and Nicholls (2004) reviewed the influence of adjacent habitats on insect populations in field crops. They concluded that habitat edges are important for the development and maintenance of natural enemies which may choose to move back and forth from the edge to the crops for feeding etc.

Gurr et al. (2004) view orchards as having high potential for ecological engineering for pest management. They suggest that orchards are usually more diverse because of some type of ground cover and are subject to lower levels of disturbance than annual crops and therefore have more potential for this type of management. Orchard managers should endeavour to manage orchard groundcover and adjacent vegetation toward enhancing opportunity for biological control of orchard pests by natural enemies (Prokopy, 1994). The understory vegetation in an orchard need not be managed uniformly (Bugg and Waddington, 1994). Different zones may be treated differently, called strip management. Various options include sowing cover crops of different floristic composition in different strips or combining it with strips of natural vegetation in or adjacent to the orchards. A complex of stands having differing floristic compositions could remain attractive to arthropods for longer periods of time. Arthropod habitat can be retained through time with the aid of strip management combined with adjacent natural edges.

KNOWLEDGE GAPS AND RESEARCH NEEDS

Gliessman (2007) maintains that there is an urgent need for more research on the sustainability of agroecosystems. Wezel et al. (2014) distinguished fifteen categories of agroecological practices of which only 6 are currently well integrated in practices for sustainable agriculture. One of the gaps in existing knowledge that needs to be addressed relates to the transition of conventional sub-tropical fruit cultivation which depends heavily on agrochemicals, to more sustainable cultivation practices which are based on ecological principles. In conventional fruit production systems, the external input of inorganic fertilizers circumvent the ecological processes of nutrient cycling, capture and release in soils. Conventional crop protection practices in fruit orchards that depend largely on the application of synthetic agrochemicals similarly disrupt natural ecological processes and populations of both target and non-target species. The potential of cover crops to build soil quality have been well documented (Clark, 2007; Magdoff and van Es, 2009; Ramos et al., 2010; Seiter and Horwath, 2004). Various cover crops have also proven to be highly attractive to pentatomid stinkbugs (Knight and Gurr, 2006; Mizell et al., 2008; Rea et al., 2002; Shelton and Badenes-Perez, 2006). The question that arises is whether cover crops can be deployed within sub-tropical fruit orchards in such a way that a dual goal is achieved? Can cover crops be utilized in sub-tropical fruit orchards to restore soil quality or to maintain it at levels where agrochemical inputs may be reduced significantly without compromising yield and simultaneously act as trap crops to reduce insect damage to sub-tropical fruit crops significantly? There is a need to investigate the use of cover crops or combinations thereof which have already proven not only to be good soil builders, but which also have the potential to concurrently act as trap crops for pentatomid pest insects in sub-tropical fruit cropping systems. Mustard (*Brassica* spp.), Sunnhemp (*Crotolaria juncea*) and Cowpea (*Vigna unguiculata*) have all been identified as crops which all have twofold potential in this regard (Bensen and Temple, 2008; Bugg and Waddington, 1994; Fischler et al., 1999; Rea et al., 2002; Shelton and Badenes-Perez, 2006; Yost and Evans, 1988). All three of these cover crops are leguminous and considered to be reputable soil builders (De Baets et al., 2011; Fatokun et al., 2002; Hubbard et al., 2013; Munoz-Carpena et al., 2008; Singh et al., 2010; Snapp et al., *2006;* Wang et al., 2011). A number of studies have also demonstrated their potential as trap crops for various insect pests as well as promoting an increase in natural enemies (Agboka et al., 2013; Bone et al., 2009; Hinds and Hooks, 2013; Hokkanen, 1991). Will cover crops be more effective if the biodiversity within and adjacent to the main crop can be increased through habitat manipulation?

CONCLUSION

The principles on which sustainability can be built are well established, but there is a lack for more detailed knowledge necessary to apply these principles to the design of sustainable systems and the global conversion of agriculture to sustainability. Cover crops may contribute significantly to this cause if their correct combination, application and management can be determined within the existing circumstances of sub-tropical fruit cropping systems. Where the latter occur in developing countries facing resource constraints, the optimal configuration of cover and trap crops have the potential to significantly reduce external farm inputs, prevent disruption of natural ecosystem processes and improve agricultural sustainability. We propose that mustard (*Brassica* spp.), sunnhemp (*Crotolaria juncea*) and cowpea (*Vigna unguiculata*) be investigated in sub-tropical fruit cropping agroecosystems to determine their potential in this regard. The contribution that edge vegetation combined with cover crops can make for the development and maintenance of natural enemy populations should also be investigated. Agroecology aims to create sustainable agroecosystems and conversions which are mediated by the application of supplementary crops serving a dual trap and cover purpose, may achieve the goal of ecosystem conformity in sub-tropical fruit orchards more rapidly than conventional organic conversions.

Conflict of Interests

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

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