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Full Length Research Paper

Land use and soil type influence on soil quality: A comparison between tree and arable crops in basement complex soils

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Land degradation has become a great concern for sustainable land management. There is therefore the need to monitor land use impact on the soil to prevent degradation. This study was set up to assess soil quality under tree and arable uses and their impacts on the soils capacity. Four farmlands (cocoa, cashew, cassava and maize) on three soil types (Apomu, Ibadan and Iwo series) were selected within Aiyedire local government area of Osun State. In each location, ten points were located and soil samples collected at 0 - 30 cm depth. The samples were subjected to laboratory analysis of selected indicators. The indicators' values were combined into indices using soil management assessment framework for physical, chemical and overall soil quality. The indices were subjected to analysis of variance and the means separated least significant differences. Physical, chemical and overall soil quality indices ranged from 58 to 90% with the highest value under cocoa plantation on Apomu Series. Both land use and soil type have significant effect on physical, chemical and overall soil quality. Arable crops especially maize degrades soil quality quickly. Also, soils located at the lower slope are enriched with nutrients and should be well managed for sustainable use.

Key words: Soil quality, land use, degradation, sustainable.

INTRODUCTION

Soil is a fundamental resource base for agricultural production systems. Besides being the main medium for crop growth, soil functions to sustain crop productivity, among other functions and soil quality describes the soil's ability to perform these critical functions (Doran and Zeiss, 2000). It has biological, physical and chemical properties, which are both inherent and dynamic and can change as a result of some natural processes and in response to use. Natural or inherent capacity of soil to support crops varies, and depreciates with use. The rate of depreciation also varies depending on the kind of use and the soil properties that are most affected.

For long in Nigeria, land use was based on trial-and-error approach. This has led to waste of money and

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efforts. Many large-scale farms in Nigeria folded up after 2 or 3 years of cropping due to lack of adequate information on the potentials of the soil for the particular kind of use. This has also led to land degradation which although may be slow and gradual, is very costly and difficult to correct; while some are even rapid and catastrophic. For instance, loss of organic matter through topsoil removal by bulldozing can take several decades to remedy. So, it is important that land users prevent degradation rather than try to 'cure' it after it had commenced.

Farmers have been concerned on how to keep their soil in good condition because they understand that soil quality has a direct impact on crop performance. Land managers also need information on dynamic soil properties to test whether their system of land use and management are sustainable or whether change is required. They are also concerned that the properties are not being degraded by the use and management practices. The success in soil management to maintain soil quality depends on an understanding of how the soil responds to use and management over time. For this reason, recent interest in soil quality assessment has been stimulated by increasing awareness on the critical functions of the soil in production of food and fibre, maintenance of environmental quality (Doran and Parkin, 1994). On the other hand, feeding the ever-increasing human population is most challenging in developing countries because of soil degradation. For instance, fertility depletion is the fundamental cause for the declining per capital food production in Sub-Saharan African countries (Sanchez et al., 1997). The rate of soil quality degradation depends on land use systems, soil types, topography, and climatic conditions. Among these factors, inappropriate land use aggravates the degradation of soil physicochemical and biological properties (He et al., 1999). Maddonni et al. (1999) also reported that land use affects basic soil processes such as erosion, soil structural stability, nutrient cycling, leaching, carbon sesquestration, and other similar physical and biochemical processes. Soil degradation due to inappropriate land use system is threatening the livelihood of millions of people in many African countries.

This study therefore aimed at assessing the effects of soil type, arable and tree crops land use on soil quality.

MATERIALS AND METHODS

Study site

The study was conducted within Aiyedire and Egbedore Local Government Areas in Osun State, Southwestern Nigeria under four agricultural land use types (Cocoa, Cashew, Cassava and Maize). The study locations fall within longitudes 4° 10'' E and 4° 30'' E and latitudes 7° 30'' N and 7° 45''N of the equator (Figure 1).

The climate of the study sites can be described as humid to sub-humid tropical with distinct dry and wet seasons. The dry season runs from early November to the end of March or early April, while the wet season is from end of March or early April to about middle of November. There are two rainfall peaks in June and September with dry spell in August (August break) which produces the bimodal rainfall pattern in southwestern Nigeria. The average annual rainfall is 1279 mm. The mean annual temperature ranged between 26 and 32°C, relative humidity is high and ranged between 60 and 90% at 16.00 hours.

The soils of the study sites are formed on Crystalline Basement Complex rocks with granite gneiss as dominant parent rock. There is a very strong geological and geomorphological influence on the pattern of soil distribution in the study sites. Vegetation also contributes to the pattern of soil development in the area. The soils encountered at the sites were classified majorly into Iwo association (Smyth and Montgomery, 1962). The vegetation of the study site is derived savannah.

Selection of indicators (minimum data set)

The indicators used as minimum data set for soil quality assessment were selected by modifying the approaches of Cameron et al. (1998), Merrington et al. (2006) and Gugino et al. (2007).

Field study

For each of the four land uses, one farmland was chosen for the study. The soil map of Southwestern Nigeria prepared by Smyth and Montgomery (1962) was used as base map to identify the soil types. Auger soil examination was done to ascertain the information on the map. One soil profile pit each was dug on each farmland, described and sampled for laboratory analysis to further confirm the information on the map.

In each of the locations, ten sampling points were located and soil samples were collected at 0 - 30 cm depth. The samples were air-dried, passed through 2 mm sieve and subjected to laboratory analysis of the selected indicators.

Soil quality assessment

The values of soil quality indicators were then combined into a quantitative index using the framework for evaluating indicators of soil quality by Andrews et al. (2004) called soil management assessment framework (SMAF). This technique uses the principle that soil quality can only be assessed by a combination of different properties or indicators based on the critical values of the indicators and the soil processes relevant to crop productivity (Nearing et al., 1990). In this study, six soil processes relating to crop productivity (nutrient availability, nutrient retention, root penetration, biotic environment, water entry capacity and ability to resist degradation) were identified; relative weights were also assigned based on the level of importance. Soil quality indicators relating to each process were identified and given weights as well (Nearing et al., 1990). For this study, the six processes, minimum data sets, their relative weights for both tree and arable crops are shown on Tables 1 and 2.

All weights within each level summed up to 1.0 and 100% equivalent. The different processes and indicators were combined using Standard Scoring Functions (SSF) which enables users to convert numerical or subjective ratings to unitless values on a scale of 0 - 1. All indicators affecting a particular process were grouped together, given scores and relative weights based on relative importance. After scoring each indicator, the value was multiplied by the appropriate weight producing a matrix that was summed to provide the soil quality rating for crop productivity as follows:

Figure 1. Study locations for the four land use types.

Table 1. Soil processes, minimum data set for tree crop production and their relative weights.

Soil processes	Relative weights	Soil quality indicators	Relative weights
Nutrient availability	0.25	Active carbon	0.35
		pH	0.35
		Base saturation	0.30
Nutrient retention	0.25	Cation exchange capacity	0.35
		Organic matter	0.35
		Texture	0.30
Root penetration	0.20	Bulk density	0.5
		Effective soil depth	0.5
Biotic environment	0.10	Potentially mineralizable N	1
Degradation resistance	0.20	Aggregate stability	1

$$Q = q.s.p(1) \text{ X wt.} + \ldots\ldots\ldots + q.s.p(n) \text{ X wt} \quad (1)$$

Where, Q = Overall soil quality index for crop productivity; q.s.p (1) = soil quality rating for soil process 1; q.s.p (n) = soil quality rating for nth process, and The value of Q for each location was also expressed as percentage.

RESULTS

Table 3 shows the values of soil quality indicators assessed under cocoa and cashew plantations in each of the soil types. Under cocoa plantations, pH is 5.7 for

Table 2. Soil processes, minimum data sets for arable crop production and their relative weights.

Soil processes	Relative weights	Soil quality indicators	Relative weights
Nutrient availability	0.25	Active carbon	0.30
		pH	0.25
		Base saturation	0.25
		Available phosphorus	0.20
Nutrient retention	0.25	Cation exchange capacity	0.35
		Organic matter	0.35
		Texture	0.30
Root penetration	0.20	Bulk density	1
Biotic environment	0.10	Potentially mineralizable N	1
Degradation resistance	0.20	Aggregate stability	1

Table 3. Average values of soil quality indicators under cocoa and cashew plantations.

Indicators	Ibadan series		Apomu series		Iwo series	
	Cocoa (Typic Kanhapludalf)	Cashew (Arenic Paleudalf)	Cocoa (Aquic Dystrudept)	Cashew (Typic Kanhapludalf)	Cocoa (Typic Dystrudept)	Cashew (Typic Kandiudalf)
pH	5.7	6.0	5.9	6.3	6.5	6.1
Active C	7.4	7.2	13.0	17.35	10.1	5.1
PMN	1.1	1.0	1.35	2.5	1.1	0.8
Avail. P	3.5	7.3	3.85	12.5	1.7	4.25
Base Sat.	94.2	92.5	98.3	98.5	97.5	96.1
CEC	8.5	9.2	15.45	12.5	8.2	11.2
Bulk D.(g/cm^3)	1.25	1.45	1.3	1.35	1.3	1.4
ESD (cm)	178	153	162	155	150	181
Porosity (m^3/m^3)	0.5	0.45	0.5	0.4	0.55	0.5
Aggt. Stab. (%)	86.5	68.2	80.5	70.5	86.5	86.1
Texture	SCL	SL	LS	SL	SCL	SL
WHC	0.4	0.3	0.35	0.3	0.35	0.35
Org. C (g/kg)	15.1	14.4	22.1	33.6	14.5	8.4

Ibadan Series, 5.9 for Apomu Series and 6.5 for Iwo series indicating that the soils are slightly acidic to near neutral. Active carbon ranged between 7.4 g/kg (Ibadan Series) to 13.0 g/kg under Iwo Series. PMN ranged between 1.1 g/kg to 1.35 g/kg and follow the same trend as active carbon. Available phosphorus is very low ranging between 1.7 and 3.85 mg/kg with highest value under Apomu series. Base saturation is generally high (94.2 to 98.3%) indicating that the exchange sites are well occupied with basic cations. CEC is low to moderate (8.2 to 15.45 cmol/kg soil) with the highest value under Apomu Series. Porosity ranged between 0.5 and 0.55 m^3/m^3, aggregate stability ranged between 80.5 and 86.5%, organic carbon is moderate to high and ranged between 14.5 and 22.1 g/kg with the highest value under Apomu Series. WHC ranged between 0.35 and 0.40 and texture is loamy sand to sandy clay loam. Similar trend was obtained under cashew plantations with all the indicators.

Table 4 shows the values of soil quality indicators under cassava and maize fields in each of the soil types. Under cassava fields, pH ranged from 5.6 to 6.3, active carbon ranged from 4.3 to 17.3 g/kg with the highest value under Apomu Series. PMN follow the same trend as active carbon and ranged from 0.8 to 2.3 g/kg. Available phosphorus which is very low ranged between 2.45 and 7.5 mg/kg. Organic carbon is low to high ranging from 8.4 to 34.2 g/kg, Base saturation is high (93.5 to 97.3%) and CEC is low to high (2.6 to 16.3 cmol/kg) with the highest value under Apomu Series. Porosity is 0.4 to 0.5 m^3/m^3; aggregate stability ranged from 60.5 to 68.2%, WHC is 0.3 and texture varied as loamy sand to sandy clay. Values of soil quality indicators under maize fields follow the same trend with cassava fields but are lower.

Table 5 shows the aggregate physical, chemical and

Table 4. Average values of soil quality indicators under cassava and maize.

Indicator	Ibadan		Apomu		Iwo	
	Cassava (Dystric Eutrudept)	Maize (Typic Kanhapludalf)	Cassava (Arenic Eutrudept)	Maize (Typic Kanhapludalf)	Cassava (Typic Kandiudalf)	Maize (Oxic Haplustept)
pH	6.1	5.6	6.3	5.9	5.6	6.0
Active C	4.8	2.2	17.3	1.7	4.3	2.2
PMN	1.5	0.5	2.3	0.4	0.8	0.3
Avail. P	7.5	2.1	2.45	1.85	2.5	5.7
Base Sat.	93.5	88.9	97.3	92.6	95.0	80.3
CEC	16.3	4.6	6.3	1.45	2.6	1.65
Bulk D.(g/cm^3)	1.4	1.3	1.3	1.35	1.5	1.5
ESD (cm)	180	127	115	158	140	180
Porosity (m^3/m^3)	0.5	0.5	0.5	0.5	0.4	0.4
Aggt. Stab. (%)	68.2	71.2	60.5	69.2	62.1	68.2
Texture	SC	SL	LS	LS	SC	SL
WHC	0.3	0.3	0.3	0.35	0.3	0.3
Org. C (g/kg)	8.4	8.5	34.2	12.4	9.7	5.5

Table 5. Aggregate physical, chemical and overall soil quality index for each of the farms under Apomu soil series (%).

S/N	Physical quality (%)				Chemical quality (%)				Overall soil quality (%)			
	Cocoa	Cashew	Cassava	Maize	Cocoa	Cashew	Cassava	Maize	Cocoa	Cashew	Cassava	Maize
1	90	81	76	62	79	78	77	58	85	78	77	61
2	85	80	77	62	80	72	75	57	85	76	73	60
3	85	79	75	61	80	75	68	58	87	77	72	60
4	88	78	77	60	79	71	74	61	86	73	77	61
5	87	78	77	62	80	72	69	57	84	77	75	59
6	80	80	69	65	84	71	60	62	85	76	64	64
7	84	79	65	65	82	71	58	60	85	74	62	62
8	84	81	62	63	82	72	61	62	84	78	63	63
9	88	79	64	65	78	71	60	60	83	75	62	62
10	88	80	63	66	80	72	62	61	84	76	64	64

overall soil quality index for each of the farms under Apomu soil series. Physical soil quality index ranged from moderate to high (60 to 90%) with the highest value under cocoa plantation and the lowest value under maize field. Chemical soil quality is lower (57 to 84%) and follow the same trend as physical index. Overall soil quality index also follow the same trend with physical and chemical indices, ranging between 59 and 87%.

Aggregate physical, chemical and overall soil quality index for each of the farms under Iwo Series are shown on Table 6. All the indices follow the same trend as in Apomu series and ranged as: Physical (59 to 90%), chemical (58 to 84%) and overall (60 to 89%).

Aggregate physical, chemical and overall soil quality index for each of the farms under Ibadan Series are shown on Table 7. Similar trend with that of Apomu and Iwo series was also obtained with Ibadan series and they ranged as: Physical (62 to 90%), chemical (58 to 82%) and overall (60 to 89%).

Land use has highly significant effect on soil physical, chemical and overall quality (Table 8 and Figures 2 to 4). Similarly, soil type has highly significant effect on soil physical, chemical and overall quality (Table 9 and Figures 2 to 4).

DISCUSSION

The essence of this study is the assessment of soil quality as a means of (a) establishing its capacity to function for crop production and (b) monitoring the impact of land use and/or management on this capacity. From the results, soil quality indices ranged from moderate to high which could be as a result of the fact that all the soil

Table 6. Aggregate physical, chemical and overall soil quality index for each of the farms under Iwo soil series (%).

S/N	Physical quality (%)				Chemical quality (%)				Overall soil quality (%)			
	Cocoa	Cashew	Cassava	Maize	Cocoa	Cashew	Cassava	Maize	Cocoa	Cashew	Cassava	Maize
1	90	78	67	62	80	76	65	58	87	67	60	61
2	89	79	65	61	80	76	65	60	89	65	58	60
3	90	81	72	59	81	77	69	60	86	66	61	61
4	87	80	75	63	79	79	69	58	87	67	60	61
5	88	82	69	60	80	80	66	59	89	66	62	60
6	80	80	64	61	84	78	62	59	86	76	61	65
7	85	79	68	63	82	78	66	60	84	74	64	62
8	84	79	71	64	84	79	65	60	84	76	60	62
9	80	80	70	62	84	79	66	58	86	75	62	62
10	84	81	69	62	80	80	60	59	86	75	61	63

Table 7. Aggregate physical, chemical and overall soil quality index for each of the farms under Ibadan soil series (%).

S/N	Physical quality (%)				Chemical quality (%)				Overall soil quality (%)			
	Cocoa	Cashew	Cassava	Maize	Cocoa	Cashew	Cassava	Maize	Cocoa	Cashew	Cassava	Maize
1	89	80	65	69	80	70	60	60	87	71	64	65
2	89	79	62	65	79	70	60	59	89	73	62	62
3	90	75	68	70	80	69	59	59	86	70	63	62
4	87	77	67	64	82	67	65	60	87	73	62	63
5	88	75	70	64	82	69	64	58	89	72	64	61
6	90	74	66	62	78	69	59	61	88	67	60	63
7	89	77	67	67	78	65	59	58	88	67	61	65
8	88	77	67	66	77	64	60	59	87	72	62	65
9	89	76	65	62	80	63	64	62	85	75	61	61
10	89	78	68	63	79	64	64	59	86	74	59	61

Table 8. Effect of land use on soil physical quality, soil chemical quality and overall soil quality.

Treatment	Physical quality (%)	Chemical quality (%)	Overall soil quality (%)
Cocoa	86.7	80.4	86.1
Cashew	78.7	72.6	72.7
Cassava	68.7	64.4	63.9
Maize	68.1	59.4	62.0
LSD	142***	1.45***	1.48***

quality indicators assessed are of moderate to high values.

Soil quality was generally higher under tree crops (cocoa and cashew) than the arable crops (cassava and maize). This may be due to the fact that tree crops produce debris which when decomposed helps to improve the levels of some of the soil quality indicators. For instance, organic matter is improved, and will positively influence aggregate stability, water holding capacity, and reduce compaction and erosion (Pagliai et al., 1998). Solomon et al. (2002) also reported that a change in organic matter content of the surface soil significantly influenced other key soil properties. Soil organic matter play key roles in soil function, determining soil nutrient status, water holding capacity and susceptibility of soil to degradation (Feller et al., 2001). In addition, soil organic matter may serve as a source or sink to atmospheric CO_2 (Lal, 1997) and an increase in the soil carbon content is indicated by a higher microbial biomass and elevated respiration (Sparling et al., 2003). It

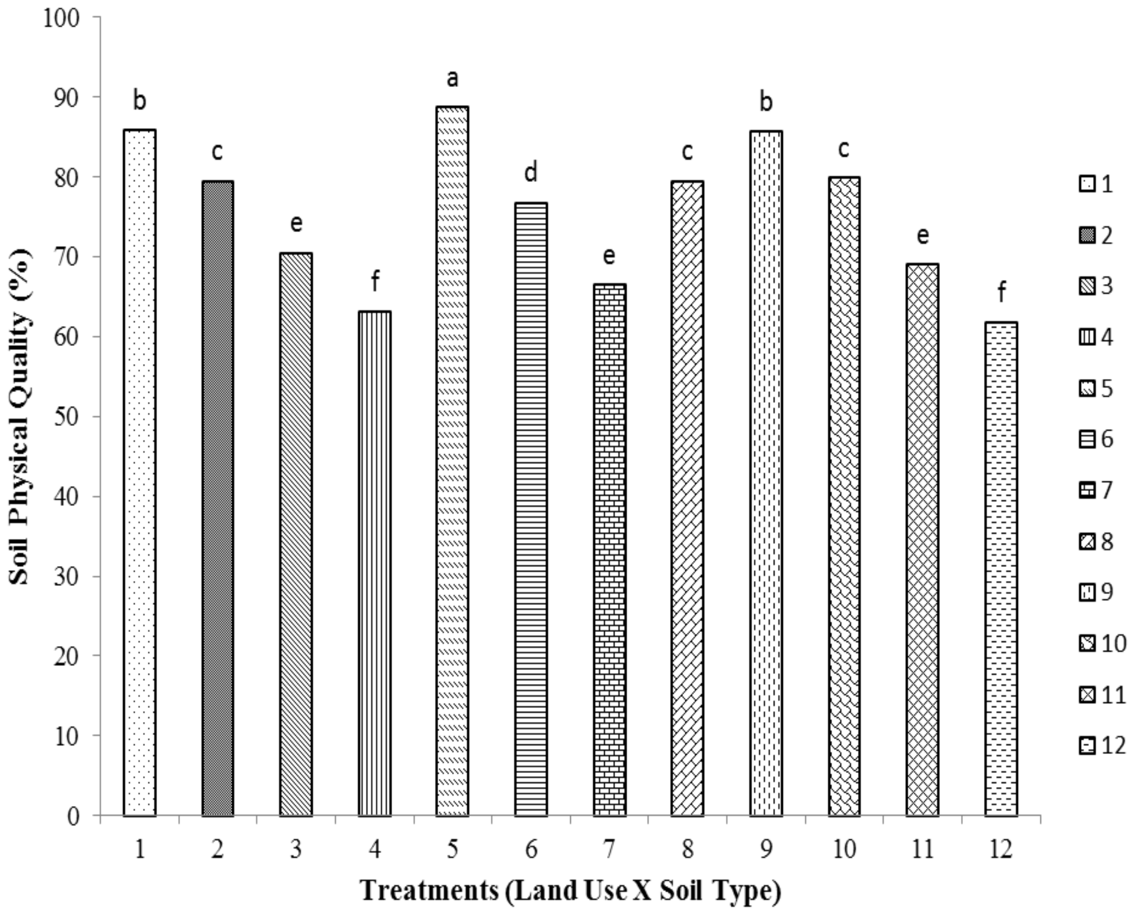

Figure 2. Effect of land use and soil type on soil physical quality. 1, Soil quality index of Apomu series under cocoa plantation; 2, soil quality index of Apomu series under cashew plantation; 3, soil quality index of Apomu series under cassava field; 4, soil quality index of Apomu series under maize field; 5, soil quality index of Ibadan series under cocoa plantation; 6, soil quality index of Ibadan series under cashew plantation; 7, soil quality index of Ibadan series under cassava field; 8, soil quality index of Ibadan series under maize field; 9, soil quality index of Iwo series under cocoa plantation; 10, soil quality index of Iwo series under cashew plantation; 11, soil quality index of Iwo series under cassava field, and12, soil quality index of Iwo series under maize field.

Table 9. Effect of soil type on soil physical quality, soil chemical quality and overall soil quality.

Treatment	Physical quality (%)	Chemical quality (%)	Overall soil quality (%)
Ibadan	74.8	69.7	72.8
Apomu	77.9	66.9	70.8
Iwo	74.0	71.0	69.9
LSD	1.23***	1.26***	1.28***

is also the principal reserve of nutrients such as N in the soil and some tropical soils may contain large quantities of mineral N in the top 2 m depth (Havlin et al., 2005). Furthermore, tree crops produce large amount of biomass which cover the soil surface and prevent the direct impact of raindrops on the soil surface. This is supporting the submission of Paudel et al. (2011) that perennial vegetation enhances soil organic matter accumulation and minimizes topsoil disturbance. Also, the canopies produced by tree crops can also protect the topsoil from the direct impact of raindrops which can detach the soil particles and result in soil erosion. With the arable crops (cassava and maize) however, soil quality was better under cassava farm than under maize. This could be due to the fact that maize is a nutrient miner and requires high input and management practices

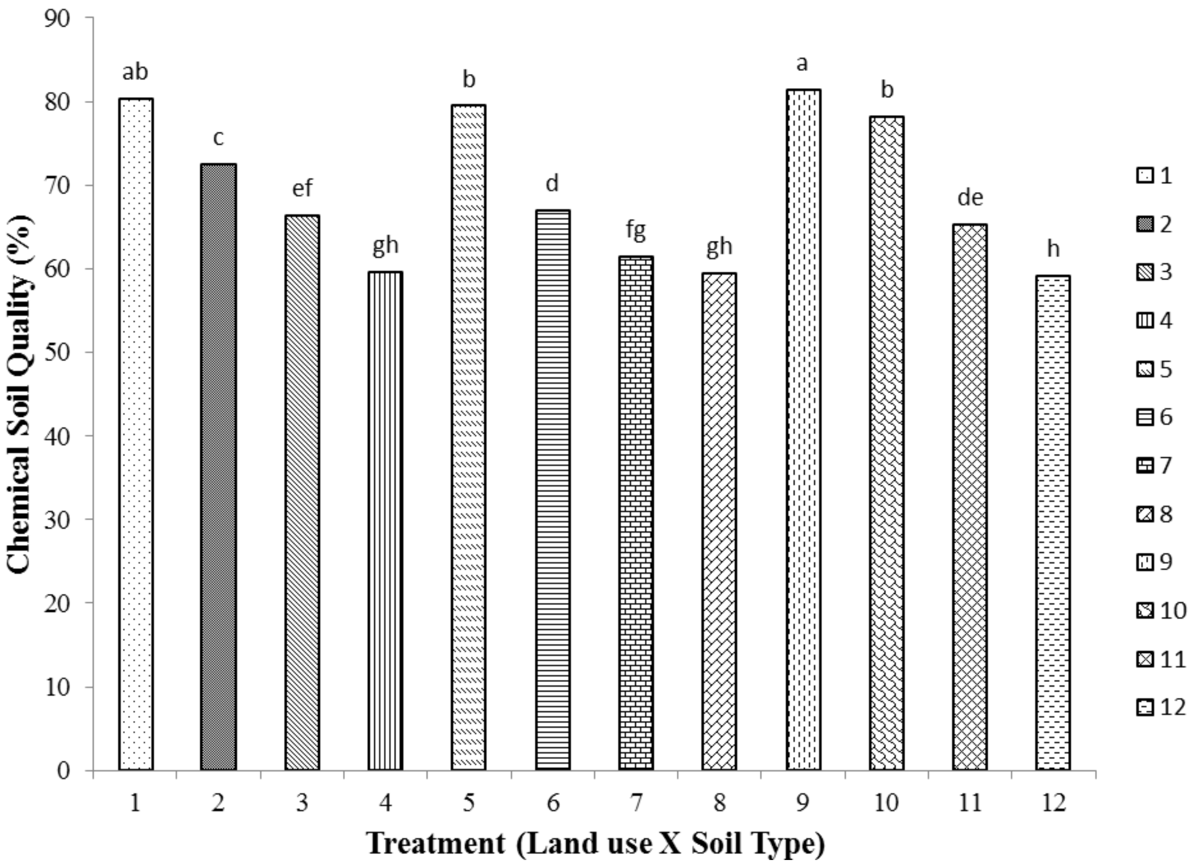

Figure 3. Effect of land use and soil type on soil chemical quality. 1, Soil quality index of Apomu series under cocoa plantation; 2, soil quality index of Apomu series under cashew plantation; 3, soil quality index of Apomu series under cassava field; 4, soil quality index of Apomu series under maize field; 5, soil quality index of Ibadan series under cocoa plantation; 6, soil quality index of Ibadan series under cashew plantation; 7, soil quality index of Ibadan series under cassava field; 8, soil quality index of Ibadan series under maize field; 9, soil quality index of Iwo series under cocoa plantation; 10, soil quality index of Iwo series under cashew plantation; 11, soil quality index of Iwo series under cassava field, and12, soil quality index of Iwo series under maize field.

while cassava is hardy. It has been established that continuous cultivation of arable crops especially maize degrades soil properties faster than tree crops (Bonanomi et al., 2011).

Generally, Apomu series recorded higher soil quality index than the other two soil types (Ibadan and Iwo Series). This could be due to the fact that Apomu Series is usually located at the lower slope of the toposequence which make it possible for organic matter and other nutrients deposition resulting into high nutrient level, low bulk density, good tilth and water holding capacity. Oluwatosin, et al. (2003) also submitted that lower slope soils are usually enriched with materials transported from the uplands.

Conclusions

The concern for sustainable land management has necessitated the need to put in place efficient assessment method that will make monitoring of land use impact on land resources possible in order to prevent land degradation. This study was set up to assess soil quality under tree and arable land uses and their impacts on the soils capacity. Four farmlands (cocoa, cashew, cassava and maize) on the three soil types (Apomu, Ibadan and Iwo Series) were selected within Aiyedire local government area of Osun State. Soil management assessment framework was used to assess the physical, chemical and overall soil quality. The soil quality indices were subjected to analysis of variance and means separated least significant differences. Physical, chemical and overall soil quality indices ranged from moderate to high with the highest value occurring under cocoa plantation on Apomu series and the lowest under maize field. Both land use and soil type have significant effect on soil physical, chemical and overall quality. Arable crops especially maize will degrade soil quality quickly if not well managed. Also, soils located at the lower slope are enriched with nutrients and should be well managed

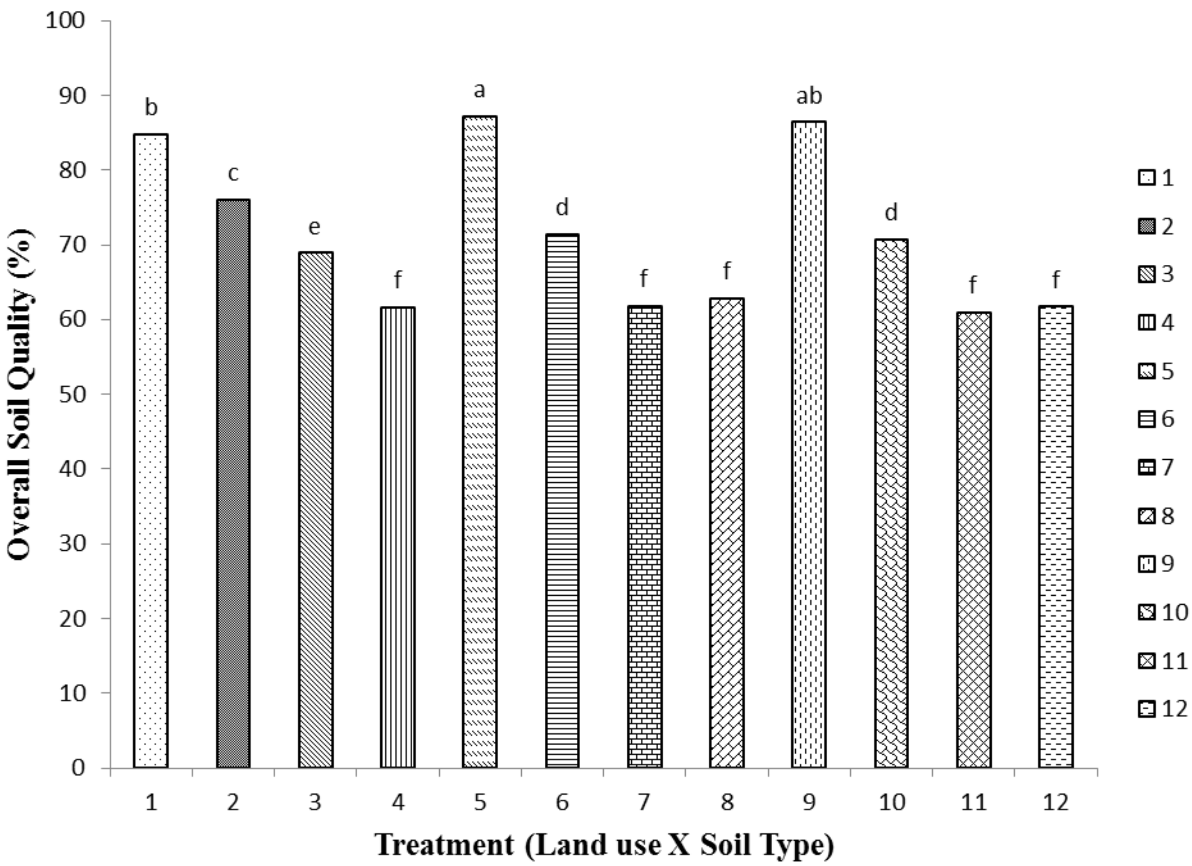

Figure 4. Effect of land use and soil type on overall soil quality. 1, Soil quality index of Apomu series under cocoa plantation; 2, soil quality index of Apomu series under cashew plantation; 3, soil quality index of Apomu series under cassava field; 4, soil quality index of Apomu series under maize field; 5, soil quality index of Ibadan series under cocoa plantation; 6, soil quality index of Ibadan series under cashew plantation; 7, soil quality index of Ibadan series under cassava field; 8, soil quality index of Ibadan series under maize field; 9, soil quality index of Iwo series under cocoa plantation; 10, soil quality index of Iwo series under cashew plantation; 11, soil quality index of Iwo series under cassava field, and12, soil quality index of Iwo series under maize field.

for sustainable use.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Andrews SS, Karlen DL, Cambardella CA (2004). The soil management assessment framework: a quantitative soil quality evaluation method. Soil Sci. Soc. Am. J. 68:1945-1962.

Bonanomi G, D'Ascoli R, Antignani V, Capodilupo M, Cozzolino L, Marzaioli R, Puopolo G, Rutigliano FA, Scelza R, Scotti R, Rao MA, Zoina A (2011). Assessing soil quality under intensive cultivation and tree orchards in Southern Italy. Appl. Soil Ecol. 47(3):184-194.

Cameron K, Beare MH, McLaren RP, Di H (1998). Selecting physical, chemical and biological indicators of soil quality for degraded or polluted soils. Proceedings of 16th World Congress of Soil Science. Montpellier, France, Symposium. P. 37.

Doran JW, Parkin TB (1994). Defining and assessing soil quality for a sustainable environment. SSSA Spec. Public. 35:1-21.

Doran JW, Zeiss MR (2000). Soil health and sustainability: managing the biotic component of soil quality. Appl. Soil Ecol. 15:3-11.

Feller C, Balesdent J, Nicolardot B, Cerri C (2001). Approaching functional soil organic matter pools through particle-size fractionation. Examples for tropical soils. In: Lal, R., Kimble, K.M. and Follet, R.F. (eds). Assessment methods for soil carbon. Adv. Soil Sci. pp. 53-67.

Gugino BK, Idowu OJ, Schindelbeck RR, Van Es HM, Wolf DW, Thies JE, Abawi GS (2007). Cornel soil health assessment training manual. Edition 1.2. Cornel University, Geneva, NY.

Havlin JL, Beaton JD, Tisdale SL, Nelson WL (2005). Soil fertility and nutrient management: An introduction to nutrient management. 7th edition. P. 515. Pearson/Prentice Hall. Upper Saddle River, NJ.

He ZI, Alva AK, Calvert DV, Li YC, Banks DJ (1999). Effects of N fertilization of grapefruit trees on soil acidification and nutrient availability in a Riviera fine sand. Plant Soil 206:11-19.

Lal R, Blum WEH, Valentin C, Stewart BA (1997). Methods for assessment of soil degradation. CRC Press P. 576.

Maddoni GA, Urricariet S, Ghersa CM, Lavado RS (1999). Assessing soil fertility in the rolling Pampa, using soil properties and maize characteristics. J. Agric. Res. Sci. 91:280-286.

Merrington G, Fishwick S, Barraclough D, Morris J, Preedy N, Boucard T, Reeve M, Smith P, Fang C (2006). The development and use of soil quality indicators for assessing the role of soil in environmental interactions. Environmental Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol. P. 241.

Nearing MA, Deer-Ascough L, Laflen JM (1990b). Sensitivity analysis of the WEPP hillslope profile erosion model. Trans. ASAE. 33:839-849.
Oluwatosin GA, Adeyolanu OD, Idowu OJ (2003). Soil quality and sustainability: an experience from osun basin of southwestern Nigeria. Land 7(3):215-233.
Pagliai M, Rousseva S, Vignozzi N, Pivanelli C, Pellegrini S, Miclaus N (1998). Tillage impact on soil quality: Soil porosity and related physical properties. Ital. J. Agron. 1(2):11-20.
Paudel BR, Udawatta RP, Anderson SH (2011). Agroforestry and grass buffer effects on soil quality parameters for grazed pasture and row-crop systems. Appl. Soil Ecol. 48(2):125-132.
Sanchez PA, Sheperd KD, Soule FM, Place RJ Buresh AMN, Izac AU, Mokwunye FR, Kwesiga CG, Ndiritu WPL (1997). Soil fertility replenishment in Africa. An investment in natural resources capital. In: Buresh RJ, Sanchez PA, Calnoun F (eds.), SSSA Spec. public. 51:1-46.
Smyth AJ, Montgomery RF (1962). Soil and Land Use in Central Western Nigeria. Government Printer, Ibadan, Nigeria. P. 265.
Solomon DF, Fritzsche F, Tekalign M, Lehmann J, Zech W (2002). Soil organic matter composition in the subhumid Ethiopian highlands as influenced by deforestation and agricultural management. Soil Sci. Soc. Am. J. 66:68-82.
Sparling G, Liburne L, Vojvodic-Vukovic M (2003). Provisional target for soil quality indicators in New Zealand. Landcare Research, Palmerston North, New Zealand. P. 224.

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Spatial variability of available nutrients in soils of Nainpur tehsil of Mandla district of Madhya Pradesh, India using Geo-statistical approach

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Scientific information concerning spatial variability and distribution of soil properties is critical for farmers attempting to increase fertilization efficiency and crop productivity; fertilization based on maps with recommendations related to soil fertility may lead to reduced fertilizer inputs without reducing yield. In the present study, GPS based one hundred fifty surface soil samples (0-15 cm) were collected from dominant cropping system. After processing, the soil samples were analyzed for different soil characteristics in laboratory using standard procedures. The data obtain from laboratory analysis was statistically and geo-statistical interpreted. The results revealed that the 23.6, 28.30, 48.6, 13.9, 25.5 and 54.7% soil samples were found to be deficient in OC, N, P, K, S and Zn, respectively. None of the soil samples were tested low in Cu, Fe, Mn and B. Exponential model was found as the best fit for considered soil parameters whereas, spherical model was found as the best fit for Mn. The best model was used to generate the spatial distribution maps. Spatial maps showed that the soil pH, EC, organic carbon, available N, P, K, S, Zn, Cu, Fe, Mn and B spatially varied and N, P, K, S and Zn were deficient in major areas. Therefore these maps are more useful for guiding site-specific field management for agricultural production and environmental protection. In addition, reduce the losses of nutrients and could be save time and money for fertilizers.

Key words: Geo-statistical, soil types, land use, semi-variogram, kriging, nutrient status.

INTRODUCTION

Soil is the primary source of plant nutrients that control its fertility and thus yield of crops (Qu et al., 2014). Expectation of higher productivity using adequate amount of fertilizer nutrients may lead to become limiting to some micronutrients in the soil and most times due to their over mining by the crops and shortage of which often show the

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deficiency symptoms and yields are reduced. However, intensive cultivation, indiscriminate use of high analysis chemical fertilizers results deficiency of micronutrients (Singh et al., 2007). The soil must supply all the essential nutrients for desired growth of plants has contributed to a tremendous increase in yields of agricultural crops that feed the world's population (Hak-Jin et al., 2009). Ideally, application rates should be adjusted based on estimates of the requirements for optimum production at each location because there is high spatial variability of N, P, and K within individual fields (Page et al., 2005; Ruffo et al., 2005). In this context, it is necessary to evaluate the fertility status of the soil and promote the recommendations of soil test for balanced nutrition to maintain soil health. Classical statistics requires the validity of some basic hypotheses, such as the independence between observations, due to the randomness of variations from one place to another. Farmer's of the tribal areas have very little knowledge of fertility status of their fields; therefore, the desired level of productivity is not being achieved even after utilizing all inputs.

In the last few decades, geo-statistics has been used extensively to characterize the spatial variability of soil attributes due to its ability of quantifying and reducing sampling uncertainties and minimizing investigation costs (Cambule et al., 2014). Numerous studies have been conducted based on geo-statistical analysis to characterize the spatial variability of soil physical (Li et al., 2007; Weindorf and Zhu, 2010), chemical (Liu et al., 2013; Lin et al., 2009; Huang et al., 2007), and biochemical (Šnajdr et al., 2008) properties, as well as microbiological processes (Cao et al., 2011). Thus, information on spatial variability of soil nutrients is important for sustainable management of soil fertility (Fraisse et al., 1999). Hence, the present study was conducted.

MATERIALS AND METHODS

Description study area

Geographical location of study area

Mandla district is located in the east-central part of the Madhya Pradesh, India covering an area of 8771 km^2 and consists of a rugged high tableland in the eastern part of the Satpura hills. Geographically, Nainpur is located between 79°56'45.0" to 80°26'15.0" E longitudes and 22°17'31.0" to 22°37'30" N latitudes, having an area of 845.79 km^2 of the total geographical area of district.

Climate

The climate of this district is characterized by hot summer season and general dryness except in the southwest monsoon season. May is the hottest month with the mean daily minimum temperature at 41.3°C and the mean daily minimum at 24°C (Figure 1).

Land use and cropping pattern

Land use map prepared by using Indian remote-sensing satellite-P6, linear imaging self-scanning satellite-III (IRS-P6, LISS-III) satellite imagery dated January-2014, October-2013 and April-2013. The satellite data has the characteristics of 23.5 m spatial resolution, four spectral channels green (0.52 to 0.59 µ), red (0.62 to 0.68 µ), NIR (0.77 to 0.86 µ), and SWIR (1.55 to 1.70 µ) and five days temporal resolution with 141 km swath. The statistics reveals area extent of land mainly under agricultural (46.37%), followed by dense forest (19.98%), open forest (9.79%), fallow land (9.23%) waste land- dense (3.22%) and waste land open scrub (6.53%) and others etc. Based on ground truth data collected from local agriculture departments and farmers interviewed, the rice and wheat are major food grain crops. Paddy, maize, kodo, kutki, soybean are important crops during *Kharif* season and wheat, pea, gram, lentil, and mustard crops during *Rabi* season in tribal areas of Mandla district (Figure 2).

Soil types

The survey of India topographical maps (1:50000) and the map of soil as a secondary data was used from NBSSLUP Nagpur. The highest area occupied under vertisols followed by inceptisols, entisols and alfisols. These soils are fine montmorillonitic, hyperthermic and having high swell shrink potential (Table 1 and Figure 3).

Soil sampling and analysis

Sampling sites were generated using land use and soil association maps. The sites decided randomly distributed over agricultural land of the study area by considering of topography and heterogeneity of the soil type. Field data collection and soil sampling were carried out by using GPS by navigating those points. One hundred fifty soil samples (0 to 15 cm) were collected from farmer's field during the 2013 off season from the agricultural land. For each main sampling point, 1.0 kg of representative composite soil sample was collected and logged into properly labeled sample bag.

Laboratory analysis

Soil samples collected from the study area were dried and crushed with the help of wooden rod and passed through 2 mm sieve and then used for the determination of soil pH, electrical conductivity, organic carbon, calcium carbonate and macronutrients like N using Subbiah and Asija (1956), P using Olsen et al. (1954) and K content by adopting standard laboratory methods described in Jackson (1973) (Table 2).

Available micronutrients (Zn, Cu, Fe and Mn) were extracted by DTPA-$CaCl_2$ solution and analyzed using atomic absorption spectrophotometer (Lindsay and Norvell, 1978). Hot water soluble boron in soil was analyzed by azomethine-H method as outlined by Berger and Truog (1939). The available sulphur was extracted by 0.15% $CaCl_2$ solution and the concentration of sulphur was determined by the turbidimetric method using spectrophotometer (Chesnin and Yien, 1951).

Nutrient index calculation

The nutrient index (NI) values for available nutrients present in the soils were calculated utilizing the formula suggested by Parker et al. (1951) and classified this index as low (<1.67), medium (1.67 to 2.33) and high (>2.33).

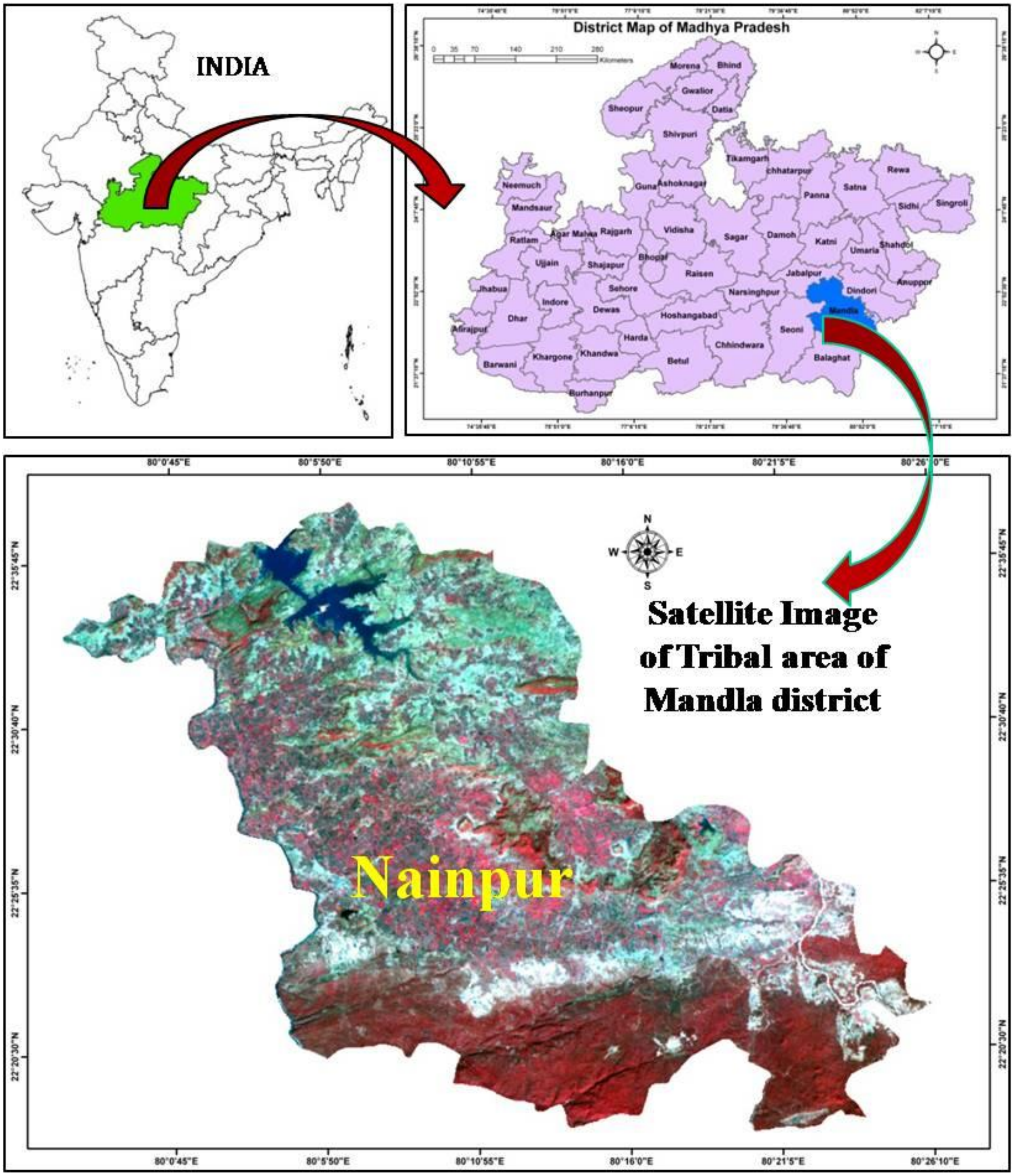


Figure 1. Location map of study area.

$$NI = [(NL \times 1) + (NM \times 2) + (NH \times 3)]/NT$$

Where: Nl, Nm and Nh are the number of soil samples falling in low, medium and high categories for nutrient status and are given weight age of 1, 2 and 3, respectively. Nt is the total number of sample.

Statistical and geo-statistical analysis

It is necessary to check whether the available contents of N, P, K and S and micronutrients in soil samples are approximately normally distributed or not because Kriging assumes the normal distribution for each estimated variable. A normal distribution was estimating based on skewness values and the variable datasets

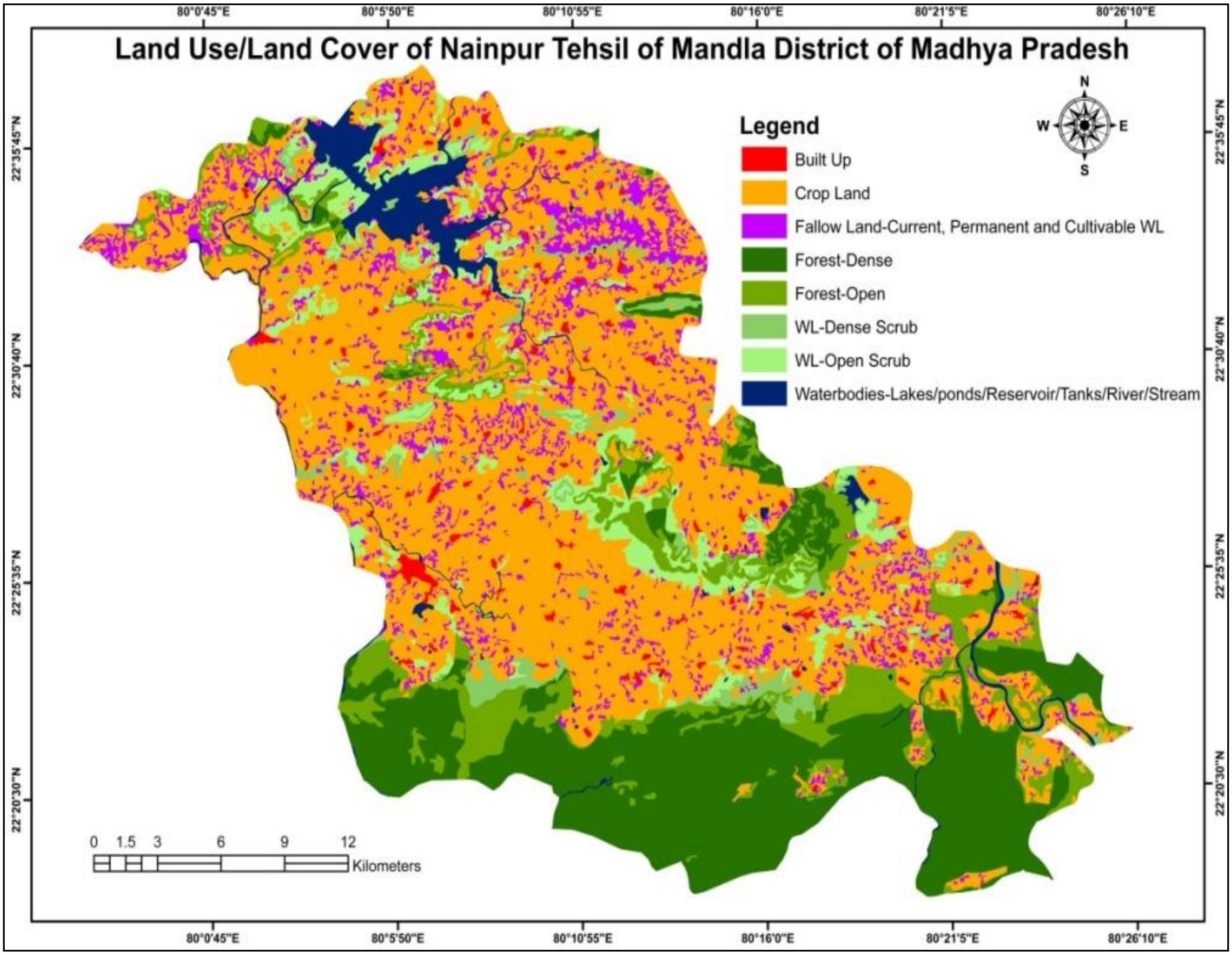


Figure 2. Land use/land cover of study area.

having a skewness ranging between -1 and 1 were considered normally distributed. For non-datasets, a logarithmic transformation was performed to achieve a normal distribution for use in the next step of the statistical analysis.

Geo-statistical methods were used to analyze the spatial correlation structures of the available contents of N, P, K and S and micronutrients in soil and spatially estimate their values at unsampled locations using geo-statistical tool in GIS 9.3.1 software. The spatial dependency of selected soil parameters was analyzed using semi-variogram analyses with normalized data. Semi variogam analyses have been proven as an excellent approach to exploring the structure of spatial variogram in agricultural soils.

The above phenomena is the best accomplished studying the semivariogram (Warrick et al., 1986) which is a plot of semi-variance that characterizes the rate of change of a mapped variable with respect to distance. Semi-variogram $y(h)$ is computed as half the average squared difference between the soil properties of data pairs. The structure of spatial variability was analyzed through semi-variograms (Figure 4). A semi variogram was calculated for each soil property. The semi variance γ(h) is estimated as:

$$y(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2,$$

where N(h) is the number of data pairs within a given class of distance and direction, z(xi) is the value of the variable at the location xi and z(xi + h) is the value of the variable at a lag of h from the location xi.

An experimental semi-variogram was calculated using the measured data. Next, this was generally fitted with a theoretical model, such as Exponential, spherical and Gaussian models (Goovaerts, 1999). Choice of the best-fitted model was based on the lowest residual sum of square (RSS) and the largest coefficient of determination (R^2). The model provided information about the spatial structure as well as the input parameters (that is, nugget, sill and range) for the Kriging interpolation. Nugget is the variance at distance zero, sill is the semi- variance value at which the Semi-variogram reaches the upper bound after its initial increase, and range is a value (x axis) at which one variable becomes spatially independent.

Table 1. Soil associations in Nainpur tehsil of Mandla district.

Code	ASS1	ASS2	Area(km^2)
9	Loamy mixed hyperthermic, Typic Ustochrepts	Loamy mixed hyperthermic, Lithic Ustorthents	62.65
23	Loamy skeletal mixed hyperthermic Lithic Ustochrepts	Loamy mixed hyperthermic, Lithic Ustorthents	19.70
28	Loamy mixed hyperthermic Lithic Ustochrepts	Fine mixed hyperthermic, Typic Ustochrepts	16.05
54	Fine montmorilonitic hyperthermic Vertic Ustochrepts	Fine montmorilonitic hyperthermic Typic Haplusterts	2.80
58	Loamy mixed hyperthermic, Lithic Ustorthents	Clayey mixed hyperthermic, Typic Ustochrepts	17.40
60	Fine montmorilonitic hyperthermic Typic Haplusterts	Fine montmorilonitic hyperthermic Vertic Ustochrepts	130.82
81	Fine montmorilonitic hyperthermic Typic Haplusterts	Fine montmorilonitic hyperthermic Chromic Haplustrets	280.01
85	Fine montmorilonitic hyperthermic Chromic Haplusterts	Fine montmorilonitic hyperthermic Typic Ustochrepts	23.79
97	Fine Loamy Kaolinitic hyperthermic Typic Ustochrepts	Fine Loamy Kaolinitic hyperthermicTypic Haplustalfs	201.94
101	Fine Loamy Kaolinitic hyperthermicTypic Haplustalfs	Fine Loamy Kaolinitic hyperthermicTypic Ustochrepts	70.23
109	Loamy mixed hyperthermic, Lithic Ustohrepts	Fine mixed hyperthermic, Typic Ustochrepts	17.87
122	Fine mixed isohyperthermic Typic Haplusterts	Fine mixed isohyperthermic Typic Ustropepts	15.90

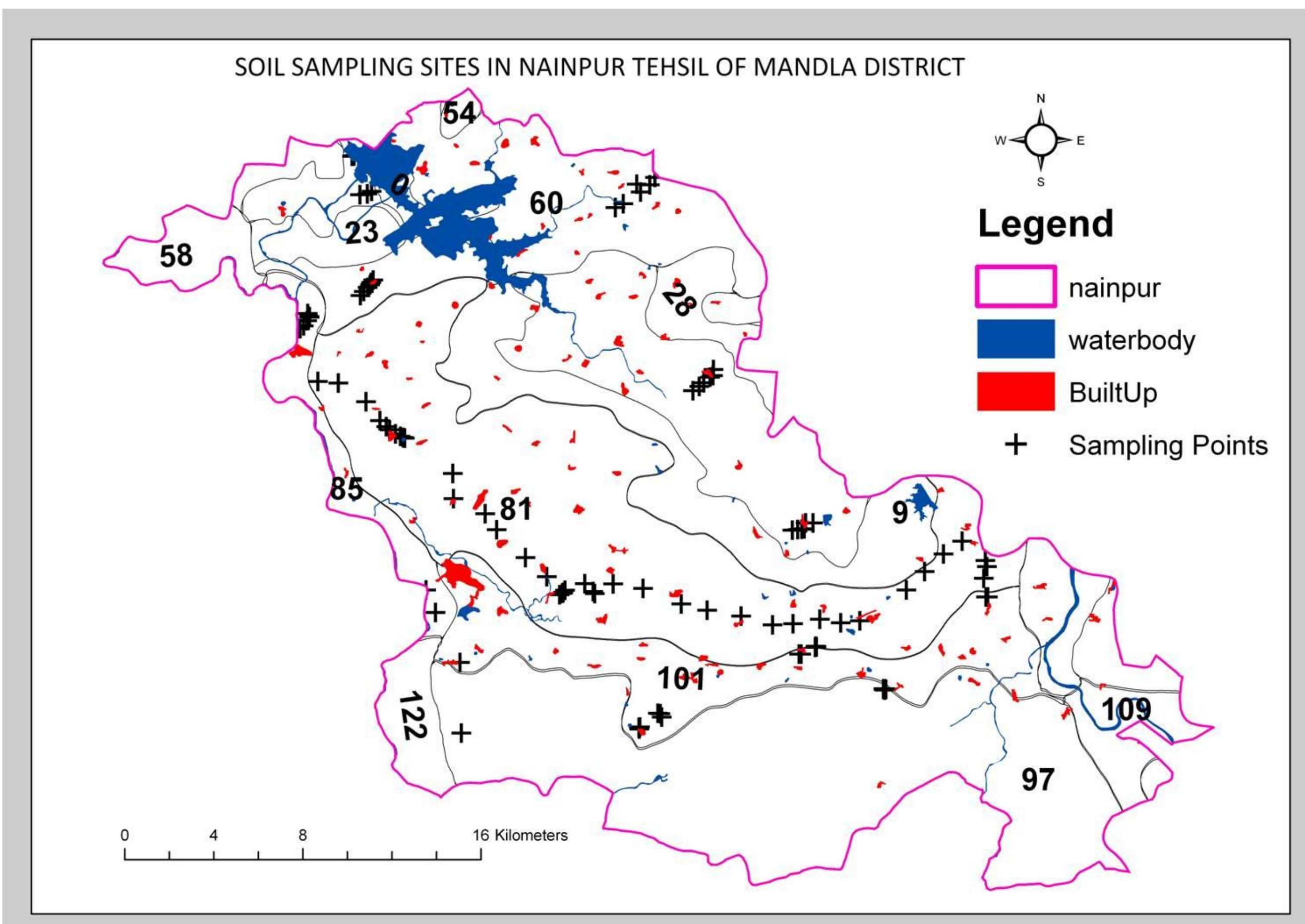
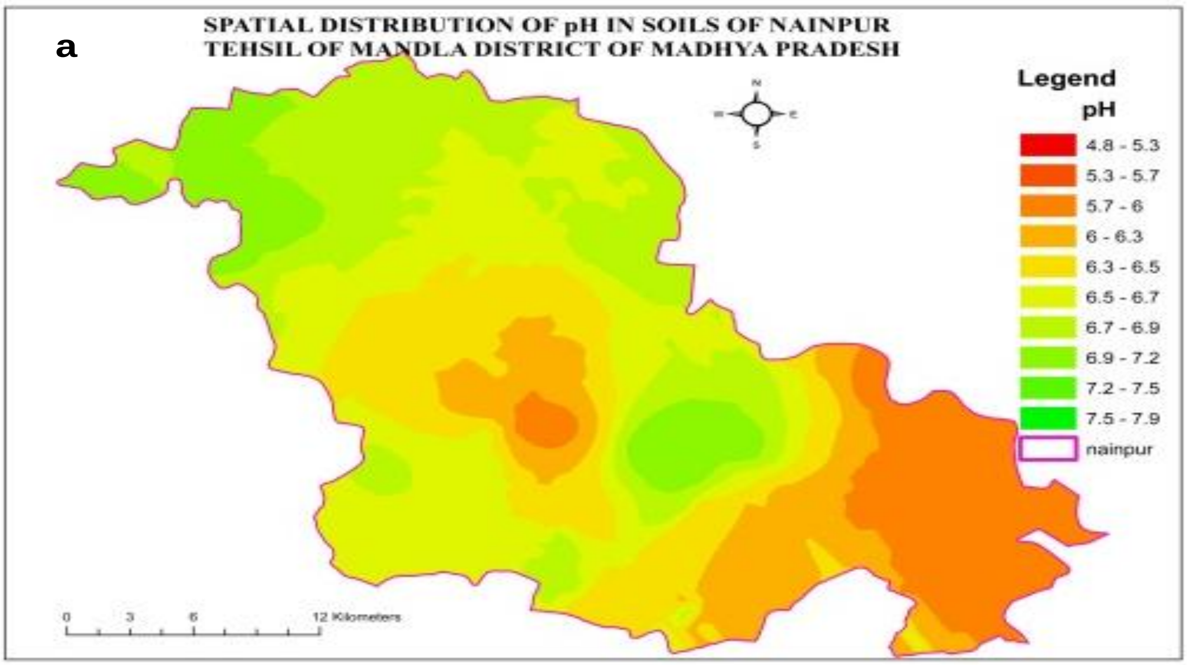
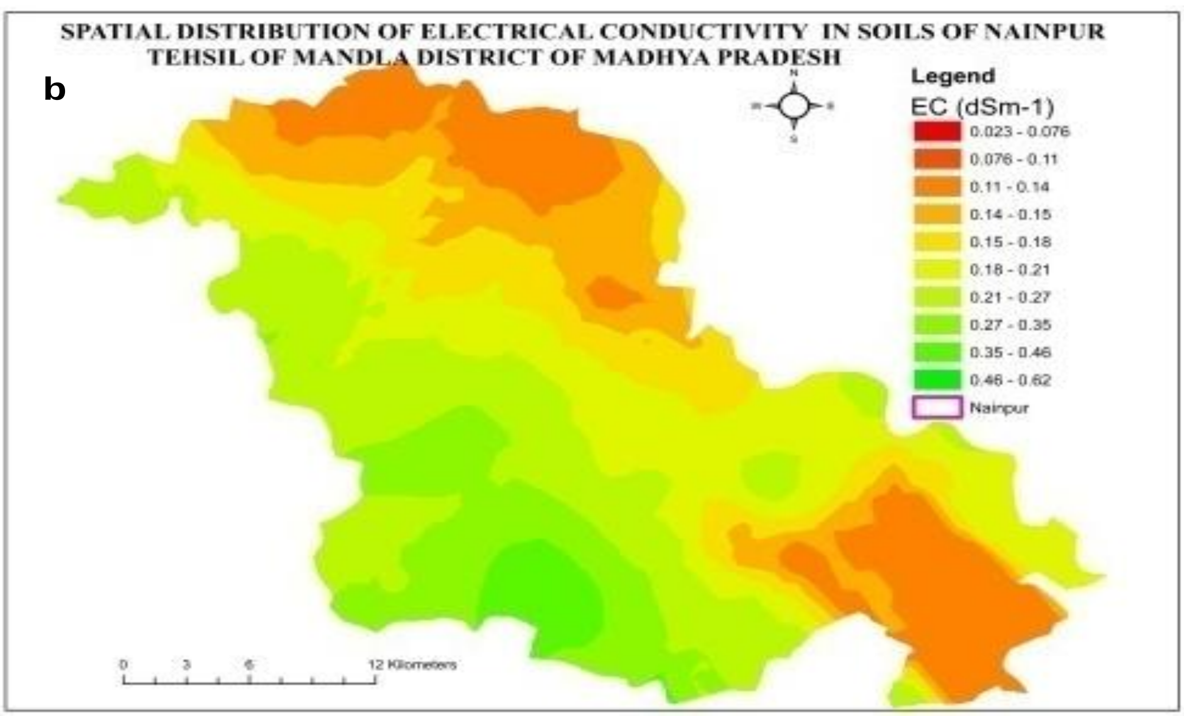


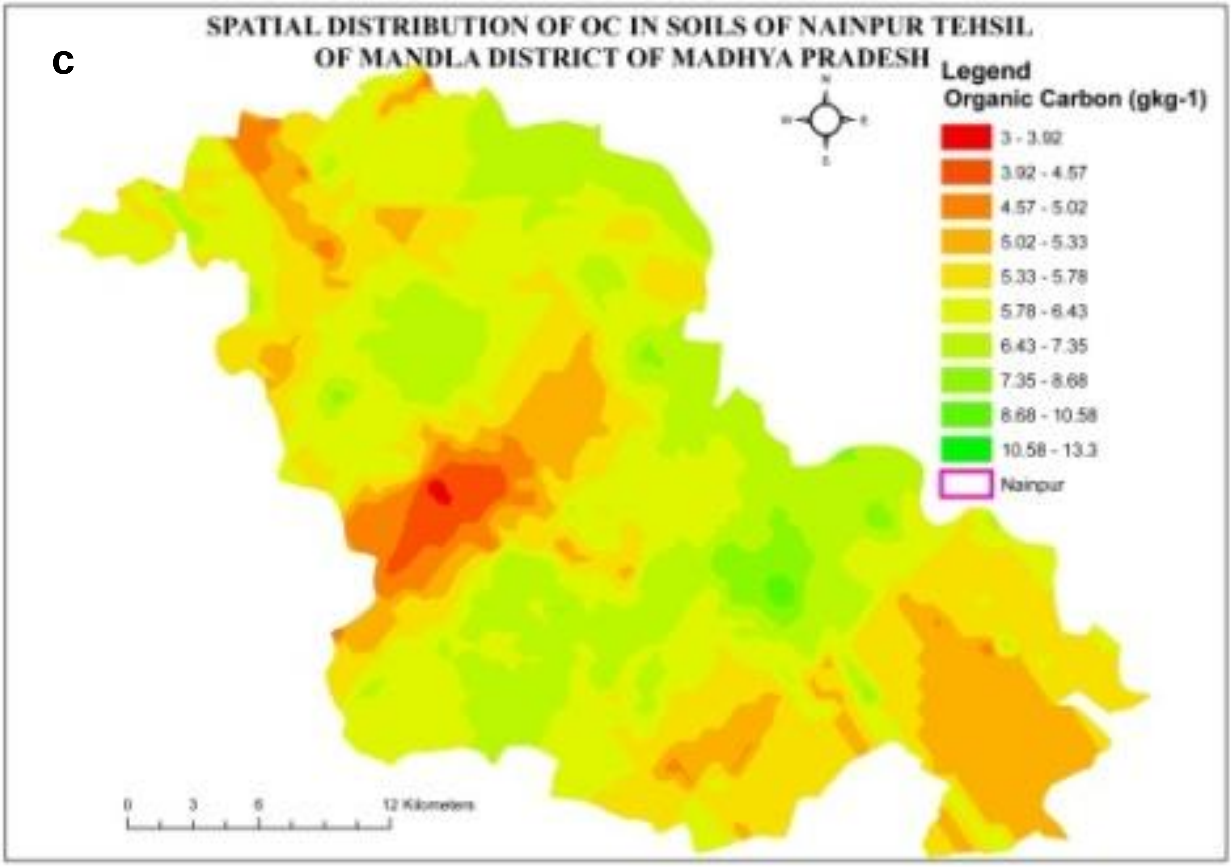
Figure 3. Sampling sites distribution under different soil associations of Nainpur tehsil of Mandla district of M.P.

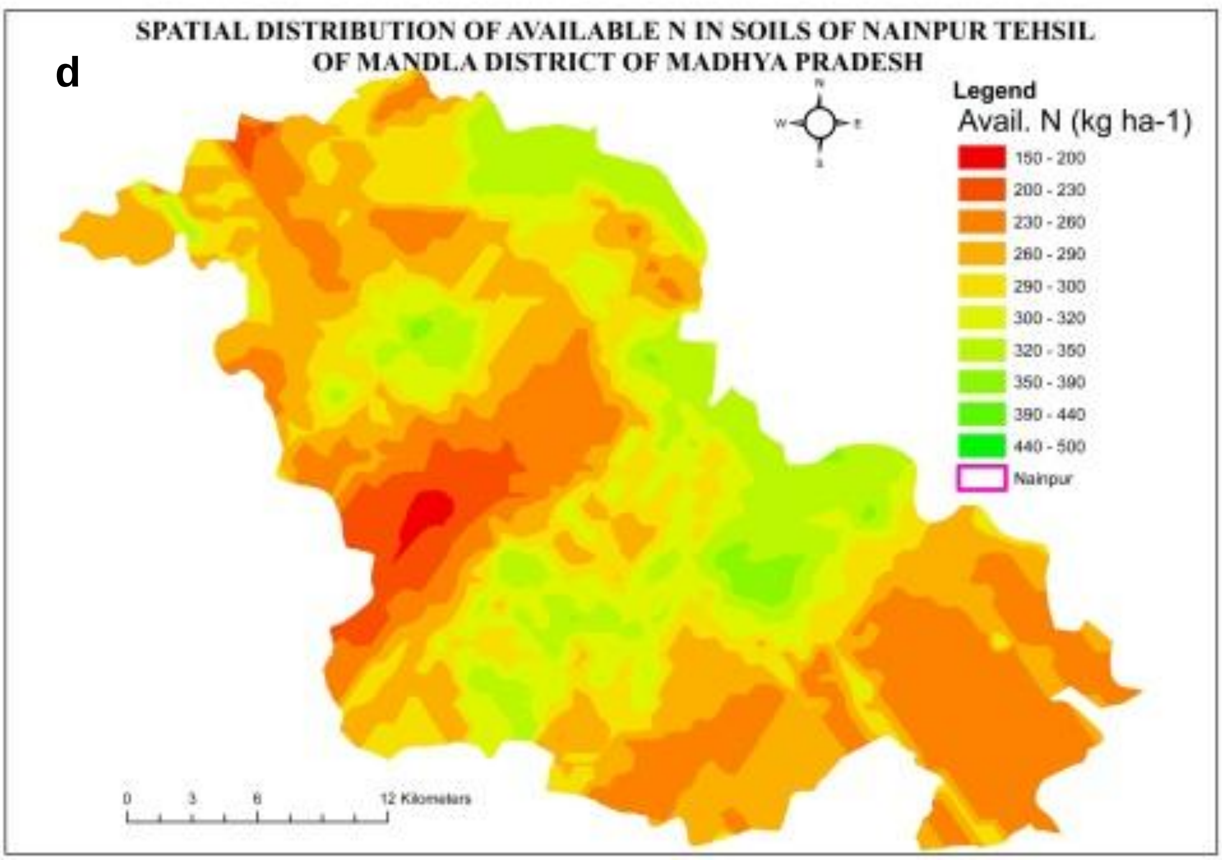
Table 2. The critical limits of micronutrients (mg kg^{-1}) were used for various categories (low, medium and high) as suggested by Singh et al., (2007).

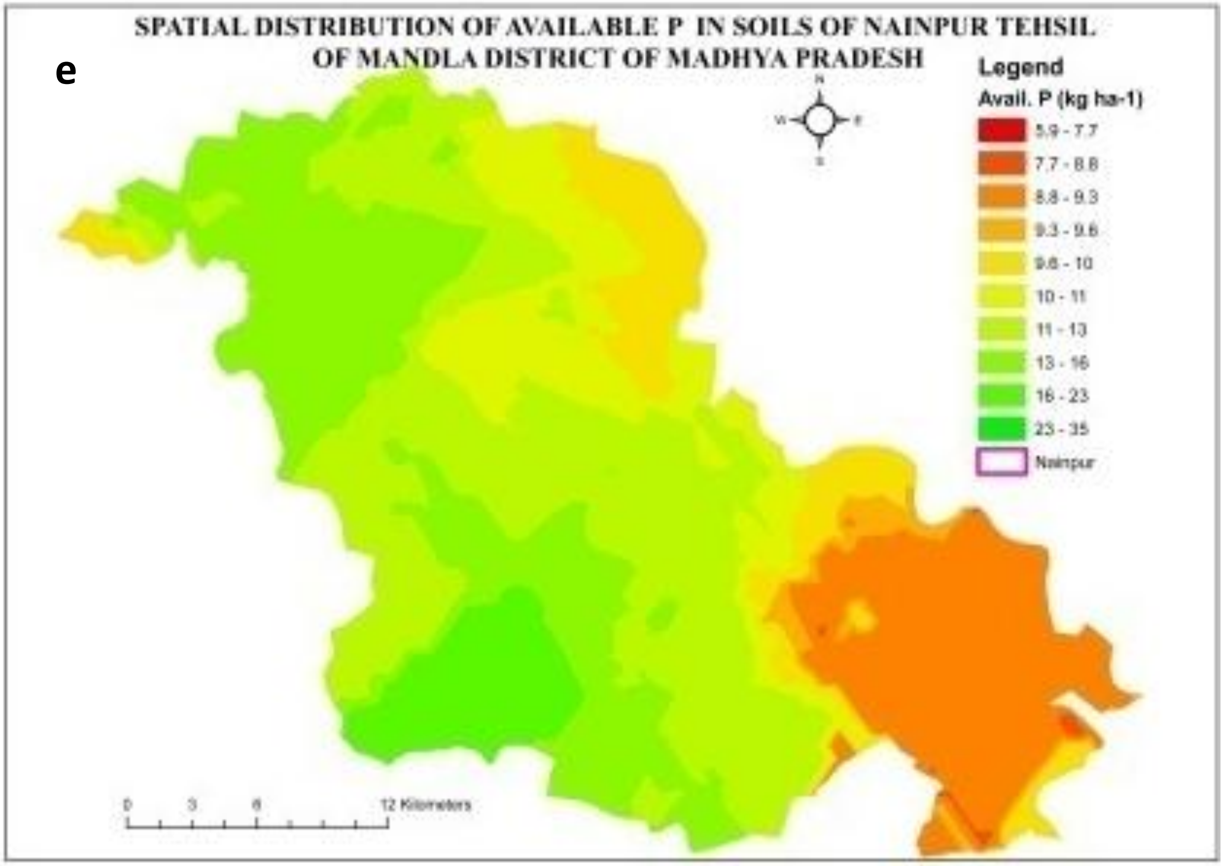
Micronutrients	Low	Medium	High
Zn	<0.6	0.6-1.2	>1.2
Cu	<0.2	0.2-0.4	> 0.4
Fe	< 4.5	4.5-9.0	>9.0
Mn	<2.0	2.0-4.0	>4.0
B	<0.1	0.1-0.60	>0.60

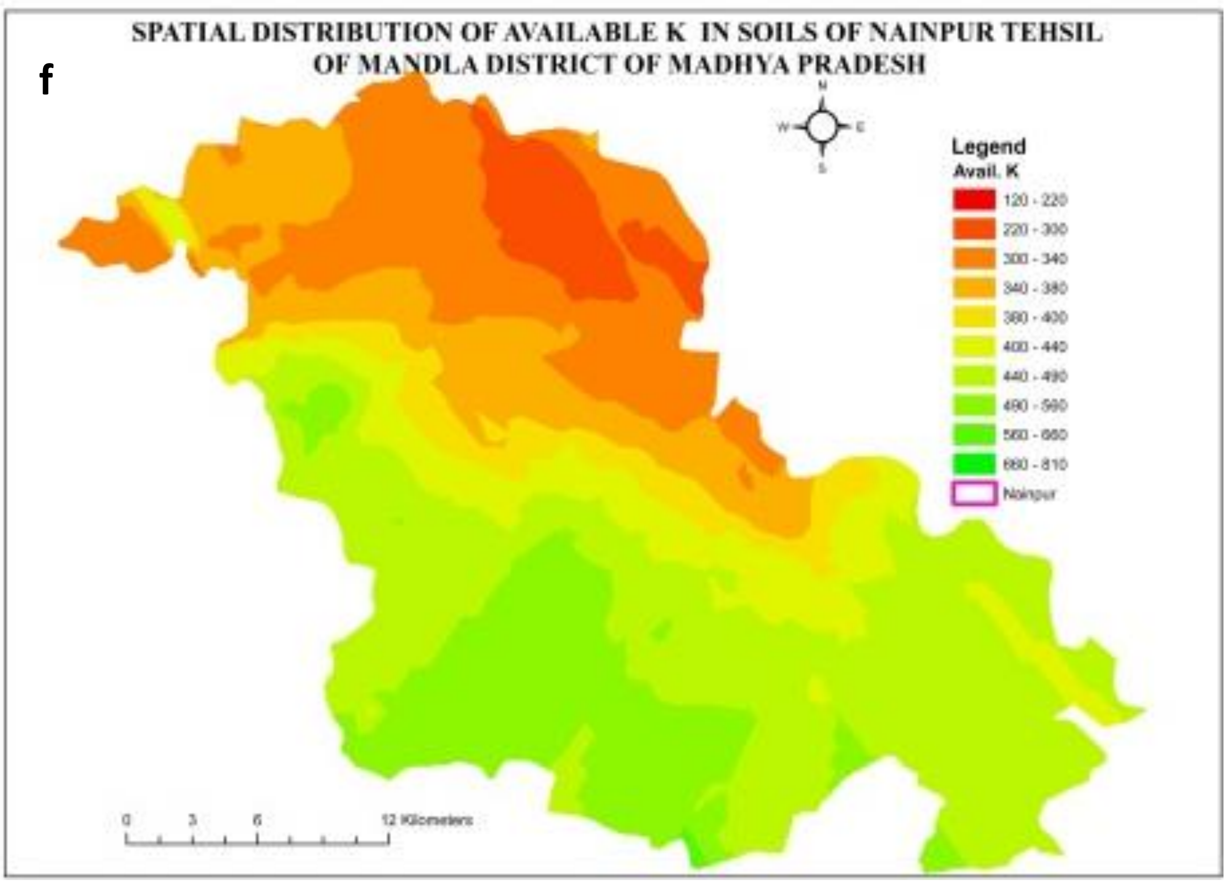


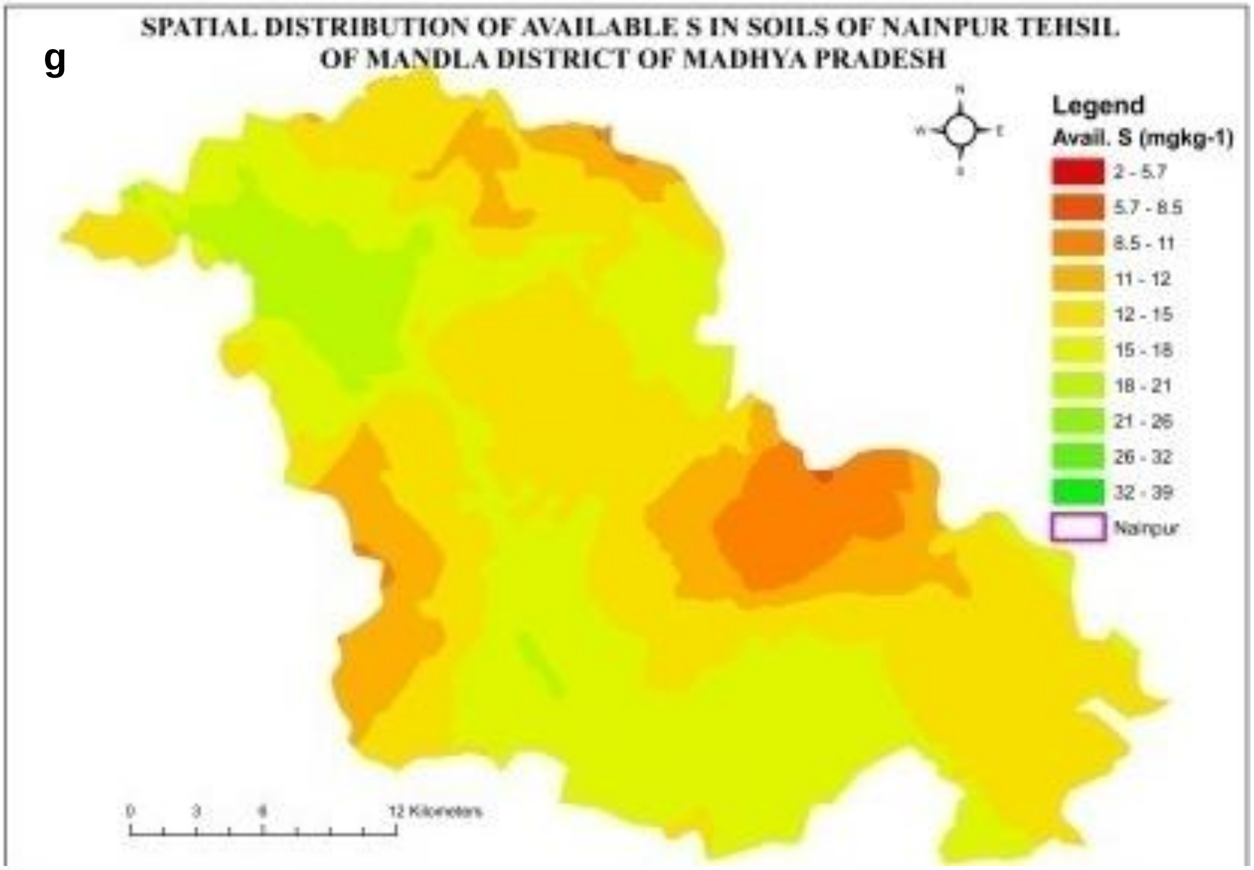


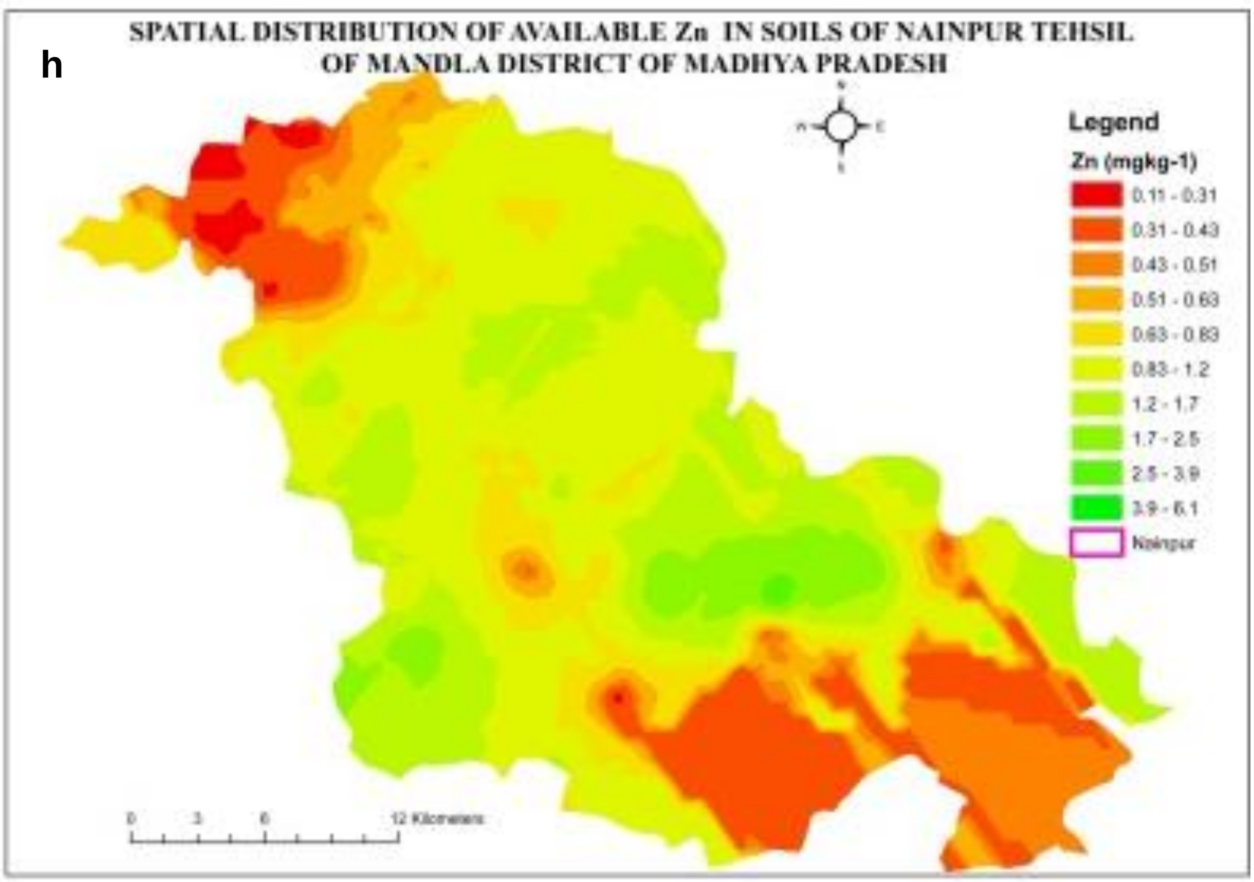

c
SPATIAL DISTRIBUTION OF OC IN SOILS OF NAINPUR TEHSIL
OF MANDLA DISTRICT OF MADHYA PRADESH
Legend
Organic Carbon (gkg-1)
3 - 3.92
3.92 - 4.57
4.57 - 5.02
5.02 - 5.33
5.33 - 5.78
5.78 - 6.43
6.43 - 7.35
7.35 - 8.68
8.68 - 10.58
10.58 - 13.3
Nainpur
0 3 6 12 Kilometers

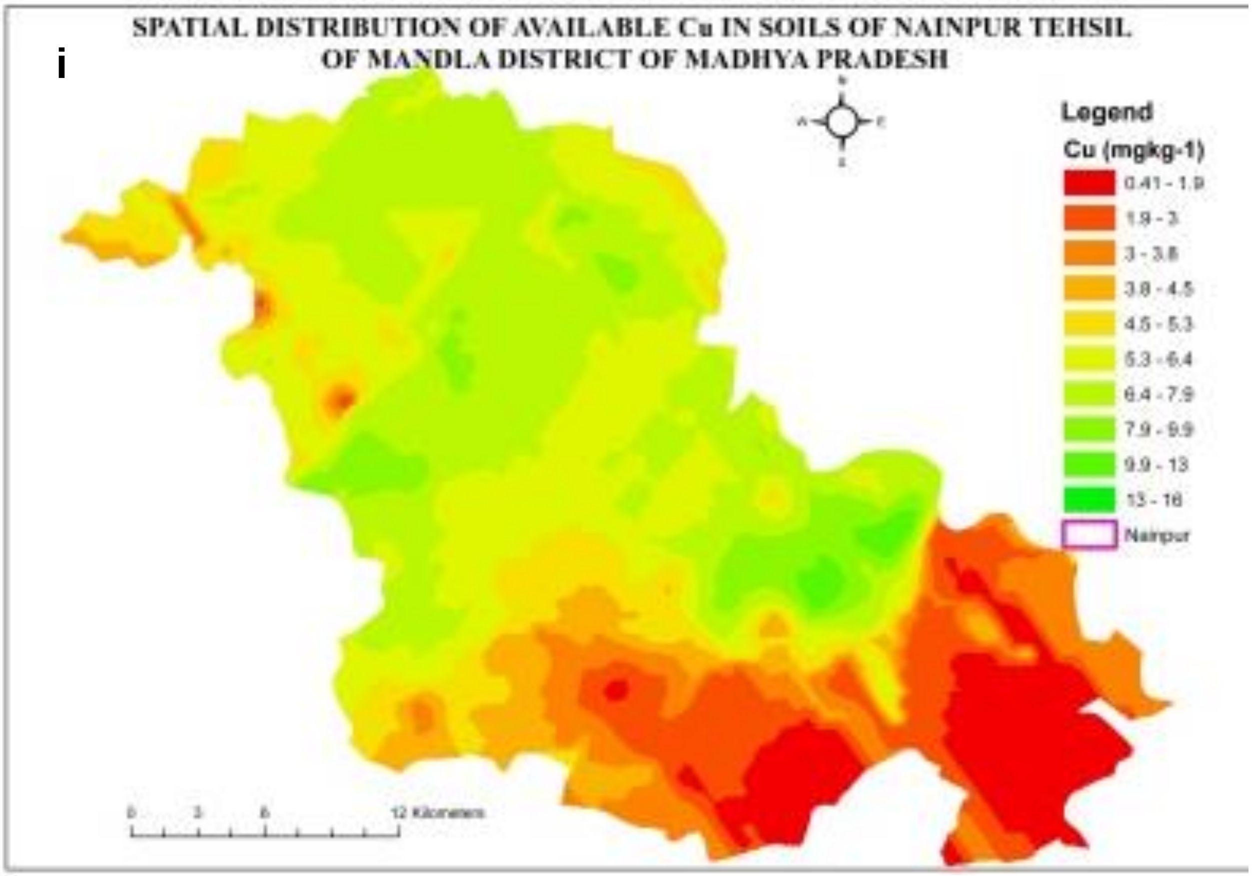

d
SPATIAL DISTRIBUTION OF AVAILABLE N IN SOILS OF NAINPUR TEHSIL
OF MANDLA DISTRICT OF MADHYA PRADESH
Legend
Avail. N (kg ha-1)
150 - 200
200 - 230
230 - 260
260 - 290
290 - 300
300 - 320
320 - 350
350 - 390
390 - 440
440 - 500
Nainpur
0 3 6 12 Kilometers

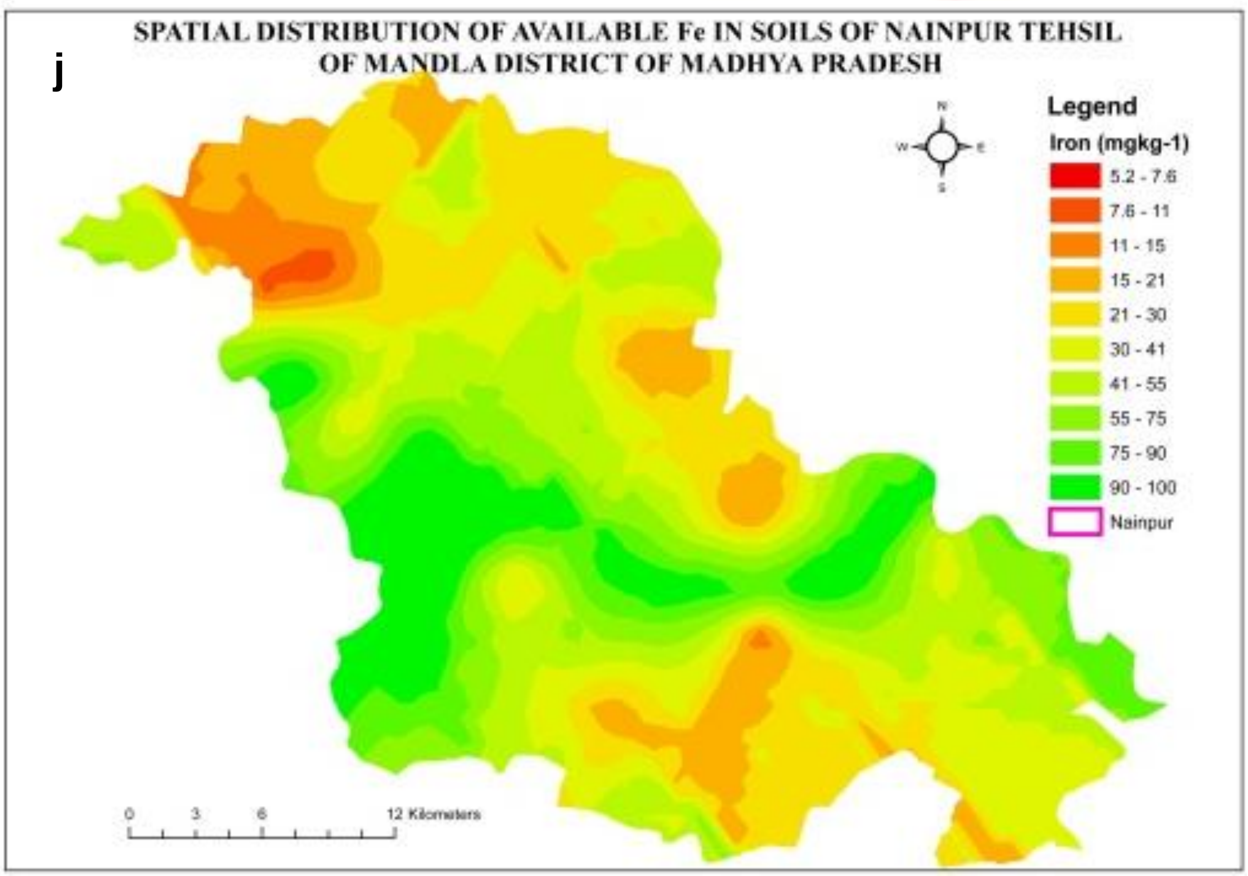

e
SPATIAL DISTRIBUTION OF AVAILABLE P IN SOILS OF NAINPUR TEHSIL
OF MANDLA DISTRICT OF MADHYA PRADESH
Legend
Avail. P (kg ha-1)
5.9 - 7.7
7.7 - 8.8
8.8 - 9.3
9.3 - 9.6
9.6 - 10
10 - 11
11 - 13
13 - 16
16 - 23
23 - 35
Nainpur
0 3 6 12 Kilometers

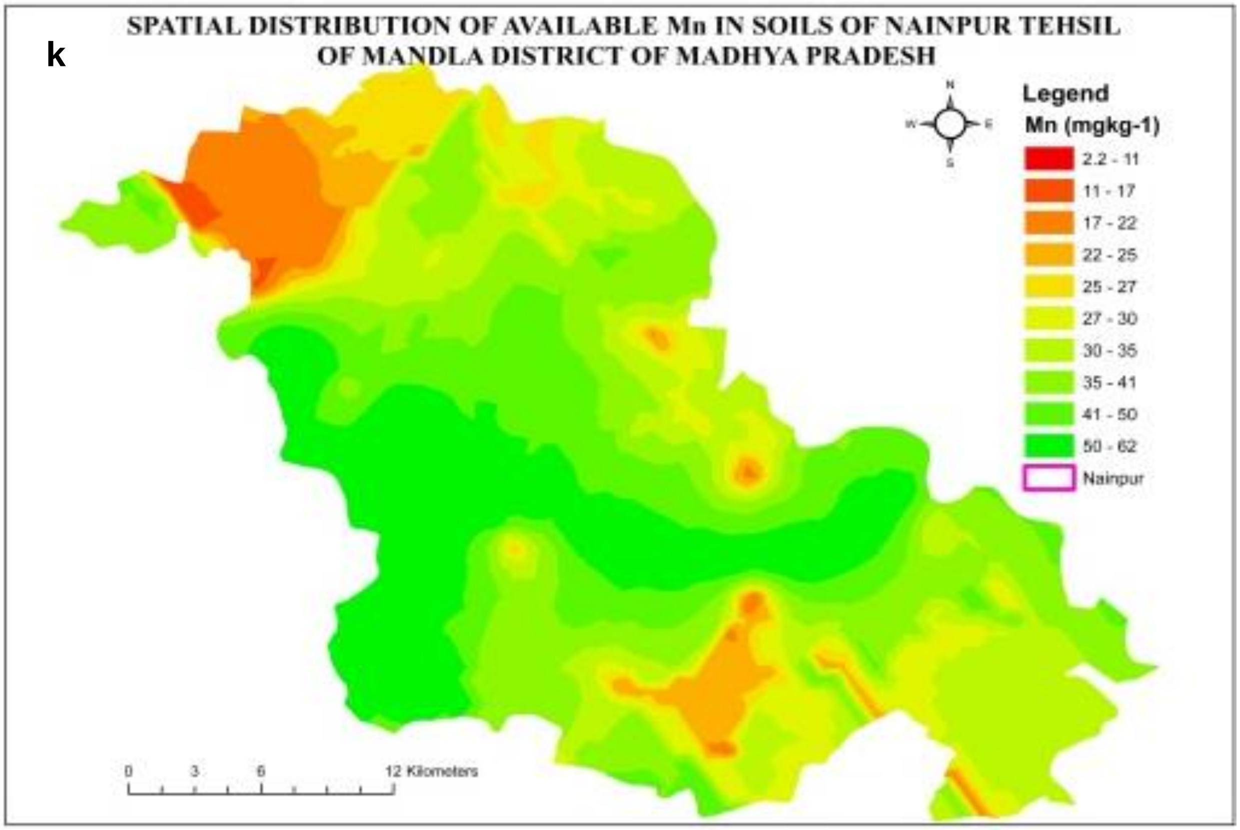

f
SPATIAL DISTRIBUTION OF AVAILABLE K IN SOILS OF NAINPUR TEHSIL
OF MANDLA DISTRICT OF MADHYA PRADESH
Legend
Avail. K
120 - 220
220 - 300
300 - 340
340 - 380
380 - 400
400 - 440
440 - 490
490 - 560
560 - 660
660 - 810
Nainpur
0 3 6 12 Kilometers


SPATIAL DISTRIBUTION OF AVAILABLE S IN SOILS OF NAINPUR TEHSIL
OF MANDLA DISTRICT OF MADHYA PRADESH
g
Legend
Avail. S (mgkg-1)
2 - 5.7
5.7 - 8.5
8.5 - 11
11 - 12
12 - 15
15 - 18
18 - 21
21 - 26
26 - 32
32 - 39
Nainpur
0 3 6 12 Kilometers


SPATIAL DISTRIBUTION OF AVAILABLE Zn IN SOILS OF NAINPUR TEHSIL
OF MANDLA DISTRICT OF MADHYA PRADESH
h
Legend
Zn (mgkg-1)
0.11 - 0.31
0.31 - 0.43
0.43 - 0.51
0.51 - 0.63
0.63 - 0.83
0.83 - 1.2
1.2 - 1.7
1.7 - 2.5
2.5 - 3.9
3.9 - 6.1
Nainpur
0 3 6 12 Kilometers


i
SPATIAL DISTRIBUTION OF AVAILABLE Cu IN SOILS OF NAINPUR TEHSIL OF MANDLA DISTRICT OF MADHYA PRADESH
Legend
Cu (mgkg-1)
0.41 - 1.9
1.9 - 3
3 - 3.8
3.8 - 4.5
4.5 - 5.3
5.3 - 6.4
6.4 - 7.9
7.9 - 9.9
9.9 - 13
13 - 16
Nainpur
0 3 6 12 Kilometers


j
SPATIAL DISTRIBUTION OF AVAILABLE Fe IN SOILS OF NAINPUR TEHSIL OF MANDLA DISTRICT OF MADHYA PRADESH
Legend
Iron (mgkg-1)
5.2 - 7.6
7.6 - 11
11 - 15
15 - 21
21 - 30
30 - 41
41 - 55
55 - 75
75 - 90
90 - 100
Nainpur
0 3 6 12 Kilometers



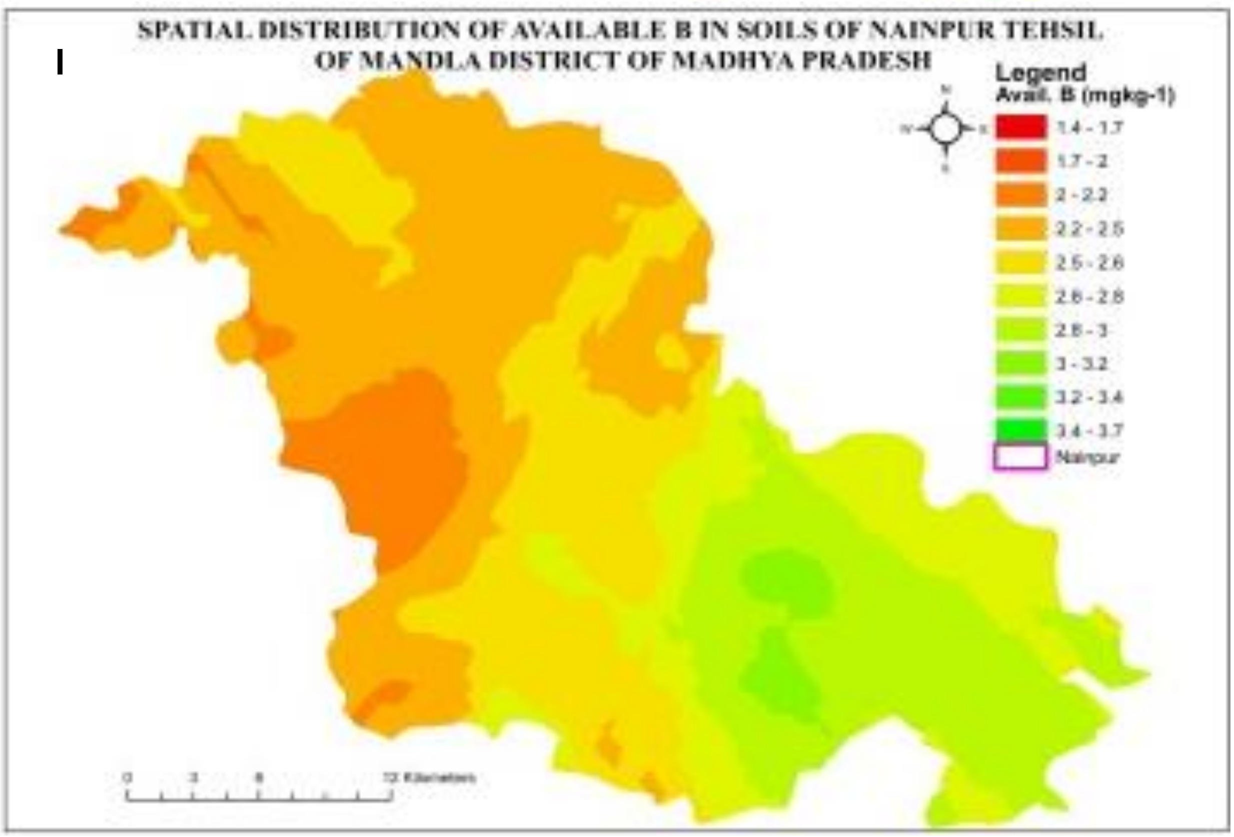


Figure 4. Kriged maps showing spatial variability of pH (a), EC (b), OC (c), AN (d), AP (e), AK (f), AS (g), Zn(h),Cu(i), Fe(j), Mn (k) and B (l).

The nugget to sill ratio was used to define different classes of spatial dependence for the soil properties (Emadi et al., 2008; Zuo et al., 2008). Nugget/sill ratio of 25%, 25 to 75% and >75% were classified as having strong, moderate and weak spatial dependence, respectively, according to Cambardella et al. (1994). Ordinary Kriging was used for the spatial interpolation because it is best at providing an unbiased prediction for specific unsampled locations and minimizing the influence of outliers (Tesfahunegn et al., 2011; Kavianpoor et al., 2012).

Evaluation criteria

Accuracy of the soil maps was evaluated through cross-validation approach (Davis et al., 1987; Santra et al., 2008). Among three evaluation indices used in this study, mean absolute error (MAE), and mean squared error (MSE) measure the accuracy of pre effectiveness of prediction. MAE is a measure of the sum of the residuals (e.g. predicted minus observed)(Voltz and Webster, 1990).

$$\text{MAE} = \frac{1}{N}\sum_{i=1}^{N}\left[\left|z(x_i) - \hat{z}(x_i)\right|\right]$$

where z^(xi) is the predicted value at location i. small MAE values indicate few errors. The MAE measure, however, does not reveal the magnitude of error that might occur at any point and hence MSE will be calculated,

$$\text{MSE} = \frac{1}{N}\sum_{i=1}^{N}\left[z(x_i) - \hat{z}(x_i)\right]^2$$

Squaring the difference at any point gives an indication of the magnitude, e.g. small MSE values indicate more accurate estimation, point-by-point. The G measure gives an indication of how effective a prediction might be, relative to that which could have been derived from using the sample mean alone (Agterberg 1984).

$$G = \left(1 - \frac{\sum_{i=1}^{N}\left[z(x_i) - \hat{z}(x_i)\right]^2}{\sum_{i=1}^{N}\left[z(x_i) - \bar{z}\right]^2}\right) \times 100$$

where z is the sample mean. If G = 100, it indicates perfect prediction, while negative values indicate that the predictions are less reliable than using sample mean as the predictors.

RESULTS AND DISCUSSION

Descriptive statistics of soil properties

The mean values for pH, EC, OC content were 6.58, 0.21 dSm^{-1} and 6.30 g kg^{-1} with a range of 4.8 to 7.90, 0.02 to 0.60 dS m^{-1} and 3.0 to 13.30 g kg^{-1}, respectively. The available N, P, and K varied from 150 to 500 kg ha^{-1}, 5.88 to 34.89 kg ha^{-1} and 122.08 to 807.52 kg ha^{-1} with mean value of 299.43 kg ha^{-1}, 12.31 kg ha^{-1} and 405.30 kg ha^{-1}, respectively. The S varied from 2.04 to 39.0 mg kg^{-1} with a mean value of 14.69 mg kg^{-1}. The available micronutrients Zn, Cu, Fe, Mn and B varied from 0.11 to 6.08, 0.41 to 16.35, 5.15 to 101.20, 2.24 to 61.80 mg kg^{-1} and 1.40 to 3.72 with mean values of 0.83, 4.81, 40.81, 35.29 and 2.54 mg kg^{-1}, respectively (Table 3).

The coefficient of variation, which is the ratio of the standard deviation to mean expressed as a percentage is a useful measure of overall variability. According Hillel (1980) and Yang and Yang (2005), there are three classes about coefficient of variation of soil nutrients (C.V.), weak variation (C.V. <0.1), medium variation (C.V. = 0.1–1.0), strong variation (C.V. > 1.0). The EC had the largest variation (CV = 50.12%) followed by OC (CV = 27.83%) while pH was found least variable (CV = 8.71%). The macronutrients are, NPK, the available P had the highest variability (CV=49.21%) and followed by avail. K (CV = 35.75%) whereas N had the lowest variability (CV= 27.00). The S was found to be moderately variable (CV = 56.84%). Among the micronutrients, the Zn was found to be highly variable (CV = 98.80%), followed by Fe (CV = 86.22%), Cu (CV =60.55 percent) and Mn (CV = 52.57 percent) while B was found least variable (CV= 25.75%). The range of CV for the area suggested different degrees of heterogeneity among the properties studied. All the macronutrients were found to be moderately variable with ranging from 27.00 to 49.21%. All the micronutrients were highly variable with CV ranging from 25.57 to 98.80%. Among the soil fertility parameters, $CaCO_3$, Zn, Cu and Fe were found not normally distributed due to higher value of skewness and kurtosis.

Soil nutrient status

It is evident from the data presented in Table 4 that soil organic carbon content was found to be low in 23.6% and only 2% soil samples were medium and rest of soil samples were high (74.5%). It indicates that majority of these soils were low to moderately high in organic carbon content. On the basis of the ratings suggested by Subbiah and Asija (1956), the available N was found to be low (28.30%), medium (1.9%) and high (74.5%) in soil samples. It may be due low organic matter content of soil as well as rapid loss of applied N in soil. On the basis of the limits suggested by Muhr et al. (1963), the available phosphorus content was found to be low 48.6% in soil samples, none of the samples were found in medium and rest of soil samples were fall in high category (51.4%). The low amount of available P may be due to application of lower doses of P fertilizer, fixation of P on clay minerals or $CaCO_3$ surfaces with the time elapsed between fertilizer application and crop uptake. It may also be due low organic matter content of soil (Sanyal et al., 2015).

According to Muhr et al. (1963), the available potassium content was found to be low in 13.9 soil samples, high in 86.1% soil samples and non of soil samples were found in medium. For these soils available micronutrients status using critical limit as given in Table 4 for DTPA-extractable Zn content was found to be deficient in 54.7%, medium in 26.4% and high in 18.9% soil samples. The data showed the DTPA extractable Fe

Table 3. Statistical overview for physico-chemical properties and macro and micronutrients of soils of study area (N=150).

Parameter	Min	Max	Range	Mean	SD	β	Skewness	CV%
pH	4.8	7.9	3.1	6.58	0.57	0.02	-0.39	8.71
EC	0.02	0.62	0.6	0.21	0.11	4.32	1.75	50.12
OC	3	13.3	10.3	6.3	1.75	1.1	0.59	27.83
N	150	500	350	299.43	80.84	-0.71	0.2	27.0
P	5.88	34.89	29.01	12.31	6.06	5.36	2.31	49.21
K	122.08	807.52	685.44	405.3	144.9	0.78	0.67	35.75
S	2.04	39	36.96	14.69	8.35	0.51	0.91	56.84
Zn	0.11	6.08	5.97	0.83	0.82	**16.26**	3.35	98.8
Cu	0.41	16.35	15.94	4.81	2.91	2.97	1.34	60.55
Fe	5.15	101.2	96.05	40.81	35.19	-1.43	0.64	86.22
Mn	2.24	61.8	59.56	35.29	18.55	-1.23	0.3	52.57
B	1.4	3.72	2.32	2.54	0.65	-0.86	0.24	25.57

Table 4. Nutrient status and NI of soils of Nainpur tehsil of Mandla district (N=150).

Nutrients		Per cent samples under different categories			NI	NI class
		Low	Medium	High		
OC		23.6	1.9	74.5	2.51	High
Available macronutrients	N	28.3	1.9	69.8	2.42	High
	P	48.6	0	51.4	2.03	Medium
	K	13.9	0	86.1	2.72	High
S		25.5	0	74.5	2.49	High
Micronutrients	Zn	54.7	26.4	18.9	1.64	Low
	Cu	0	0	100	3.00	High
	Fe	0	87.7	12.3	2.88	High
	Mn	0.0	0.9	99.1	2.99	High
	B	0	0	100	3.00	High

content was found medium in 87.7% soil samples and none of the soil samples were tested low in Cu, Fe, Mn and B content, respectively. All soil samples were found insufficient in case of Cu content. The present study result was supported by Athokpam et al. (2013). Considering soil nutrient index suggested by Parker et al. (1951) (Table 4), soils of Nainpur were found of high status in respect of all fertility status except medium P while low fertility status in case of Zn.

Spatial variability maps preparation using geo-statistical approach

It was necessary to normalize the data prior to the geo-statistical analysis because of high skewness (Table 3) and the presence of outliers. Logarithmic transformations were selected to normalize the dataset. The skewness and kurtosis coefficients are zero for a normally distributed random variable. If the data distributions are largely deviated from a normal distribution, data transformations are often performed in order to reduce the influence of extreme values on spatial analysis (Webster and Oliver, 2001).

$$f(x) = \ln(x) \quad \lambda=0,$$

where f(x) is the transformed value and x is the value to be transformed. For a given data set (x_1, x_2,…..xn), the parameter is estimated based on the assumption that the transformed values (y_1,y_2,…..y_n) are normally distributed. When λ = 0, the transformed becomes the logarithmic transformation.

The logarithmic transformation resulted in smaller skewness and kurtosis for $CaCO_3$, Zn, Cu and Fe and the transformed data passed the normality test. Log-transformed data were used in the spatial analysis (Table 5).

Geo-statistical analysis

Ordinary Kriging was chosen to create the spatial distribution maps of soil fertility parameters, with the

Table 5. Skewness and kurtosis values for the original and transformed data.

Parameters	Original data		Log transformed data	
	Skewness	β	Skewness	β
$CaCO_3$	1.35	1.11	.095	2.40
Zn	3.35	16.26	0.12	2.96
Cu	1.34	2.97	-0.79	3.85
Fe	0.64	-1.43	0.14	1.59

Table 6. Characteristic of calculated semi-variogram of spatial data sets.

Soil property	Range (m)	Nugget (C_0)	Partial Sill (C)	Sill (C_0+C)	NS ratio	Spatial dependence
pH	12950.9	0.14	0.25	0.39	0.36	Moderate
EC	18880.1	0.00	0.01	0.01	0.38	Moderate
OC	2376.58	0.79	3.70	4.49	0.18	Strong
ln $CaCO_3$	3793.05	0.10934	0.15	0.26	0.42	Moderate
N	2575.95	3597.50	3178.40	6775.90	0.53	Moderate
P	11538	30.14	9.79	39.93	0.75	Moderate
K	15094	11578.00	12098.00	23676.00	0.49	Moderate
S	18470.3	53.84	20.32	74.15	0.73	Moderate
lnZn	3611.75	0.07	0.55	0.62	0.12	Strong
lnCu	3349.73	0.11	0.55	0.66	0.16	Strong
lnFe	5797.27	0.22	0.71	0.93	0.24	Strong
B	22774.9	0.28	0.22	0.50	0.56	Moderate
Mn	5443.27	80.188	272.71	352.90	0.23	Strong

maximum search radius being set to the autocorrelation range of the corresponding variable. The best model for fitting on experimental variogram was selected based on less RSS value. The exponential model was selected from standard models that are available to fit experimental semi-variograms based on more favorable weighted residual mean squares, and visual fit to the data at short lags. Wasiullah et al. (2010) and Gore et al. (2012) reported the spherical model for Mn. Therefore, the authors recognized the exponential and spherical model to be suitable for estimation of soil properties. The results supported by Ferreira et al. (2015) who reported exponential model is best for most of soil properties. Similar result reported by Eltaib et al. (2002), Nayanaka et al. (2010) and Cao et al. (2011) in case of soil organic carbon (Table 6).

In this study, no apparent anisotropy was found for any studied variable through experimental variograms. So, all experimental variograms were in isotropic form and ratio of nugget variance to sill expressed in percentages (C_0/C+C_0) can be regarded as a criterion for classifying the spatial dependence of the soil parameters. If this ratio is less than 25%, then the variable has strong spatial dependence (Shi et al., 2005) 25% and 75%, and higher than 75% correspond to moderate, and weak spatial dependencies, respectively. The OC, Zn, Cu, Fe and Mn showed strong spatial dependence and the values between 25 and 75% have moderate spatial dependence as shown in table, pH, EC, $CaCO_3$, N, P, K, S and B have moderate spatial structure. According to Cambardella et al. (1994), these spatial auto dependencies may be attributed to both intrinsic factors such as other soil properties and extrinsic factors such as human activities (Table 7).

The mean absolute error (MAE) was found to be zero for pH, EC, OC, P, S, Zn, Cu, Fe and Mn. The highest mean squared error (MSE) was observed for K followed by N, Fe, $CaCO_3$, Mn, S, P, Cu, OC, Zn, pH and EC. The performance of the interpolation technique was considered in term of the G value nutrients that showed positive. The goodness of fit (G) values was positive and highest G value was observed for Fe followed by Mn, EC, pH, Cu, Zn. The G values for B and P were negative. The spatial distribution of P could be related to geology, especially parent material of the study area (Wang et al., 2009). Among the micronutrients, available Zn was spatially correlated for a shorter distance and at a distance less than the range, measured soil property of two samples become more alike with decreasing distance between them (Eltaib et al., 2002). Spatial dependence of DTPA extractable Zn, Fe, Cu and Mn were also reported by Nayak et al. (2006).

Table 7. Evaluation performance of Krigged map of soil properties through cross-validation.

Soil property	MAE	MSE	G
pH	0.0	0	35.52
EC	0.0	0	39.86
OC	0.1	3	7.04
ln $CaCO_3$	-2.2	170	14.39
N	3.4	5965	7.84
P	-0.1	38	-4.32
K	-2.3	17550	15.23
S	-0.1	65	5.22
lnZn	-0.1	1	23.34
lnCu	0.2	6	29.52
lnFe	0.6	314	74.43
B	-0.01	0.42	-5.88
Mn	-1.1	99	70.84

Conclusions

On the basis of laboratory data, soil fertility assessment in respect to available macro and micro nutrients have been drawn in terms of nutrient indexing (Low, medium and high). The available N, P, K and S were high, medium, high respectively and micro-nutrients, that is, Zn was low and rest of that were sufficient in their status. It was concluded that it is applicable to investigate the spatial variability of soil properties. Exponential model was found as the best fit of all the parameters except Mn. The spherical model was found as the best fit for Mn. Based on prediction maps, it was realized that all nutrients has no toxic status and that the application of fertilizer will improve crop yields. Hence, study area requires phosphatic and zinc fertilizers for better crop growth and productivity of crops. The spatial variability maps on nutrient status generated geo-statistical techniques will be helpful for the farmers or researchers for the location specific correction of nutrient deficiency. These maps are very much helpful for guiding the farmers to decide the amount and kind of nutrient they can apply for in terms of optimum/economic returns, as the nutrient management will be different for areas having deficiency of one or more nutrients than those having sufficient nutrients.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Agterberg FP (1984). Trend surface analysis. In Spatial Statistics and Models (eds Gaile, G. L. and Willmott, C. J.), Reidel, Dordrecht, The Netherlands pp. 147–171.

Athokpam H, Wani SH, Kamei D, Athokpam HS, Nongmaithem J, Kumar D, Singh YK, Naorem BS, Thokchom RD, Devi L (2013). Soil macro- and micronutrient status of Senapati district, Manipur (India). Afr. J. Agric. Res. 8(39):4932-4936.

Berger KC, Truog E (1939). Boron determination in soils and plants. Ind. Eng.Chem. Anal. Ed.11: 540-545.

Cambardella CA, Moorman TB, Novak JM, Parkin TB, Karlen DL, Turco RF, Konopka AE (1994). Field scale variability of soil properties in Central Iowa soils. Soil Sci. Soc. Am. J. 58:1501–1511.

Cambule AH, Rossiter DG, Stoorvogel JJ, Smaling EMA (2014). Soil organic carbon stocks in the Limpopo National Park, Mozambique: amount, spatial distribution and uncertainty. Geoderma 213:46–56.

Cao SK, Chena KL, Cao GC, Zhang L, Ma J, Yang L, Lu BL, Chen L, Lu H (2011).The Analysis of Characteristic and Spatial Variability for Soil Organic Matter and Organic Carbon around Qinghai Lake. Procedia Env. Sci. 10:678 –684.

Chesnin L, Yien CH (1951). TurbidImetric determination of available suiphates. Soil Sci. Soc. Am. Proc. 15:149-151.

Davis BM (1987). Uses and abuses of cross-validation in geo-statistics. Math. Geol. 19:241–248.

Eltaib SM, Amin, MSM, Hanfi MM, Sharif, ARM Wayayok A (2002). Spatial variability of N, P and K in rice field in Sawah Sempadan, Malaysia. Songklanakarin J. Sci. Technol. 24:321–328.

Emadi M, Baghernejad M, Maftoun M (2008). Assessment of some soil properties by spatial variability in saline and sodic soils in Arsanjan plain. Southern Iran. Pak. J. Biol. Sci. 11(2):238–243.

Ferreira V, Panagopoulos T, Andrade R, Guerrero C, Loures L (2015). Spatial variability of soil properties and soil erodibility in the Alqueva reservoir watershed. Solid Earth 6:383–392.

Fraisse CW, Sudduth KA, Kitchen NR, Fridgen JJ (1999). Use of unsupervised clustering algorithms for delineating within Colfield management zones. ASAE Paper 993043, ASAE, Ontario, Canada.

Goovaerts P (1999). Geo-statistics in soil science: state-of-the-art and perspectives. Geoderma 89:1-45.

Gore Yogita D, Nagaraju MSS, Srivastava R, Nasre RA (2012). Spatial variability of soil properties in basaltic terrain for Precision agriculture using geospatial techniques: a case study in savli village of Wardha district of Maharashtra. Proceeding of AIPA.

Hak-Jin K, Kenneth K, Sudduth A, Hummel JW (2009). Soil macronutrient sensing for precision agriculture. J. Environ. Monit.11: 1810-1824.

Hillel D (1980). Fundamentals of Soil Physics. Academic Press, Inc., New York.

Huang B, Sun WX, Zhao YC, Zhu J, Yang RQ, Zhou Z, Ding F, Su JP (2007). Temporal and spatial variability of soil organic matter and total nitrogen in an agricultural ecosystem as affected by farming practices. Geoderma 139:336–345.

Jackson ML (1973). Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi.

Kavianpoor H, Esmali Ouri A, Jafarian Jeloudar Z, Kavian A (2012). Spatial variability of some chemical and physical soil properties in nesho mountainous rangelands. Am. J. Environ. Eng. 2(1):34-44.
Li XG, Li FM, Zed R, Zhan ZY, Singh B (2007). Soil physical properties and their relations to organic carbon pools as affected by land use in an alpine pastureland. Geoderma 15:98–105.
Lin JS, Shi XZ, Lu XX, Yu DS, Wang HJ, Zhao, YC, Sun, WX (2009). Storage and spatial variation of phosphorus in paddy soils of China. Pedosphere 19:790–798.
Lindsay WL, Norvell WA (1978). Development of a DTPA soil test for Zn, Fe, Mn and Cu. Soil Sci. Soc. Am. J. 42: 421-428.
Liu ZP, Shao MA, Wang YQ (2013). Spatial patterns of soil total nitrogen and soil total phosphorus across the entire Loess Plateau region of China. Geoderma 197–198, 67–78.
Muhr GR, Datta NP, Shankara SN, Dever F, Lecy VK Donahue RR (1963). Soil Testing in India. USAID Mission to India.
Nayak AK, Chinchmalatpure AR, Rao G, Khandelwal MK, Tyagi NK (2006). Spatial Variability of DTPA Extractable Micronutrients in the Soils of Bara Tract of Sardar Sarovar Canal Command in Gujarat. J. Indian Soc.Soil Sci.54(2):137-145.
Nayanaka VGD, Vitharana WAU, Mapa RB (2010). Geo-statistical Analysis of Soil Properties to Support Spatial Sampling in a Paddy Growing Alfisol. Trop. Agric. Res. 22(1):34–44.
Olsen SR, Cole CV, Vatanabe FS, Dean LA (1954). Estimation of available phosphorus in soil by extraction with sodium bicarbonate. Circ. U.S Dept. Agric. 939:1-19.
Page T, Haygarth PM, Beven KJ, Jones A, Butler T, Keeler C, Freer J, Owens PN, Wood GA (2005). The spatial variability of soil phosphorus GA in relation to topographic indices and important source areas: samples to assess the risks to water quality. J. Environ. Qual. 34: 2263-2277.
Parker FW, Nelson WL, Winter Eric, Miller LE (1951). The broad interpretation of soil test informations. Agron. J. 43:105-112.
Qu M, Li W, Zhang C (2014). Country-Scale Spatial Variability of Macronutrient Availability Ratios in Paddy Soils. Appl. Environ. Soil Sci. 3:1-10.
Ruffo ML, Bollero GA, Hoeft RG, Bullock DG (2005). Spatial variability of the Illinois soil nitrogen test: Implications for soil sampling. Agron. J. 97:1485-1492.
Santra P, Chopra UK, Chakraborty D (2008). Spatial variability of soil properties and its application in predicting surface map of hydraulic parameters in an agricultural farm. Curr. Sci. 95(7):937-945.
Sanyal SK, Dwivedi BS, Singh VK, Majumdar K, Datta SC, Pattanayak SK, Annapurna K (2015). Phosphorus in relation to dominant cropping sequences in India: chemistry, fertility relations and management options. Curr. Sci. 108:7-10
Shi Z, Li Y, Makeschine F, Wang RC (2005). Assessment of temporal and spatial variability of soil salinity in a coastal saline field. Environ Geo. 48:171-178.
Singh D, Chhonkar PK, Dwivedi BS (2007). Manual on Soil, Plant and Water Analysis Westville Publishing House, New Delhi.
Šnajdr J, Valášková V, Merhautová V, Herinková J, Cajthaml T, Baldrian P (2008). Spatial variability of enzyme activies and microbial biomass in the upper layers of *Quercus petraea* forest soil. Soil Biol. Biochem. 40:2068–2075.
Subbiah BV, Asija GL (1956). A rapid procedure for the determination of available nitrogen in soils. Curr. Sci. 25:259-260.
Tesfahunegn GB, Tamene L, Vlek Paul LG (2011). Catchment-scale spatial variability of soil properties and implications on site-specific soil management in northern Ethiopia. Soil Till. Res. 117:124–139.
Voltz M, Webster R (1990). A comparison of kriging, cubic splines and classification for predicting soil properties from sample information. J. Soil Sci. 41:473–490.
Wang YQ, Zhang XC, Zhang JL, Li SJ (2009). Spatial variability of soil organic carbon in a watershed on the Loess Plateau. Pedosphere 19:486-495.
Warrick AW, Myers DE, Nielsen DR (1986). Geo-statistical methods applied to soil science. In: Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods. Agronomy Monograph 9(2):53–82.
Wasiullah AU, Bhatti KF, Akmal M (2010). Spatial variability and geo-statistics application for mapping of soil properties and nutrients in semi arid district Kohat of Khyber Pakhtunkhwa (Pakistan). Soil Environ. 29(2):159-166.
Webster R, Oliver MA (2001). Statistical Methods in Soil Science and Resource Survey. Oxford University Press, New York, NY.
Weindorf DC, Zhu Y (2010). Spatial variability of soil properties at Capulin Volcano, Mew Mexico, USA: implications for sampling strategy. Pedosphere 20:185–197.
Yang Y, Yang J (2005). The trend variability of soil organic matter content in the salinity region of Yucheng city in Shandong Province. Chin. J. Soil Sci. 36(5):647-651.
Zuo X, Zhao H, Zhao X, Zhang T, Guo Y, Wang S, Drake S (2008). Spatial pattern and heterogeneity of soil properties in sand dunes under grazing and restoration in Horqin Sandy Land. Northern China. Soil Till. Res. 99:202–212.

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Full Length Research Paper

Adoption and impact of early maturing maize varieties on farmers income in Safana Local Government Area of Katsina, Nigeria

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This paper examined the adoption and impact of early maturing maize varieties on farmers' income in Safana Local Government Area of Katsina State, Nigeria. Using random sampling techniques, 300 maize farmers were selected across 10 communities in the Local Government. Data obtained were analyzed using descriptive statistics, adoption index, double difference method and Z-statistics to estimate impact of early maturing maize varieties on income of farmers. The study divided the respondents into 137 adopters and 163 non adopters. The major findings showed that 88% of respondents were male headed, average age of household head was 44 years, average household size was 11 persons, dependency ratio was 1.49, level of education was Islamic education, average years of schooling was 5 years and average years of farming was 25 years. About 65% of farmers had access to extension agent, only about 10% had access to credit and labor force was mostly family labor. Result from the study showed that out of 300 maize farmers sampled, 137 farming household adopted the varieties with a general adoption rate of 45.67%. The mean difference analysis of the impact on adoption of early maturing maize varieties on income status between adopters and non-adopters of early maturing maize varieties shows that there is a positive mean income of ₦ 42,689. The result of the T-test showed that there was significant difference at 1% level of significance between adopters and non-adopters in relation to income level. Policy which provides adequately trained and equipped extension workers to disseminate improved agricultural technology has the potential to raise farmers' income.

Key words: Adoption, impact, farmers, income.

INTRODUCTION

Maize is a major cereal and one of the most important food crops in Nigeria. It is one of the major crops grown in Katsina State. Its genetic content has made it the most widely cultivated crop in the country, from the wet evergreen climate of the forest zone, to the dry ecology of the Sudan savanna. Being photoperiod insensitive, it can be grown anytime of the year giving greater flexibility to fit into different cropping patterns. It is one of the most

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dominant cereal crops in the southern and northern Guinea and Sudan savannas (Onyibe et al., 2006). In West and Central Africa in the last 20 years widespread adoption of early maturing maize varieties in the savannas means that maize is no longer a backyard crop but a major cereal grown for both cash and food (Eckebil, 1994; Fajemish, 1994; Smith et al., 1997).

However, despite the potential for further yield increases, maize production faces numerous problems including poor soil fertility, *Striga*, disease, drought, low and erratic rainfall, and long dry season (Tambo and Abdoulaye, 2011). Over years the International Institute of Tropical Agriculture (IITA) has in collaboration with national partners developed and disseminated a number of early maturing maize technologies that meet the requirement of their major clients and small-scale farmers in northern Nigeria and West Africa savanna at large.

IITA has made significant advances in improving the productivity of maize, by developing a number of improved varieties such as: 2000 SYN EE (white), ACR 95 TZE COMP 5 W (white), EV 99 DT W STR (SAMMAZ 27) (white) and 99 TZEE Y STR (yellow), with generally high grain and yields, resistance to major insects, pests and diseases (Alene and Manyong, 2007). Despite the development of a large number of early maturing maize varieties, farmers in northern Nigeria including Katsina State have continued to grow predominantly local varieties (Tarawali and Kureh, 2004). The limited use of improved varieties in a predominantly maize growing region may be due to several factors; lack of information on early maturing maize varieties, unavailability of seed, or the unacceptability of new varieties due to low market values or unsuitability for the farming system (Ellis-Jones et al., 2009).

In order to reduce these constraints to crop production in Katsina State, the Sudan Savanna Task Force of the KKM PLS project funded by the Forum for Agricultural Research in Africa (FARA) and led by IITA in collaboration with IAR and other collaborative bodies to disseminate agricultural technologies to enhance farmers' incomes (Ellis-Jones et al., 2009). The objective of this paper was to calculate the adoption of early maturing maize varieties and its impact on farmers' income.

METHODOLOGY

Study area

This study was conducted in Safana LGA Katsina State, Nigeria. Safana Local Government Area (LGA) has a projected population of about 183,779 based on 3.2% growth rate (NPC, 2006) and an area of 282 km^2 (KTARDA, 2012). The Local Government is located at 12° N and 7°E of the equator. April is warmest with an average temperature of 37.9°C at noon. December is coldest with an average temperature of 13°C at night. Safana has no distinct temperature seasons; the temperature is relatively constant during the year.

Sampling procedure

The target populations for this study were male and female maize farmers from the 10 communities of the Sorghum/Legume/Livestock platform in Safana LGA. These communities are Mai Jaura, Kunamawa A, Kunamawa B, Dogon Ruwa, Kanbiri, Sabon Garin Baure, Sabon Garin Gamji, Doga, Takatsaba, Kwayawa. There was no complete list of farmers in these communities but a list of maize farmers was generated with the help of both the village heads and extension agents in these communities. From each of the 10 communities, 30 respondents were randomly selected giving a total of 300 respondents. Out of the 300 respondents sampled, 163 were non-adopters and 137 were adopters.

Data collection

Primary data were used for this study. Data were collected using structured questionnaire administered by trained enumerators. The information collected was on sex, age, marital status farm size and family size based on 2012 farming season. The survey was conducted in March 2013.

Data analysis

The analytical tool that was employed for this study was descriptive statistics, adoption index and double difference method.

Adoption index

Adoption rate was computed for farmers based on expressing the total number of farmers adopting varieties as a percentage of the total number of farmers under study. It is expressed as:

$$\beta_v = \frac{\beta_{vi}}{\beta} \times 100 \qquad (1)$$

Where: β_v = Adoption rate for early maturing maize variety v, β_{vi} = Adopter of early maturing maize variety v and β = Number of maize farmers (300).

Double difference method

$$DD = \left[\left(\frac{1}{N_A}\sum_{1=i}^{N_A}(\bar{Y}_1^A - \bar{Y}_0^A)\right) - \left(\frac{1}{N_{NA}}\sum_{1=j}^{N_{NA}}(\bar{Y}_1^{NA} - \bar{Y}_0^{NA})\right)\right] \qquad (2)$$

Where, $\bar{Y}_0^A$ =Average income (N) of the adopters 2008; $\bar{Y}_1^A$ =Average income (N) of the adopters 2012, $\bar{Y}_0^{NA}$ =Average income (N) of the non-adopters 2008, $\bar{Y}_1^{NA}$ =Average income (N) of the non-adopters 2012, N_A = number of adopters, N_{NA} = number of non-adopters and DD = the difference between the average changes in the income for the adopters and non-adopters.

It is common to find difference in difference estimators presented in a Table 1.

RESULTS AND DISCUSSION

Socio-economic characteristics of maize farmers

A summary of demographic data is provided in Table 1. It

Table 1. Double difference estimate of the impact of adoption of early maturing maize varieties on farmers' income.

	2008	2012	Difference between periods
Adopters	$\bar{Y}_0^A$	$\bar{Y}_1^A$	$\bar{Y}_1^A - \bar{Y}_0^A$
Non-adopters	$\bar{Y}_0^{NA}$	$\bar{Y}_1^{NA}$	$\bar{Y}_1^{NA} - \bar{Y}_0^{NA}$
Difference between groups	$\bar{Y}_0^A - \bar{Y}_0^{NA}$	$\bar{Y}_1^A - \bar{Y}_1^{NA}$	$\bar{Y}_1^A - \bar{Y}_1^{NA} - (\bar{Y}_0^A - \bar{Y}_0^{NA})$

examined the distribution of respondents by gender, age, household size, education, farming experience, extension contacts, sources of information, membership of association, credit facilities and labor force.

Gender

The result of the analysis showed 88% of households were headed by males and 12% were female headed in the study area. The result is in agreement with findings of Yanguba (2004) who reported that 96% of farm households surveyed in Katsina State were male headed. Mbavai (2013) reported similar trend in a study of cowpea farmers in Musawa LGA of Katisna States. This result shows that men are more involved in maize farming. Because of the influence of tradition and religion women are generally restricted to their compounds.

Age

Results from the study show that majority of the farmers were between the ages of 35-54. Thirty-six percent of the respondents were aged 35-44 years while 32.7% were aged 45-54%. The average age of respondent was 44 years. Idrisa (2009) reported 40 years as active age of farmers for farm households in Southern Borno, Nigeria. This result agree with those of Mbavai (2013), Idrisa (2009), Kamara (2009), Akudugu, Guo and Dadzie (2012), Mignouna et al. (2013) which showed the farming population in the study area and that of northern Nigeria generally is relatively young. This means that there is an active labor force available for farming.

Household size

Result from the study shows that about 80% of responding households had not less than nine members. The average household size in the study area was 11 persons per household. Household size determines the available human labor force that can be employed in carrying out crop production activities. Agwu (2004) in his work discovered an average of seven people per household, Amos (2007) found average household size to be nine persons; Idrisa (2009) in his findings recorded an average of seven persons while Mignouna et al. (2013) in his result documented an average of nine persons per family. According to them, household size determines the availability of household labor supply.

Dependency ratio

The result from this work showed the dependency ratio of 1.49. This implies that there are more dependents (children below 15 years old and adults above 64 years old) compared to adults (>15 years and <64 years old) in the study area. This finding is in-line with Mignouna et al. (2013) whose result showed a dependency ratio of 1.29 and they concluded that the sampled population in their study area was more dependents.

Education

The result shows that 14% of the respondents had no formal education, 12.3% had primary school education, 10.3% had secondary school education, 3.7% had tertiary education and Islamic education had 59.7% which is the highest. Education increases the ability to assess, interpret, and process information about a new technology, enhancing farmers' managerial skills including efficient use of agricultural inputs. From the result majority of respondents had Islamic education. This is due to the fact that the study area is a predominantly Muslim community where Islamic knowledge is given a high priority. The low level formal education in Safana LGA might limit adoption of the technology. This result contradict the results of Bonabana-Wabbi (2002) in Uganda, Jones (2005) in Togo-Benin, Muyanga (2009) in Kenya, Kudi et al. (2011) in Kwara (Nigeria) who reported high level of formal education among households in their study areas. High level of formal education in a study area would mean that majority of farmers are expected to accept new technology within a relative shorter period of time.

Farming experience

The distribution of respondents based on years of farming experience shows that 17% of maize farmers in the study area had experience in maize production from 1 and 10 years, 32% had been producing maize for eleven and twenty years, 24.7% had experience for twenty-one

Table 2. Socio-economic characteristics of respondent farming households.

Variables	Adopters	Non-adopters	Pooled
Male-headed households (%)	92.7	84.0	88.0
Age			
<24	0.6	-	0.3
25-34	8.6	14.6	11.3
35-44	37.4	34.3	36
45-54	31.1	34.3	32.7
55-64	14.1	13.1	13.7
>65	8.0	3.6	6
Age of household heads (Average)	42	43	44
Average Household size	9	13	11
Dependency ratio	1.36	1.61	1.49
Level of education (%)			
No formal	11.7	16	14
Primary	12.4	12.3	12.3
Secondary	13.9	7.4	10.3
Tertiary	5.1	2.5	3.7
Islamic	56.9	62	59.7
Average years of schooling	6	5	5
Years of farming experience (%)			
1-10	16.1	17.8	17
11-20	35	29.4	32
21-30	24.1	25.4	24.7
31-40	19	21.8	20.6
41-50	5.8	5.8	5.7
Average years of farming	25	24	25
Contact with extension agent (%)			
Contact	86.9	68.1	76.67
No Contact	13.1	31.9	23.33

Sources of information on early maturing maize varieties.

to thirty years, 20.6% had experience for thirty-one to forty years and 5.7% had experience for more than forty-one years. The mean years of experience for the farmers were 25 years. This implies that majority of maize farmers had long period of farming experience and therefore would be conversant with constraints to increased maize production. Yanguba (2004) found similar result in his work that farmers in Katsina had 24 years farming experience. Bello et al. (2012) found out that most (83.70%) of the respondents in Jenkwe Development Area of Nasarawa State, Nigeria had above 10 years of farming experience. Years of experience in farming were important because management skills of farmers improved with experience.

Contact with extension agents

The result from Table 2 showed that both adopters and non-adopters had contact with extension agents to a percentage greater than 60%. About 86.9% of the adopters had contact with an extension agent while 13.1% had no contact with extension agents. About 68.1% of non-adopters had contact with extension agents while 31.9% did not. Farmers must have information about the intrinsic characteristics of improved varieties before they can consider planting them or not. Ayayi and Solomon (2010), Ede (2011), Gama (2013) found that about Fifty-Three percent and above of the respondents in their study area had contact with extension agents.

The result on Table 3 reveals that majority (41%) of farmers got the information on early maturing maize varieties from extension agents. The impact of this information on farmers' decisions varies according to its channel, sources, content, motivation and especially, frequency of visit. Also, it could be due to the various interventions received by Safana LGA through different

Table 3. Classification of responses based on sources of information on early maturing maize varieties.

Sources of Information	Adopters	Non-adopters	Pooled
0	4(2.9)	32(19.6)	36(12.0)
1	0	1(0.6)	1(0.3)
1, 2	11(8.0)	19(11.6)	30(9.9)
1, 2, 5	2(1.5)	3(1.8)	10(3.3)
1, 3	5(3.6)	4(2.4)	5(1.6)
1, 3, 5	5(3.6)	2(1.2)	9(3.0)
1, 5	9(6.5)	10(6.1)	7(2.3)
1, 2, 3	5(3.6)	5(3.1)	19(6.3)
2	3(2.2)	7(4.3)	11(3.6)
3	24(17.5)	5(3.1)	29(9.7)
3, 5	0	2(1.2)	3(1.0)
4	3(2.2)	1(0.6)	4(1.3)
5	5(4.4)	7(4.3)	13(4.3)
6	58(42.3)	65(39.9)	123(41.0)
Total	137(100)	163(100)	300(100)

0=no response, 1=market visit, 2=TV/Radio, 3=other farmers, 4=middlemen, 5=friend/relative, 6=extension agents. Figures in parenthesis are percentages.

Table 4. Membership of association of early maturing maize varieties farmers.

Variable	Adopters	Non-adopters
Member	99(72.3)	87(53.4)
Non member	38(27.7)	76(46.6)
Total	**137(100)**	**163(100)**

Figures in parenthesis are percentages.

Governmental and Non-Governmental Organizations. Adesope et al. (2012) and Ango et al. (2013) found in their study that respondents (farming households) had good source of information on agricultural technologies.

Membership of association of early maturing maize varieties farmers

Analysis on Table 4 shows the distribution of respondents based on membership of associations. Obviously, the percentage of membership was higher among the adopters (72.1%). About 46.6% of the non-adopters had nothing to do with an association. The average years spent in an association was five years for adopters and three years for non-adopters. The overall mean number of years respondents were registered as members of an association was 4 years. Membership of an association enables farmers to interact with other farmers, share their experiences and assist themselves. Interaction of farmers with other farmers is an avenue through which innovation diffusion can occur. According to Oboh et al. (2008), membership of an association or any farming group is a strong determinant of adoption of cassava varieties in Benue State.

Credit facilities on early maturing maize varieties

The result presented on Table 5 shows that only 11.7% adapters had access to credit and 10.4% for non-adopters. The importance of agricultural credit in production cannot be over emphasized. It increases the purchasing power of farmers and adoption of improved technology. The study observed that the crop farmers in the study area used different amounts of credit to finance their production activities. Results from this study showed that very few farmers have access to credit which may limit their ability to expand production of maize. This finding agrees with Idrisa (2009), Ayayi and Solomon (2010), Adesope et al. (2012) found out that credit availability was very essential for agricultural productivity.

Table 5. Access to Credit on early maturing maize varieties.

Variable	Adopters	Non-adopters
Yes	16(11.7)	17(10.4)
No	121(88.3)	146(89.6)
Total	**137(100)**	**163(100)**

Figures in parenthesis are percentage.

Table 6. Labor force on early maturing maize varieties.

Variables	Adopters	Non-adopters
Family labor	68(49.6)	63(38.7)
Hired labor	16(11.7)	60(36.8)
Family and hired labor	53(38.7)	40(24.5)
Total	**137(100)**	**163(100)**

Figures in parenthesis are percentages

Table 7. Double difference estimate of the impact of adoption of early maturing maize varieties on farmers' mean income.

	2008	2012	Difference (2012-2008)
Adopters	62,002	129,189	67,187***
Non-adopters	66,625	91,123	24,498***
Difference between groups	-4,622	38,066	42,689***

*** P<0.01

Labor force on early maturing maize varieties

The result on the Table 6 indicated that about 49.6% of adopters and 38.7% of non-adopters used only family labor, while about 11.7 and 36.8% employed solely hired labor for adopters and non-adopters respectively, and 38.7 and 24.5% combination of family and hired labor respectively. The crop farmers were distributed based on the source of human labor employed in their crop production process. This further explains why household size is large.

Adoption rate

Result from the study showed that out of three hundred maize farmers sampled, 137 farming household adopted the varieties with a general adoption rate of 45.67% this indicated an increase in adoption. Ayanwale et al. (2013) in the baseline report reported that as at 2008 adoption rate of early maturing maize varieties in Safana LGA was 36%. This implies that there is an increase in adoption rate by 9.6%. This result coincide with that of Saka and Lawal (2009), whose result shows that farmers in their study area responded appreciably to intervention programme that promote the use of improved rice varieties with an adoption rate of 68.7% which has resulted in an estimated proportional production increase of 19.4%.

Estimation of the impact of the project on farmers' income

The double difference estimate of the impact of adoption of early maturing maize varieties on farmers' mean income on Table 7 shows those adopters of early maturing maize varieties enjoyed an increase of 52% in their income (N 62,002- 129,189), resulting in a difference of income of N 67,187which is significant at 1%. The non-adopters had an increment of 26.9% (N 66,625- 91,123) but not as high as that of non-adopters in their income within the same period of time. Double difference analysis result further proved the fact that the increase in income realized by the adopters was attributed to their usage of early maturing maize varieties based on the positive mean income value obtained which was significant at 1% level of probability. The finding is in-line with Simonyan and Omolehin (2012) who found a positive mean double income difference of about N 30,973 was realized between beneficiaries and non-beneficiaries before and after Fadama II project.

Table 8. Z-Test on income of adopters and non-adopters.

Category	Number	Mean Income	z-value
Adopters	137	95,596	3.53***
Non-adopters	163	87,874	

*** P<0.01.

The difference in income was significant at 10% level.

A Z-test was run to determine the impact of adopting early maturing maize varieties on farmers' income. The data on the income of farmers was disaggregated into groups – adopters and non-adopters for comparison. The incomes for before intervention and after intervention were combined to get the result shown on Table 8. From the Table, the mean income of adopters (N 95,596) is higher than the mean income of non-adopters (N 87,874) by N 7,721and it is significant at 1% probability level. This implies that there was a significant difference in the adoption of early maturing maize varieties among adopters and non-adopters. Therefore, adopting these maize varieties had contributed in enhancing the income of the maize farming households in the study area. Morris, Tripp and Dankyi (1999), in their work Adoption and Impacts of Early maturing maize Production Technology: A Case Study of the Ghana Grains Development Project sited that Farmers who reported increased income from maize sales use the income to pay children's school fees. The next most common reported uses included purchasing building materials to expand or renovate the farmer's house, investing in merchandise for a family-owned retail trading business, and purchasing additional agricultural land. The additional income earned through maize farming (much of which presumably can be attributed to the adoption of GGDP-generated technologies) for the most part seems to have been invested productively, rather than spent on short term consumption.

Conclusion

Many socio-economic factors that affect adoption of early maturing maize varieties throughout Safana were discussed in this paper. The main factors are age of household head, farm size, membership of an association, number of extension contacts, and previous farm income for maize. The adoption of early maturing maize varieties has contributed in increasing the income of maize farming households as well as enhancing the status of maize farming households and this suggests that the adoption of early maturing maize varieties by maize farming households was very instrumental in enhancing the income and well-being of the maize farming households.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Adesope OM, Matthews-Njoku EC, Oguzor NS, Ugwuja VC (2012). Effect of socio-economic characteristics of farmers on their adoption of organic farming practices, Crop Production Technologies, Dr. Peeyush Sharma (Ed.), ISBN: 978-953-307-787-1.

Akudugu MA, Guo E, Dadzie SK (2012). Adoption of modern agricultural production technologies by farm households in Ghana: What Factors Influence their Decisions?. J. Biol. Agric. Healthc. 2(3):12-20.

Alene AD, Manyong VM (2007). Gains from high-yielding varieties with and without complementary technologies: The case of improved cowpea in Northern Nigeria. J. Agric. Food Econ. 2(1):1-14.

Ango AK, Illo AI, Abdullahi AN, Maikasuwaand MA, Amina A (2013). Role of farm-radio agricultural programmes in disseminating agricultural technology to rural famers for agricultural development in Zaria, Kaduna State, Nigeria. Asian J. Agric. Ext. Econ. Sociol. 2(1):54-68.

Ayanwale A, Abdoulaye T, Ayedun B, Akinola A, (2013). Baseline Report of the Sudan Savannah Zone of the Kano-Katsina-Maradi Pilot Learning Sites of The Sub Saharan Africa-Challenge Program (SSA CP) Baseline Report.

Ayayi MT, Solomon O (2010). Influence of extension contact and farmers socio-economic characteristics on adoption of oil palm technology in Aniocha North Local Government, Delta State- Nigeria.

Bello M, Daudu S, Galadima OE, Anzaku TKA, Abubakar AA (2012). Factors Influencing Adoption of Crop-Based Technologies in Jenkwe Development Area of Nasarawa State, Nigeria. Glob. Adv. Res. J. Agric. Sci. 1(8):250-256.

Bonabana-Wabbi J (2002). Assessing factors affecting adoption of agricultural technologies: The case of Integrated Pest Management (IPM) in Kumi District, Eastern Uganda. Unpublished M.Sc Thesis, Virginia Polythenic Institute of State University.

Ede DE (2011). Adoption of early maturing maize and cassava technology packages by farmers in Nkanu East and West of Enugu State, Nigeria. Unpublished M.Sc. Thesis submitted to the School of Postgraduate Studies, Ahmadu Bello University, Zaria-Nigeria.

Ellis-Jones J (2009). Kano-Katsina-Maradi Pilot Learning Site Sudan Savanna Agro- Ecological Zone Innovation Platform Creation. Sub Saharan Challenge Programme for Integrated Agricultural Research for Development. Draft Report, November 2009.

Gama EN (2013). Analysis of productivity and economic efficiency of cocoa farmers in the South West Region of Cameroon. Unpublished

Ph.D Dissertation submitted to the School of Postgraduate Studies, Ahmadu Bello University, Zaria-Nigeria.
Idrisa YI (2009). Analysis of the determinant of soybean production technology adoption by farmers in southern Borno State. Unpublished Ph.D Dissertation submitted to the School of Postgraduate Studies, University of Maiduguri, Borno-Nigeria. Jones KM (2005). Technology Adoption in West Africa: adoption and disadoption of soybean on the Togo-Benin border. Unpublished M.Sc Thesis, North Carolina State University.
Kamara SM (2009). Factors influencing the adoption of Soybean Production among male and female farmers in Borno State: Implications for Community Development. Unpublished M.Ed. Thesis, Kano, Bayero University, Kano, Nigeria.
Kudi TM, Bolaji M, Akintola M, Nasa'I DH (2011). Analysis of adoption of early maturing maize varieties among farmers in Kwara State, Nigeria. Int. J. Peace Dev. Stud. 1(3):8-12.
Mbavai JJ (2013). An assessment of the effectiveness of the Sudan Savanna Taskforce project in adoption and diffusion of improved cowpea varieties in selected communities in Musawa Local Government Area of Katsina State. An M.Ed unpublished thesis submitted to the Department of Adult Education and Community Services, Faculty of Education, Bayero University Kano.
Mignouna BD, Abdoulaye T, Kamara A, Oluoch M (2013). Baseline study of smallholder farmers in Striga-infested maize and cowpea-growing areas of northern Nigeria. International Institute for Tropical Agriculture, Ibadan, Nigeria. P. 60.
Morris ML, Tripp R, Dankyi AA (1999). Adoption and Impacts of Early maturing maize Production Technology: A Case Study of the Ghana Grains Development Project. Econ. Program Paper 99-01.Mexico, D.F.: CIMMYT.
Muyanga M (2009). Smallholder adoption and economic impacts of tissue culture banana in Kenya. Afr. J. Biotechnol. 8(23):6548-6555.
Onyibe JE, Kamara AY, Omoigui LO (2006). Guide to maize production in Borno State Nigeria. Published by IITA press Nigeria.
Population Census (2006). National Bureau of Statistics, Federal Republic of Nigeria. www.nigerianstat.gov.ng
Saka JO, Lawal BO (2009). Determinants of Adoption and productivity of improved rice varieties in south western Nigeria. Afr. J. Biotechnol. 8(19):4923-4932.
Simonyan JB, Omolehin RA (2012). Analysis of Impact of Fadama II Project on Beneficiary Farmers Income in Kaduna State: A double difference method approach. Int. J. Econ. Manag. Sci. 1(11):01-08.
Smith J, Weber J, Mangong MV, Fakorede MAB (1997). Fostering sustainable increases in maize productivity in Nigeria. Chapter 8 in Africa's emerging maize revolution, edited by Byerlee D. and C. K. Eicher. Lynne Rienner Publishers, London, UK: pp. 107-115.
Tambo AJ, Abdoulaye T (2011). Climate change and agricultural technology adoption: The case of drought tolerant maize in rural Nigeria. Springer Science + Business Media B.V. 2011.
Tarawali G, Kureh I (2004). Promoting sustainable agriculture in Borno State, a synthesis of livelihood analysis in three contrasting agro-ecological zones. Borno State. Nigeria: PROSAB. pp. 1-45.
Yanguba A (2004). Agricultural technology adoption by small-scale farmers: The case of extra-early maize varieties in the Sudan savannas of Katsina State, Northern Nigeria. Unpublished M.Sc. Thesis: University of Ibadan, Nigeria.

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Analysis of leaf area in black wattle throughout its plantation cycle

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Leaf area is one of the most important biophysical characteristics of a plant, as it determines how much photosynthetic radiation is intercepted so that the photosynthesis can occur. The presented research aim was to generate numerical indicators of leaf area and to study the behavior of black wattle *(Acacia mearnsii* De Wild.) throughout a plantation cycle (7 years), relating them with environmental variables. The study was conducted in commercial stands located in agroecological regions with high densities of black wattle plantations in the state of Rio Grande do Sul, Brazil. The leaf area was obtained by measuring leaf biomass and leaf area with an integrator (3000 Canopy Analyser, *Li-Cor).* Leaf area was found to be strongly related to leaf biomass, and is not influenced by planting site, but rather by stand age. Values of individual leaf area vary depending on stand age and plantation area. The leaf area is related to soil properties and particularly with the phosphorus content. It is also related to meteorological conditions, most notably accumulated solar radiation. The obtained model, which involves global accumulated solar radiation, phosphorus and clay content, adequately explain variations in leaf area.

Key words: Global solar radiation, phosphorus, leaf biomass, black wattle, plantation cycle.

INTRODUCTION

Black wattle (*Acacia mearnsii* De Wild.) is a commonly occurring tree species today in the state of Rio Grande do Sul, and stands of the species rank among the most widely planted in the region behind the genera *Eucalyptus* and *Pinus*. According to Simon (2005) black wattle is the primary source of bark for the global plant-based tannin industry, used mostly in leather tanning. The high-quality wood from the species is ideal for pulp

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and paper production, and most of the wood is consumed in these industries. Cultivation of the species currently benefits nearly 40 thousand families and thus plays an important socioeconomic role (Stein and Tonietto, 1997).

Leaf area is a variable indicator of productivity because plant growth (when soil nutrition, water availability and temperature are not limiting factors) depends on the amount of photosynthetically active radiation intercepted and the utilization efficiency of this energy during photosynthesis for biomass production (Monteith, 1977). Thus, leaf area is one of the most important biophysical characteristics of the plant since it determines how much light energy is intercepted so that the photosynthesis can occur. It is therefore related to growth and yield (Linhares et al., 2000; Xavier and Vettorazzi, 2003).

Although the recognized importance of leaf area as indicator of stands productivity, few studies have been developed regarding the environmental factors influencing this variable and even its behavior throughout the plantation cycle. Generating numerical indicators of leaf area with the purpose to address these points will allow further studies to be conducted relating leaf area to yield (either in timber, volume or biomass) of certain species. Thus, the present study sought to analyze leaf area in stands of black wattle *(Acacia mearnsii* De Wild.) for the duration of the plantation cycle; and with the following hypothesis to be tested: Leaf area in plantations of black wattle can be evaluated as a function of the climatic and soil variables.

MATERIALS AND METHODS

This study was conducted using data from temporary plots in commercial plantations of black wattle in the municipalities of Cristal and Piratini, Rio Grande do Sul, Brazil, where the species is planted at high concentrations. In each municipality stands were studied in an age sequence: one, three, five and seven years. In the municipality of Cristal, central coordinates of stands are located at 30° 55' S and 52° 10' W. In Piratini central coordinates of stands are located at 31° 24' S and 52° 57' W. Plantings were spaced in a 3 × 1.75 m configuration (1,904 plants per hectare) for year one and 3 × 1.5 m for all other ages (2,222 plants per hectare).

In each stand a North-facing slope was selected where one plot was demarcated in the each of the upper, middle and bottom thirds of the slope. The size of the plots was 9 × 16 m for the forest stands one-year old and 9 × 14 m for all other ages, making four rows of 10 plants in each row. In each of the plots the circumferences at breast height (1.3 m) of all trees were measured using a graduated metric tape, and two average trees with respect to this variable in each plot were selected for evaluation of leaf biomass and leaf area.

Leaf biomass was analyzed by separating it from the other compartments (stem, branches and flowers + fruits) and then determining its wet weight on a digital scale (Portable Electronic Scale) with accuracy to 0.5 g. To determine the dry weight, 200 g samples were removed and immediately weighed to determine the wet weight. These samples were then dried in a mechanical convection oven at 75°C to constant weight and the material was weighed again to obtain the moisture content and, consequently, the dry weight of the leaves by the expression:

$$\mathrm{DWL} = \frac{\mathrm{WWL} * \mathrm{DW_S}}{\mathrm{WW_S}} \quad (1)$$

Where: DWL = dry weight of leaves, in kg; WWL = wet weight of leaves, in kg; DW_s = dry weight of the sample in kg. WW_S = wet weight of sample, in kg.

In this study, leaf area was preferred instead of leaf area index for its simplicity and easy applicability in the analysis performed. To determine leaf area three samples of 50 g each were taken from the tree canopy. The leaflets were separated from the petiole and rachis and spread flat using an ironing board heated to 65°C. Leaf area was then determined using an integrator (3000 *Canopy Analyser Li-Cor).* At the end of the process, all material (petiole, rachis and leaflets) was dried in a mechanical convection oven at 65°C to constant mass and weighed on an analytical balance. Thus, the plant leaf area was calculated by the expression:

$$\mathrm{LA} = \frac{\mathrm{LDW} * \mathrm{LA_S}}{\mathrm{DW_S}} \quad (2)$$

Where: LA = leaf area in m²; LDW = total dry weight of the leaves, in kg; LA_s = leaf area of the sample, in m²; DW_s = dry weight of the sample, in kg;

Additionally, an evaluation of the chemical characteristics of the soil surface horizon (0-20 cm) was conducted in the plots. To this end, three samples were collected in each plot using an auger which was then combined to yield a single mixed sample for the stand. Samples were sent to the Soil and Plant Tissues Analysis Laboratory of the Universidade Regional Integrada do Alto-Uruguai e das Missões in the municipality of Frederico Westphalen, Rio Grande do Sul, to determine the following variables: pH (potential Hydrogen), SMP Index (SMPI) (Shoemaker, Mac lean and Pratt Index), clay (Arg), organic matter (OM), phosphorus (P), potassium (K), aluminum (Al), calcium (Ca), magnesium (Mg), calcium + aluminum, CEC at pH 7, CEC base saturation and CEC aluminum saturation.

The meteorological data used were: Maximum, minimum and mean air temperature, relative air humidity, rainfall and hours of sunshine were obtained at the INMET (National Institute of Meteorology) of the Climatological Station of Pelotas. This was the station closest to the study site when the research was being conducted, about 85 km from the municipality of Cristal and 70 km from Piratini. The global incident radiation was estimated using the Angstrom equation, modified by Prescot and Penman using the mathematical development of Vianello and Alves (2000). Coefficients were fitted for the municipality of Pelotas by Steinmetz et al. (1999).

Initially, the relationship between the dry weight of leaves (DLW) and leaf area (LA) of samples was studied. The linear model LA = $\mathrm{B_0} + \mathrm{B_1}\,\mathrm{PSF} + \varepsilon i$ was evaluated and fit statistics were derived: coefficient of determination, standard error of the estimate, F significance, significance of coefficients, confidence interval for the coefficients, and distribution of residuals. To verify if the relationship between dry leaf weight and leaf area was constant over time and among planting sites, a covariance analysis (ANACOVA) was performed. The analysis evaluated the necessity of using independent functions over time and in different planting sites. In other words, the hypothesis of equality of the line slopes was tested. The ANACOVA was calculated using the Snedecor method, with the lines slope verified by the F value for 1% error for the mean square of the differences.

The second step was to study the variation in the average leaf area of individuals by analysis of variance. The study factors were the local combination of planting site versus stand age. Initially, we tested the basic assumptions of the analysis of variance (homogeneity) using the Bartlett's test, to then determine F by analysis of variance. The effects of any significant factor ($p < 0.05$) in the study were dismembered and the comparison of means was made by the Tukey's test. When the age factor was significant, we performed regression analysis and F test, which indicated what, should be the degree of the polynomial to be used.

The third step was to verify the relationship between the chemical properties of the soil surface horizon and meteorological conditions and the mean leaf area. To this end, a Pearson correlation analysis was conducted, which was qualitatively assessed for intensity using the criteria proposed by Callegari-Jacques (2003). Such relationships were also analyzed by the stepwise variable selection technique, one of the most recommended methods to select appropriate explanatory variables.

The models generated by this method were tested with respect to the regression conditions using the White test (homoscedasticity), Shapiro-Wilk test (normality) and Durbin-Watson test (independence). For the multiples, the level of tolerance and hence the variance inflation factor (VIF) was determined. Finally, a regression was also performed on the standardized variables, which permitted identification of the relative impact of independent variables on the dependent variances with respect to changes in standard deviation.

Dummy variables were added to the model chosen to describe leaf area over time. This permitted one to determine whether the relationships between the dependent variables (estimators of the probabilistic function) and the independent variables (variables selected by the *stepwise* method) were the same between the two planting sites.

RESULTS AND DISCUSSION

Relationship between dry leaf weight and leaf area

The correlation between leaf area (LA) and dry leaf weight (DLW) was 0.99, that is, very strongly related. The model equation intercepts (LA = $\mathrm{B_0 + B_1\,MSF + \varepsilon i}$) were not significant for either planting site (municipalities of Cristal and Piratini) nor at any age of the sampled stands (1, 3, 5 and 7 years). New model adjustments were conducted without an intercept, that is, LA = $\mathrm{B_1\,MSF + \varepsilon i}$ and fit statistics were excellent, resulting in coefficients of determination greater than 93%, standard error in the estimates smaller than 7%, F highly significant ($p < 0.01$) and adequate distribution of residuals. Thus the relationship between leaf area and leaf weight can be used to obtain leaf area. Analysis of covariance revealed that ratios do not need to be used independently (that is, for each combination of age and site). Several groups were identified, though mean square differences were not significant ($p > 0.01$). Two groups were defined; the first representing stands aged 0-3 years and the second representing stands older than 3 years. Therefore, Group 1 was composed of stands sampled in the municipality of Cristal + Piratini aged 3 years or less. Group 2 was composed of stands sampled in both municipalities and greater than 3 years old.

The relationship between mass and dry leaf weight for group 1 was 65.57 (that is, one kilogram of leaves represented 6.56 m² leaf area). In group 2, the relationship was 61.63 (that is, one kilogram of leaves represented a leaf area of 6.16 m²). This significant difference expresses the vitality of the leaves at young ages in the stand regardless of the planting site. The relationship between leaf specific density (given by the mass of the leaflet) and the petiole + rachis tends to decrease over the course of the plantation cycle, since some of the pinnae will fall from the leaflet. Thus, mass increases while leaf area is diminished. Factors related to competition between trees in the stand are among the causes, as well as canopy formation that shades leaves of the lower canopy, morphological and physiological changes, and leaf age.

Both groups were tested for fit quality statistics as well as regression constraints (Table 1). Both adjustments resulted in excellent coefficients of determination, standard error in the estimate, standard error in the coefficients, appropriate distribution of residuals and met the requirements of the regression; thus, revealing that the relationships obtained can be used to predict leaf area. No previous studies in the literature were found that describe the aforementioned relationship in black wattle.

Variation in black wattle leaf area throughout the plantation cycle and by planting site

Analysis of variance revealed that the interaction between planting site and stand age was statistically significant ($p < 0.01$), indicating that the effects are not independent. The main factors, planting site and stand age, were also significant (Table 2).

Mean of the leaf areas are presented in Table 3. In the municipality of Cristal the highest mean of leaf areas tended to occur in the year 3, decreasing to the initial levels in the year 5, when averages between stands of 1 and 5 years old were similar. From that point, again the values of leaf area tended to be larger, reaching maximum levels by the seventh year, in which the mean was identical to the observed in the 3 year old stand, and both of these values were greater than the rest. In the municipality of Piratini, leaf area tended to increase until year 3 and remain constant to year 5, with similar means between 3 and 5 years. The 7 year old forest stand has presented the highest leaf area average. This divergent behavior over the duration of the planting cycle and between planting sites resulted in a (planting location *versus* age) highly significant interaction.

Within the same age group, statistical differences

Table 1. Model fit statistics describing leaf area as a function of dry leaf weight in black wattle in Rio Grande do Sul, Brazil.

Statistics	Group 1: ≤ 3 years	Group 2: > 3 years
Correlation coefficient (%)	99.94	99.86
Coefficient of determination (%)	99.87	99.72
Standard error ($cm^2\ g^{-1}$)	10.14	13.71
Standard error	4.01%	5.79%
F	55218.32**	25452.73**
White	7.62^{ns}	6.24^{ns}
Shapiro-Wilk	0.96^{ns}	0.98^{ns}
Durbin-Watson	1.80^{ns}	1.87^{ns}

Group	Coefficients		Standard error	*t*	Confidence interval		
1: ≤ 3 years	b_1	65.5715	0.28	234.99**	65.0151	≤ Y ≤	66.1279
2: > 3 years	b_1	61.6306	0.39	159.54**	60.8603	≤ Y ≤	62.4009

** = Significant at 1% probability. ns = not significant at 1% probability.

Table 2. Analysis of variance of area of individuals in average sample diameter at breast height in black wattle stands in Rio Grande do Sul, Brazil.

Source of variation		Degrees of freedom	Mean square
Main effect			
Plantation site		1	0.0364**
Stand age		3	0.1293**
Site*age		3	0.0278**
Coefficient of determination		81.01%	
Coefficient of variation		4.31%	
Simple effects			
Age	1	1	0.00002^{ns}
	3	1	0.0054^{ns}
	5	1	0.0214*
	7	1	0.0927**
Site	Cristal	3	0.0396**
	Piratini	3	0.1175**

** = Significant at 99 of probability. Ns = not significant at 1% probability. * = Significant at 95% probability.

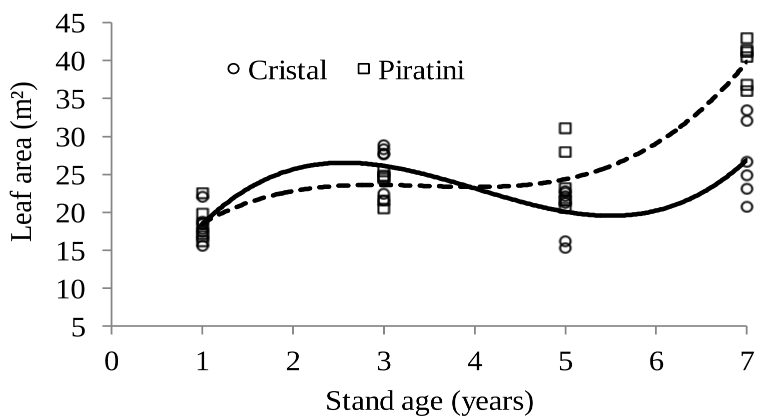
among planting sites in 5 and 7 year old stands were observed (Table 2 - simple effects), and those stands established in Piratini had the highest mean leaf area values. These results suggest that when mean values of leaf area are used, one must consider planting location and stand age. These may be derived from the trend curves fitted to represent the relationship between leaf area and stand age and are presented in Figure 1. The relationship between variables was represented by third degree equations, explaining 55.91 and 89.69% of the variation in leaf area as a function of age for the municipalities of Crystal and Piratini, respectively.

It was observed that in Piratini's stands the leaf area follows a gradual increase as the stand age increases. On the other hand, leaf area in Cristal follows a different trend, increasing up to the third year, decreasing up to the fifth year and then, it tends to increase up to the end of the cycle. The variation in leaf area observed here was also observed for black wattle leaf biomass in the same study sites and throughout the plantation cycle by Mochiutti (2007) who noted that leaf biomass increased until year 3, decreased until year 4 and stabilized after 5

Table 3. Tukey's test comparing mean leaf areas of mean diameter at breast height sampled in individuals from black wattle populations in Rio Grande do Sul, Brazil.

Plantation site	Stand age (years)			
	1	3	5	7
Cristal	18.44 aB	26.13 aA	20.09 bB	26.90 bA
Piratini	18.55 aC	23.62 aB	24.38 aB	39.82 aA

Means followed by the same lowercase letter vertically and uppercase letter horizontally, did not differ by the Tukey test at 95% probability.



$$\text{Piratini LA} = 0.3953x^3 - 4.0947x^2 + 13.769x + 8.4875 \quad R^2 = 89.69\%$$
$$\text{Cristal LA} = 0.5535x^3 - 6.6974x^2 + 23.437x + 1.1478 \quad R^2 = 55.91\%$$

Figure 1. Trends in leaf area in individuals of average sampled diameter at breast height in black wattle stands in Rio Grande do Sul, Brazil.

years of growth. Kozlowski et al. (1991) report that leaf biomass or leaf area index (leaf area) increases with age of the forest stand until a maximum is reached. The value subsequently stabilizes or declines slightly. These authors also point out that the age of maximum leaf biomass and the slope of the decline depends on the species, spacing and the forest site. Thus, it is evident that environmental conditions in which plants are grown contribute to leaf area dynamics. The observations generated interest in relating the variable to the chemical features of the soil and meteorological conditions (that is, factors determining site quality.)

Relationship between chemical attributes of the soil surface horizon and leaf area

Through simple linear correlation analysis, the element phosphorus (P) was the variable found to be most strongly correlated with leaf area (r = 0.71). Three other variables were frequently correlated, namely: potassium (r = 0.55), calcium (r = 0.39) and base CEC (r = 0.30). Other variables were found to be weakly correlated with leaf area (pH = 0.23, Mg = 0.27, SMPI = 0.27, H + AL = -0.28, Clay = -0.25, MO = -0.20, CEC Al = -0.18 and CEC pH 7= -0.05).

No studies were found in the literature that addresses the relationship between soil and leaf area in black wattle stands or other forest species. Studies have been conducted in black wattle to determine the correlation between soil attributes and dendrometric variables (Rachwal et al., 1997): dominant height (Mochiutti, 2007), diameter at breast height and wood volume (Rachwal et al., 1997; Mochiutti, 2007), and the patterns observed in the present study are consistent with the correlations cited by the above authors. Such evidence highlights the interrelationship between soil and leaf area and consequently growth and yield of the species.

The effect of P on dendrometric variables in black wattle stands is already known. Mochiutti (2007) evaluated the influence of physical and chemical features of the soil on the growth of this species (in the same location) and observed that the only soil variables that were significantly correlated with dominant height were P, Al and A horizon CEC, although the strength of the relationship is low (r = 0.237, -0.232 and -0.219, respectively).

Moreover, the aforementioned author observed that assessing the effects of Ca and Mg and fertilization with P and K on growth and yield of black wattle wood by year 3 revealed that P was the most important nutrient for growth and yield. According to Stein and Tonietto (1997), these nutrients are part of basic fertilization programs used in cultivating the species and, according to Mochiutti (2007), growth could be improved by adequate fertilization in areas where P and K are less available. In the Southeast Range, also in the state of Rio Grande do Sul, on Litholic Neossols, Cambissols, and Gleisols, Rachwal et al. (1997) observed correlations between the DBH in black wattle with other attributes: Aluminum saturation (r = -0.65), Ca + Mg (r = 0.55) and base saturation (r = 0.60) of the surface horizon, thus demonstrating that soil composition affects stand growth.

The stepwise method resulted only in a single step, in which only the most correlated variable was retained in the model, producing the equation: LA = 18.4050 + 1.9571 P. The fit resulted in a coefficient of determination of 50.05% and a standard error in the estimate of 21.34%, and all coefficients of the model were significant. Also, it was observed that the algebraic signs of the regression coefficients were positive, indicating an increase in leaf area for every unit increase in P and consistent with expectations (that is, a direct relationship between these variables). The positive value of B1 found in the model can be interpreted as an increase in leaf area on the order of 1.9571 m² with the addition of 1 mg L^{-1} of P in the soil.

Vieira et al. (2011) emphasize that P is considered an essential element, participating directly in compounds and vital reactions in the plants, and indirectly since the absence of that element would interrupt the plant's life cycle. Because of its role in the protein synthesis, lack of the element is reflected in retarded plant growth (Malavolta, 1980), and this effect was also observed in the leaf area of black wattle. Phosphorus deficiency may negatively affect the Calvin cycle, according to Walker (1983).

Relationship between meteorological conditions and leaf area

Meteorological conditions related to leaf area were: Accumulated precipitation, average maximum air temperature, average minimum and average relative humidity, and accumulated solar radiation. A simple linear correlation analysis revealed that the cumulative global solar radiation (Rgac) was most strongly correlated with leaf area (r = 0.71), followed by accumulated rainfall (r = 0.69), and strong in both cases. Mean temperature was frequently seen to be correlated with leaf area (r = 0.41) while other variables such as maximum temperature (r = 0.17), minimum temperature (r = 0.23) and relative humidity (0.28) were weakly related. Caron et al., (2003) also observed high correlations between lettuce biomass and solar radiation and low correlations with mean air temperature.

The stepwise method resulted only in a single step, in which only the most correlated variable was retained in the model, producing the following equation: LA = 16.1080 + 0.0004 Rgac. The fit resulted in a coefficient of determination of 50.41% and standard error in the estimate of 21.27 %, and all model coefficients were significant. Furthermore, it was found that the algebraic signs of regression coefficients were positive; thereby, indicating an increase in leaf area for each Rgac unit increases. This was consistent with expectations (that is, a direct relationship between these variables). The positive value of B1 found in the model can be interpreted as an increase in leaf area of 0.0004 m² above 1 MJ m^{-2} Rgac.

No studies in the literature were found that simulate or relate growth in leaf area with accumulated solar radiation. Solar radiation is a recognized factor linked to crop production because it directly influences the formation of biomass. Caron et al. (2003) proposed equations for estimating plant biomass that include solar radiation as an input variable, resulting in a model that performed better at predicting lettuce growth. Such a model may also prove useful in explaining the variations in leaf area in black wattle.

Relationship between chemical attributes of soil surface horizon and meteorological conditions with leaf area

The stepwise method resulted in three steps. The first input variable in the model was the accumulated solar radiation (Rgac), the second was phosphorus (P) content, and the third was clay (Arg) content. In the first step we obtained the equation LA = 16.1080 + 0.0004 Rgac, and the fit revealed a coefficient of determination of 50.41%, standard error in the estimate of 21.27 % and all model coefficients were significant. In the second step the equation LA = 12.3566 + 0.0003 Rgac was obtained and the coefficient of determination of the fit was 83.10%, the standard error in the estimate was 13.60%, and all

Table 4. Statistical fit for models obtained by the *stepwise* method for estimating leaf area in black wattle stands.

Model	R^2	R^2aj	Syx	F	α (F)	W	SW	DW
$LA = b_0+b_1Rg$	50.41%	42.14%	21.27%	6.099	0.048	4.37^{ns}	0.97^{ns}	1.54*
$LA = b_0+b_1 Rg+b_2 P$	83.10%	76.34%	13.60%	12.295	0.012	6.41^{ns}	0.91^{ns}	3.08*
$LA=b_0+b_1Rg+b_2P+b_3 Arg$	93.84%	89.22%	9.18%	20.317	0.007	8.00^{ns}	0.25^{ns}	2.19^{ns}

Model	Coefficients		Syx	t	α (t)	Confidence interval		
$LA = b_0+b_1Rgac$	b_0	16.1078	3.96	4.07	0.007	6.4178	≤ Y ≤	25.7978
	b_1	0.0004	0.00	2.47	0.048	0.000003	≤ Y ≤	0.0008
$LA = b_0+b_1 Rgac+b_2 P$	b_0	12.3566	2.80	4.41	0.007	5.1467	≤ Y ≤	19.5665
	b_1	0.0003	0.00	3.13	0.026	0.0001	≤ Y ≤	0.0006
	b_2	1.6174	0.52	3.11	0.027	0.2807	≤ Y ≤	2.9542
$LA=b_0+b_1Rgac+b_2P+_{b3} Arg$	b_0	20.0836	3.48	5.76	0.004	10.4083	≤ Y ≤	29.7589
	b_1	0.0004	0.00	5.13	0.007	0.0002	≤ Y ≤	0.0006
	b_2	1.4799	0.35	4.17	0.014	0.4947	≤ Y ≤	2.4650
	b_3	-0.3561	0.13	-2.64	0.058	-0.7305	≤ Y ≤	0.0183

R = coefficient of determination, R²adj = adjusted coefficient of determination; Syx = standard error, F = F value, bi = coefficient of the model, LA = leaf area; Rgac = solar radiation accumulated in MJ m^{-2}; P = phosphorus content in MG/L; Arg = clay content in %, W = White, SW = Shapiro-Wilk, DW = Durbin-Watson.

model coefficients were significant ($p < 0.05$). These two variables were expected, since they were the most related with leaf area as was shown earlier (Table 4).

In the third step, clay content was the variable with the highest significant partial correlation coefficient ($\alpha_F<0.15$, value set for the input variable) since Rgac and P were already in the equation, resulting in the equation: LA = 20.0836 + 0.0004 + 1.4799 Rgac P - 0.3561 Arg, which showed a correlation coefficient of 93.84% and standard error of estimate of 9.18% (Table 4). Clay was the only variable with significance value greater than 5% (α_t = 0.058) a fact related to the weak correlation between it and leaf area.

The clay content in the soil is strongly correlated with Al (r = 0.80), and is also very strongly related to the combination of H + Al (r = 0.92), which are considered elements harmful to plant growth. Negative correlations between soil Al and DBH (r = -0.65) were observed in black wattle stands by Rachwal et al. (1997), as observed between Al and Al + H and leaf area (r = -0.26 and r = -0.28, respectively). Thus, the inclusion of clay in the model is valid, though it is weakly correlated with leaf area (-0.25). Caron et al. (2003) and Machado et al. (2008) also obtained the best equations with regard to the fit indicators and precision when all variables were involved in the models, including those with low simple linear correlation.

It was noted that all the algebraic signs of the coefficients are consistent with expectations (that is, direct relationship between leaf area and the variables Rgac and P variables and inverse relationship with Arg). Furthermore, it was observed that models that include Rgac and Rgac + P did not meet all the regression conditions tested, because the residuals distribution independence test was significant. Therefore, the only model that met all the regression requirements (homoscedasticity, homogeneity and independence) was the model obtained in the third step, which included Rgac, phosphorus and clay. It was also verified that this model does suffer multicollinearity problems, given that the tolerance values range from 0.90 and 0.84 and the variance inflation factor is less than 10 (ranging from 1.06 to 1.10), that is, the independent variables that compose it are not correlated.

To eliminate the effects of different measurement units of the independent variables and to verify the relative impact on the dependent variables, they were standardized before making estimates of model coefficients LA = bo + b1 Rgac + b2 P - b3 Arg. This transformation created a common unit with which was possible to determine the variable of greatest impact. The obtained equation was: LA = 0.6699 Rgac + 0.5350 P - 0.3390 Arg. The expression allows one to identify that Rgac is the most influential variable in explaining the variation in leaf area, followed by P and Arg, which in turn, is less important in the estimation process.

When soil and climatic factors are studied simultaneously, as in the model: LA = b0 + b1 Rgac + b2 P + b3 Arg, the multiple correlation coefficient of the expression was 96.87%, residuals were adequately distributed, making the equation an appropriate tool to explain variations in leaf area. Though, based on a small data set, the resultant model appears to be adequate for simulating the effects of climatic variations and soil fertility on leaf area, and hence growth and yield in black wattle stands.

In the equation obtained leaf area (as a function of Rgac and P and Arg) was related to planting site and subjected to regression analysis using a dummy variable. This suggests that a single equation can be fit, and planting site need not be considered since the dummy variable used to evaluate the effect of planting site was not significant ($p > 0.05$).

Conclusions

Leaf area was strongly related to dry leaf weight. The relationship between leaf area and dry leaf weight was not influenced by planting site, but rather by the age of the stand. The coefficients of leaf area/dry leaf weight could be used to estimate leaf area. Values of leaf area varied depending on stand age and plantation site. Leaf area was related to soil properties and particularly with phosphorus content. Similarly, it was also related to meteorological conditions, most notably accumulated solar radiation. The obtained model, which involves global accumulated solar radiation and phosphorus and clay contents, adequately explained variations in leaf area.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Callegari-Jacques SM (2003). Bioestatística – Princípios e Aplicações. ArtMed: Porto Alegre.

Caron BO, Medeiros SPL, Manfron PA, Schmidt D, Pommer SF, Biachi C (2003). Eficiência de conversão da radiação solar fotossinteticamente ativa interceptada em fitomassa de alface. RBA. 11(2):261-268.

Kozlowski TT, Kramer PJ, Pallardy SG (1991). The physiological ecology of woody plants. Academic Press, New York.

Linhares CA, Ponzoni FJ, Shimabukuro YE (2000). Relação entre volume de madeira e índice de área foliar em um povoamento de *Pinus* spp.: estudo de caso. Árv. 24:47-54.

Machado SA, Aguiar LP, Figueiredo Filho A, Koehler HS (2008). Modelagem do volume do povoamento para *Mimosa scabrella* Benth. na região metropolitana de Curitiba. Árv. 32(3):465-478.

Malavolta E (1980). Elementos de nutrição mineral de plantas. Agronômica Ceres Ltda., São Paulo.

Mochiutti S (2007). Produtividade e sustentabilidade de plantações de acácia-negra (*Acaica mearnsii* De Wild.) no Rio Grande do Sul. PhD Dissertation, Federal University of Paraná.

Monteith JL (1977). Climate and the efficiency of crop production en Britain. Proc. R. Soc. Lond. 281(980):277-294.

Rachwal MFG, Curcio GR, Dedecek RA (1997). Caracterização do desenvolvimento e produção de madeira da *Acacia mearnsii* aos 3 e 5 anos de idade em solos derivados de micaxistos no município de Piratini, RS. Embrapa Florestas, Colombo.

Simon AA (2005). A cadeia produtiva da acácia-negra, aspectos econômicos, sociais e ambientais. In: Strohschoen, A.G., Rempel, C. (Eds.), Reflorestamento e recuperação ambiental, ambiente e tecnologia: o desenvolvimento sustentável em foco. Univates, Lajeado, pp. 149-166.

Stein PP, Tonietto L (1997). Black Wattle silviculture in Brazil. In: Brown AG, Ko HC. (Eds.), Black Wattle and its Utilization. RIRDC, Barton, pp. 78-82.

Steinmetz S, Assis FN, Soares WR (1999). Estimativa da radiação solar global a partir da insolação na região de Pelotas, Rio Grande do Sul. Agropecu. Clim. Temp. 2(1):77-85.

Vianello RL, Alves AR (2000). Meteorologia Básica e Aplicações. UFV, Viçosa.

Walker D (1983). C3, C4: mechanisms, and cellular and environmental regulation, of photosynthesis. Bookplan, Worcester.

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Cropping systems evaluation, fertilization, and effects on technological quality and sugarcane productivity

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The scarification has been used in soil descompaction and when combined with fertilizer and harrowing has been called triple operation, which together can change the quality and increase the productivity of sugarcane. In this study we evaluated the influence two cropping systems in ratoon, associated with different forms of fertilization on the technological quality and productivity of sugarcane. The design was randomized blocks, with split plots, with four replications. In the main plots we evaluated two treatments: C/HE=with chisel plow; S/HE=without chisel plow. The subplots were tested for fertilization treatments: M=mineral fertilization; T=M+filter cake; H=M+humic extract; M+T+H. We evaluated the technological analysis and the production of sugarcane. It was observed that the use of the chisel during the period of the 2nd and 3rd ratoon did not cause changes in technological variables and sugarcane productivity. The fertilizers used did not provided increases in the number of stems per meter nor the productivity of sugarcane stems. The values obtained for brix degree of syrup, apparent sucrose, broth purity, fiber, reducing sugars and total reducing sugars were above minimum values defined by the standard the cane quality in all the treatments, but did not increase the number of stems and crop productivity.

Key words: Triple cultivation, scarification, organic fertilization, filter cake.

INTRODUCTION

Current techniques of management of sugarcane culture are based on soil plowing during the preparation and planting, which added to the harvest and the transhipment production system, have high potential for compression because the traffic is repeated during the crop cycles under different humidity conditions, thereby

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altering the physical, chemical and soil organic matter (Materechera, 2009; Oliveira et al., 2014).

Sugarcane is one of the crops that is most affected by soil compaction, because its root system is formed by rhizomes and fasciculated roots, of which 85% are in the layer 50 cm deep, and 60% in the layer 20-30 cm deep (Oliveira Filho et al., 2015). This compaction creates a less favorable environment for the development of the root system of cane (Otto et al., 2011; Kingwell and Fuchsbichler, 2011).

The subsoiling has been used to break through layers of soil in those agricultural areas that have suffered compaction (Gorucu et al., 2006), however before the new planting plants use scarification between the lines of ratoon cane, which associated with fertilizer and harrowing, it has been called triple cultivation (Camilotti et al., 2005).

These three post-harvest operations have been simultaneously conducted with the purposes of decompression, chemical fertilization and weeds control (Paulino et al., 2004), besides reducing operating costs. Souza et al. (2014) noted that soil scarification enables better development of the roots of sugarcane in depth, causing it to remain stable in dry periods. Plant responses to soil compaction are measures by changes in the development and functioning of roots, which can affect productivity and product quality (Alameda et al., 2012).

With the expansion of sugar-alcohol market and the incorporation of new areas of Savanna to the production process, studies have been conducted with the aim of improving the potential of the varieties making them more productive, what can be obtained through the use of new management techniques and monitoring the nutritional requirements of the plants to achieve economically viable production in these regions (Flores et al., 2012).

Currently, the focus is on the huge amounts of organic waste produced in the sugar cane industry. Among them, there is the filter cake which is a residue coming from the crushed bagasse mixture and decantation sludge, from the sugar clarification process. It is an organic compound rich in calcium, phosphorus, nitrogen and potassium, which generates a volume ranging from 30 to 40 kg per ton of cane crushed, with a variable composition depending on the variety of sugarcane and maturation (Santos et al., 2010). However, it can be noted that phosphorus is the predominant element (Almeida Júnior et al., 2011) because the deficiency of this element results in significant decrease in sucrose accumulation, since the phosphate fertilizer directly affects the amount of sugar and juice purity (Elamin et al., 2007). Rossetto et al. (2008) noted that the filter cake plays key role in agricultural production, fertility and as a soil conditioner.

Another option to increase the absorption of water and nutrients by sugarcane is to stimulate root development and, consequently, the agronomic performance of the plants. Some mills have been using products based on humic-fulvic substances, however, studies about its efficiency in soil and plant are still scarce.

Evaluating the application of humic substances in soil and their influence on technological quality varieties of sugarcane, Rosato et al. (2010) found that these humic substances at a dose of 20 t ha^{-1} gave positive effect on the accumulation of sucrose in most varieties. Santos et al. (2010) evaluated the vegetative growth and productivity of sugarcane, depending on fertilization with filter cake enriched with soluble phosphate. They found that pie application at planting, promoted an increase in sugarcane stalks and tillering.

Technological variables of sugarcane are important for the industry and for suppliers, which are paid by the quality of the sugarcane produced, which is directly influenced by the fertilizer used in the area (Vischi Filho, 2014). The quality of this raw material can be measured by means of some variables, among them the total solids content in the syrup, sugarcane apparent sucrose, fiber and syrup purity (Larrahondo et al., 2009).

Due to the importance of the sugarcane culture in the country and its expansion in Savanna where medium textured soils and low fertility dominate, besides the need to generate techniques aimed at sustainability management system, this study has been developed aiming to evaluate the influence of two cropping systems in ratoon, associated with different forms of fertilization on the technological quality and productivity of sugarcane.

MATERIALS AND METHODS

The study was conducted at the 'Farm Freedom', in an area of Alcoolvale plant in the city of Aparecida do Taboado-Brazil, which covers an area of 2.750.130 km², representing 0.77% of the state, located between the geographical coordinates 51°13' west longitude and 20º13' south latitude, average altitude of 392 m. The area was planted to pasture (*Urochloa decumbens*) for 35 years and since 2004 sugarcane has been cultivated. Treatments were installed shortly after the mechanical harvesting of sugarcane in November 2006 (2nd ratoon) and 2007 (3rd ratoon), where sugarcane variety RB 867515 was cultivated.

The climate is classified as AW, tropical humid according to the International Classification of Köppen, with rainy season in summer and dry season in winter. Average rainfall is around 1.595 mm (Abranches and Bolonhesi, 2011).

The soil of the experimental area was classified as Oxisol, medium texture, highly weathered, deep and well drained (Embrapa, 2006), which features in the layer of 0.0 to 0.20 m: 180 g kg^{-1} clay, 770 g kg^{-1} sand and 50 g kg^{-1} silt. Before the implementation of the experiment, the soil had pH in water=6.3, P=17 mg dm^{-3}, K=96 mg dm^{-3}, Ca=1.90 cmol$_c$ dm^{-3}, Mg=0.60 cmol$_c$ dm^{-3}, H+Al=2.0 cmol$_c$ dm^{-3} and total organic carbon (COT)=9.28 g kg^{-1}. In the preparation of the area, according to the soil analysis, 2.0 t ha^{-1} dolomitic limestone were applied with 89% relative neutralization total power (PRNT), half the dose before deep plowing and the other half before harrowing of the total area. Before planting 1.0 t ha^{-1} gypsum surface was applied.

The experimental design was of randomized blocks in a split plot

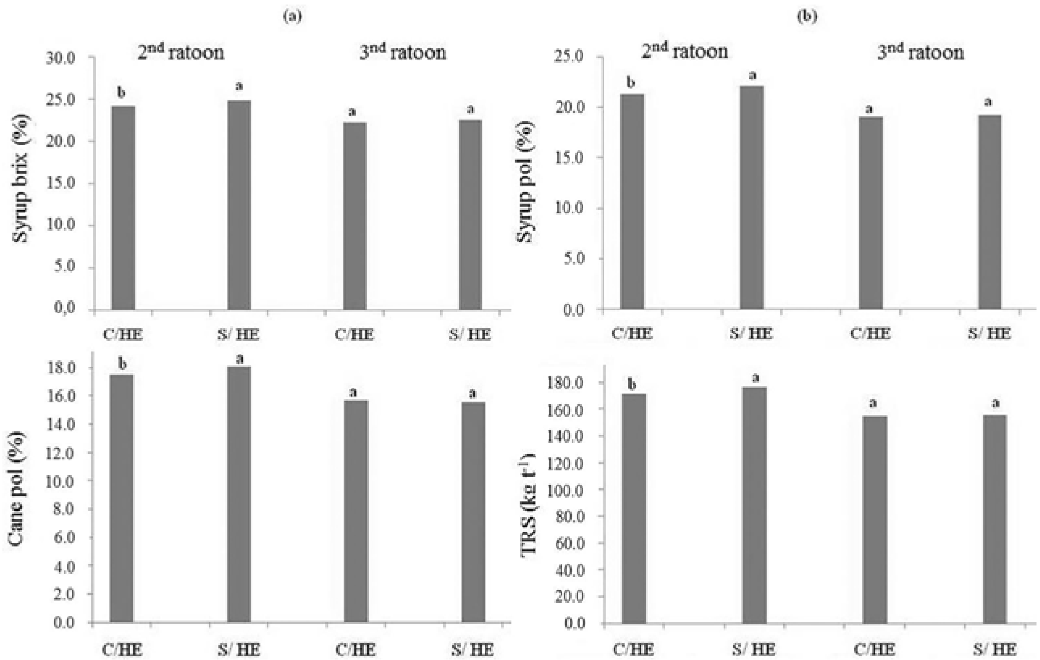

Figure 1. Treatments with (C/HE) and without chisel plow (S/HE), and technological variables in sugarcane of 2nd and 3rd ratoon in Aparecida do Taboado-Brazil, in 2006 and 2007, respectively. The same letters do not differ significantly from each other, by Tukey test (p>0.05).

design with four replications. The main plots received two treatments: C/HE=with chisel plow; S/HE=without chisel plow. In the subplots four forms of fertilization were estimated: M=mineral fertilizer (control); T=mineral fertilization+filter cake; H=mineral fertilization+humic extract; M+T+M=mineral fertilization+pie filter+humic extract.

Treatments in the main plots were represented by cropping systems with chisel plow (C/HE), which associated with fertilization and cultivation is called triple operation in dealing with ratoon, and without the use of the chisel plow (S/HE) and fertilization. This operation was conducted with a cultivator of seven branches, DMB model attached to a tractor of 110 hp and traction 4 × 4, where two lines at a time were grown at 0.25 m deep.

The experimental plots consisted of five lines of sugarcane 10 m long, spaced 1.40 m, totaling 70 m^2 per plot with dividers of 2.0 m between plots, and 3.0 m between blocks. The experiment was conducted in the 2nd and 3rd ratoon of sugarcane cultivation.

The mineral fertilizer was conducted by applying applying 90 kg ha^{-1} of N, 30 kg ha^{-1} of P_2O_5 and 120 kg ha^{-1} of K_2O, while for the filter cake in natura 13 t ha^{-1} (dry base) and 20 L ha^{-1} humic extract were applied in the subplots, using the triple operation in the area with scarification. In the main plot where the triple operation was not carried out, the distribution of fertilizer was made with the suspension of the chisel plow, only applying fertilizer between rows, without the incorporation of mineral fertilizer, filter cake and humic extract to the ground.

The chemical characterization of the filter cake presented temperature between 60-65 °C and humidity of 5.35%, water pH=7.2; N=12.75 g kg^{-1}; P=4.15 g kg^{-1}; K=91.6 g kg^{-1}; Ca=23.60 g kg^{-1}, Mg=3.0 g kg^{-1}; organic carbon=423 g kg^{-1}, with C/N ratio of 33.3%. These data were provided by the Laboratory of the Agronomic Institute Soil Center of Campinas. The filter cake used had a water content of 0.58 kg kg^{-1} at the time of the experiment.

The characterization of the humic extract was of 12% humic acids, 3% fulvic acids, 4% K_2O and 8% of total nitrogen, data on the product showed on the label of Tradecorp Company. Samples for determining the quality of the syrup were established of ten stems of sugarcane collected in sequence on the center line of the field but excluding the first three meters on each side. After the collection the green and dried leaves were taken out and stripping occurred in the apex bud. We analyzed: brix degree of syrup (°Brix), purity, apparent percentage of sucrose in syrup (Syrup Pol), apparent percentage of sucrose in sugarcane (Cane Pol), percentage of reducing sugars in syrup (Syrup RS), percentage of reducing sugars in the cane (cane RS), sugarcane fiber and total recoverable sugars (TRS), according to Consecana method (2006).

To determine the yield (t ha^{-1}), the authors collected 45 stems of the three center lines in diagonal arrangement, following the methodology of Gheller et al. (1999). The results were analyzed for normality and homogeneity of data through Lilliefors, Cochran and Barttlet tests, respectively. Variance analysis was made using the statistical program SISVAR, and the F test was applied for significance. Averages were compared by Tukey test ($p<0.05$).

RESULTS AND DISCUSSION

Analyzing data obtained in the treatments with and without the use of chisel plow in ratoon cane in the second year, it was observed that the average values for ºBrix, syrup Pol, cane Pol and TRS were higher for growing system without chisel plow while in the third year ratoon cane, there were no differences between treatments for the variables analyzed (Figure 1). These results evidence that the stages of sugarcane 2nd and 3rd ratoon scarification operation is unnecessary because it did not change the technological quality of sugarcane. According to Carvalho et al. (2011) ºBrix, syrup Pol and TRS variables are among the most important for the sugar industry where the best rates in the area were evidenced without the use of the chisel plow since they are related to the amount of raw materials produced by agriculture that are available for manufacturing sugar or alcohol.

Soil scarification is a minimum preparation operation, which is used alone in order to reduce soil density and its mechanical resistance to root penetration, and increase soil permeability, through the breakup of compacted soil layers, especially in fifth or sixth cut of the cane (Paulino et al., 2004). However, when associated with topdressing and harrowing (triple cultivation), serves to incorporate the fertilizer and control infestations of invasive plants.

The results proved that the application of fertilizers carried out on the soil surface and the control of invasive plants, without the use of soil scarification, did not significantly alter sugarcane technological quality in the most important variables. Consequently, you can save fuel and speed up the operation. Probably in these areas of 2th and 3rd cut the compression levels should not be causing restriction to root growth.

Similar results were observed by Chiba et al. (2008) evaluating the sugarcane cultivation in Argisol treated with sewage sludge. They found that the incorporation of the product through the triple operating equipment did not increase the ºBrix values, cane Pol and total reducing sugars in agricultural period of 2003/04. Souza et al. (2005) studied the management of cane straw harvested without burning, the sugarcane productivity and the quality of the syrup. They found that scarification up to 0.30 m, carried out with the Coopersucar model with two winged Ikeda rods, did not promote increased fiber content, purity, apparent sucrose in syrup or reducing syrup sugars.

Analyzing the influence of forms of fertilizer on the technological variables in the 2nd ratoon in 2006 they did not notice differences among the treatments tested (Figure 2), just as there were no differences between S/HE and C/HE (Figure 1). In general, ºBrix values, sugarcane apparent sucrose (Pol), syrup purity, fiber, reducing sugars (RS) and total reducing sugars (TRS) were above the minimum values recommended as quality standards (Figure 1), being they > 18%, > 14%, > 85%, 11-13%, <1% 121.96 kg t^{-1} (Consecana, 2006). That can be explained by the forms of fertilizer used that provided all the nutrients necessary so that cane variety RB 867515 expresses its genetic potential.

Analyzed 18 varieties of sugarcane in the state of São Paulo, Souza et al. (2005) found average values of fiber, purity and syrup apparent sucrose of 91, 11 and 18%, respectively, for management conditions of straw maintained on the soil surface or incorporated with ripper.

The ºBrix values ranged between 22.23 and 24.85%. These values are above the limits mentioned in the literature as the minimum necessary for the sugarcane to present conditions to be sampled in order to conduct a detailed technological analysis, to characterize the degree of maturation. Santos et al. (2010) studied the productivity of sugarcane under fertilization with filter cake enriched with soluble phosphate. They found that the filter cake doses and their combinations with phosphate did not alter the quality of cane syrup, when evaluating the syrup ºBrix at harvest.

Analyzing the influence of the forms of fertilization on the technological variables in the 3rd ratoon in 2007 they verified difference ($p>0.05$) to the syrup Pol and total recoverable sugars (TRS), which on treatment with mineral fertilizer + filter cake showed higher value of sucrose in syrup, differing only from treatment with mineral fertilizer (Figure 3).

The effect of the filter cake on the variable of the syrup Pol can be attributed in large scale to the benefits provided by organic matter from the filter cake and the nutrients found in it, especially phosphorus and nitrogen. This result is in agreement with Santos et al. (2011) who studied the isolated or combined effect of organic and mineral fertilizers. They noted that the mineral fertilizer, combined with the organic one, promoted increases in sucrose content in the cane syrup.

Evaluating the effect of humic substances on technological quality of varieties of sugarcane, Rosato et al. (2010) found a positive effect of humic substances (HSs) on the accumulation of sucrose as HSs can be an important technique for improving the quality of raw materials and for the varietal management. The average amount of total recoverable sugars (TRS) at the end of the 2010/2011 Brazilian crop was of 140.86 kg Mg^{-1}, indicating that the data presented in this study were in accordance with the national commercial production standards.

For ºBrix, cane Pol, purity, syrup and sugarcane RS, and fiber there were no significant difference between the treatments with fertilization (Figures 2 and 3).That is in agreement with the results obtained by Fravet et al. (2010) which found that the ºBrix and syrup Pol variables fell on their values with increasing application of filter cake. The authors cited found that smaller Pol and ºBrix values occurred in the treatment, where filter cake was applied, could be explained by the high content of organic matter and high water retention capacity provided by the application of the pie along the root system, compromising the induction of maturation.

Souza et al. (2014) studied the control of agricultural traffic and its effect on soil physical properties and technological quality of sugarcane. They did not observed effects of treatments on ºBrix values, purity, fiber or TRS.

With regard to the parameters evaluated for number of

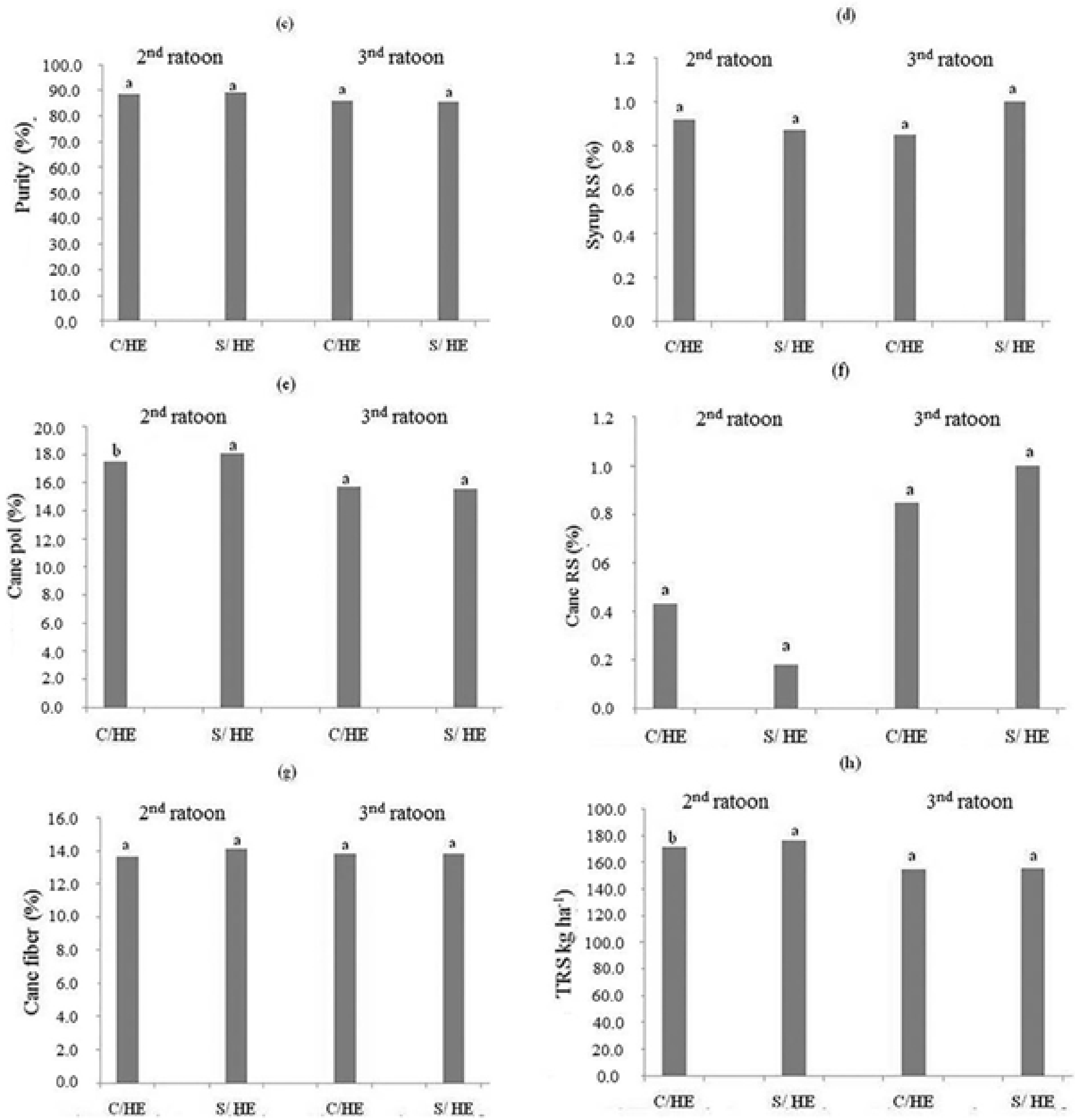

Figure 2. Influence of ways of fertilization on the technological variables in sugarcane of 2nd ratoon in the city of Aparecida do Taboado-Brazil, in 2006. M=mineral fertilizer; T=Mineral fertilization+filter cake; H=Mineral fertilization+humic extract; M+T+M=Mineral fertilization+pie filter+humic extract. The same letters do not differ significantly from each other, by Tukey test (p>0.05).

stems per meter of furrow and productivity there were no differences ($p > 0.05$) between treatments C/HE and S/HE in cane of 2nd and 3rd ratoon (Figure 4).

These results are similar to those obtained by Pauline et al. (2004) who studied the effect of the triple operation with scarification to the depth of 0.15 to 0.30 m between the lines of ratoon of sugarcane, and observed that these post-harvest management practices did not differ as to productivity. Souza et al. (2014) affirm that the use of the leading disk harrow cultivation compared to the fallow system is not important in the production and quality of stems.

There were no differences ($p>0.05$) between forms of fertilization on sugarcane of 2nd and 3rd ratoon. Yet the treatments with humic extract, mineral+filter cake+humic extract and mineral+filter cake, produced, respectively, 8, 7 and 6% more in tons of sugarcane than the treatment with mineral fertilizers (Figure 4).

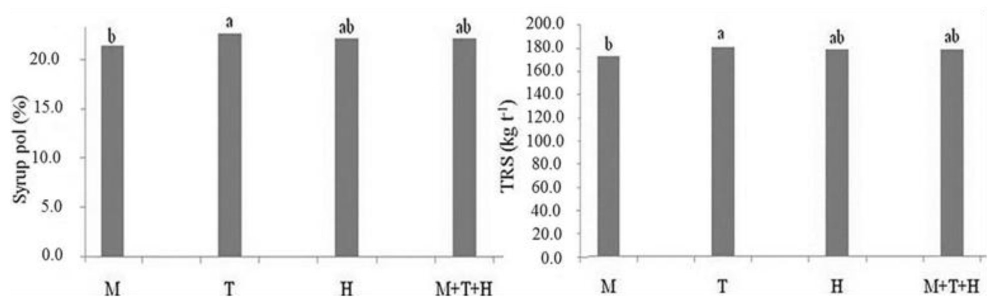

Figure 3. Influence of ways of fertilization on the technological variables in sugarcane of 2nd ratoon in the city of Aparecida do Taboado-Brazil, in 2007. M=Mineral fertilizer; T=Mineral fertilization+filter cake; H=Mineral fertilization+humic extract; M+T+H=Mineral fertilization+pie filter+humic extract. The same letters do not differ significantly from each other, by Tukey test (p>0.05).

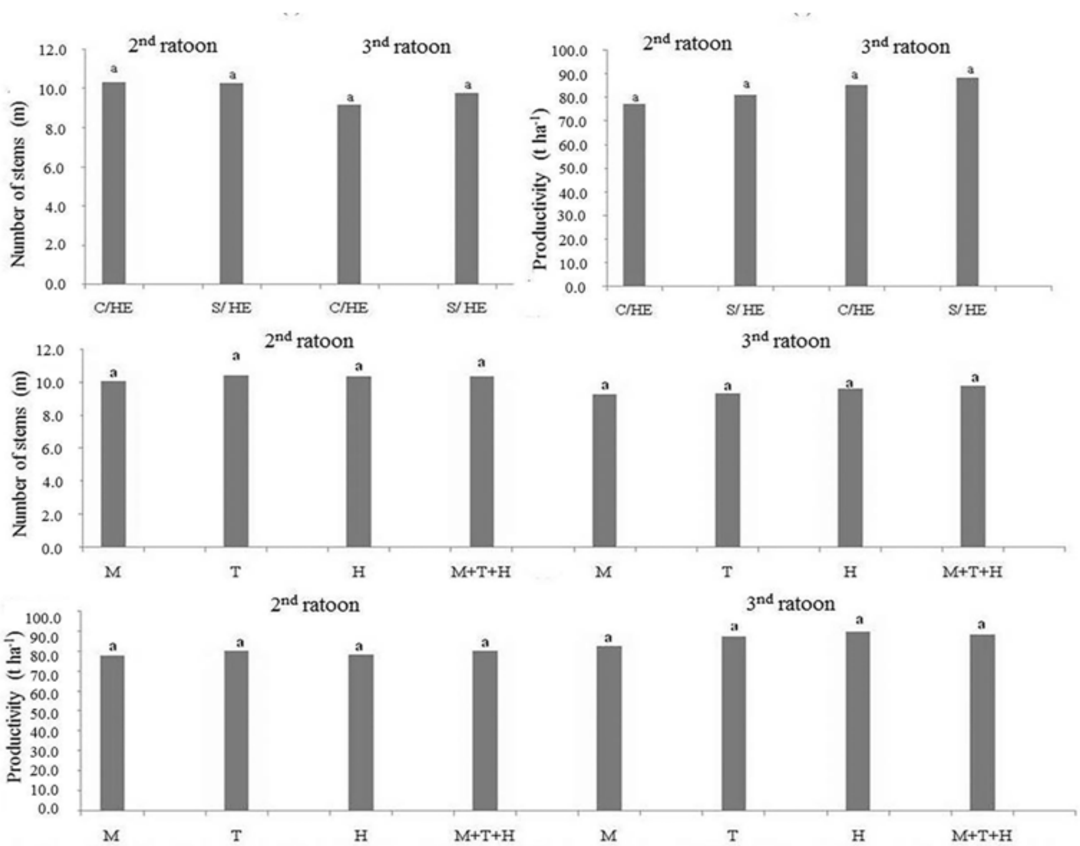

Figure 4. Number of stems per meter and stem yield (t ha^{-1}) of sugarcane at 11 months of application in treatments with (C/HE) and without using the chisel plow (S/HE), and forms of fertilization for the 2nd and 3rd ratoon. M=Mineral fertilizer; T=Mineral fertilization+filter cake; H=Mineral fertilization+humic extract; M+T+H=Mineral fertilization+pie filter+humic extract. The same letters do not differ significantly from each other, by Tukey test (p>0.05).

According to Nardin (2007), the use of filter cake in clay was not enough for significant differences on the productivity of sugarcane, regardless of application. Fravet et al. (2010) in studies on the filter cake and its effects on some attributes of sugarcane, found an effect of the application of this by-product in stem yield.

Conclusion

Using the chisel plow to incorporate the fertilizer in the post-harvest period in the 2nd and 3rd ratoon cane did not cause changes in technological variables or sugarcane crop yield. The values obtained for brix degree of syrup, apparent sucrose sugarcane, broth purity, fiber, reducing sugars and total reducing sugars were above minimum values defined by the standard of the cane quality in all the treatments, but did not increase the number of stems and crop productivity.

Conflict of Interest

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

REFERÊNCIAS

Abranches JL, Bolonhesi AC (2011). Desenvolvimento inicial de variedades e clones de cana-de-açúcar em Latossolo Vermelho Distrófico, Aparecida do Taboado-MS. R. Br. Ci. Agric. 6:369-375.

Alameda D, Anten NPR, Villar R (2012). Soil compaction effects on growth and root traits of tobacco depend on light, water regime and mechanical stress. Soil Till. Res. 120:121-129.

Almeida Júnior AB, do Nascimento CWA, Sobral MF, da Silva FBV, Gomes WA (2011). Fertilidade do solo e absorção de nutrientes em cana-de-açúcar fertilizada com torta de filtro. R. Br. Eng. Agric. Amb. 15:1001-1013.

Camilotti F, Andrioli I, Dias FLF, Casagrande AA, da Silva AR, Mutton MA, Centurion JF (2005). Efeito prolongado de sistemas de preparo do solo com e sem cultivo de soqueira de cana crua em algumas propriedades físicas do solo. Eng. Agric. 25:189-98.

Carvalho LA, Silva Junior CA, Nunes WAGA, Meurer I, de Souza Júnior WS (2011). Produtividade e viabilidade econômica da cana-de-açúcar em diferentes sistemas de preparo do solo no centro-oeste do Brasil. R. Ci. Agric. 34:199-211.

Chiba MK, Mattiazzo ME, Oliveira FC (2008). Cultivo de cana-de-açúcar em argissolo tratado com lodo de esgoto. I- disponibilidade de nitrogênio no solo e componentes de produção. R. Br. Ci. Sol. 32:643-652.

Consecana (2006). Conselho dos produtores de cana-de-açúcar, açúcar e álcool do estado de São Paulo. Manual de instruções. Piracicaba: CONSECANA P. 112.

Elamin EA, Eltilib MA, Elnasikh MH, Ibrahim SH, Elsheikh MA, Babiker EE (2007). The influence of phosphorus and potassium fertilization on the quality of sugar of two sugarcane varieties grown on three soil series of Sudan. J. Appl. Sci. 7:2345-2350.

EMBRAPA (2006). EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. Sistema Brasileiro de Classificação de Solos. Rio de Janeiro, Brasil. P. 412 .

Flores RA, Prado RM, Politi LS, De Almeida TBF (2012). Potássio no desenvolvimento inicial da soqueira de cana crua. Pesq. Agric. Tr. 42:106-111.

Fravet PRF, Soares RAB, Lana RMQ, Lana AMQ, Korndorfer GH (2010). Efeitos de doses de torta de filtro e modo de aplicação sobre produtividade e qualidade tecnológica da soqueira de cana-de-açúcar. Ci. Agrot. 34:618-624.

Gheller ACA, Menezes LL, Matsuoka S, Masuda Y, Hoffmann HP, Arizono H (1999). Manual de métodos alternativos para medição da produção da cana-de-açúcar. Araras: UFCar, P. 7.

Gorucu S, Khalilian A, Han YJ, Dodd RB, Smith BR (2006). An algorithm to determine the optimum tillage depth from soil penetrometer data in coastal plain soils. Appl. Eng. Agric. 22:625-63.

Kingwell R, Fuchsbichler A (2011). The whole-farm benefits of controlled traffic farming: An Australian appraisal. Agric. Syst. 104:513-521.

Materechera SA (2009). Tillage and tractor traffic effects on soil compaction in horticultural fields used for peri-urban agriculture in a semi-arid environment of the North West Province, South Africa. Soil Till. Res. 103:11-15.

Nardin RR (2007). Torta de filtro aplicada em Argissolo e seus efeitos agronômicos em duas variedades de cana-de-açúcar colhidas em duas épocas. P. 39. Dissertação (Mestrado em Produção Agrícola) – Pós-Graduação em Agricultura Tropica e Subtropical, Instituto Agronômico de Campinas.

Larrahondo JE, Castillo EF, Peralta Y, Jaramillo A, Palma A, Briceño C, Giraldo F (2009). Impact of extraneous matter on post-harvest sucrose losses and quality parameters in sugarcane. Sugar Technol. 11:171-175.

Oliveira APP, Lima E, Anjos LHC, Zonta E, Pereira MG (2014). Sistemas de colheita da cana-de-açúcar: Conhecimento atual sobre modificações em atributos de solos de tabuleiro. R. Br. Eng. Agric. Amb. 18:939–947.

Oliveira Filho FX, Miranda NO, Medeiros JF, Silva PCM, Mesquita FO, Costa TKG (2015). Zona de manejo para o preparo do solo na cultura da cana-de-açúcar. R. Br. Eng. Agric. Amb. 19:186-193.

Otto R, Silva AP, Franco HCJ, Oliveira ECA, Trivelin PCO (2011). High soil penetration resistance reduces sugarcane root system development. Soil Till. Res. 117:201-210. http://dx.doi:10.1016/j.still.2011.10.005

Paulino AF, Medina CC, Azevedo MCB, Silveira KRP, Trevisan AA, Murata M (2004). Escarificação de um Latossolo Vermelho na pós-colheita de soqueira de cana-de-açúcar. R. Br. Ci. Sol. 28:911-917.

Rosato MM, Bolonhezi AC, Ferreira LHZ (2010). Substâncias húmicas sobre a qualidade tecnológica de variedade de cana-de-açúcar. Sci. Agric. 11:43-48.

Rossetto R, Dias FLF, Vitti AC (2008). Problemas nutricionais dos solos nas novas fronteiras canavieiras. R. Id. New 8:78-90.

Santos DH, Tiritan CS, Foloni JSS, Fabris LB (2010). Produtividade de cana-de-açúcar sob adubação com torta de filtro enriquecida com fosfato solúvel. P. Agric. Trop. 40:454-461.

Santos DH, Silva MA, Tiritan CS, Foloni JSS, Echer FR (2011). Qualidade tecnológica da cana-de-açúcar sob adubação com torta de filtro enriquecida com fosfato solúvel. R. Br. Eng. Agric. Amb. 15:443-449.

Souza ZM, Paixão ACS, Prado RM, Cesarin LG, de Souza SR (2005). Manejo de palhada de cana colhida sem queima, produtividade do canavial e qualidade do caldo. Ci. Rural 35:1062-1068.

Souza GS, Souza ZM, Silva RB, Barbosa RS, Araújo FS (2014). Effects of traffic control on the soil physical quality and the cultivation of sugarcane. R. Br. Ci. Sol 38:135-146.

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Full Length Research Paper

Performance of American lettuce under different plant covers for no-tillage system

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This study aimed to evaluate the agronomic performance of American lettuce "Lucy Brown" in different types of straw from dried cover crops, for a no-tillage system, under the climatic conditions of Campo Grande (Mato Grosso do Sul state, Brazil). The experiment was set up in a randomized block design with five treatments and six replications, totalizing 30 plots. The treatments were: T1 (control) - planting lettuce in bare soil; T2 - planting lettuce on millet straw; T3 - planting lettuce on white oat straw; T4 - planting lettuce on forage radish straw; and T5 - planting lettuce on sunn hemp straw. After 37 days from sprouting the plants were assessed for fresh weight. They were dried at 38 days after planting, and at 11 days after drying they were evaluated for dry weight. The transplantation of the lettuce seedlings was carried out 12 days after the cover crop was dried, leaving a space of 25 x 25 cm for cultivation of a total of 24 plants. The plots were evaluated for weed control 20 days after transplanting lettuce. At 35 days after transplantation six central plants were evaluated in each plot, assessing the following variables: Above-ground fresh mass from shoot and root, dry weight of shoot and root and head diameter. Under the conditions in Campo Grande, for no-tillage cultivation of "Lucy Brown" lettuce, hemp is the most suitable cover, followed by millet.

Key words: *Lactuca sativa, Avena sativa* L, *Pennisetum glaucum* L., *Crotalaria spectabilis* Roth, *Raphanus sativus* L, yield.

INTRODUCTION

Lettuce (*Lactuca sativa* L.) is a herbaceous plant belonging to the Asteraceae family. It is the leafy vegetable that is most consumed in the Brazilian diet, which ensures that this crop has significant economic importance (Henz and Suinaga, 2009).

In Brazil, since the 1990s, there have been significant changes in the productive chain for vegetables, giving prominence to American lettuce. This is mainly due to demand from fast-food networks and because this variety presents a longer period of conservation after being harvested than do other types of lettuce (Sala and Costa, 2012).

The demand by consumers for leafy vegetables in the right quantity and quality has led to the use of high-technology cultivation systems, such as planting on straw (direct planting) (Furlani and Purqueiro, 2010). The direct planting technique is very well known in Brazil for use with grain crops, but it has been little studied for leafy

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vegetables (Purqueiro and Tivelli, 2007). Based on minimum soil turning, crop rotation and soil dressing with plant residue, it presents the advantages of improved soil structure, increased infiltration and retention of water in the soil, improved development of the plant root system, control of invasive plants, and the fact that the soil temperature remains more temperate (Henz and Suinaga, 2009; Marouelli et al., 2008). For the lettuce crop, a dead cover crop or straw is commonly used, providing a microclimate that is more favorable to crop development (Henz and Suinaga, 2009). High temperature is a factor that directly interferes in the development of lettuce plants, leading to losses of up to 60%, as well as early bolting (Sala and Costa, 2012). According to Setúbal and Silva (1992), even using hybrid cultivars, high temperatures modify the texture of lettuce leaves, making them more fibrous. As lettuce is from temperate zones, this is an important factor in the Brazilian summer, because the crop may present low yield and low quality (Filgueira, 2008).

In the state of Mato Grosso do Sul, producers face the problem of high temperatures, and so they often collect lettuce plants before these have reached their maximum vegetative development, leading to losses with low-weight plants. Crop dressing aims to reduce the oscillations in soil temperature, decrease the excessive loss of water and, as a result, improve the performance of crops (Souza and Resende, 2003).

In recent years, some researchers have carried out successful experiments with vegetables cultivated among dead plant cover (Purqueiro et al., 2009; Tivelli et al., 2010). The use of soil cover in lettuce growing has proved to be a determining factor in increasing product yields and quality (Andrade Júnior et al., 2005), and according to Carvalho et al. (2005) it has become an essential practice in hot regions. However, to optimize the use of plant cover on the soil, the most suitable species and varieties need to be identified for different regions, and they should be matched with the best management system (Ceretta et al., 1994).

It is a challenge to make planting feasible and to increase the yield of lettuce in hot regions, especially for American lettuce. This work aimed to evaluate the agronomic performance of the American lettuce "Lucy Brown", cultivated from October to November under different dried plant covers, for the direct planting system in the soil and climate conditions of Campo Grande, Mato Grosso do Sul state (MS).

MATERIALS and METHODS

The experiment was carried out in Campo Grande, MS, in the period from August to November 2012, in soil classified as Orthic Quartizarenic Neosol (Quartzite sand) at the geographic coordinates of latitude 20°26'21" S and longitude 54°32'27" W, at an altitude of 531.2 m above sea level. According to the Köppen classification, the climate in the region is considered tropical humid, with a rainy season in summer and a dry season in winter.

Accumulated precipitation in the experimental period was 350 mm, with a mean maximum temperature of 29.2°C and a mean minimum temperature of 18.9°C (Brasil, 1992).

The experimental area was used for vegetables in the year 2010 and until September 2011. In October 2011 maize was planted and collected at the beginning of February 2012, and fertilization was applied in accordance with soil analysis and the crop being planted. After the maize had been harvested the area remained fallow for a period of four months, covered with spontaneous plant growth. The chemical and physical characteristics of the soil before the experiment was set up were determined in accordance with Embrapa (2006), and they are described as follows: pH in water 6.82, pH in $CaCl_2$ (0.01 M) 6.22; Phosphorus in Melich-1 (P) 47 mg dm^{-3}; Potassium (K^+) 136 mg dm^{-3}; Calcium (Ca^{+2}) 3.40 $cmol_+ dm^{-3}$; (Mg^{+2}) 1.30 $cmol_+ dm^{-3}$; (H^+) 2.0 $cmol_+ dm^{-3}$; organic matter (OM) 19.5 g kg^{-1}; cation exchange capacity (CEC) 6.7 $cmol_+ dm^{-3}$; base saturation (V) 71%; clay 115 g kg^{-1}; silt 30 g kg^{-1} and total sand 855 g kg^{-1}, by the pipette method.

The experiment was composed of five treatments: T1 (Blank control) – lettuce planted on soil with no plant cover, T2 – lettuce planted on millet straw (*Pennisetum glaucum* L.), T3 – lettuce planted on white oat straw (*Avena sativa* L.), T4 – lettuce planted on forage radish straw (*Raphanus sativus* L.) and T5 – lettuce planted on sunn hemp straw (*Crotalaria spectabilis* Roth.). The experimental plots were 2 m² (1 m x 2 m) with six repetitions, totaling 30 plots, and the treatments were distributed according to random block design. The plant covers for the formation of straw were sown on 08/27/2012 by scattering, without any fertilization, at the following as recommended by Embrapa (2006).

At 37 days after sowing, evaluations were carried out for fresh and dry matter of the cover crops, using a square iron frame of 20 cm placed in the center of each experimental plot, discarding the edge. The fresh and dry matter was cut within the area delimited by the square frame and weighed on a precision scale; the values were extrapolated for kg/ha. Next, chemical desiccation of the cover crops was done with glyphosate at 720 g ha^{-1} of a.i. The application was carried out with a backpack sprayer pressurized by CO_2 with a fan-type nozzle (80.03), at 8 to 9 a.m., a time of day when the temperature was 26°C, relative humidity was 55% and there was almost no breeze. The lettuce seedlings were produced in a greenhouse, using pelletized seeds of the American lettuce cultivar "Lucy Brown", sown (one seed per cell) in a polystyrene tray with 128 cells, previously filled with commercial substrate (Plantmax®), where they remained for 29 days. For irrigation, 1000 mL of water per tray was used each day, distributed in two irrigations of 500 mL each.

The transplantation of lettuce seedlings to the straw-covered sections took place 12 days after chemical desiccation of the straw, spaced at 25 x 25 cm, totaling 24 plants per straw section. At transplantation, fertilization of the crop took place, as recommended for lettuce, at a dose of 200g of super phosphate (P_2O_5)/m^2 (Ribeiro et al., 1999). Cover fertilization with N and K_2O was applied at 10, 20 and 30 days after transplantation of the seedlings to the beds, using sources of urea and potassium chloride at doses of 15 g/m^2 of N and 10 g/m^2 of K_2O for each application. At 35 days after transplantation, the lettuce was harvested, taking the whole plant out of the soil (aboveground part and root). The six plants at the center of each plot were evaluated. After harvesting, the plants were washed, and the excess water was dried with a paper towel. Plants were sectioned, separating the aboveground part and the root and checking the following variables: aboveground fresh matter (AFM) and dry matter (ADM) and root fresh matter (RFM) and dry matter (RDM). The drying was done in an oven with forced air circulation at ± 65°C until constant weight was reached. The diameter of the head (HD) was measured individually in two positions, using a ruler graduated in cm, considering only the central compact heart of the lettuce plant.

The treatments were evaluated for infestation of weeds, 20 days

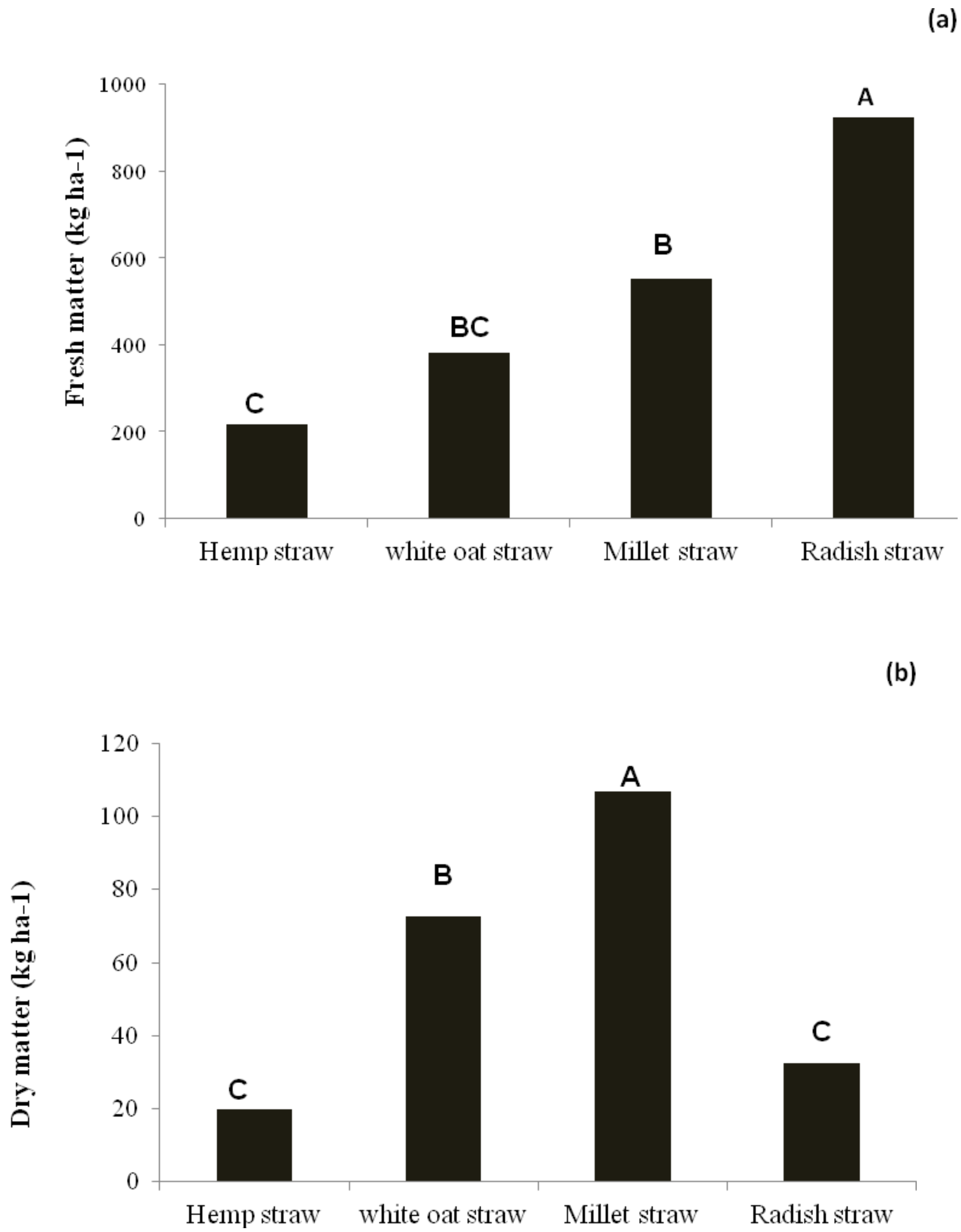

Figure 1. Means of fresh matter (a) and dry matter (b) for the plant cover crops. Bars followed by the same letter in the column do not differ among themselves by the Tukey test at 5% of probability, Campo Grande, 2013.

after the lettuce was transplanted, by a method adapted from Research Methods in Weed Science (1997). This method proposes that the efficiency of control should receive scores from 0 to 100, where: 100 (total control – death of all individuals in the population); 90 to 99 (excellent control); 80 to 89 (acceptable control - 80 is the minimum acceptable score from the point of view of agronomic efficiency); 50 to 79 (unacceptable control); 0 to 49 (insufficient control). The data were submitted to analysis of variance and to a means test by the PROC GLM procedure, using the program SAS (SAS, 2001), and the means were compared using the Tukey test at 5% of probability. Contrast was also carried out by the F test for analysis of variance among the treatments, using sunn hemp (*Fabaceae*), millet and oat (*Poaceae*) and forage radish (*Brassicaceae*).

RESULTS AND DISCUSSION

The plant covers were evaluated for fresh and dry matter, and the data can be found in Figure 1(a) and (b). Forage radish was the cover that presented the greatest yield of

Table 1. Statistical indicators for the variables analyzed in American lettuce “Lucy Brown” cultivated on different dried plant cover crops, Campo Grande, 2013.

Causes of variation	AFM	RFM	RDM	ADM	HD	CFM	CDM	WP
	Value of F							
Block	1.12ns	1.30ns	1.91ns	8.58**	2.00ns	1.47ns	1.39ns	1.62ns
Treatments	3.96**	4.17**	6.79**	3.92**	3.42*	3.77**	3.81**	7.52**
CV (%)	23.39	26.20	28.46	24.94	14.20	21.31	26.57	28.74

AFM= aboveground fresh matter RFM= root fresh matter RDM= root dry matter ADM =aboveground dry matter HD= head diameter CFM= cover fresh matter CDM = cover dry matter WP= weed presence, ns= non-significant; ** and * = significant at 1% and 5% of probability, respectively. SH= Sunn hemp; M= Millet; O= Oat; FR= Forage Radish.

Table 2. Biometric evaluations of American lettuce “Lucy Brown” cultivated on different dried plant cover crops, Campo Grande, 2013.

Treatments	AFM		RFM		RDM		ADM		HD	
	g pl^{-1}								cm pl^{-1}	
White Oat	412.01	C	7.60	B	4.92	A	22.46	BC	15.08	B
Sunn hemp	496.17	A	8.53	A	5.07	A	24.44	AB	16.40	A
Millet	422.32	BC	6.95	B	4.03	B	23.79	AB	15.18	B
Radish	430.30	BC	7.01	B	3.96	B	20.63	C	14.56	B
Control	463.82	AB	7.01	B	4.02	B	26.02	A	15.04	B

AFM= aboveground fresh matter RFM= root fresh matter RDM= root dry matter ADM = aboveground dry matter HD= head diameter. Means followed by the same letter in the column do not differ among themselves by the Tukey test at 5% of probability

fresh matter and sunn hemp the lowest (Figure 1a). For dry matter, millet yielded the most (Figure 1b). Sunn hemp, which produced least fresh matter, provided the highest yield in terms of the lettuce crop. This can be explained by the fact that sunn hemp releases a greater amount of nutrients. However, in the present study the greater yield of dry matter from millet and oat did not provide a higher yield in the next crop, in this case for the lettuce “Lucy Brown”. For the cultivation of eggplant under direct planting, Castro et al. (2005), verified that sunn hemp made more Ca, Mg and N available than did millet. In a study carried out by Andreotti et al. (2008) millet also produced less dry matter than did a species of sunn hemp, in this case *Crotalaria juncea*.

A similar result was found by Oliveira et al. (2008) with the lettuce cultivar Regina, confirming that leguminous plants, used as cover crops, release more N to the soil compared to grasses, and thus influence lettuce growth positively. The summary of the analysis of variance and its significance in function of the F test for aboveground fresh matter (AFM), root fresh matter (RFM), aboveground dry matter (ADM), root dry matter (RDM) and head diameter (HD) of the American lettuce “Lucy Brown”, in function of the different dried cover crops, is presented in Table 1. In the same table, the cover crop fresh matter (CFM), cover dry matter (CDM) and weed presence (WP), as well as the contrasts between sunn hemp, millet and white oat (SH x M x O), forage radish, millet and oat (FR x M x O) and forage radish and sunn hemp (FR x SH) are shown.

The results demonstrate that there was a significant effect of the treatments for all the analyzed variables. The means of the treatments for the variables AFM, RFM, ADM, RDM and HF are presented in Table 2. The lettuce plants presented more aboveground and root fresh matter, more root dry matter and a greater head diameter when cultivated under the sunn hemp cover. For the variable AFM there was a difference between the blank control and the cover with oat, corroborating the data of Maluf et al. (2004), in a study with American lettuce under direct planting, in which the authors confirmed greater fresh matter yield under black oat cover than with uncovered soil.

In studies of the effect of plant covers on lettuce production, various authors have observed better results for crops on covered soil. They have emphasized that cover crops promote better lettuce development, as confirmed by the data in the present study, for the cover with sunn hemp, for the variables RFM, RDM and HD (Mógor and Câmara, 2007 and Carvalho et al., 2005). The RDM of lettuces on oat cover was greater than on millet and forage radish covers. This may be related to the decomposition rate of oat, which occurs in up to 40 days (Crusciol et al., 2008). Thus, nutrients in the soil are mineralized more quickly than by millet and radish, benefiting the development of lettuce roots. With regard to the weed presence, Indian goosegrass (*Eleusine indica,* Figure 2a) and common purslane (*Portulaca oleraceae,* Figure 2b) were identified among the weeds.

The covers studied here significantly reduced the

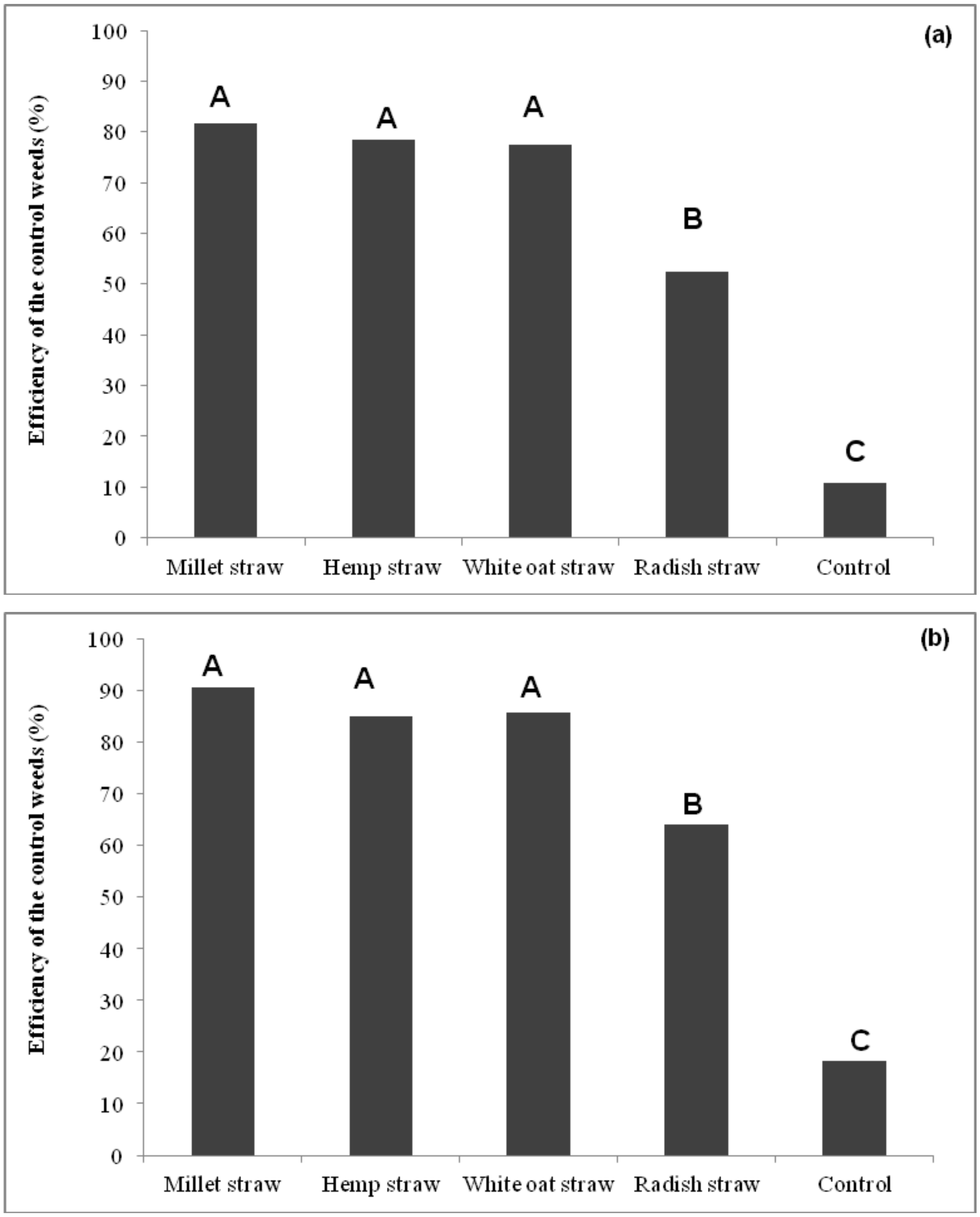

Figure 2. Efficiency of the control of weeds, (a) *E. indica* and (b) *P. oleraceae,* on different dried plant covers in the cultivation of American lettuce "Lucy Brown", Campo Grande, 2013. *Means followed by the same letter in the column do not differ among themselves by the Tukey test at 5% of probability.

density of weeds in relation to uncovered soil (blank control). Millet, despite not differing statistically from sunn hemp and oat, was the cover that presented the best control of *E. indica* (81, 67), while for *P. oleraceae* the best cover crops were millet, sunn hemp and oat. The cover with forage radish and the blank control (uncovered soil) presented higher indices of invasive plants.

Similar results were found by other authors in work with vegetable crops grown on straw cover. Among these we can cite Rezende et al. (2005), whose study confirmed that the use of dead cover in the production of the summer carrot crop was efficient in controlling *E. indica* and *P. oleraceae*; additionally, Carvalho et al. (2005) affirmed that dead cover favored the control of weeds in cultivation of lettuce cv. Regina.

Cover crops of millet, oat and sunn hemp did not present significant differences in the control of invasive plants, corroborating the data of Oliveira et al. (2008), in work with different cover crops in the cultivation of

Table 3. Comparison of biometric data of American lettuce “Lucy Brown” in function of plant cover from three families, Campo Grande, 2013.

Treatments	AFM		RFM		RDM		ADM		HD	
	g pl^{-1}								cm pl^{-1}	
Fabaceae	496.17	A	8.53	A	5.07	A	24.44	A	16.40	A
Poaceae	417.16	B	7.27	B	4.47	B	23.12	A	15.13	B
Brassicaceae	430.30	AB	7.01	B	3.96	B	20.63	A	14.56	B

AFM= aboveground fresh matter RFM= root fresh matter RDM= root dry matter ADM = aboveground dry matter HD= head diameter. Means followed by the same letter in the column do not differ among themselves by contrast using the F test of analysis of variance at 5% of probability.

lettuce, which showed that all the covers used were efficient in controlling weeds. For Kieling et al. (2009), tomato direct-planted on different straw covers underwent efficient suppression of invasive plants, and oat and forage radish covers did not differ between themselves.

The effect of controlling invasive plants may be attributed to physical and chemical alterations in the soil, provided by the cover crops. Physically, according to Constantin (2001), dead cover alters the humidity, light and superficial temperature of the soil. According to the same author, the straw also constitutes a mechanical barrier to the development of weeds. According to Pires and Oliveira (2001), many plant residues, used as plant cover, have the capacity to produce substances that have an allelopathic effect on the seeds of invasive plants, delaying and even inhibiting their germination and growth.

In this study, when we compared sunn hemp (*Fabaceae*) with millet and oat (*Poaceae*) and forage radish (*Brassicaceae*), in lettuce yield, it was observed that the first of these stood out as a soil cover, except for AFM, which did not differ from forage radish (*Brassicaceae*) and for ADM, in which the covers did not show differences among themselves (Table 3).

Oliveira et al. (2008) also worked with plant covers and confirmed better results for fresh matter and above-ground diameter for the lettuce cultivar “*Regina*”, grown on a leguminous cover crop, which is in agreement with the results of the present study. Plants from species of the families *Fabaceae* and *Brassicaceae* possess faster decomposition when compared to *Poaceae*, making nutrients available to the soil in less time. Among the nutrients, nitrogen stands out, arising mainly from the association of leguminous plants with fixative bacteria. This association increases the potential performance of nitrogen in the soil, benefiting the next crop. Grasses (*Poaceae*), in turn, present a slower decomposition, thus holding back the nutrients for the subsequent crop (Barradas et al., 2001; Aita and Giacomini, 2003; Espíndola et al., 2006; Oliveira et al., 2008). Under the soil and climatic conditions of Campo Grande, MS, the American lettuce cultivar “Lucy Brown” grown on sunn hemp (*Crotalaria spectabilis* Roth) straw is the most recommended treatment for the variables AFM, RFM, RDM and HD, when compared to straw of millet (*Pennisetum glaucum* L.), white oat (*Avena sativa* L.) and forage radish (*Raphanus sativus* L.).

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Aita C, Giacomini SJ (2003). Decomposição e liberação de nitrogênio de resíduos culturais de plantas de cobertura de solo solteiras e consorciadas. Rev. Brasileira de Ciênc. do Solo 27:601-612.

Andrade Júnior VCD, Yuri JE, Nunes UR, Pimenta FL, Matos CDSD, Florio FCDA, Madeira DM (2005). Emprego de tipos de cobertura de canteiro no cultivo da alface. Hortic. Brasil. 23:899-903.

AndreottI M, Araldi M, Guimarães VF, Furlani Junior E, Buzetti S (2008). Produtividade do milho safrinha e modificações químicas de um latossolo em sistema plantio direto em função de espécies de cobertura após calagem superficial. Acta Sci. Agron. 30:109-115.

Barradas CA, Freire LR, Almeida DL, de-polli H (2001). Comportamento de adubos verdes de inverno na região serrana fluminense. Pesquisa Agro. Brasil. 36:1461-1468.

Brasil (1992). Ministério da Agricultura, Pecuária e da Reforma Agrária. Departamento Nacional de Meteorologia. Normais climatológicas: 1961-1990.

Carvalho JE, Zanella F, Mota JH, Lima ADS (2005). Cobertura morta do solo no cultivo de alface cv. Regina 2000. Ji-Paraná/RO. Ciênc. Agrotecnol. 29:935-939.

Castro CM, Almeida DL, Ribeiro RLD (2005). Plantio direto, adubação verde e suplementação com esterco de aves na produção orgânica de berinjela. Pesquisa Agropecuária Brasileira, Brasília 40(5):495-502.

Ceretta CA, Aita C, Braida JA, Pavinato A, Salet RL (1994). Fornecimento de nitrogênio por leguminosas na primavera para o milho em sucessão nos sistemas de cultivo mínimo e convencional. Rev. Brasil. Ciênc. Solo. 18:215-220.

Constantin J (2001). Métodos de manejo. In: Oliveira Junior RS, Constantin J. (Eds). Plantas daninhas e seu manejo. Guaíba: Agropecuária. pp.103-121.

Crusciol CAC, Moro E, Lima EV, Andreotti M (2008). Taxas de decomposição e de liberação de macronutrientes da palhada de aveia preta em plantio direto. Bragantia 67:481-489.

Embrapa- Empresa Brasileira de Pesquisa Agropecuária (2006). Cerrado: adubação verde. Planaltina, DF: Embrapa Cerrados. P. 369.

Espindola JAA, Guerra JGM, Almeida DL, Teixeira MG, Urquiaga S (2006). Decomposição e liberação de nutrientes acumulados em leguminosas herbáceas perenes consorciadas com bananeira. Revista Brasileira de Ciência do Solo 30:321-328.

Filgueira FAR (2008). Manual de olericultura. Agrotecnologia moderna na produção e comercialização de hortaliças. Viçosa: UFV, 2. ed. P. 421.
Furlani PR, Purquerio LFV (2010). Avanços e desafios na nutrição de hortaliças. In: Mello RP. Nutrição de Plantas: diagnose foliar em hortaliças. Jaboticabal: FCAV/CAPES/FUNDUNESP. pp. 45-62.
Henz GP, Suinaga F (2009). Tipos de Alface Cultivadas no Brasil. Brasília: Embrapa Hortaliças. P. 7.
Kieling A, Comin JJ, Fayad JA, Lana MA, Lovato PE (2009). Plantas de cobertura de inverno em sistema de plantio direto de hortaliças sem herbicidas: efeitos sobre plantas espontâneas e na produção de tomate. Ciênc. Rural 39:2207-2209.
Maluf LEJ, Madeira NR, Biguzzi FA, Dariolli L, Santos FHV, Gomes LAA (2004). Avaliação de cultivares de alface americana em diferentes tipos de coberturas do solo. In: CONGRESSO BRASILEIRO DE OLERICULTURA, 44. Anais... Campo Grande, MS. Also published as an abstract in: Hortic. Brasil. Brasília 22:492-493.
Marouelli WA, Abdalla RP, Madeira NP (2008). Irrigação de Cebola em Sistema de Plantio Direto. Revista Plantio Direto 105. Available at: <http://www.plantiodireto.com.br/?body=cont_int&id=859>. Accessed on: May 25, 2013.
Mógor AF, Câmara FLA (2007). Produção de alface no sistema orgânico em sucessão a aveia preta, sobre a palha, e diferentes coberturas do solo. Sci. Agraria 8:239-245.
Oliveira FF, Guerra JG, M, Almeida DL, Ribeiro RLD, Espindola JAA, Ricci MSF, Ceddia MB (2008). Avaliação de coberturas mortas em cultura de alface sob manejo orgânico. Hortic. Brasil. 26:216-220.
Pires NM, Oliveira VR (2001). Alelopatia. In: Oliveira Junior, RS; Constantin J. (Eds). Plantas daninhas e seu manejo. Guaíba: Agropecuária. pp. 145-185.
Purquerio LFV, Factor TL, Lima JRS, Tivelli SW, Trani PE, Breda JR JM, Rocha MAV (2009). Produtividade e qualidade de beterraba em plantio direto em função do nitrogênio e do molibdênio. Hortic. Brasil. Vol. 27 (Supplement - CD-ROM).
Purquerio LFV, Tivelli SW (2007). Multicultivo de alface em sistema de plantio direto. In: CONGRESSO BRASILEIRO DE OLERICULTURA, 47. Anais... Brasília. Also published as an abstract in: Hortic. Brasil. Vol. 25 (Supplement – CD-ROM).
Research Methods in Weed Science, (1997). Design of field experiments and the measurement and analysis of plant responses. 2 ed. Cap. 2. Champaigne, IL.
Rezende FV, Souza LD, Oliveira PD, Gualberto R (2005). Uso de cobertura morta vegetal no controle da umidade e temperatura do solo, na incidência de plantas invasoras e na produção da cenoura em cultivo de verão. Ciênc. Agrotecnol. 29:100-105.
Ribeiro AC, Guimarães PTG, Alvarez VH (1999). Recomendação para uso de corretivos e fertilizantes em Minas Gerais: (5ª aproximação). Viçosa: UFV, P. 359.
Sala FC, Costa CP (2012). Retrospectiva e tendência da alfacicultura brasileira. Horticultura Brasileira 30:187-194.
SAS (2001). Sas User's Guide: Statistics, 6. ed. Cary: SAS Institute. P. 846.
Setubal WJ, Silva AR (1992). Avaliação do comportamento de alface de verão em condições de calor no município de Teresina- PI. Teresina: UFPI, P. 17.
Souza JL, Resende P (2003). Manual de horticultura orgânica. Viçosa: Aprenda Fácil, P. 564.
Tivelli SW, Purqueiro LFV, Kano C, (2010). Adubação verde e plantio direto em hortaliças. Pesquisa & Tecnologia 7.

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Competition and supplier loyalty: Lessons from the Brazilian tobacco industry

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This paper aims to identify both the level and the reasons of the decreasing loyalty in the transactions between tobacco growers and tobacco processors in Brazil. The theoretical approach relies on Transaction Cost Economics. Semi-structured interviews were held with growers and companies' directors, and a structured questionnaire was used to obtain data from a sample of 381 tobacco growers in Brazil. Indicators of loyalty were created and analyzed. Based on the Euclidean distance, an original method to measure the level of loyalty is provided. It was found that 55% of growers were yet loyal. The number of non-loyal growers was increasing due to increasing competition among processors. Processors´ procurement strategies disturbed the traditional hybrid governance structure, which was based on loyalty, introducing uncertainty, higher costs and unknown consequences to competitiveness. The article brings empirical evidence on how sector competitiveness can be threatened by competition for suppliers. There are lessons for business managers and for anti-trust authorities.

Key words: Tobacco, buyer-supplier relations, coordination, contracts, competitiveness, Brazil.

INTRODUCTION

The tobacco market has been conditioned by an unfavorable institutional environment and constraints of various kinds, such as government restrictions on production, sales and advertising, as well as declining social acceptance of smoking and smuggling (WHO, 2008). The market has undergone structural changes associated with an unfavorable institutional context and changing habits of customers. The demand for higher quality tobacco increased, thus requiring tighter control of suppliers and production processes.

The Brazilian tobacco industry has undeniably achieved a leading position in the new context of the world market. While the other two main production regions of high-grade tobacco, which are within the U.S.A. and Zimbabwe, face difficulties to sustain their level of production, the Brazilian industry was able to run a highly competitive production chain. In the U.S.A., restrictions on production and reduction of government support determined the end of its dominance in the production of high-grade tobacco. In Zimbabwe, the civil war and land reform led to a severe breakdown in tobacco growing. In opposition, production has increased in Brazil, which has become the largest exporter since 1993, when it overtook the U.S.A. In 2010, Brazilian

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exports were 505 thousand metric tons, a 22% share of total world exports (AFUBRA, 2011).

The coordination of small farmers, as suppliers of tobacco leaf, adopted in Brazil by most tobacco processors is pointed out as a platform from which it was possible to build up Brazilian leadership in the international market for high-grade tobacco. The structure of governance adopted comprises a number of agents and organizations with different profiles, sizes, specialties and functions. The central roles are played by tobacco leaf processing companies, which coordinate their own network of suppliers (mostly small family farmers) by setting volumes and production specifications, buying predetermined amounts of tobacco leaves at predetermined minimum prices, and carrying out exports. There are also organizations representing the interests of growers and processing companies, regulatory bodies and technical and/or political discussion forums.

Transactions between growers and processing companies are ruled by contract farming that sets up overall production and trade conditions. Traditionally, these contracts were based on ad hoc no written loyalty, which is said to be essential for companies' control of their production flows and quality, and to reduce the cost of selection and monitoring suppliers. Also, it enables the companies the appropriation of a quasi-rent and getting return of investment on assets dedicated to the transactions. Loss of loyalty would certainly have an impact on both costs and effectiveness of this governance in the medium term. From the standpoint of processing companies, control of production process would weaken and risk would increase. Therefore, decreasing loyalty jeopardizes management of both supply planning and costs. If growers undertake more than one contract with more than one company or sells to third parties in the spot market, returns on investment may not be appropriated exclusively. If worse comes to worst, the governance structure would be no longer appropriate to sustain competitiveness because processing companies would no longer be able to get return on investment.

In midst of the years 2000, the major tobacco processing companies in Brazil identified decreasing loyalty of their suppliers. The number of growers undertaking contracts with two or more companies, contract default and the number growers selling off-contracted tobacco in the spot market was increasing. Some companies and Brazilian tobacco organizations were concerned about this fact. Overall, Brazilian competitiveness was threatened. A research project was then designed in order to better understand the tobacco market in Brazil and find out the causes of the problem, as well as measure the decrease of loyalty. This paper presents the results of this research project, with special focus on both the level and the reasons of the decreasing loyalty. A simple indicator for the latter is also provided.

Theoretical background

Transaction Cost Economics (TCE) gave support to the analysis presented in this article. In opposition to the neoclassical microeconomic theory, TCE assumes that markets cannot works by the price mechanism alone. Organizations are also necessary, and so TCE aims to identify the best way of organizing economic transactions. TCE attempts to explain the organizational forms of markets and the contractual arrangements established in transactions. Agents should seek governance structures that enable the reduction of transaction costs (North, 1994). Williamson (1985) proposes three basic forms of governance: classical market (spot), hybrid forms and vertical integration or hierarchy. Williamson's emphasis on the analysis of governance structures brought out hybrid structures that were between the market and hierarchy.

Ménard (2004) highlights the importance of building a theory that explains the structures that lie between market and hierarchy, even if the agents engaged in these transactions are totally independent, but work together in some kind of business. There are a variety of arrangements, in which the price mechanisms of market clearing are less important than sharing technologies, capital, products or services; although full integration of the agents is not adopted. In hybrid structures, the coordination of activities would be based on cooperation of independent agents and sharing of important decisions, such as investment to be made. On the one hand, cooperation creates a culture of joint search for higher performance and profitability for all. On the other hand, a poor distribution of efforts and profits can easily generate conflicts that destabilize the arrangement.

To reduce the problem of opportunism, three factors must be observed (Ménard, 2004). First, agents must be carefully chosen on the basis of screening and reputation. Second, the choice of the governance should consider the necessary balance between independence of agents and the need to take common actions. In this sense, the governance structure of the transactions must include neither rigid firm´s hierarchical controls nor fragile spot market controls. Third, an information system is highly recommended to underpin the hybrid form of coordination and reduce information asymmetry.

Another issue found in the literature on hybrid forms is the importance of competitive pressure in the modeling of the governance structure. This pressure operates on two levels. For instance, on one level, suppliers can compete with each other for the same buyer. On another level, a firm and its suppliers compete with other firms and their own suppliers. In this case, suppliers could be either loyal or non-loyal.

In agrifood chains, processors competing within the same product market sign formal contracts with farmers in which loyalty is demanded. Where asset specificity is low or moderate, and the market is highly competitive,

Table 1. Sale composition of two hypothetic growers, % of season production quantity.

Sale composition	Sale (%)	Grower A (%)	Grower B (%)
Processor 1	s_1	100	40
Processor 2	s_2	0	50
Spot 1	s_3	0	5
Spot 2	s_4	0	5
Total sale		100	100

farmers are able to migrate from one processor to another in order to increase profit. Thereby, this move increases the instability of the structure. In highly competitive markets, where uncertainty is a constant, hybrid forms of coordination are adopted as a way to facilitate union of efforts and flexibility in order to reduce instability.

In fact, several studies have used TCE with the aim of identifying the simultaneous adoption of different governance structures in the same market. Although, Williamson (1985) had not addressed this possibility, Bradach and Eccles (1989) identified it in the real world. The authors have termed this as plural forms, in which "[…] distinct organizational control mechanisms operate simultaneously for the same function by the same firm." (Bradach and Eccles, 1989: 112). The explanations for the existence of plural forms have been classified into three groups: (a) different features of the transactions; (b) plural forms as a transitional situation and (c) stable plural forms as a strategy to coordinate the transactions over time. The second one is especially relevant for this study as it brings additional discussion on the stability of governance structures. Authors of the second group consider the use of more than one form of governance as transitional, where one or another governance structure should prevail given that adjustments occur. Zylbersztajn and Nogueira (2002) assumed that one of the forms of governance, the most efficient one, would gradually be adopted by the agents. Alternative types of governance could coexist as points of disequilibrium in an adjustment process. Plurality of arrangements could be explained by: (a) situations of disequilibrium, in which the presence of plural forms could represent a situation of adjustment between the current and future forms, driven by modifications in the features of the transactions; (b) barriers to the adoption of a new improved governance due to the existence of specific non-transferrable routines; (c) effects of the institutional environment in which governance occurs as an event generating multiple alignments. However, establishing and operating mechanisms such as economic incentives, regulation and contracts in order to reduce conflicts, contradictions and transaction costs is a big challenge, particularly when agents have to adopt plural and hybrid governances to respond to market complexities and different types of requirements posed by their clients and institutional rules. This is the case of the tobacco industry, as will be shown below.

METHODOLOGY

The study was conducted in 2005, in the Rio Pardo Valley, State of Rio Grande do Sul, Brazil. Semi-structured interviews with a non-statistical sample of 40 growers (landowners, sharecroppers and tenants) were conducted in a first stage. In a second stage, structured questionnaires were applied to a statistically representative sample of 381 tobacco growers. Semi-structured questionnaires were also designed for interviews with managers of processing companies. However, researchers faced enormous difficulties in obtaining information on/from this source. Few of the managers were willing to talk, and only three responded to an open format questionnaire. Companies reacted negatively because of distrust and competition among them. The approach adopted to circumvent this problem involved procuring information from AFUBRA (Brazilian Association of Tobacco Growers), SINDITABACO (Tobacco Processing Industry Association) and from growers themselves. Managers of both associations agreed to answer open format questions.

In order to measure loyalty, the sampled growers provided information on their selling strategies before sowing and during the harvest. Before sowing, growers usually sign one or more contracts with processors. During the harvest, when the tobacco production is ready for delivery, they have following options: (a) complying with contracts signed before sowing, (b) sell all or part of its production in a spot transaction (without contract) to one or more processors, (c) sell all or part of its production in a spot transaction (without contract) to middlemen. The grower can establish his final selling strategy by combining the options above. For example, a grower could compromise 100% of his production to a single processor by signing a contract before sowing. When production comes in the harvest period, he complies with his contract and do not sell tobacco to other buyers. This grower is a loyal supplier, ideal in the established governance structure. Table 1 illustrates the sale composition of two hypothetical growers. Grower A signed a farming contract with a processor before sowing, selling 100% of his production to this processor. Grower B signed two contracts with two processors, but also sells tobacco in the spot market to one middleman and a third processor. His sales are allocated as follow: 40% for the first processor, 50% for the second processor, 5% for the middleman and 5% for a third processor without contract. Grower A is a loyal supplier while Grower B is not.

The increasing number of type B growers threatened the established governance structure. It meant a loss in control of suppliers, which could have negative consequences, not only in terms of product quality as well as increasing cost. However, from the standpoint of growers this was a positive move, as they had more options than before.

The system would not be threatened if growers with more than one contract fulfilled all obligations by selling exactly what was

Table 2. Initial estimated distribution of selling and final selling of a hypothetic grower, % of grower´s total estimated production and % of grower´s actual selling.

Selling composition	Estimated		Actual	
	1	**2** (%)	**3**	**4** (%)
Processor 1	e_1	60	s_1	40
Processor 2	e_2	40	s_2	50
Spot 1	e_3	0	s_3	10
Spot 2	e_4	0	s_4	0
Total sale		100		100

promised to each processor. In fact, one of the main threatening is growers´ decision to sell their production under contract farming with a processor to another buyer. In this case, loyalty would not be a problem, but default would be. Default can be either total or partial, as any percentage of contracted production can be reallocated to a third party. This kind of production reallocation should be measured in order to provide a better understanding of the impact of loss of loyalty.

In order to estimate this reallocation, we obtained valid information on the amount of production that each sampled grower contracted with processors. This estimation is made by processors´ advisors when they visit the growers' crops. This procedure is taken before signing the contract. The estimated amounts are then written in the contracts. Information on the final selling strategy adopted by each grower was also obtained in order to be compared with the estimations written in the contracts. Reallocation would be determined by the difference between estimation written in the contracts and the production that was actually delivered to each processor or spot market buyers. For example, suppose a grower has two different contracts, each with a different processor. A contract is signed with processor 1, in which the grower is committed to sell an estimated production of 4.500 kilos. Another contract is signed with processor 2, in which the grower is committed to sell an estimated production of 3.000 kilos. Therefore, the grower would have an estimated production of 7.500 kilos. Assuming that both estimations do not fail due to weather and growers do not reallocate, one would expect that the grower will sell exactly 4.500 kilos to processor 1 and 3.000 kilos to processor 2, fulfilling contract obligations. However, suppose that during the harvest period, the second processor offers additional incentives to grower, who decides to increase his sales to this processor, say, to 6.000 kilos, and, as a consequence, decrease his sales to the first processor, say to 1.500 kilos. In this case, there would be a large reallocation from the first to the second processor.

The example above can be modified to include two possible additional grower´s transactions during the harvest period: one with a third processor and another with a middleman, both of them being spot market transactions. Table 2 illustrates a possible combination of final transactions considering these two new options. The grower committed 60% of his production to Processor 1 and 40% to Processor 2, both of them with contract. However, the composition of his final transactions shows that 40% of production was sold to Processor 1, 50% to Processor 2 and 10% to a Middleman.

An indicator for this kind of reallocations was then created, taking the information as provided in the example of Table 2. Columns 2 and 4 of Table 2 can be considered as two vectors, each of which establishes a point in a four-dimensional space. For example, Column 2 vector in is (60, 40, 0, 0), and the Column 4 vector is (40, 50, 10, 0). Therefore, two points in a four-dimensional space are observed. If reallocations are not observed, one would expect that these two points are in the same position. In other words, Column 4 would be the same as Column 2. In this case, they coincide in a four-dimensional space, so the distance between them would be zero. Therefore, we can consider the distance between two points as a measure of the reallocation.

The formula of the Euclidean distance between two points can be used:

$$D = \sqrt{\sum_{i=1}^{p} (x_i - y_i)^2}$$

Where D is the distance between the points x and y; and xi and yi are the respective coordinates. The calculated Euclidean distance of the points of Table 2 is 26.5. Suppose a grower who committed with 100% of his production to a single processor, but has sold 100% to another. This is a case of total default. The Euclidean distance of these two points would be 141.4.

Data on the composition of growers´ estimated sales established in contracts and on the composition of the actual sales of 289 growers allow for calculating the Euclidean distance. In the case of 88 growers, this calculation could not be performed due to missing data. The Euclidean distance was then normalized in order to obtain an indicator ranging from 0 to 100.

INCREASING MARKET COMPETITION AND DECREASING FARMER LOYALTY

Tobacco production in the South of Brazil is not recent. An embryonic form of the current hybrid structure of governance was established in the early decades of the 20th century and consolidated in the 1970s. A tobacco cluster in the South of Brazil was developed during this period, alongside a regulatory framework (Mesquita and Oliveira, 2003). The social capital of growers and the experience and knowledge of the local population in connection with tobacco growing have been handing down from generation to generation. These factors are also among the main assets responsible for the competitiveness of Brazilian tobacco and its significant share of the international market.

Family farms dominate the scenario. Around 180 thousand families were growing tobacco in three states of the South of Brazil in 2010 (AFUBRA, 2009). The field survey found an average of 3.7 people per household. Each household had 2.9 people on average working mostly in tobacco growing. Hired labor accounted for only 8% of the total workforce, reflecting the predominance of family production. The average size of the farms was 11 ha, with tobacco occupying 4 ha on average. Besides tobacco, the main cash crop, most farms have areas dedicated to staple food.

Processing companies act as a link between growers and cigarette manufacturers, with whom they have contractual relationships calling for continuous supply, reputation building and implicit partnerships to comply with standards and meet requirements of the market. Processing companies enter into commitments with cigarette manufactures well before the tobacco crop season starts, so they must plan in advance for tobacco leaf supplies to fulfil these commitments.

The market for tobacco leaves in Brazil is dominated by three large processing corporations, Universal Leaf Tobacco, Souza Cruz (controlled by British American Tobacco) and Alliance One. In 2003, they had 75% of Brazil's installed capacity to grade, process and market tobacco leaves (SEAE, 2005). Around 20 small and medium firms also participate in this market. Despite this concentration, there were no signs of the accommodation in the tobacco leaf market. In fact, fierce rivalry was found among competing tobacco processors due to relatively low entry barriers (SEAE, 2005).

Each major processing company established its own supply chain of tobacco leaves. They aim for centralized control of all key variables that affect supply, so as to reduce uncertainty regarding raw material quantity, quality and cost. This coordination involves an array of economic and legal mechanisms that contractually define the relations between the processor and each grower. Although the sale and purchase contract is the main legal mechanism of coordination, relations between companies and growers transcend contracts and extend to a universe of values relating to tradition and the local culture. Coordination of each processor's suppliers is responsibility of his/her own team of agricultural advisers who monitor and transmit information in both directions between the processor and the growers. Each processor also has its own links to banks, agricultural input suppliers, transporters and service providers in general to provide grower's needs.

This governance is justified by the needs and aims of both tobacco processors and growers. From the processors' standpoint, beyond planning in advance for huge volumes of tobacco leaves, a set of strict specifications in terms of both quantity and quality has to be met. Extrinsic and intrinsic tobacco properties are demanded by cigarettes manufactures related to quality and lack of contaminants as well as social responsibility standards such as a ban on child labor and environmental protection. Processing companies are obliged to devote a large proportion of their resources to compliance of increasing restrictions, oversight and penalties both in Brazil and abroad.

From the growers' standpoint, the rationale for the governance also involves several factors. Tobacco is the main source of earnings and usually the only one for these small, sometimes very small, farmers. Tobacco growing incurs high costs per unit area, with unstable yields. Its quality is highly sensitive to variation under weather conditions, with direct effects on income. It is also labor-intensive and this makes it hard to combine with other cash crops. Unlike in other countries, the Brazilian government offers no policy or market mechanisms to properly mitigate the risks associated with tobacco farming and marketing, so farmers are totally exposed to high risks associated to weather conditions and market. It is unlikely that tobacco growing could be carried on by small farmers without guaranteed purchase volumes and prices, as well as facilitated access to inputs and credit provided by tobacco processors. This hybrid structure of governance addresses all these difficulties and enables family farmers to engage successfully in tobacco production even under such challenging conditions.

In the sale and purchase contract, growers and processing companies formalize their reciprocal commitments before the start of the crop year. In order to assure the flow of tobacco supplies, processors undertake to provide transportation services, procurement of inputs, technological information and support in obtaining credit for growers. Growers have also to guarantee the purchase of the crop for a price that, in some of the years, is set by an agreement between growers' and processors' organizations. In addition, growers who sign contracts have access to the hail insurance policy managed by their association AFUBRA. Processors subtract the insurance premium from growers´ revenue when they are paid for their tobacco leaves. Thus, the contract reduces growers' economic risk and enables participation by family farmers who otherwise would find it difficult to engage in the activity.

Implementing and managing this hybrid governance incurs high operational and transaction costs that are hard to measure. Data from interviews with managers of processing companies enable us to obtain a not very accurate measurement of the cost of installing such a system for a new entrant. According to the interviews, the cost of maintaining the operating structures can be as much as 10 to 12% of a processing company's revenue. This includes the cost of hiring advisers, transportation, clerical staff to perform all the office work relating to contracts, and ex-post transaction costs in the event of debt renegotiation or default.

In the middle of the years 2000, processors perceived a decreasing loyalty of their tobacco leaves suppliers. Behind this decreasing loyalty, processors were fiercely competing to poach growers from rivals. In the past, there was an unwritten rule that each processor had its own suppliers and strove to build up loyalty among them: this amounted to what is known as an "institutional or corporate culture". However, loyalty was undermined by the proliferation of growers with more than one formal contract and sales in the spot market. The increasing number of transactions in the spot market between growers, middlemen and processors indicated that the market was more complex and competitive than might have appeared from a description of a well-coordinated structure of governance. It should be recognized that the rising number of growers with more than one contract and the increasing market-share of the middlemen at the service of other companies have opened up the old model of coordination, giving growers more leeway in marketing their tobacco than they used to have in the past.

From the growers' standpoint, having contracts with more than one company is fully justified as a strategy to add another source of income while creating options for selling, and increasing their bargaining power versus the processors. Thus, from the market standpoint, this opening-up is positive.

The fact that growers can sell to more than one buyer confirms the intense competition among processors. In fact, competition among companies has been one of the main determinants of the changes pointed out above. The main reason for an increasing competition can be found in the international market. The Zimbabwe debacle and falling production in the United States have driven up international demand for Brazilian tobacco. As a result, new companies have established themselves in Brazil, traditional companies have rapidly expanded production capacity, the activities of spot dealers have increased, and major international buyers have set up offices to buy tobacco in the country. These sudden changes in market structure, with expanding production and the entry of new players, translates into an intensification of competition among companies for growers and tobacco leaf production.

Competition for tobacco leaves has led to a tug-of-war between players, both new and old. Processors adopted aggressive strategies to recruit new growers and defensive strategies to avoid loss of loyalty. In this environment, the ability of traditional processors to coordinate and manage their supplies of tobacco leaves has weakened considerably. Meanwhile, the cost-benefit of the hybrid governance has dropped, making traditional processing companies more vulnerable to competition from outsiders that operate at lower cost precisely because they buy high quality tobacco leaves reallocated from contracts to the spot market. For new entrants and/or smaller firms with less capital, the strategy of buying tobacco leaves from growers already integrated with and trained by other companies was highly advantageous. They could buy first-class tobacco without having to spend large amounts of capital into the formation and maintenance of a hybrid structure of governance. And since they do not incur in high coordination costs, they can offer higher prices to growers, thus introducing strong incentives to selling off the contracts.

In a context of intense competition, the major players adopt contradictory strategies. In order to expand their base of growers they try to attract growers from competitors. The first step is to offer to growers the second, sometimes the third, formal contract. The victim processor reacts by offering the same to the growers of his rivals´ base. Also, large processors buy tobacco from the smaller ones and the middlemen. In this non-cooperative game, in an environment of increasing demand for high quality tobacco, minor players are used as intermediaries between large processors and the growers. This kind of game mutually disrupts the traditional governance.

Processors adopted defensive strategies in an attempt to strengthen the loyalty of already contracted growers. These strategies were based on promises of financial and non-financial advantages. The most widespread practice has been to offer additional payments in advance. Although this strategy tries to build loyalty and trust, it increased growers´ indebtedness and repayment default. This was exactly the situation that has led many growers to sell tobacco to competitors, thereby avoiding the repayment deductions. According to perceptions of companies´ managers, repayment default reached almost 20% of growers in 2005, an astonishing increase if compared to the historical pattern of less than 5%.

Because of loss of loyalty, rising competition and default, transaction cost was increasing. In order to compensate for this, major processors adopted measures to reduce costs, such as increasing the number of growers per adviser. In this case, advisers become much more like credit agents, input sellers and purchase representatives than an agent for technology diffusion and production control. This too was a contradictory strategy, which disturbs the structure of governance.

According to interviews with managers, a large number of growers with more than one contract failed to repay financial commitments. Besides the financial default, difficult to recover, one must also consider that other costs, such as those related to monitoring and supply disruptions, are not recovered. Supply disruptions undermine processors´ ability to fulfil contracts with cigarettes companies triggering a search for compensation by means of strategies that undermines the governance itself.

MEASURING LOSS OF LOYALTY

The number of contracts each grower had undertaken with different processing companies and the number of off-contract sales in the spot market, in 2005, were used to create proxy variables for loyalty. A grower can be considered loyal if he or she attained two conditions: (1) had one contract with a single processing company and (2) did not sell tobacco in the spot market. Loss of loyalty

Table 3. Loyal growers, number and percentage of growers by processor.

Processors	Number of loyal growers	% of loyal growers
Universal	41	43
Souza Cruz	21	46
Alliance One	86	60
CTA	32	54
Total sample	208	55

occurs in cases in which either a grower sign more than one contract with more than one processing company or sell off-contract tobacco in the spot market.

Taking the definition above, data from the sample showed that 55% of growers were loyal suppliers (Table 3). During the 2005 crop season, each of these growers signed one contract with one processor. They did not sell to any other, either a processor or a middleman. Segregating data for the major processors, figures are: Universal, 43%, Souza Cruz, 46%, CTA, 54% and Alliance One, 60%. Considering these data, Alliance One and CTA were the most successful processors in setting up a group of suppliers that would fit in the ideal model of loyalty. However, both were still far from having 100% of loyal suppliers.

Non-loyal growers, 45% of the samples, establish their own combination of transactions with large and small processors, as well as middlemen. As a rule, middlemen are supplied by growers who have a contract with a processor. They had been traditionally functional to the system as they used to buy small amount of tobacco leaves, which was often either production that exceeded the quantity under contract or rejected by the processor. In this sense, transactions with middlemen are functional for processors in the traditional governance, as middlemen liberate a processor from the obligation to buy when they do not want to. For instance, a processor may not be interested in the tobacco leaves of one particular contracted grower because of unexpected low quality of his production. Then, this processor liberates the growers to sell to middlemen, who resell to other processors in need of these tobacco leaves. Thus, middlemen give flexibility to the traditional structure of governance.

Most of middlemen are self-employed, buying in small quantities, adding brokering service value, which basically consists in collecting small quantities of tobacco leaves from small farms and shipping them to the wholesale centers or processors. In the case of middlemen, it is common to operate in the market for and on behalf of a processor that also maintains its own network of growers with contracts. Data from sampled growers and interviews with processors´ managers showed that processors were increasing their transactions with middlemen beyond of what would be expected in terms of the functionality of middlemen in the traditional governance. The main explanation for this fact was the new procurement strategies adopted by processors when market rivalry increases.

The large number of non-loyal growers revealed a new picture. The most frequent selling strategies adopted by these growers were of two types: two contracts with two large processors; and a contract with a large processor combined to another contract with a small processor. Less frequent selling strategies were also found, such as a grower selling to two processors, with contracts, as well as selling to either a third processor or a middleman in a spot market transaction.

Table 4 shows the number and frequency of loyal and non-loyal sampled growers, according to the four major processors, Universal, Souza Cruz, Alliance One and CTA, in the columns. In this table, growers with one contract, and additionally selling to middlemen, were considered loyal, assuming that this combination is functional, as stated before. Non-loyal growers are those who: hold more than one contract with processors, hold more than one contract and sell part of his production in spot transactions with other processors, and hold one contract and sell part of his production in spot transactions with other processors. The data in the table also show the number non-loyal growers' second contracts, stating the name of respective second buyers. For example, it was observed that 74% of the suppliers of Universal are loyal and the remaining 26% are non-loyal. These non-loyal growers held two formal contracts, one with Universal and another with the processors identified in the lines of Table 4. For the set of Universal's suppliers in the sample, 9% held also one contract with one of the three other major processors (Souza Cruz, Alliance One and CTA), while 17% held the second contract with smaller processors. This pattern, with minor variations, is repeated for Souza Cruz and Alliance One. In the case of CTA, it was observed that 20% of its suppliers held a second contract with one of the other three major processors, while 9% held contracts with smaller suppliers.

These figures indicate the existence of competition for suppliers among processors. In the past, the unwritten rule in the market was that each processor had its own suppliers, with whom they had ties and loyalty, and instilled the "culture of the company." Even taking into

Table 4. Loyal and non-loyal growers of the major four processors, combinations of non-loyal growers, Universal, Souza Cruz, Alliance One e CTA, 381 sampled growers.

Loyal and non-loyal growers	Universal		Souza Cruz		Alliance one		CTA	
	N	%	N	%	N	%	N	%
Loyal growers	71	74	35	76	120	84	42	71
Non-loyal growers	25	26	11	24	23	16	17	29
Alliance One	4	4					5	8
ATC	2	2	1	2	5	3		
Botucarai					2	1		
Brasfumo	4	4			1	1		
Brazil Tobaccos					1	1		
CTA	4	4	3	7	5	3		
Industrial Boettcher					1	1		
INTAB	1	1	1	2	1	1		
Kannenberg	2	2	1	2	1	1	1	2
L. Beth	2	2						
Marasca	1	1	1	2	1	1	2	3
Premium	3	3					1	2
Souza Cruz	1	1					3	5
Unifumos					1	1		
Universal			1	2	4	3	4	7
Vale Sul	1	1	3	7			1	2
Total with contract	96	100	46	100	143	100	59	100

account that the technical requirements and quality demanded by processors are quite similar, the advent, and increasing number, of non-loyal growers implied some loss of control over the supply chain, as far as reallocations of production among processors are facilitated. Consequently, uncertainty on the planned amount of tobacco leaf supply increases. From the point of view of growers, the strategy of having more than one contract is fully justified, as competition makes room for better prices. However, in the view of companies' staff members, double contracts would have a deleterious impact on the system by raising transaction costs and reducing its effectiveness formal contracts.

It should be stressed that 9% of production quantity was sold without contracts, with 6.5% going to spot market middlemen and 2.5% to processors. These percentages may seem small, but they are significant when extrapolated to total Brazilian production, indicating that approximately 80,000 metric tons of tobacco leaves were outside a strictly coordinated supply chain. Up to that moment, middlemen accounted for an insignificant share of the market and never threatened the functioning of the integration system. Even in 2005, their market-share was small, but it was growing, according to the interviews, and was enough to create a number of disruptions in the system, such as increasing defaults and minor breaches of contract.

The study found that smaller firms in the sample acquired 72% of their need for tobacco without contracts. The strategy pursued by them was clear: they focused on recruiting experienced growers already integrated with the major players, and as quickly as possible buying tobacco leaves either directly or through middlemen in the spot market. The three largest companies account for the remaining 28% of tobacco bought without contract. These figures confirm that the existing system no longer represents a model of perfect centrally coordinated supply chain based on loyalty. Taken together, these trends suggested a certain loss of control over the supply chain and an increase in transaction costs.

Data from sampled growers allow computing frequencies of different types of selling strategies adopted by growers, as illustrated in Table 1 in the methodological section of this article. From 381 growers, data on 376 selling strategies were available (5 growers were excluded because missing data). From these, four groups of growers with similar selling strategies were identified by using cluster analysis, as showed in Table 5. Each group in Table 5 can be described as follows:

Group 1 is composed of 78% of sampled growers, which account for 76% of the total amount of tobacco sold by all growers in the sample. In this group, growers have, on average, 96% of sales to a single processor, with contract; 1% to a second processor, with contract; and 2% to middlemen or other processors, without contract. This group of growers would be closer to the

Table 5. Groups of growers` selling strategies, average percentage and standard deviation of each type of buyer, 376 sampled tobacco leaf growers.

Buyers	Groups								Total
	1		2		3		4		
	%	**S.D.** (%)	**%**	**S.D.** (%)	**%**	**S.D.** (%)	**%**	**S.D.** (%)	
Processor 1 (with contract)	96	7	3	5	53	18	52	16	-
Processor 2 (with contract)	1	4	1	2	37	13	1	5	-
Spot 1 (no contract)	2	5	96	6	2	5	41	15	-
Spot 2 (no contract)	0	2	0	0	0	1	6	9	-
Number of growers	**293**		**6**		**39**		**38**		**376**
% of number of growers	78%		2%		10%		10%		100%
% of quantity sold	76%		1%		14%		9%		100%

desirable loyalty.

Group 2 consists of only six growers who are 2% of the number of sampled growers and who sold 1% of the total quantity. It is the smallest group. On average, these growers have sold 96% of their production to a middlemen or a processor, without a formal contract. Therefore, they are entirely outside of the desirable loyalty. The low percentage of the number of growers and the production of this group in the sample confirms the strength and dominance of formal contracts. This is evidence that the advantages of the formal contracts inhibit the growth of autonomous growers, despite the higher profitability of this crop in the face of other commercial crops available to family farmers in the region.

Group 3 is mostly composed of non-loyal growers who hold contracts with two companies, reallocating a small portion of their sales to middlemen and other processors without a formal contract. This group comprised 10% of the total number of growers in the sample, and accounted for 14% of the total quantity sold. On average, the share of production sold to one processor is greater than the share sold to the other (53% and 37%), suggesting the existence of a primary buyer and a secondary buyer, though important. This confirms some statements obtained from processors' staff members in the interviews, in which a new entrant processor adopts the strategy of gradually increasing the amount tobacco leaves bought from growers who already hold a contract with other processor.

Group 4 is mainly composed of growers who, on average, sell 52% of their production to one processor, with contract, and 48% in spot transactions with other processors or middlemen. Therefore a large share of production is sold in the spot market. This group comprised 10% of the number of growers and 9% of total production. These figures suggest that a large number of growers are ultimately able to divert a share of their production under bilateral contracts to other buyers in the spot market.

MEASURING REALLOCATION OF CONTRACTED TOBACCO

As stated in the methodological section, the non-loyal grower would be perfectly compatible with the main goal of loyalty if contracts were fulfilled. In other words, growers with more than one contract fulfil all obligations by selling exactly what was promised to each processor. However, default due to undesirable reallocation of contracted tobacco can threaten the system competitiveness. In order to measure this kind of reallocation the Euclidean distance was used as indicator, as presented in the methodological section. From processors´ perspective, reallocations should be close to zero.

The Euclidean distance was calculated then normalized in order to obtain an indicator ranging from 0 to 100. Table 6 presents the averages for this indicator, according to the groups established in Table 5. The calculated average for the total of 289 sampled growers was 9.7, which is a relatively low value, indicating that, overall, the reallocation was relatively low. However, the calculated standard deviation around this average was large, indicating some heterogeneity already established among the groups.

The indicators of Group 1 reallocations presented an average of 3.9, which is very low. This group is mostly composed of growers who have a formal contract and sell a very small share of their production to a second buyer in a spot market transaction. As already stated, they are the "ideal group" in terms of loyalty. One should be aware that this group comprised 82% of growers of this sub-sample.

Group 2 comprises four growers who sold their final production to middlemen. The average indicator of 94.5, which was close to the maximum of 100, as well as inspection of the data, showed that this small group of growers reallocated a large share of their contracted production to the spot market.

Table 6. Indicator of production reallocation, average values according to group of growers, 289 sampled growers.

Groups	Average	Frequency	Standard deviation
1	3.9	238	7.8
2	94.5	4	11.0
3	10.4	18	13.6
4	45.5	29	14.5
Total	**9.7**	**289**	**18.4**

Group 3 are mostly non-loyal growers who signed contracts with two processors, so the indicator should show the level of reallocation of production from one processor to another. The mean value for the indicator was 10.4, thus one can say that the level of reallocation is low, although it was higher than the one found in Group 1, which is composed mostly by loyal growers. From an analytical standpoint, the existence of reallocations performed by non-loyal growers is even more important than the level of current reallocations, as it reveals that a relatively large number of growers are learning the new game, which offers advantages for them and, therefore, has an appeal to newcomers.

Finally, Group 4 is composed of growers who sell about half of their production to a processor with a contract and half to middlemen. As in Group 2, reallocation is a possibility which has to be evaluated. This group comprises 10% of the number of growers of this sub-sample. The average value of the indicator of reallocation was 45.5, which is quite high. As middlemen resell to other processors, this high level of reallocation establishes a planning problem for processors whose contracts are not fulfilled.

As seen before, contract farming is useful for processors, since commitments on quantity and quality of tobacco leaf are established. All clauses are important, including those related to environmental protection and child labour. However, for processors, contractual breaches related to undesirable reallocation of the growers' production and default of advance payments are the most uncontrollable and economically harmful. The gravity is twofold: on one hand, because the processor needs the specified tobacco leaf to accomplish its own selling contracts, on the other hand because the effect it can have on other ex-post transaction costs, such as costs of lengthy litigation. According to non-structured interviews with members of the processors' staff, the default level was growing, and for some processors it reached almost 20% in the 2005 crop season.

In contract farming, processors bear costs, such as those related to technical assistance, credit collaterals and distribution of agricultural inputs. In cases of undesirable reallocation and payment default, the punishment would be litigation and exclusion of the grower from its list of suppliers. However, this is not the usually observed practice. Litigation is the last approach to the problem. First, judges are reluctant to establish sentences which aggravate social problems of small farmers. Second, with the growing demand and fierce competition for suppliers, processors would benefit from singing a new contract with the grower for the next crop season. Processors are motivated to renegotiate debts, which would be paid in the following crop season. This solution avoids reduction in the number of suppliers and has the potential to increase the amount of tobacco leaf contracted in the following year. The general rule is that "debt is paid with tobacco leaf, and growers are only able to pay if they receive the support of the processor." In this case, processors double the bet, as well as the risk. According to interviews with processors' staff members, the results of this approach have been positive. Processors end up recovering the credits over the years. From an accounting perspective, a restructured debt is not as damaging to profitability indicators as a debt under litigation, and this is another reason to facilitate the renegotiation of debt, even with increased risk. The drawback is an increasing level of the growers' indebtedness.

Final remarks

This article showed that an efficient hybrid governance structure was created for transactions between tobacco growers and tobacco processors. This governance structures was able to reduce the problem of opportunism, taking into account three factors mentioned by Ménard (2004). First, processors carefully selected growers based on screening and reputation, so that loyalty could succeed. Second, they took into consideration the necessary balance between independence of agents and the need to take common actions such as adoption of rigid quality controls, guarantee of purchase, crop insurance and information channels between processors and growers organizations. In this sense, the adopted governance structure included neither rigid firm's hierarchical controls nor fragile spot market controls as proposed by Mernard (2004). Third, company advisers and AFUBRA were able to reduce asymmetry and facilitate coordination.

However, the data and the indicators presented in this paper show how an efficient governance of transactions can be threatened by competition among buyers. The article brings empirical evidence on how sector competitiveness can be threatened by competition for suppliers. In particular, it shows how transactions based on loyalty can be changed, bringing deleterious consequences for sector competitiveness. There are lessons for business managers and for anti-trust authorities. Buyers and suppliers should be aware of the deleterious consequences for sector competitiveness when they design and introduce new forms of transactions.

The number of transactions in the spot market has increased as a result of changes in buyers´ procurement strategies. This change introduced uncertainty and higher costs for processors. The system was moving towards a new shape, with unknown consequences to its own competitiveness. These are exactly the undesirable conditions that efficient governance of transactions tries to overcome. Sector competitiveness could be jeopardized by the processors' competitive strategies; assuming that non-written loyalty in bi-lateral contracts was one of the main determinants of its competitiveness.

In fact, the co-existence of spot market and contractual forms revealed the adoption of plural forms of governance, as proposed by Bradach and Eccles (1989). Zylbersztajn and Nogueira (2002) proposed that alternative types of governance could coexist as points of disequilibrium and plural forms could represent a situation of adjustment between the current and future forms. They also stressed the effects of changes of the institutional environment in generating multiple alignments. This article is an empirical confirmation of adoption of plural forms due to the occurrence of changes in the institutional environment. However, there is no evidence that a new equilibrium would be reached with a new and more efficient form of governance.

The article showed how to measure the loss of loyalty. Based on the Euclidean distance, an original method to measure the level of loyalty is provided. Additionally, it raises an important question. How to sustain efficient forms of transactions in an environment of tough competition for suppliers? If one considers hybrid governances, such as contract farming and unwritten loyalty, is efficient for a certain industry, taking Williamson's (1996) terms, tough competition should be avoided. After all, loss of competitiveness is harmful not only for processors but also for suppliers. Solutions, such as agreements, are not easy. For instance, cooperative strategies are not easy to build up in an environment of tough competition; and anti-trust regulations must be considered. Solutions for this problem are beyond the scope of this article.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

AFUBRA (Associação dos Fumicultores do Brasil) (2009). Fumicultura no Brasil, Estrutura Familiar. Available at: http://www.afubra.com.br/ (accessed 8 March 2009).

AFUBRA (Associação dos Fumicultores do Brasil) (2011). http://www.afubra.com.br/index.php/conteudo/show/id/93, (acessed 29 november 2011).

Bradach JL, Eccles RG (1989). Price, authority, and trust: from ideal types to plural forms, Annu. Rev. Soc. 15:97-118.

FAO Food and Agriculture Organization (2009). FAOSTAT, available at: http://www.faostat.fao.org/ (accessed 20 January 2009).

MÉNARD C (2004). The economics of hybrid organizations. J. Inst. Theor Econ. 160:345-376.

Mesquita AS, Oliveira JMC (2003). A Cultura do Fumo na Bahia: da Excelência à Decadência. Available at: http://www.seagri.ba.gov.br/ (accessed 11 May 2005).

NORTH Douglass (1994). Custos de Transação, Instituições e Desempenho Econômico. Rio de Janeiro: Instituto Liberal, P. 38.

SEAE Secretaria de Acompanhamento Econômico (2005). Parecer nº 06056/2005/RJ, Ato de Concentração Dimon Inc. E Standard Commercial Co. Available at: http://www.fazenda.gov.br/seae/ (accessed 16 January 2005).

WHO World Health Organization (2008), Report on the Global Tobacco Epidemic, 2008: the MPOWER Package, World Health Organization, Geneva.

Williamson OE (1985). The economic institutions of capitalism – firms, markets, relational contracting. New York: The Free Press. P. 468.

Williamson OE (1996). The Mechanisms of Governance. Oxford: Oxford University Press.

Zylbersztajn D, Nogueira ACL (2002). Estabilidade e difusão de arranjos verticais de produção: uma contribuição teórica, Economia e Sociedade, 11(2):329-346.

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Phytosociology and interference of weeds in upland rice in Maranhão State, northeastern Brazil

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The objective of this research was to identify the weed species and to determine the critical periods of weed interference in upland rice in Maranhão State, northeastern Brazil. The experiment was laid out in a randomized complete block design with 16 treatments and four replications in two growing seasons. Treatments were increasing periods of control and coexistence of the crop with weeds, for every 10 days. Weeds were sampled with a 0.5 × 0.3 m metal rectangle which was randomly thrown four times in each plot. Phytosociological parameters computed were Density, Frequency, Dominance and Importance Value Index of each species. The more important families in both growing seasons were Poaceae and Cyperaceae. *Cyperus* spp., *Phyllanthus niruri* L., *Alternanthera tenella* Colla and *Digitaria* spp. reached higher values of relative importance than the other species. Coexistence of weeds with rice during the whole crop cycle in both growing seasons decreased rice grain yield by 83.4 and 72.0%, respectively. Taking into account 5% tolerance in yield reduction in cropping seasons 2010/2011 and 2011/2012, the periods before interference (PBI) were 15 and 13 days after emergence (DAE), the total periods of interference prevention (TPIP) were 25 and 45 DAE and the critical periods of interference prevention (CPIP) were from 15 to 25 and from 13 to 45 DAE, respectively. It was concluded that the weed control in upland rice must be carried out from 13 till 45 DAE to promote weed free development since the crop has low natural competitive capacity.

Key words: Competition, critical period, *Oryza sativa* L., weed community.

INTRODUCTION

Rice is an annual crop of great socio-economic importance in Brazil because it is a staple food and it is grown in all over the country. According to CONAB (2014), Brazilian rice production in the growing season

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2002/2003 was 11,819.7 thousand tons. Major rice regions in terms of production are the South (9,132.9 thousand tons) followed by Center-West (770.8 thousand tons) and Northeast with (588.2 thousand tons). Maranhão State was the major producer in the Northeast region contributing with 66.33% of the total rice production.

Weeds are the major biological constraint for rice farmers in Maranhão State because they are favored by local climatic conditions. According to Silva and Durigan (2006), weeds are the most sensitive factor affecting upland rice growth, development and yield since they compete for light, space, nutrients and water, which results in qualitative and quantitative yield reductions, besides increasing operational costs of harvest, drying and grain processing.

Uncontrolled weed growth is reported to cause grain yield losses in upland rice in the range of 66-100% (Silva and Durigan, 2006; Silva and Durigan, 2009; Chauhan and Johnson, 2011; Toure et al., 2013). This shows that it is necessary to implement weed control practices to avoid yield losses and associated economic damages.

The first step to develop a weed management program in any crop is the identification of the weed species present in the agroecosystems, particularly those that are more important, taking into account phytosociological parameters such as Frequency, Density and Dominance. These parameters enable a decision making about more suitable control method whether it is cultural, mechanical, physical, biological, chemical or an integrated weed management program (Oliveira and Freitas, 2008).

According to Pitelli (2000), phytosociological parameters permit comparisons of weed populations in a certain time in the weed community thereby revealing the impacts of some cultural practices over weed community growth and space occupation in cropping fields. The weed species controlled by cultural practices tend to decrease their relative importance, while indifferent or favored weed species tend to increase. The most affected component analysis (Density, Frequency or Dominance) may provide evidences about the mode of action of the environmental pressure agents against weed populations.

Knowledge of time and extension of periods which weed coexistence with the rice affect crop yield is crucial for weed management in rice. These periods were defined by Pitelli and Durigan (1984), as period before interference (PBI), the total period of prevention interference (TPIP) and the critical period of interference prevention (CPIP). The PBI corresponds to the period of time starting from planting that the crop can coexist with weeds before its yield or other biological characteristics are negatively affected. The TPIP is the period starting from emergence or planting which the crop must be kept free from weeds to its quality and yield and other characteristics are not adversely altered. The CPIP is the period of time which weed control must be compulsory to prevent weed interference in yield or other crop characteristics.

Silva and Durigan (2006) found critical interference periods between 12 and 42 DAE for the IAC 202 variety. Conversely, the said period was between 26 and 29 DAE for the variety Caiapó (Silva and Durigan, 2009). However, for upland rice varieties in Africa, Moukoumbi et al. (2011) observed that the critical interference period was between 30 and 60 days after seeding (DAS). However, for three new upland rice varieties in Africa, the critical period was between 14 and 42 DAS and between 28 and 42 DAS for *Oryza glaberrima* (Toure et al., 2013). This shows that rice varieties behave differently in their competitiveness to suppress weeds under different weed communities and climate conditions, therefore weed control should be regionalized (Pitelli, 2014).

The objective of this research was to identify the major weed species and to determine their critical interference periods on upland rice in the Center-West region of Maranhão State to provide a better definition of the weed control time.

MATERIALS AND METHODS

The experiment was carried out in the growing seasons from January till May 2011 and 2012 in the Farm School of the Maranhão State University at São Luis (2°31′47″ S; 44°18′10″ W). The climate in the region, according to Thornthwaite classification, is type B_1WA'a, humid (B_1), with moderate water deficit in winter (between June and September), megathermal (A'), that is, with average monthly temperature always above 18ºC, annual rainfall ranging from 2,400 and 2,800 mm and annual relative humidity above 82% (GEPLAN, 2002). During the two growing seasons rainfall and temperature varied according to Figure 1.

The soil in the experimental area is classified as Alfisol. The rice cultivar used was BRS Seraneja which was developed based on multiple cross carried out in 1993, at EMBRAPA Arroz and Feijão (Brazilian Research Corporation for Rice and Beans), involving lines and cultivars (Carajás // IAC 165²/ Labelle //// Três Marias / IAC 25³ /// A8-204-1 / Guarani // IRAT 216). This cultivar is characterized by vigorous plants, medium height, moderately tillered and resistant to lodging (Breseghello et al., 2006).

Fertilization and seeding were performed manually in the same day. Seeding density was 70 seeds per running meter in rows with fertilizers placed at five and seeds placed at three cm deep respectively simulating mechanical sowing. Basal fertilization was made with the application of 30 kg of N, 60 kg of P_2O_5 and 50 kg of K_2O h^{-1} in the form of ammonium sulfate (20% N), triple superphosphate (43% P) and potassium chloride (60% K). Top dressing was made with 60 kg N ha^{-1} in the form of urea at 30 days after emergences (DAE).

The experiment was laid out in a randomized complete block design with 16 treatments and four replications. Plots contained five rows with five meters each; row spacing was 0.45 cm. Useful plot size was three central rows discarding two rows in borders and 0.50 cm at each end totalizing 5.40 m^2.

The treatments were control and coexistence of weeds in increasing time periods of crop cycle starting from crop emergence. The initial periods of control and coexistence with the weeds were: 0 – 10; 0 – 20; 0 - 30; 0 - 40; 0 - 50; 0 - 60; 0 - 70; 0 – 120 DAE. In addition, season long weedy and weed free checks were included

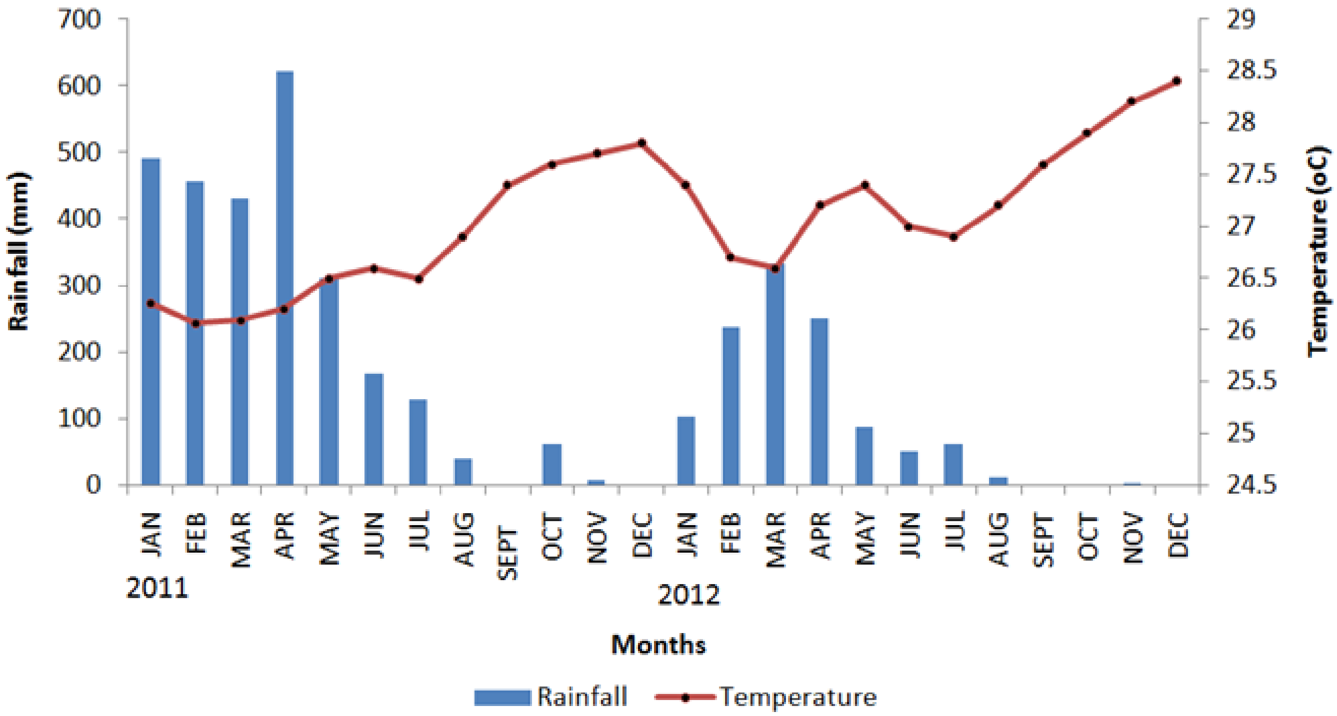

Figure 1. Rainfall and temperature in 2011 and 2012, in São Luís, Maranhão State, northeastBrazil. Source: INMETRO (2013).

as controls. Weed samplings were performed at the end of the coexistence time periods and weed control was performed by means of hand weeding every 10 days.

Four weed samples per plot were taken by means of a 0.50 × 0.30 cm open metal rectangle which was randomly placed in the plot area. Weeds species were cut at the ground level, identified by species, counted and oven dried at 65-70°C till constant weights were obtained to determine weed dry weight. Data on weed density, weed dry weight and frequency of each species present in the weed community were used to compute the following phytosociological parameters: Relative Density, Relative Frequency, Relative Dominance, Importance Value Index (IVI) and Relative Importance (RI) according to methodology suggested by Pitelli (2000).

The crop was manually harvested at 120 DAE from 5.40 m area kept for yield estimation in each plot. Yield data were expressed in kg ha^{-1} and were subjected to regression analysis by the Sigmoidal Boltzmann Model (Kuva et al., 2000) by means of the software ORIGIN 8.0 (Originlab Corporation, 2002). This Model follows the equation: Y= A2 + [(A1-A2)/(1-exp (x-xo)/dx)], where y is rice yield in percentage; X in the superior limit of the coexistence period or control; A1 and A2 are the curve asymptotes; Xo is the superior limit from coexistence or control which corresponds to the inflexion point of the curve and dx indicates velocity of losses or production gains (tg α in the point Xo). Based on regression equations, we determined the time periods of weed interference for arbitrary levels of 5% decrease in rice grain yield with respect to the treatment kept weed free.

Rice grain yield data were subjected to the Analysis of Variance with F test and means were tested for significant differences using the Tukey test at 5% probability. Statistical analyses were carried out by means of the software Assistat 7.7 (Silva and Azevedo, 2009).

RESULTS AND DISCUSSION

For the first growing season (2010/2011), 52 weed species from 18 families were identified. The families with higher species richness were Poaceae and Cyperaceae with 25 and 21.5%, respectively. In contrast only 37 species from 17 families were identified in the second growing season (2011/2012). Poaceae and Cyperaeae were again the families with higher species richness with 41 and 47%, of the species total, respectively (Table 1). Therefore lower weed species diversity was noted in the second growing season, even though higher percent values for species of the Poaceae and Cyperaceae families were observed.

The lower diversity might be due to the amount of rainfall in the second growing season which favored more species from families of Poaceae and Cyperaceae that possess the more aggressive weed species to the rice crop. Species of these families were also identified competing with upland rice by Silva et al. (2014) in the Pré-Amazônia Maranhense, region in Brazil and in Punjab, Pakistan by Rabbani et al. (2011). According to Lorenzi (2008) many species from Poaceae and Cyperaceae produce great number of propagules thereby facilitating dissemination and occupation of ecological niches in many environments, even in those considered unfavorable for plant growth.

Table 1. List of families and weed species identified in upland rice crop in the Farm School of São Luís from the Maranhão State University at São Luís, Maranhão State, northeast Brazil in the growing seasons 2010/2011 and 2011/2012.

Families	Species	
	Growing season 2010/2011	**Growing season 2011/2012**
Asteraceae	*Blainvillea rhomboidea* Cass.	---------------------------
	Emilia coccinea (Sims). G.Don.	*Emilia coccinea* (Sims). G.Don.
	Emilia fosbergii Nicolson	---------------------------
	Tridax procumbens L.	---------------------------
	Synedrella nodiflora (L.) Gaertn.	---------------------------
	Siegesbeckia orientalis L.	---------------------------
	---------------------------	*Galinsoga quadriradiata* Ruiz & Pav.
Amaranthaceae	*Alternanthera brasiliana* (L.) Kuntze	*Alternanthera brasiliana* (L.) Kuntze
	Amaranthus spp.	*Amaranthus* spp.
	Alternanthera tenella Colla	*Alternanthera tenella* Colla
Brassicaceae	---------------------	*Cleome affinis* DC
Cyperaceae	*Cyperus sphacelatus* Rotttb.	*Cyperus sphacelatus* Rotttb.
	Cyperus rotundus L.	*Cyperus rotundus* L.
	Cyperus flavus (Vajl) Nees	*Cyperus flavus* (Vajl) Nees
	Cyperus lanceolatus Poiret	*Cyperus lanceolatus* Poiret
	Cyperus brevifolius (Rottb.) Hassk	------------------------
	Fimbristyllis spp.	*Fimbristyllis* spp.
	Bulbostilys capillaris (L.) C.B. Clarke	*Bulbostilys capillaris* (L.) C.B. Clarke
	Cyperus iria L.	*Cyperus iria L.*
	Cyperus diffusus Vahl	*Cyperus diffusus* Vahl
	Pycreus polystachyos ((Rottb) P.Beauv.)	------------------------
	Pycreus decumbens T. Koyama	-----------------------
	------------------------	*Rhynchospora corymbosa* (L.) Britton
Commelinaceae	*Commelina benghalensis* L.	*Commelina benghalensis* L.
Convolvulaceae	*Ipomoea* spp.	*Ipomoea* spp.
	Ipomoea asarifolia (Desr.) Roem. & Schult	*Ipomoea asarifolia* (Desr.) Roem. & Schult
	------------------------	*Ipomoea purpurea* (L.) Roth
Euphorbiaceae	*Chamaesyce hirta* (L.) Millsp.	-----------------------
	Croton lobatus L.	*Croton lobatus* L.
Fabaceae	*Calopogonim mucunoides* Desv.	-----------------------
	Mimosa pudica L.	*Mimosa pudica* L.
	Senna obtusifolia (L.) Irwin & Barneby	-----------------------
	Indigofera hirsuta L.	-----------------------
Lamiaceae	*Marsypianthes chamaedrys* (Vahl) Kuntze	*Marsypianthes chamaedrys* (Vahl) Kuntze
Loganiaceae	*Spigelia anthelmia* L.	*Spigelia anthelmia* L.
Malvaceae	*Sida* spp.	*Sida* spp.

Table 1. Contd.

	Sida rhombifolia L.	----------------------------
	Pavonia cancelata (L.) Cav.	----------------------------
	----------------------------	*Sidastrum micranthum* (A. St. –Hil.)Fryxell
Melastomataceae	*Rhynchathera* spp.	----------------------------
Molluginaceae	*Mollugo verticillata* L.	*Mollugo verticillata* L.
Onagraceae	*Ludwigia leptocarpa* (Nutt.) H. Hara	----------------------------
Poaceae	*Digitaria* spp.	*Digitaria* spp.
	Eleusine indica (L.) Gaertn.	*Eleusine indica* (L.) Gaertn.
	Cenchrus echinatus L.	*Cenchrus echinatus* L.
	Coix lacryma-jobi (L.) Sw.	----------------------------
	Dactyloctenium aegyptium (L.) Willd.	*Dactyloctenium aegyptium* (L.) Willd.
	Digitaria bicornis (Lam.) Roem & Schult	----------------------------
	Digitaria horizontalis Wild.	----------------------------
	Eragrostis ciliaris (L.) R. Br	*Eragrostis ciliaris* (L.) R. Br
	Brachiaria brizantha (Hochst. Ex A.Rich.) Stapf	----------------------------
	Brachiaria mutica (Forssk.) Stapf	----------------------------
	Panicum tricoides L.	*Panicum tricoides* L.
	Digitaria ciliaris (Retz.) Koeler	*Digitaria ciliaris* (Retz.) Koeler
	Setaria parviflora (Poir.) Kerguélen	----------------------------
Phyllanthaceae	*Phyllanthus niruri* L.	*Phyllanthus niruri* L.
Plantaginaceae	*Lindernia crustacea* (L.) F. Muell	*Lindernia crustacea* (L.) F. Muell
Rubiaceae	*Hedyotis corymbosa* (L.) F. Muell	*Hedyotis corymbosa* (L.) F. Muell
	Spermacoce latifolia Aubl.	*Spermacoce latifolia* Aubl.
	Spermacoce capitata Ruiz & Pav.	*Spermacoce capitata* Ruiz & Pav.
	Spermacoce verticilata L.	*Spermacoce verticilata* L.
	Staelia aurea K.Schum.	---------------------------
Turneraceae	*Turnera ulmifolia* L.	*Turnera ulmifolia* L.

Cyperus spp. had higher Relative Importance values than the others during the whole coexistence period in the growing season 2010/2011, reaching 35.22% at 50 DAE (Figure 2A). This was probably due to the higher incidence of light on the soil in the initial periods of their coexistence with the crop which favored their growth since they have the C4 carbon fixation cycle. According to Silva et al. (2007) the C4 species can dominate completely the C3 species when growing in environments with high temperatures, high light intensity and even with temporary soil water deficit. In addition, they accumulate two times more biomass per leaf area in the same period of time.

Other relevant species recorded in the weed community in the growing season 2010/2011 were *Phyllanthus niruri* followed by *Alternanthera tenella* and *Digitaria* spp. (Figure 2A). The species *P. niruri* stood out mainly from 10 till 40 DAE, reaching higher Importance Value than the others at 30 DAE with 22.4% of the total. On the other hand, *A. tenella* obtained higher Importance Value than the other species in the weed community at 10 DAE with 19%; maintaining values above 10% from 50 DAE till the last evaluation, while *Digitaria* spp. expressed their higher relevance than the other species

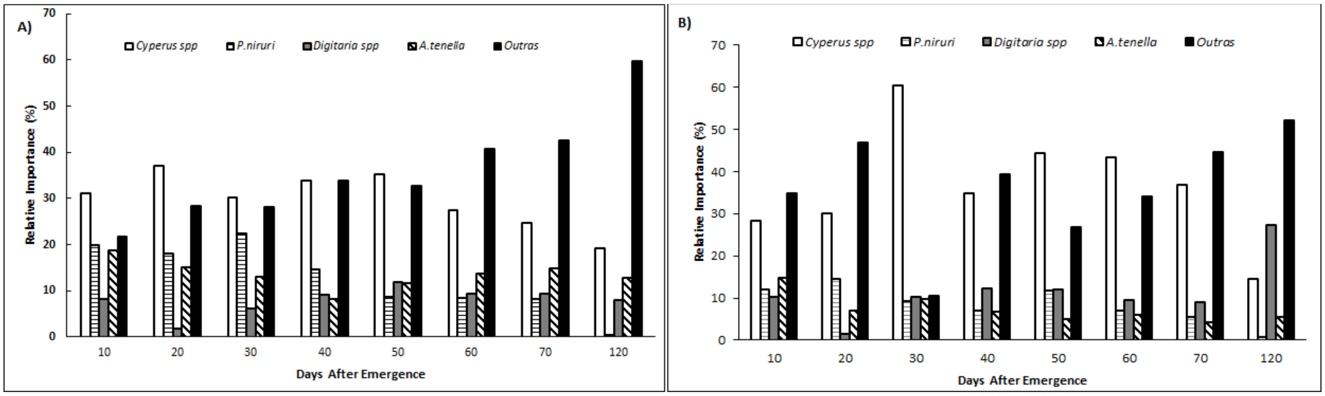

Figure 2. Relative Importance of the main weed species in coexistence with the rice crop variety BRS Sertaneja in the Farm School at São Luis /CCA/UEMA, São Luís, Maranhão State, northeastern Brazil. A) Growing season 2010/2011 and B) Growing season 2011/2012.

in the weed community at 50 DAE, with 12%. At the end of crop cycle the other species corresponded to 60% of the weed community (Figure 2A). Therefore a decrease in the relative importance of *Digitaria* spp. was observed at the end of the crop cycle indicating higher level of interespecific competition.

In the second growing season (2011/2012) species from Cyperaceae family showed higher relevance than species from the other families in the weed community during the whole crop cycle, except at harvest when they were superseded by *Digitaria* spp. with 60% of the total (Figure 2B). These results show that Cyperaceae species may be considered to have higher influence to damage the rice crop at early growth stage. Among Cyperaceae species, *C. rotundus* stood out in the beginning of the crop cycle. It prefers open places with high light intensity. However, by the end of the crop cycle the weed community was dominated by *C. sphachelatus, C. diffusus* and *C. brevifolius* that thrive better in more humid and shaded conditions. According to Moreira and Bragança (2010), Cyperaceae species prefer humid, shaded or open places and tend to form difficult to control communities which compete for space and nutrients. Research results reported by Rabbani et al. (2011) also show that *C. rotundus* is among the most abundant species in rice fields of Punjab, Pakistan.

Digitaria spp. were relevant only at the end of the crop cycle but they must be controlled because they are highly aggressive weeds (Kissmann and Groth, 1991). Furthermore *Digitaria* spp. are also potential inoculum sources of the rice blast disease (*Piricularia oryzae* Cav.). In a phytosociological weed survey carried out in upland rice in Maranhão State, Silva et al. (2013) also reported that species from this genus were among the most important in the weed community.

The species *P. niruri* and *A. tenella* reached higher relative importance than the other species at 20 and 10 DAE with 15 and 14.5%, respectively (Figure 2B). These species showed lower values of Relative importance in the second growing season. This suggests that the lower amount of rainfall affected their growth (Figure 2).

Taking into account a 5% yield loss in the variety BRS Sertaneja in the growing season 2010/2011, it was observed that the coexistence time with weeds started to affect the crop (PBI) at 15 DAE, extending up to numerical weed control (TPIP) till 25 DAE (Figure 3). The critical period of interference prevention (CPIP) was characterized by an interval between 15 and 25 DAE. This lower PAI indicates that the crop shows low competitive capacity in the early stage of its growth cycle, thus requiring weed removal so as to not adversely interfere with crop yield. However the TPIP obtained suggests that the crop enhanced weed control by shading the soil. Research results with variety Caiapó in the growing season 2004/05 determined TPIP at 26 DAE, due to the lower incidence of weeds, thereby the crop was able to soon shade the soil (Silva and Durigan, 2009). However, in research carried out by Moukoumbi et al. (2011) in Africa under weeding at 14 DAS, the critical period of competition between weeds and cultivated plants varied between 30 and 60 DAS.

In the second growing season (2011/2012), taking into account the same 5% crop yield loss, it was obtained PBI from 13 DAE and TPBI of 45 DAE. Therefore the CPIP, was between, 13 and 45 DAE (Figure 4). In this year, the variety extended the TPBI for 17 days compared to the first growing season. This suggests that the weed community was more aggressive. Because of this, weeding had to be extended.

Although lower species diversity was observed in the second growing season when compared with the first, there was a higher amount of species from Poaceae and

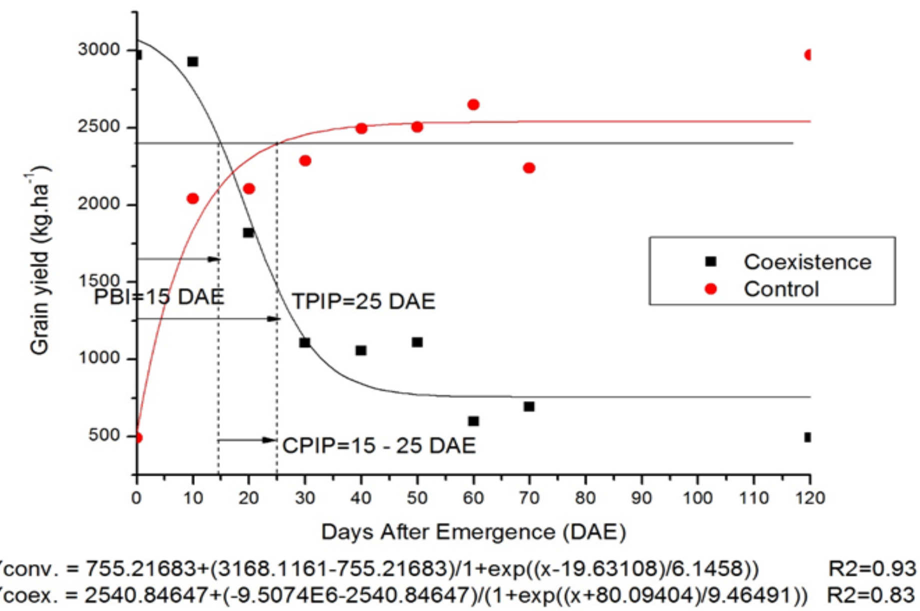

Figure 3. Upland rice grain yield (BRS Sertaneja) and data adjustment by the Sigmoidal Boltzmann Model, based on coexistence periods with weeds taking into account a 5% yield loss in the growing season 2010/2011. São Luis, Maranhão State, northeastern Brazil.

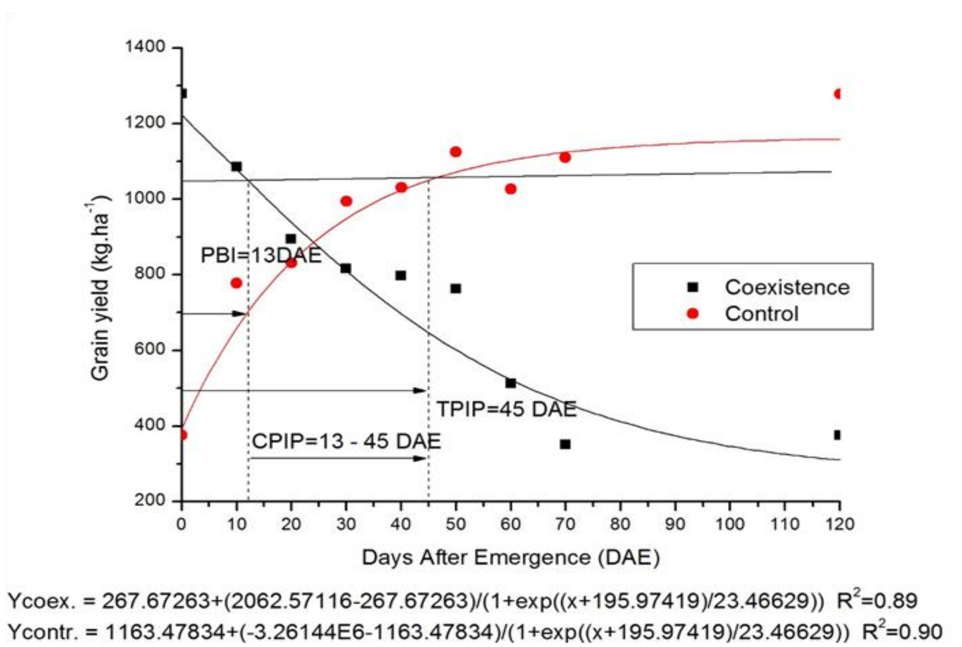

Figure 4. Upland rice grain yield (BRS Sertaneja) and data adjustment by the Sigmoidal Boltzmann Model, based on coexistence periods with weeds taking into account a 5% yield loss in the growing season 2011/12. São Luis, Maranhão State, northeastern Brazil.

Cyperaceae families that have very aggressive weed species to the rice crop (Table 1). With respect to PBI, one difference of three days was observed, confirming the need to perform weed control in the beginning of the crop growth cycle, since emerging weeds negatively affected yield. Silva and Durigan (2006) reported a critical period between 12 and 40 DAE for the variety IAC 202 in the growing season 2003/2004. In Africa, Kolo and Umaru (2012) reported a critical period between 25 and 45 DAE for the variety NERICA 1. Toure et al. (2013) determined the critical period between 14 and 42 DAS for three new rice varieties in Africa. Thus, it is concluded that regardless of the soil and climatic conditions, upland rice does not show great competitive capacity with the weed community.

BRS Sertaneja grain yield in total absence of weed interference in the growing season 2010/2011 was 2,971.8 kg ha^{-1}, while in the growing season 2011/2012 was 1,278.5 kg ha^{-1}. Therefore, there was a 43% yield reduction from the said variety in the second growing season. This fact can be explained by the lower rainfall amount in the time of panicle differentiation. Research conducted by Kolo and Umaru (2012) in Africa showed that the cultivar Nerica 1 had higher grain yield due to less weed competition which favored its higher growth.

The coexistence with weeds during the whole crop cycle resulted in yield losses of 83.4 and 71% in the growing seasons 2010/2011 and 2011/2012, respectively. This highlights the great crop susceptibility to weed interference. These results are similar to those noted by Touré et al. (2013) who reported 85% yield reduction when coexistence with weeds occurred in the whole crop cycle. Harding and Jalloh (2011) reported average yield losses ranged from 22 to 66%. This shows that rice varieties behave differently in their competitiveness to suppress weeds under severe competition. Kolo and Umaru (2012) stated that the drooping leaves and higher tillering ability of NERICA 1 resulted in good canopy formation which contributed to its weed suppressing ability resulting in higher grain yield.

Conclusions

The main families and weed species in coexistence with upland rice crop during the two growing seasons of this study were Cyperaceae and Poaceae, and *Cyperus* spp., *P. niruri*, *A. tenella* and *Digitaria* spp.

Weed interference must be minimized in the first stage of upland rice crop growth to promote its free development since it has low natural competitive capacity. Weed control in upland rice crop must be carried out in the period starting from 13 till 45 DAE; beyond this period it is not economically recommended for the farmers to continue weeding.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Breseghello F, Morais OP, Castro EM (2006). Cultivation of upland rice in the State of Matogrosso. Sistema de produção versão eletrônica. Embrapa P. 7.

Chauhan BS, Johnson DE (2011). Row spacing and weed control timing affect yield of aerobic rice. Field Crops Res. 121:226-231.

CONAB (National Supply Company) (2014). Historical Series Relating to crops 1976/77 - 2013/14.

EMBRAPA (2013). Sistema brasileiro de classificação de solos / Humberto Gonçalves dos Santos ... [et al.]. – 3ª ed. rev. ampl. – Brasília, DF: Embrapa. P. 353.

GEPLAN (Planning and Development Management) 2002. Atlas do Maranhão. Laboratório de Geoprocessamento-UEMA. São Luís.

Harding SS, Jalloh AB (2011). Evaluation of the relative weed competitiveness of upland rice varieties in Sierra Leone. Afr. J. Plant Sci. 5:396-400.

Kolo MGM, Umaru I (2012). Weed competitiveness and yield of inter- and intraspecific upland rice (*Oryza sativa* L.) under different weed control practices at Badeggi, Niger State, Nigeria. Afr. J. Agric. Res. 7:1687-1693

Kissman KG, Groth D (1991). Plantas infestantes e nocivas. São Paulo: BASF. P. 812.

Kuva MA, Pitelli RA, Christoffoleti PJ, Alves PLCA (2000). Interference periods of weeds in the sugarcane culture: I - Purple nutsedge. Planta Daninha. 18:241-251.

Lorenzi H (2008). Weeds: land, water, parasites and toxic. Nova Odessa, SP. Institute Plantarum.

Moreira HJC, Bragança HBN (2010). Weed identification guide: summer crops. Campinas, SP.

Moukoumbi YD, Sie M , Vodouhe R, Bonou W, Toulou B, Ahanchede A (2011). Screening of rice varieties for their weed competitiveness. Afr. J. Agric. Res. 6:5446-5456.

Oliveira AR, Freitas SP (2008). Interference periods of weeds in the sugarcane culture: I - Purple nutsedge. Planta Daninha. 26:33-46.

Originlab Corporation (2002). Origin 8.0 origin user guide. P. 246. Available from: <http://cloud.originlab.com/pdfs/Origin2015_Documentation/English/Origin_User_Guide_2015_E.pdf

Rabbani N, Bajwa R, Javaid A (2011). Interference of five problematic weed species with rice growth and yield. Afr. J. Biotechnol. 10:1854-1862.

Pitelli RA, Durigan JC (1984). Terminology for control periods and coexistence of weeds in annual and biennial crops. In: CONGRESSO BRASILEIRO DE HERBICIDAS E PLANTAS DANINHAS, 15 Belo Horizonte. Resumos...Piracicaba: SBHPD P. 37.

Pitelli RA (2000). Phytosociological studies in weed communities of agroecosystems. J. Consherb. 1:1-7.

Pitelli RA (2014). Competition between weeds and cultivated plants. In: Monquero, PA (Ed). Aspects of biology and weed management. São Carlos. Ed. RiMA pp. 61-81.

Silva MRM, Durigan JC (2006). Periods of weed interference in the upland rice: I - Variety IAC 202 2006. Planta Daninha. 24:685-694.

Silva MRM, Durigan JC (2009). Interference periods of weeds in the upland rice caiapó variety. J Bragantia.68:373-379.

Silva MRM, Campos DR, Souza RL, Corrêa MJP (2013). Phytossociological registration weed in rice upland in Santa Luzia - MA. Revista de Ciências Agro-Ambientais, Alta Floresta-MT.11:51-60.

Silva MRM, Costa EA, Marques, LJP, Corrêa MJP (2014). Bank of weed seeds in upland rice growing area in the Pre-Amazon

Maranhense. Amazon. J. Agric. Environ. Sci. 57:351-357.
Silva AA, Silva JF (2007). Topics in weed management**.** Viçosa University Press Minas Gerais pp. 17-61.
Silva FASE, Azevedo CAV (2009). Principal Components Analysis in the Software Assistat-Statistical Attendance. World Congress on Computers in Agriculture, 7, eno-NV-USA: American Society of Agricultural and Biological Engineers.
Touré A, Sogbedji JM, Gumedzoé YMD (2013). The critical period of weed interference in upland rice in northern Guinea savana: Field measurement and model predicition. Afr. J. Agric. Res. 8:1748-1759.

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Full Length Research Paper

Characterization of cattle husbandry practices in Essera *Woreda*, Dawuro Zone, Southern Ethiopia

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This study was conducted in Essera Woreda, Dawuro Zone of South Nations Nationalities and People Region with the objectives of characterizing cattle husbandry practices as well as identifying and prioritizing cattle production constraints of the study area. Ninety households (HHs) owning cattle were selected randomly. A semi-structured questionnaire was prepared and used to collect data on cattle production system, production constraints and available feed resources. The average family size was 6.74±0.32 per HH. Crop-livestock mixed farming was the commonly used farming system (95.5%). The mean total land holding was 2.91±0.18 ha per HH and there was no significant (P>0.05) difference in total land holding among three agro-ecologies. The average land allocated for crop production, fallow land, others and grazing land were 1.00 ± 0.26, 0.92 ± 0.20, 0.46 ± 0.19 and 0.42 ± 0.19, respectively. The results of this study showed that the average cattle herd size per HH was 11.12 ± 0.69 and was significantly (p<0.05) varied across agro-ecologies. The purpose of keeping cattle in *Woreda* was for milk (46.7%), meat (44.4%), manure (100%), traction (4.4%), and others (37.8%). Natural mating (82.2%) was the most widely used breeding practice and was significantly (p<0.05) differed among agro-ecologies. Trypanosomiasis was the first ranked disease in the study area. The first three major feed resources were natural pasture (54.4 and 90%), crop residues (63.3 and 100%), and crop aftermath (65.5 and 90%) during dry and wet season, respectively. Grazing on natural pasture was the commonly used feeding system. Majority (93.3%) of HHs kept their cattle in their living house. The sources of water for cattle were river (75.5%), spring (13.3%) and tap (11.1%). The survey showed the major constraints of cattle production to be shortage of feed, diseases and shortage of water with indices of 0.385, 0.367 and 0.111, respectively. It was concluded that more emphasis should be given to improve cattle production through strong extension services in delivery of veterinary services, feed conservation and improved fodder cultivation and improved availability of water.

Key words: Cattle production, Essera *Woreda*, feed resources, Husbandry practices, production constraints.

INTRODUCTION

In Ethiopia, agriculture is the main economic activity and more than 80% of Ethiopian population is dependent on agriculture in which livestock play a very important role (CSA, 2009). In Ethiopia, agriculture contributes about

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50% to the overall GDP, generates 90% of export earnings and provides employment for 80% of the population (CSA, 2009). Livestock is an integral part of the agriculture and the contribution of live animals and their products to the agricultural economy accounts for 47% (IGAD, 2011). Among livestock species, cattle contribute significantly to the livelihoods of farmers. They serve as a source of draught power for the rural farming population, supply farm families with milk, meat, manure, serve as source of cash income, and play significant role in the social and cultural values of the society.

Cattle contribute nearly all the draught power for agricultural production at smallholder level in Ethiopia (Melaku, 2011). Cattle are also used to generate critical cash in times of scarcity, provide collateral for local informal credit and serve other socio-cultural functions in Ethiopia (Ulfina et al., 2005). Despite the importance of cattle to the farming community in particular and to the national economy at large, the sector has remained underdeveloped and underutilized. According to CSA (2011), Ethiopia has about 52.13 million heads of cattle. Cattle produce a total of 3.2 billion liters of milk and 0.331 million tons of meat annually (FAO, 2005; CSA, 2008). In addition, 14 million tons of manure are used annually primarily for fuel and 6 million oxen provide the draught power required for the cultivation of crops (Befekadu and Birhanu, 2000).

Ethiopia has an immense potential for increasing livestock production, both for local use and for export purposes. However, expansion and productivity was constrained quantitatively and qualitatively by inadequate and imbalanced nutrition, sporadic disease outbreak, scarcity of water, lack of appropriate livestock extension services, insufficient and unreliable data to plan the services, and inadequate information to improve animal performance, marketing, processing and integration with crop and natural resources for sustainable productivity and environmental health (Aynalem et al., 2011).

Improvement in cattle productivity can be achieved through identification of production constraints and introduction of new technologies or by refining existing practices in the system. In Ethiopia, the cattle production system in different agro-ecological zones is not studied fully and farmers' needs and production constraints have not been adequately identified (EARO, 2001). Assessment of the cattle production system and identification and prioritization of the constraints of production is a prerequisite to bring improvement in cattle productivity in the country. Prioritization of the production constraints is essential as it helps to use the scarce resources efficiently. Understanding the production system helps to design appropriate technologies, which are compatible with the existing system. In general, assessment of the production system is important to plan development and research activities and bring improvements in productivity.

Although cattle play a very significant role in the livelihood of smallholder farmers in the Essera *Woreda*, cattle production system, constraints of cattle production and feed resources have not been fully studied yet. Thus, assessment of the cattle production system, identifying and prioritizing the constraints and feed resources of cattle are necessary in *Woreda* in order to design appropriate technologies compatible with the existing system and to plan development and research activities aimed at improving cattle production. Therefore, this study was conducted to characterize cattle husbandry practices and to identify and prioritize the constraints limiting cattle production in the Essera *Woreda*.

MATERIALS AND METHODS

Description of the study area

This study was conducted in Essera *Woreda* of Dawuro Zone, Southern Nation Nationalities and People Region (SNNPR) (Figure 1). The *Woreda* is 575 km from Addis Ababa through Shashemane road and 350 km from Hawassa, the regional capital city. The area is topographically undulating and rugged. *Woreda* covers a total area of 1043.1 km^2 and lies between 6.7-7.02° latitude and 36.7 to 37.1° longitudes, with an elevation ranging from 501 to 2500 m.a.s.l. The *Woreda* has 29 *kebeles* (27 rural and 2 urban) with a total population of 77,265 (EWFEDO, 2013). *Woreda* lies in three agro-ecological regions: *Kolla* region, which is within 500 and 1500 m.a.s.l; *Woyna-dega* within 1501 and 2500 m.a.s.l; and *Dega* at above 2500 m.a.s.l. The annual mean temperature varies from 17.6 to 27.5°C. The rainfall is a bimodal type: The short rainy season is between February and March and the long between May and September. The average annual rainfall varies between 1401 and 1800 mm (EWARDO, 2008). According to the land use plan of the area, 38.4% is cultivated land, 13.39% grazing land 16.81% forest bushes and shrub land, 17.09% cultivable, and 14.31% is covered by others. The livestock resources of the *Woreda* include 54, 800 cattle, 21, 684 sheep, 7, 171 goats, 2, 360 horses, 932 mules, 317 donkey, 45, 890 chicken and 26, 155 beehives (traditional, transitional and modern hives) (EWARDO, 2013).

Study population and study design

All HHs cattle owning in Essera *Woreda* of Dawuro Zone were the study population. Cross-sectional study was carried out to assess cattle husbandry system and the constraints of cattle production.

Sample size determination and sampling procedure

Prior to undertaking any sampling procedure the background information on cattle population and potential for cattle production in Essera *Woreda* was collected through rapid exploratory field visits together with focus group discussions and available secondary information. The study sites were selected purposively taking into account the agro-ecological conditions, cattle population and suitability of the areas for cattle production. Based on the available information, Essera *Woreda* has a total of 29 *kebeles* distributed into *dega* (high altitude), *woyna-dega* (medium altitude) and *kolla* (low altitude). Then the *kebeles* in each agro-ecology were ranked according to their cattle population and the first two *kebeles* with highest cattle numbers from each agro-ecological zone making a total of six *kebeles* were selected purposively to represent the *Woreda*. The sample size was determined using the formula

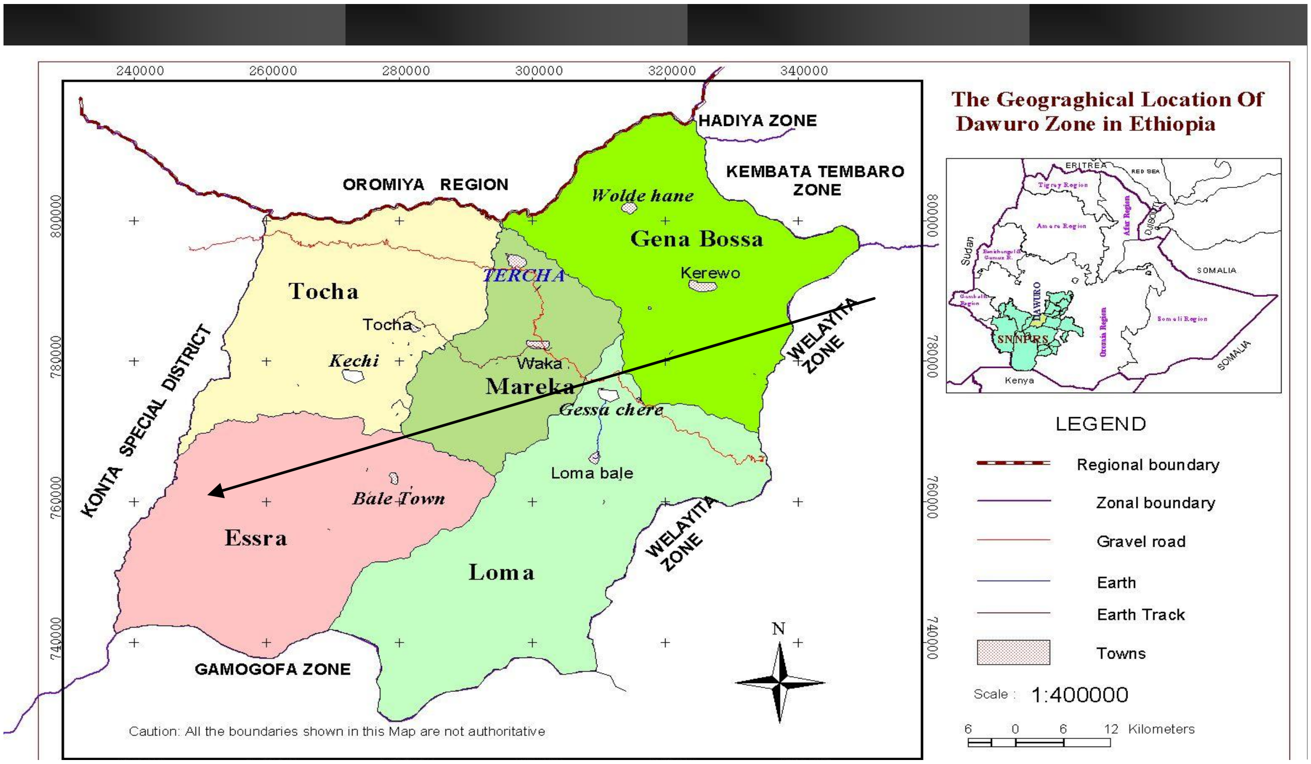

Figure 1. Map of the study area. Source: EWARDO (2013).

recommended by Arsham (2007) for survey studies:

$$N=0.25/ (SE)^2$$

Where: N= sample size, and SE= standard error of the proportion.

Assuming the standard error of 5.27% at a precision level of 5%, and the confidence interval of 95%, 90 households having cattle were selected by a simple random sampling technique for interview. Thirty from *dega*, thirty from *woyna-dega* and another thirty from *kolla* were selected randomly.

Sources and methods of data collection

Both qualitative and quantitative data were collected by employing the following methods.

Formal survey

A formal survey was conducted with the help of semi-structured questionnaire, with open-ended and closed-ended questions using trained enumerators. A semi-structured questionnaire was prepared and pre-tested before administration and some re-arrangements, reframing and corrections in accordance with respondents' perception were made. The questionnaire was administered to the randomly selected household heads by enumerators recruited and trained for this purpose with close supervision by the researcher. The questionnaire was designed to capture information such as: household demographics including sex, marital status and age of the respondent; cattle production practices, identification of constraints to production, feed resources, management practices including; feeding, watering, breeding and health provision.

Secondary data collection

Previous studies and literature and documented data were reviewed to characterize cattle husbandry practices and cattle production constraints. The secondary data pertaining to the investigation were collected from governmental organizations and various stockholders.

Focus group discussion

In each of the studied *kebeles*, discussions have been made with agricultural development agents, elders, village leaders and individuals who have knowledge about the cattle husbandry practices and cattle production constraints in the area. Group discussions consisting of 9 to 11 people were made per *kebele* to complement the survey work and the researcher facilitated the discussion at all sites. These households were selected by the help of agricultural extension workers considering their age and experience with cattle production activity, knowledge about land utilization pattern and major constraints of cattle production.

Field observation

Field observation was made to enrich the data about production practices, feed resources, watering, housing, healthcare of cattle, and any odd event pertaining to investigations were observed to strengthen the information obtained.

Key informants interview

Primary data were generated by informal interview with extension workers in addition to direct field observations and one informal discussion per *kebele* with village elders, and farmers groups was held. The informal interview was conducted with extension workers intended to gather information about the cattle production system, feed resources and constraints hindering cattle production.

Data management and statistical analysis

The computer software Excel was used for data management and entry. All the collected data were coded and entered into the computer with Excel. The SPSS software version 20 was used for data analysis (SPSS, 2013). The descriptive statistical analysis was also employed for descriptive data, which included frequencies, percentages, means and standard errors in the process of examining and describing cattle production practices, cattle production constraints and feed resources. Indices were calculated for major diseases and constraints affecting cattle production in the study area. The means of quantitative data between study sites were compared by employing one-way analysis of variance (One-way ANOVA) in SPSS. The differences between means were declared significant at $p<0.05$.

RESULTS AND DISCUSSION

Socio-economic characteristics

Socio-economic characteristics of household in the study area are shown in Table 1. The average family size was 6.74±0.32 heads/household (ranging from 2-13) and this figure seemed to be less than the Ethiopian national average (7.4) and greater than Sub-Saharan average (5.6) as reported by USAID (2009). The higher HH size could be attributed due to practices of polygamous marriage as well as meager family planning in the *Woreda*. The results of this study agreed with findings of Dhaba (2011) in *Ilubabore* zone. There were a comparatively larger number of children per household in the *Dega* and *Woyna-dega* kebeles of the study area. Having many children is thought as an asset for farming activities and being large in number in a household has social prestige showing the strength of that family or clan. Similarly, study by Agajie et al. (2005) indicated that having many wives is one of wealth indicators and commonly practiced type of marriage in the Central Rift Valley.

The statistical analysis revealed that about 70% respondents were males and remaining 30% were females of different age and educational status. The results of the current work differed from the report of Ayza et al. (2013) who reported 48.3% female-headed households and 51.7% male headed household dairy farmers in *Boditti*. Most of the respondents (36.7%) were in the age group over 55 years old, while about 21.1, 18.9, 15.6 and 7.8% were in the age group ranging from 35-44, 25-34, 45-54 and 15-24 years old, respectively. This was in congruence with the report of Ayza et al. (2013), where 38% of households were over 40 years in *Boditti*.

About 77.8% of the respondents were married followed by widowed, single and divorced at 8.9, 7.8 and 5.6%, respectively. Regardless of their gender, educational level of the surveyed households showed that 15.6, 7.8 and 4.4% had primary, secondary and junior secondary schools educational status, respectively. About 3.3% of the respondents could read and write whereby 68.9% of the respondents were illiterate, which agreed with the findings of Kechero et al. (2013), where 70% of the respondents in *Dedo* district of *Jimma* zone were illiterate. This indicates that farmers need to get basic education required for adopting new technologies. Education is an important factor if lacking can negatively influence features of enhanced cattle production. Farmers with high education levels adopt usually new technologies more rapidly than lower educated farmers (Ofuoku et al., 2009). The occupation of the sampled households is displayed in Table 1. About 71.1% of the respondents in the study area were farmers (cattle and crop production) followed by students (15.6 %) and housewives (13.3%). This figure is less than the findings of Tesfaye (2007) in *Metema* district, where 82.9% of interviewed HH practicing mixed farming agriculture. This clearly indicated that both crop and cattle farming is the main income sources for the households in *Woreda*.

Farming system

Farming system is characterized by mixed crop-livestock production system which was confirmed by 95.5% of HHs and is similar to most parts of the central southern region. Cattle are the dominant livestock species, mainly used for milk and draught power followed by meat production, income and manure for maintaining soil fertility. This is in line with the report of Belay et al. (2012) in *Dandi,* where cattle were the main species reared by the respondents and were used primarily for draught power, traction, milk, and meat as secondary interest. Cattle also have an important socio-cultural role in the study area. This was consistent with the findings of Belay et al. (2012) in *Dandi* district. Crop farming in this area was mainly practiced using oxen/draught power and oxen are given due attention next to lactating cows particularly with regard to better feeding.

The major annual food crops grown in the area included cereals such as maize *(Zea mays)*, sorghum (*Sorghum bicolor*), barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), and teff (*Eragrostis teff*)), and pulses as beans (*Phaseolus vulgare*), peas (*Pisum sativum*). Maize and teff followed by beans, sorghum and peas were the dominant crops grown in the area. Perennial crops such as enset (*Ensete ventricosum)*, banana (*Musa paradisiaca*), coffee (*Coffea arabica*), sugar cane (*Saccharum officinarum*), avocado (*Persea americana*),

Table 1. Socio-economic characteristics of sampled households in the study area.

Variables	Category	Respondents N	Respondents %
Sex	Male	63	70
	Female	27	30
Age	15-24	7	7.8
	25-34	17	18.9
	35-44	19	21.1
	45-45	14	15.6
	>=55	33	36.7
Occupation	Farmer	64	71.1
	Student	12	15.6
	Housewife	14	13.3
Marital status	Single	7	7.8
	Married	70	77.8
	Widowed	8	8.9
	Divorced	5	5.6
Education	Illiterate	62	68.9
	Read and write	3	3.3
	Primary school	14	15.6
	Junior secondary	4	4.4
	Secondary	7	7.8
Average family size		6.74±0.32	

mango (*Mangifera indica*), papaya (pawpaw) (*Carica papaya*), different agro-forestry tree species and eucalyptus plantations and root crop (potatoes (*Solanum tuberosum*), sweet potatoes (*Ipomoea batatas*), cassava (*Manihot cassave*), yam (*Dioscorea*) and taro (*Colocasia esculenta*)) are also grown in considerable amounts. This was in line with the report of Ayza et al. (2013) in *Boditti, Wolaita* zone of southern Ethiopia. Cash crops, which many farmers grow at back yard, are pumpkins (*Cucurbita spp.*), geeshoo (*Rhamnus prinoides*) for preparation of local alcoholic drinks, garlic (*Allium sativum*), onions (*Allium cepa*), ginger (*Zingibere officinale Rosc.*) and pepper (*Piper nigrum*).

Landholding and land use pattern

The average land holding per household of the overall study sites was 2.91±0.18 ha. The land holding reported in this study was higher than that reported by Belay et al. (2012), who observed 2.5 ha average landholding, per household in *Dandi* district of Oromia Regional State, which call for intensification of cattle production in the area. In the Southern Regional State and the country studies indicated that the minimum landholding is 2.01 ha and the maximum is 5 ha for 32.6% smallholder farmers in the country and 16.2% of the stallholder farmers in SNNPR, respectively and landholding ranged from 1.01 to 2.00 ha for about 30.8% of farmers in the SNNPR and for 33.3% of farmers at the national level (CACC, 2003). The results revealed significant variation ($p<0.05$) in landholding between agro-ecologies.

The average land allocated for crop production, fallow land, others and grazing land per HH were 1.00±0.26, 0.92±0.20, 0.46±0.19 and 0.42±0.19, respectively (Table 2). The average size of total landholding was significantly ($p<0.05$) higher in *woyna-dega* (3.31±0.17 ha) than *dega* and *kolla*, 2.93±0.18 and 2.43±0.21 ha, respectively. Likewise, land allocated to crop cultivation and fallow land varied in the three agro-ecologies. Grazing land and others (e*nset* and backyard cash crop cultivation and house construction) were not varied in the study district. Larger proportion of land was allocated for crop cultivation in *Woreda*. This was in agreement with the report of Belay et al. (2012), who indicated that majority of the land owned per household was used for crop production in *Dandi* district. In the study *Woreda*, less land was allocated for cattle grazing. This indirectly may indicates that there is less attention paid to grazing land, which results

Table 2. Landholding (ha) and land use pattern observed in the Essera *Woreda*.

Characteristics	Agro-ecology					
	Dega	*Woyna-dega*	*Kolla*	Overall	Test	
	N=30	N=30	N=30	N=90	F-value	p-value
Total land holding	2.93±0.18	3.31±0.17	2.43±0.21	2.91±0.18	6.086	0.003*
Crop land	1.05±0.17	1.13±0.07	0.84±0.20	1.00±0.26	3.549	0.033*
Grazing land	0.42±0.16	0.33±0.15	0.52±0.19	0.42±0.19	1.717	1.186
Fallow land	0.94±0.16	1.20±0.14	0.61±0.19	0.92±0.20	13.070	0.000*
Other land	0.51±0.16	0.40±0.14	0.46±0.18	0.46±0.19	1.954	0.148

*=Significance (p<0.05) difference; N= number of households; Other land includes land for Enset, backyard cash crops cultivation, both human and cattle house construction.

Table 3. Means and standard errors of cattle herd structure in the study area.

Herd type	Agro-ecology					
	Dega	*Woyna-dega*	*Kolla*	Over all	Test	
	N=30	N=30	N=30	N=90	F-value	p-value
Total cows	3.43±0.37	8.90±0.51	5.33±0.88	5.89±0.43	19.619	0.000*
Milking cows	1.33±0.16	2.27±0.22	1.67±0.29	1.76±0.14	4.319	0.016*
Dry cows	1.17±0.18	4.60±0.29	2.27±0.43	2.68±0.24	30.710	0.000*
Pregnant cows	0.93±0.13	2.03±0.21	1.40±0.24	1.46±0.12	7.647	0.001*
Oxen	1.33±0.18	1.60±0.13	2.60±0.43	1.84±0.17	5.788	0.004*
Total calves	1.60± 0.20	2.40± 0.22	2.00± 0.46	2.00± 0.18	1.591	0.209
Male calves	0.47± 0.09	1.27± 0.17	0.73± 0.20	0.82±0.10	6.444	0.002*
Female calves	1.13±0.18	1.13±0.13	1.27±0.28	1.18±0.12	0.137	0.872
Bulls	0.93± 0.08	0.27± 0.08	0.67 ±0.23	0.62±0.09	5.032	0.009*
Heifers	0.87± 0.12	0.67 ±0.11	0.53 ±0.23	0.69±0.09	1.056	0.352
Crossbred	0.07±0.05	0.17±0.10	0	0.08±0.04	1.831	0.166
Mean holding/HH	13.27±1.13	14.00±0.58	11.13±0.40	11.12±0.69	4.591	0.013*

* =shows significant difference (p<0.05); N=Number of households; HH=households.

in shortage of grazing land in all study *kebeles*. The findings of this study agreed with the work of Zewdie (2010) which illustrated shortage of grazing land as the major contributor to critical feed shortages in the Highland areas.

Cattle holding and herd structure

Cattle holding and the herd structure per household in the study area are given in Table 3. The overall mean of cattle holding per household was 11.12±0.69. This figure was less than that of Tesfaye (2007) with 12.25±0.6.23 cattle per household in Northwestern Ethiopia and greater than that of Belay et al. (2012) with 4.53±0.4 cattle per HH in *Dandi* district. There were differences in cattle holding within the studied area. The average size of cattle was significantly (p<0.05) higher in *woyna-dega* (14.00±0.58) than *dega* and *kolla*, 13.27±1.13 and 11.13±0.40, respectively. It was observed that the average number of cows, oxen, calves, bulls, heifers and crossbred were 5.89±0.43, 1.84 ±0.17, 2.00±0.18, 0.62±0.09, 0.69±0.09 and 0.08±0.04, respectively. This was in agreement with the findings of Belay et al. (2012), where oxen and milking cows accounted for 37 and 16%, respectively of the total cattle holding in *Dandi*. The reason for large proportion of cows was that they are maintained for producing replacement oxen, very important for draught power. The higher proportion of cows obtained in this study was in agreement with the report of Tesfaye (2007) in *Metema*. Next to calves, the higher number of oxen per HH indicated their importance for draught power. This was in agreement with the reports of CACC (2003), where cows and oxen represented 42 and 40% respectively of the total cattle in mixed farming system. The results revealed that there was a significant (p<0.005) difference in total cows, milking, pregnant and dry cows, oxen, male calves and bulls holding within the studied agro-ecologies. In *woyna-dega,* there was significantly large number of total cows

Table 4. Purposes of keeping cattle in the study area.

Variables	Category	Respondents							
		Agro-ecology							
		Dega		***Woyna-dega***		***Kolla***		**Total**	
		N	%	N	%	N	%	N	%
Purpose of keeping cattle	Milk production only	16	53.3	13	43.3	17	56.7	42	46.7
	Traction only	0	0	0	0	4	13.3	4	4.4
	Milk and traction	30	100	30	100	26	86.7	86	95.6
	Meat production only	10	33.3	13	43.3	17	56.7	40	44.4
	Manure	30	100	30	100	30	100	90	100
	Others	22	73.3	14	46.7	20	66.7	34	37.8

N=Number of households.

Table 5. Labor division of the family member for cattle management activities.

Type of activities	Agro-ecology								
	Dega **(%)**			***Woyna-dega*** **(%)**			***Kolla*** **(%)**		
	F	M	FM	F	M	FM	F	M	FM
Milking	100	0	0	100	0	0	93.3	0	6.7
Milk processing	100	0	0	100	0	0	100	0	0
Milk and milk products selling	100	0	0	100	0	0	100	0	0
Pregnant cow feeding and caring	73.3	26.7	0	40	60	0	86.7	0	13.3
Cattle herding	13.3	53.3	33.3	13.3	26.7	60	0	20	80
Bull feeding	0	100	0	0	100	0	0	100	0
Traction	0	100	0	0	100	0	0	100	0
Calf rearing	93.3	6.7	0	100	0	0	100	0	0
Heifer rearing	80	20	0	60	40	0	0	100	0
Barn cleaning	93.3	0	6.7	100	0	0	86.7	0	13.3
Herd feeding/watering	26.7	73.3	0	26.7	26.7	46.7	26.7	20	53.3
Feed collection	20	66.7	13.3	30	53.3	16.7	20	53.3	26.7

F=Female, M=male and FM=female and male.

(8.90 ± 0.51), milking (2.27±0.22), dry (4.60±0.29) pregnant cows (2.03±0.21) and male calves (1.27±0.17) than other agro-ecologies and there was significantly large number of bulls in *dega* (1.47±0.13) followed by *kolla* and *woyna-dega*.

Purpose of keeping cattle

The results of current study revealed that cattle in *Woreda* are kept for different purposes. Knowledge of reasons for keeping cattle is prerequisite for devising breeding goals (Rewe et al., 2006). As shown in Table 4, 95.6% of respondents keep cattle for both milk and traction. Etafa et al. (2013) reported that the primary purpose of keeping oxen in *Hararghe* was for draft power accounting for 99.4% of the responses, whereby cows were kept for sell of milk and for other purposes accounting for 86.6 and 12.5% of responses, respectively. In current study, about 46.7 and 44.4% of the farmers in the *Woreda* held cattle for only milk and meat production, respectively. All households keep cattle for manure purposes while 37.8% of farmers keep cattle for other purposes.

Labor division for cattle management

All HHs (100%), in *dega* and *woyna-dega* agro-ecologies indicated that only females were responsible for milking cows (Table 5). About 93.7% of the households in the *kolla* area designated that only female members of the household were responsible for cow milking (Table 5). The results were in agreement with the findings of Alganesh (2002) in eastern *Wollega*, Kedija, (2008) in *Mieso* district and Lemma (2004) in East Shoa zone where female members of the HH entirely undertook milking. However, Asaminew and Eyassu (2009) reported

Table 6. Breed, breeding system of cattle and major reasons for not using AI services.

Breed of cattle	Agro-ecology					
	Dega **(%)**	***Woyna-dega*** **(%)**	***Kolla*** **(%)**	***Overall*** **(%)**	***Test***	
					F-value	**p-value**
Local breed	97.3	97.1	100	99.5	1.482	0.233
Crossbred	2.7	2.9	0	0.5		
Breeding systems						
Natural mating	80	66.7	100	82.2	6.407	0.003*
Both natural mating and AI	20	33.3	0	17.8		
Reasons for not using AI						
Lack of awareness	10	23.3	6.7	13.8	0.663	0.321
Inaccessibility to AI services	60	43.3	73.3	57.8	0.075	0.996
Difficulty of getting inseminator	16.7	23.3	10	16.7	1.251	0.293
Small size of indigenous cattle	13.3	10	13.3	15.6	1.01	0.298

*=Significance difference ($p<0.05$).

that for Bahir Dar Zuria and Mecha districts mainly males did milking. Only 6.7% of the households in *kolla* indicated that not only females but also males take part in milking of cows. According to respondents, in all agro-ecologies, males were not involved in milk processing, milk and milk products selling. This was in line with results reported for northwestern Ethiopia where female members of the HH performed marketing of dairy products (Asaminew and Eyassu, 2009). In contrast, traction and bull feeding activities were the task of males. Irrespective of the age of family members, about 33.3 and 13.3% in *dega*, 60 and 6.7% in *woyna-dega,* and 80 and 26.7% in *kolla* of the respondents reported that cattle herding and feed collection activities were the responsibility of both sexes, respectively, which agreed with reports of Ayalew et al. (2013) in *Ilu Aba Bora* Zone of South Western Ethiopia.

Cattle husbandry and management

Cattle breeds and breeding systems

About 99.5% of the respondents owned non-descriptive local breeds of cattle, whereas 0.5% of the respondents had crossbred heifers (Table 6). About 0.3% of crossbred (Holstein Frisian X Zebu) were distributed by MoA and the rest 0.2% of crossbred were obtained through artificial insemination. Also, Ayalew et al. (2013) reported that the cattle breeds kept in *Ilu Aba bora* zone were 100% non-descriptive indigenous cattle. Correspondingly, in Ethiopia according to CSA (2003), 99.4% of the total cattle populations in the country are local breeds while the hybrids and the exotic breeds accounted for about 0.5 and 0.1%, respectively. Of total respondents, 82.2% indicated that natural mating is the only breeding system practiced and the rest 17.8% practiced both natural mating and AI, which agreed with findings of Ayalew et al. (2013). Thus, the study suggested the need to introduce artificial insemination service to increase the genetic merit of the herd in order to improve milk production.

In the current study during the breeding season, some farmers mated their cows and heifers by using superior bulls owned by themselves or the neighbors, whereas most farmers bred their cows by any bull available in the herd when their cows are on heat. Some farmers who have superior bulls are not willing to give their bulls to their neighbor for breeding service because of the notion that their bull might lose its genetic superiority due to the interbreeding process. About 84.4% of the respondents selected the best bulls for breeding purpose. Coat color and body conformation; and behavior of bulls were indicated as parameters for selection by 80 and 37.8% of respondents, respectively and 81.7% of the respondents said that breeding was uncontrolled.

This result was in line with the result reported by Mekonnen et al. (2012) in which traits like body size, physical appearance, coat color and hump size were considered by farmers for bull selection. About 51.9% of respondents had breeding bull. About 65.2% of HH having bull indicated that bull serves their own and neighbor herd freely and the rest 34.4% HH pointed that they use their bull for their own herd only. Based on the survey, majority of respondents (77.8%) had no experience of using AI. About 57.8, 16.7, 15.6 and 13.8% of respondents indicated that the reasons for the limited use of AI in the study area were inaccessibility to AI services, difficulty of getting inseminator, their fear about the small size of local cows to carry the pregnancy and deliver the offspring of improved breeds and lack of awareness, respectively (Table 6).

Table 7. Traditional cattle diseases treatment in the study *Woreda* from focus group discussion.

Diseases	Method of treatment
Trypanosomiasis	Branding the area around the swelling with hot iron.
Blackleg	Smoking white *Eucalyptus tree* leaves, drenching cattle with grinded and homogenized with water and incising around the shoulder and depositing butter inside, and branding with a very hot sickle or iron bar.
Leech	Nasal administration of grinded fresh leaves of *Colocasia esculenta (Taro)*, *Nicotiana tobacum*, *Citrus aurantiflora*, *Allium cepa (Tumuwa), Aframomum corrarima (Okashiya), Zingibere officinale*, individually homogenized in water. Oral administration of albendazole dissolved in water
Ticks	Painting the area where ticks are present with Vaseline and diesel. Provide cattle with salt added drinking water.
Cough	Oral administration of homogenized inner part of *Solanum incanum (Buluwaa)* fruit.
Diarrhea	Drenching the crushed and homogenized fresh bark of *Syzygium guineense (Ocha)* and feeding of seeds of *Lepidium sativum (Fexo)* mixed with grinded leaves.
Dystocia/ placenta retention	Feeding the cattle red colored *Enset* leaf.

Cattle health condition and treatments

Different disease types were found in the study area, indicating the need to establishing and extending veterinary service in the future to increase production of cattle in the area through reducing disease incidence and severity. Therefore, it is essential to give attention through establishing different sites of veterinary service and veterinary technician in different sites at large. In current study, major animal diseases and parasites were identified through group discussion involving key informant farmers, development agents and veterinary technicians. As reported by Tajebe et al. (2011) economic losses due to disease and parasites have quadruplet their effect further when factors such as feed shortage, poor management practices and environmental factors are prevalent.

The result showed that trypanosomiasis, mastitis, *Zuluwa* (bloody urine symptom disease) and anthrax were the major diseases that affect cattle production with indices of 0.263, 0.200, 0.166 and 0.160, respectively (Appendix 1). Leech and others such as CBPP and pasteurellosis were the next important diseases with indices of 0.115 and 0.048, respectively (Appendix 1). Others such as black leg, ticks and FMD were least ranked diseases (Appendix 1). The reason for the existence of different diseases among the study areas was probably due to the variation in agro-ecology. Bloody urine (*Zuluwa*) was the most economically important disease in the *Dega* agro-ecology of the study area. This might be due to major feed resources at Essera *Woreda* which are majorly natural pasture and is seasonally water logged. Also *Woreda* lacks clean tap water for animals to drink which tends to increase the chances of exposure to fluke infection. However, farmers perceived that the source for blood urinating (*Zuluwa*) was due to '*Keste-damena.'* When cattle urinates directing their genital organ towards rainbow (*Keste-damena)* they suffer from *Zuluwa* and this works for human being also.

Ticks were major ectoparasites of cattle in the study area and they tend to result in milk yield reduction and reduction in weight gain of cattle. Belay et al. (2012) reported that mastitis and external parasites are the major diseases of importance in *Dandi* district. Ectoparasite infestations impose economic losses because of reduction in leather quality, reduction in body weight gain and milk yield, occasional mortality, reduction in performance of draught animals and losses associated with treatment and prevention of diseases (Regasa et al., 2006).

According to group discussion, farmers indicated that feed shortage was acute during the months of January to April. Cattle in the area get sick during these periods. This might be due to feed deficiency, which predisposes the animals to low disease resistance. The shortage of feed and inadequate supplementary feeding were reported to be major causes of livestock mortality and poor performances in highland agro-ecologies of southern and central Ethiopia (Desta and Oba, 2004; Hassen et al., 2010).

Total respondents of 83.3% in the study area have access to government based para-veterinary service. In the study area, there was one animal health technician for every two *kebeles* but the service delivery was not to the required extent owing to inadequate veterinarians and veterinary supplies, cost of veterinary drugs and inadequate transport facilities. Lack of veterinary services, un-affordability of veterinary drugs and shortage of skilled technician were some of the major constraints limiting cattle production. There was no even a single private veterinary clinic in *Woreda*. The present findings were in agreement with that reported by Mekete (2008) and Belete et al. (2010).

Sampled farmers of 68% in *Woreda* use an alternative measure of ethno-veterinary treatments and indigenous knowledge. Extracts from leaves and roots, local vegetation and other ingredients are used to be applied against various diseases and parasites (Table 7). About 72% of respondents in the area perceived ethno-veterinary treatments to have a potential either to reduce pathogenic

Table 8. Respondents ranking using different feed resources based on season in the study area.

Agro-ecology	TFR	Dry season				Wet season			
		1st	2nd	3rd	4th	1st	2nd	3rd	4th
	NP	**66.7**	**20**	**13.3**	**0**	**100**	**0**	**0**	**0**
Dega	CR	6.7	66.7	26.7	0	0	0	100	0
	CAm	26.7	13.3	60	0	0	100	0	0
	Others	0	0	0	100	0	0	0	100
W. Dega	NP	46.7	20	33.3	0	80	20	0	0
	CR	40	60	0	0	0	0	100	0
	CAm	6.7	13.3	66.7	13.3	0	80	0	20
	Others	6.7	6.7	0	86.7	20	0	0	80
Kolla	NP	50	23.3	26.7	0	90	10	0	0
	CR	33.3	63.3	3.3	0	0	0	100	0
	CAm		13.3	16.7	70	10	90	0	0
	Others	0	0	0	100	0	0	0	100
Overall	NP	54.4	21.1	24.4	0	90	10	0	0
	CR	26.7	63.3	10	0	0	0	100	0
	CAm	15.6	14.4	65.6	4.4	3.3	90	0	6.7
	Others	2.2	2.2	0	95.6	6.7	0	0	93.3

TFR=Type of feed resource, NP=natural pasture, CR = crop residue, CAm=crop aftermath.

effects or cure completely. This is consistent with Kocho and Geta (2011). Farmers are using their indigenous knowledge to treat their sick animals using different mechanisms but the dosage of the treatments and the impact of the drugs are not known (Table 7). Burning of cattle body to treat their sick animal may have mechanical damage on their body. On the other hand, the efficacy and dosage of medicinal herbaceous plants should be studied for possible large-scale production and uses.

Feed resources and feeding system

Different feed types were used in the study area. Natural pasture, crop residue, crop aftermath and others were ranked 1st, 2nd, 3rd and 4th by 54.4, 63.3, 66.5 and 95.6% of HHs during dry season in overall agro-ecology, respectively (Table 8). In contrast, during wet season natural pasture, crop aftermath/stubble grazing, crop residues and others were the first, second, third and fourth ranked sources of cattle feed by 90, 90, 100 and 93.3% of HHs, respectively, which were in line with the report of Belay et al. (2012) in *Dandi* district. Free grazing on natural pastureland was the most dominating feeding system for the cattle in the study area. Natural pasture in the high altitudes was rich in pasture species, particularly indigenous legumes (Kechero et al., 2010). According to field observation and survey results, there was grazing of cattle on communal and private pastureland, roadside, swampy area and around homestead either free or tethered in the study area.

Feed shortage is prevalent throughout the year both in dry and wet seasons (Kechero et al., 2013). Results showed that there were no effects of the agro-ecology on cattle feeds, but season had effect on cattle feeds in the study area. Inadequate supply of feed in both quantity and quality was reported to be the single most important problem responsible for low productivity of livestock (Ulfina et al., 2005). Due to continuous stocking and over grazing of pastures and roadsides grasses, soil erosion has developed into major phenomenon. Encroachment of the less palatable and preferred plants like *Asracantha longifolia* locally known as *okaa* in the major grazing areas become a major problem of cattle production. Tethering and cut-and carry were mainly practiced in major cropping seasons.

Cattle housing system

Out of total HHs, 97.8% had experience of housing their cattle (Table 9). Similar results were reported by Jiregna (2007) and Oumer (2011). The results of present study also agreed with reports of Abrha (2007), who reported similar finding in Tigray National Regional State where livestock housing is very primitive even compared to sub-Saharan African standard. Out of total respondents included in the study, 93.3% kept their animals in their living house, which was not separated from the owners living houses and the rest 6.7% kept their cattle in simple

Table 9. Importance of cattle housing in the study area.

Variables	Responses		
	Yes (%)	No (%)	NC (%)
Protect from extreme climate	97.8	0	2.2
Protect from predators	97.8	0	2.2
Protect from theft	80	17.8	2.2
[1]Others	66.7	31.1	2.2

NC=not concerned: [1]Others=for ease of husbandry practices such as feeding, watering, milking, waste management.

Table 10. Water source and frequency of offering water in the study area.

Sources of water		Dega (%)	Woyna-dega (%)	Kolla (%)	Total (%)
River		100	66.7	60	75.6
Spring water		0	20	20	13.3
Tap water		0	13.3	20	11.1
Frequency of watering					
Once a day		20.3	4.7	6.7	10.56
Twice a day	Dry season	73.2	80	85.3	79.5
Ad libtum		6.5	10	13.3	9.9
Once a day		61.3	24.5	63.3	49.7
Twice a day	Wet season	5.1	5.1	16.7	8.96
Ad libtum		33.6	70.4	20	41.3

crashes within their own compounds. 93.3% of respondents housed their cattle in the dry as well as wet seasons. About 97.8% of respondents house their cattle in their home to protect them from extreme climate and predators, respectively, 80% house their cattle to protect them from theft, while 66.7% to protect from others (Table 9). Ayza et al. (2013) reported similar reasons, where Boditti cattle were housed together with the family because of protection from theft, extreme environmental hazards and ease of husbandry practices such as feeding, watering, milking, waste management.

Source of water and its utilization

Source of water and its utilization in the study areas is presented in Table 10. The sources of water for cattle were river (75.5%), spring (13.3%) and tap (11.1%). This general trend of water sourcing is in agreement with Zewdie (2010) who reported similar results in *Debre-Birhan* area. The quality of water and the distance traveled to reach are major concerns. With regard to the frequency of offering water to drink, majority (79.5%) of the respondents give water to their cattle twice a day during dry season, while 10.56% of the respondents offer water to their cattle once a day and 9.9% of the respondents offered water freely during dry season. Out of the interviewed cattle producers, 49.7% of HH offered water once a day and 41.3 and 8.96% of HH provided water to their animals freely and twice a day during wet season, respectively. About 91.1% of the respondents indicated the existence of water related problem. The major water related problems were scarcity (44%), access to water sources (35.5%) and hygiene problems (20.5%) especially during dry period. Poor quality of water leads to pathogens and helminthes infestation among the animals thereby resulting in disease outbreaks, higher morbidity and mortality, and lower productivity. The survey revealed that 71.1, 20 and 8.9% of respondents alleviated water related problems by going long distance to the river, fetching from rivers and digging the ground water, respectively. Descheemaeker et al. (2009) in the Blue Nile basin made similar observations.

Manure disposal and utilization

Hundred percent of cattle producers in the study area used animal dung as fertilizer. Similarly, Zewdie (2010) reported that animal dung around *Ziway* was used to fertilize croplands and few farmers used it for their grazing lands. In addition, according to 58.3 and 30.2% of respondents, it is also used for other purposes and

Table 11. Cattle manure utilization in the study area.

Utilization	Dega		Woyna-dega		Kolla		Over all	
	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)
Fertilizer	100	0	100	0	100	0	100	0
Fuel	43.6	56.4	27	73	20	80	30.2	69.8
[1]Other purposes	67.2	32.8	54.9	45.1	52.7	47.3	58.3	41.7

[1]Other purposes (mud house construction, pottery and wastage).

household fuel, respectively (Table 11). Belete et al. (2010) reported in *Fogera woreda* that the majority of the respondents (98.1%) used the dung as source of fuel. All HH had no practice of marketing animal dung (dung cake) for fuel or fertilizer purposes in the studied area, which is in agreement with findings of Ayza et al. (2013) in B*oditti* who reported no practice of marketing animal dung (dung cake) for fuel or fertilizer purpose. Contrastingly, Zewdie (2010) reported that dairy farmers from *Debre- Birhan* and *Sebeta* used dung mostly to make dung cake to sell at the local market or for satisfying family's own energy needs. The majority of the respondents (65.4%) indicated that they dispose manure from the barn once a day. Ayalew et al. (2013) reported also from *Ilu aba bora* zone that 43.3% of the respondents disposed manure from the barn once per day.

Major constraints of cattle production/improvement

Generally, cattle production was affected by several factors. According to respondents, feed shortage, diseases, water shortage and poor genetic makeup were the major constraints that affect cattle production with indices of 0.385, 0.367, 0.111 and 0.100, respectively (Appendix 2). Shortage of initial capital and lack of technical knowhow were other constraints. The first and second constraints of this study were in consonance with the study of Belay et al. (2012); it is also similar with the result of Ulfina et al. *(*2005), in which he reported feed shortage, diseases and parasites, labor scarcity and lack of capital and credit as the major constraints limiting livestock production. In the meantime, the third and fourth constraints were different for this study. However, all listed problems in the finding of Ulfina et al. (2005) and Belay et al. (2012) were also similar problems as observed in this study. Results of the present study were in line with the observations of Asaminew (2007) in *Bahir Dar Zuira* and *Mecha* districts.

CONCLUSION AND RECOMMENDATIONS

The study assessed cattle husbandry practices, like breeding system, watering, housing, healthcare and major feed resources. Results of the study showed that mixed crop-livestock production system was the dominant farming system in the study area. Cattle served as a source of draught power, food, manure and others like source of income. The current study showed that natural mating was the most mating system practiced. Trypanosomiasis is the first most important cattle disease followed by mastitis and anthrax in the study area. Feed availability in quantity and quality was ranked the first most important problem limiting cattle production. Natural pasture and crop residues were the main sources of feed for cattle. In the study area, the higher proportion of feed was derived from natural pasture and crop-residues, and natural pasture and stubble grazing during dry and wet season, respectively. There was cattle feed shortage in the study area. Feed shortage, diseases and parasites, water scarcity and poor genetic makeup of cattle were the major constraints limiting cattle production. Based on the results and conclusions of this study, the following recommendations are forwarded for improving cattle development in the study area. These are:

1. Provision of strong extension services and training on improved forage cultivation, cattle production and management practices.
2. The cattle breeds in the study area were not known which called for characterization of existing breeds to ascertain the different traits that will give better performance which will help in developing future intervention areas. The potential of existing breed for dairy production, beef production, etc. needs to be identified, so that specialization based improvement can be done for each breed.
3. Detailed monitoring study is imperative to investigate the productive and reproductive performance of cattle to further substantiate the results of the present study.
4. Cattle marketing and market related issues are not included in this study due to financial and time constraints. Therefore, further research on cattle marketing system and market related problems is commended to come up with recommendations to solve market related problems and play a vital role in helping farmers.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Abrha G (2007). Major animal health problems of market oriented livestock development in Atsibiwomberta Woreda, Tigray Regional State. M.Sc. Thesis, Faculty of Veterinary Medicine, Addis Ababa University, Debrezeit, Ethiopia.

Agajie T, Ebrahim J, Sitotaw F, David G, Smith (2005). Technology Transfer Pathways and Livelihood Impact Indicators in Central Ethiopia. *J. Trop. Anim. Health Prod.* 37(1):101-122.

Alganesh T (2002). Traditional milk and milk products handling practices and raw milk quality in eastern Wollega, MSc Thesis, Alemaya University, Ethiopia.

Arsham H (2007). Questionnaire design and survey sampling. http//www.mirror service. Org/site/hom.ubaltedu/ntsbarsh/Business-stat.

Asaminew T (2007). Production, handling, traditional processing practices and quality of milk in Bahir-Dar milk shed area, Ethiopia. M.Sc. Thesis. Alemaya University, Alemaya. P. 130.

Asaminew T, Eyassu S (2009). Smallholder dairy production system and emergence of dairy cooperatives in Bahir Dar Zuria and Mecha Woredas, Northwestern Ethiopia. World J. Dairy Food Sci. 4:185-192.

Ayalew T, Duguma B, Tolemariam T (2013). Smallholder Cattle Production Systems in Three Districts of Ilu Aba Bora Zone of Oromia Regional State, South Western Ethiopia, 8(1):38-46.

Aynalem H, Workneh A, Noah K, Tadele D, Azage T (2011). Breeding strategy to improve Ethiopian Boran cattle for meat and milk production. IPMS (Improving Productivity and Market Success) of Ethiopian Farmers Project. Working Paper No. 26. ILRI (International Livestock Research Institute), Nairobi, Kenya.

Ayza A, Yilma Z, Nurfeta A (2013). Characterization of milk production systems in and around Boditti, South Ethiopia. *Livestock Research for Rural Development. Volume 25, Article #183.* Retrieved November 17, 2013, from http://www.lrrd.org/lrrd25/10/ayza25183.htm

Befekadu D, Birhanu N (2000). Annual report on the Ethiopian economy. Volume 1.The Ethiopian Economics Association, Addis Ababa, Ethiopia, Bureau of African Affairs, 2006, P. 429*. http://www.state.gov/r/pa/bgn/2859.htm.*

Belay Duguma, Azage Tegegne, Hegde BP (2012). Smallholder Livestock Production System in Dandi District, Oromia Regional State, Central Ethiopia. Global Veterinarian 8(5):472-479, 2012 ISSN 1992-6197. IDOSI Publications, 2012.

Belete Anteneh, Azage Tegene, Fekadu Beyene, Berhanu Gebremedhin (2010). Cattle milk and meat production and marketing systems and opportunities for market-orientation in Fogera Woreda, Amhara region, Ethiopia. IPMS (Improving Productivity and Market Success) of Ethiopian Farmers Project Working Paper 19. ILRI (International Livestock Research Institute), Nairobi, Kenya. P. 65.

Central Agricultural Census Commission (CACC) (2003). Ethiopian Agricultural Sample Enumeration, 2001/02. Results for Southern Nations, Nationalities and peoples Region. Statistical Report on Livestock and Farm implements. Part IV. (July 2003), Addis Ababa, Ethiopia.

CSA (Central Statistical Agency) (2003). Ethiopian Agricultural sample enumeration. 2001/02 results for Amhara region, statistical report on livestock and farm implements, part 4, Addis Ababa, Ethiopia.

CSA (2008). Livestock and Livestock Characteristics, Agricultural sample Survey. Statistical Bull. 2(446):188.

CSA (2009). Federal Democratic Republic of Ethiopia, Agricultural Sample Survey. Addis Ababa, Ethiopia.

CSA (2011). Agricultural sample survey. Volume II report on livestock and livestock characteristics.

Descheemaeker K, Tilahun A, Amare H (2009). Livestock and water interactions in mixed crop-livestock farming systems of Sub-Saharan Africa: Interventions for improved productivity. Colombo, Sir Lanka: International Water Management Institute. (IWMI Working Paper 133) P. 44.

Desta Z, Oba G (2004). Feed scarcity and livestock mortality in enset farming systems in the Bale highlands of Southern Ethiopia. Outlook on Agriculture. 33:277-280.

Dhaba Urgessa (2011). Characterization of small ruminant production systems in three coffee producing districts of Ilubabore zone, southwest Ethiopia. MSc thesis submitted to school of graduate studies of Jimma University, College of Agriculture and Veterinary Medicine, P. 98.

EARO (Ethiopian Agricultural Research Organization) (2001). Feeds and nutrition research strategy. EARO (Ethiopian Agricultural Research Organization), Addis Ababa. P. 40.

EWARDO (Essera *Woreda* Agriculture and Rural Development Office) (2008). Official Document on Agro climatic Condition of the Woreda, Unpublished. Balle, SNNPR, Ethiopia.

EWARDO (Essera Woreda Agriculture and Rural Development Office) (2013). Official Document on Livestock resources and land condition of the Woreda, Unpublished. Balle, SNNPR, Ethiopia.

EWFEDO (Essera Woreda Finance and Economy Development Office) (2013). Official Document on Human population of the Woreda, Unpublished. Balle, SNNPR, Ethiopia.

Etafa A, Esmael Y, kasim K, Debela, M (2013). Cattle Production in West Hararghe : An Opportunity and Constraints Assessments in Darolabu, Odabultum, Gemechis and Chiro, 1(1):1-15.

FAO (Food and Agriculture Organization of the United Nations) (2005). Production *Year Book*. FAO, Rome, Italy.

Hassen Ahmed, Ebro Abule, Kurtu Mohammed, Treydte AC (2010). Livestock feed resources utilization and management as influenced by altitude in the Central Highlands of Ethiopia. Livest. Res. Rural Dev. 22*:*229. Retrieved March 14, 2012, from http://www.lrrd.org/lrrd22/12/hass22229.htm.

IGAD-LPI (Inter-Governmental Authority on Development-Livestock policy initiative) (2011). The Contribution of Livestock to the Ethiopian Economy - Part I.

Jiregna D (2007). Characterization of cattle genetic resources in their production systems context in danno district, west shoa, Oromia, Ethiopia, M.S. thesis, School of Graduate Studies, Alemaya Univ. of Agriculture.

Kechero Y, Belay D, Janssens GPJ (2010). Indigenous fodder trees and shrubs: Nutritional and ecological approaches. Proceedings of 14th ESVCN Congress, Zurich, Switzerland, pp. 121-121.

Kechero Y, Tolemariam T, Haile A (2013). Characteristics and Determinants of Livestock Production in Jimma Zone / Southwestern Ethiopia, **5**(2):69-81.

Kedija H (2008). Characterization of milk production system and opportunity for market orientation: A Case Study of Mieso District, Oromia Region, Ethiopia. M.Sc. Thesis. Haramaya University, Ethiopia.

Kocho T, Geta E (2011). Agro-ecologic mapping of livestock system in smallholder crop-livestock mixed farming of Wolaita and Dawuro districts, Southern Ethiopia. Livest. Res. Rural Dev. 23(51). Retrieved November 17, 2013, from http://www.lrrd.org/lrrd23/3/koch23051.htm.

Lemma F (2004). Assessment of butter quality and butter making efficiency of new churns compared to smallholders' butter making techniques in east Shoa of zone of Oromia, Ethiopia, M.S. Thesis, Alemaya Univ., Ethiopia.

Mekete B (2008). Integrating Livestock in to Water Resources Development: Assessment on Livelihood Resilience and Livestock Water Productivity at Golina and Alewuha Rivers. (MSc thesis). Hawassa University. Ethiopia. P. 144.

Mekonnen A, Haile A, Dessie T, Mekasha Y (2012). On farm characterization of Horro cattle breed production systems in western Oromia, Ethiopia. Livest. Res. Rural Dev. 24(100). Retrieved March 30, 2013, from http://www.lrrd.org/lrrd24/6/meko24100.htm

Melaku T (2011). Oxenization versus Tractorization: Options and constraints for Ethiopian framing system. Int. J. Sustain. Agric.

3(1):11-20.
Ofuoku AU, Egho EO, Enujeke EC (2009). Integrated Pest Management (IPM) adoption among farmers in Central Agro-ecological Zone of Delta State, Nigeria. *Adv. Biol. Res.* **3**(1-2):29-33.
Oumer S (2011). On - farm phenotypic characterization of cattle in Jimma zone, southwestern Ethiopia, M.S. thesis, Jimma Univ., Ethiopia.
Regasa C, Shelima B, Abalti A, Dawo F, Dinka H (2006). Survey of farmers' perception on major health constraints of cattle under smallholder management systems in eastern shoa zone of Oromia Region. Ethiopia.
Rewe TO, Indetie D, Ojango JMK, Kahi AK (2006). Breeding objectives for the Boran breed in Kenya: Model development and application to pasture-based production systems. Anim. Sci. J. 77:63-177.
SPSS (2013). Statistical package software for social science (2013) version 20.00. SPSS in.c.1989-2013, USA.
Tajebe Seare, Gangwar SK, Kefelegn Kebede (2011). Performance and physical body measurement of Abergell sheep breed under traditional management system of Tigray Regional state, Northern Ethiopia. Int. J. Sci. Nat. 2(2):225-230.
Tesfaye M (2007). Characterization of cattle milk and meat production, processing and marketing system in Metema district, Ethiopia, M.S. thesis, Hawassa Univ., Awassa, Ethiopia.
Ulfina G, Zelalem B, Jemal D, Gemeda D, Chala M, Jiregna D, Diriba G, Lemma G, Workneh A, Adam D (2005). Survey of cattle production and marketing practices in Danno District, western Ethiopia, using PRA tools. PRA Report.
USAID (United States Agency for International Development) (2009). USAID Country Health Statistical Report. USAID, Addis Ababa, Ethiopia.
Zewdie W (2010). Livestock production systems in relation with feed availability in the Highlands and central rift valley of Ethiopia, MSc Thesis presented to Haramaya University.

Appendix 1. Indices of prevalence of cattle disease in the study area.

Diseases	Agro-ecology															
	Dega				*Woyna-dega*				*Kolla*				Total			
	R1	R2	R3	Index	R1	R2	R3	Index	R1	R2	R3	Index	R1	R2	R3	Index
Trips	0	0	0	0.000	26.7	33.3	26.7	0.289	100	0	0	0.500	42.2	11.1	8.9	0.263
FMD	0	0	0	0.000	0	0	6.7	0.011	0	0	0	0.000	0	0	2.2	0.004
Anthrax	0	60	40	0.267	26.7	0	20	0.167	0	0	26.7	0.044	8.9	20	28.9	0.160
BL	0	0	0	0.000	6.7	6.7	0	0.056	0	0	26.7	0.044	2.2	2.2	8.9	0.033
Mastitis	0	40	60	0.233	40	20	6.7	0.278	0	26.7	0	0.089	13.3	28.9	22.2	0.200
BU	100	0	0	0.500	0	0	0	0.000	0	0	0	0.000	33.3	0	0	0.166
Leech	0	0	0	0.000	0	40	13.3	0.156	0	40	33.3	0.189	0	26.7	15.6	0.115
Ticks	0	0	0	0.000	0	0	13.3	0.022	0	0	6.7	0.011	0	0	6.7	0.011
Others	0	0	0	0.000	0	0	13.3	0.022	0	33.3	6.7	0.122	0	11.1	6.7	0.048
Total	100	100	100	1.00	100	100	100	1.00	100	100	100	1.00	100	100	100	1.00

Index = [3 for rank 1) + (2 for rank 2) + (1 for rank 3)] for each of the factor divided by sum of all of the factors, Trips=*Trpanosomiasis*, FMD=foot and mouth disease, BL= blackleg, BU=blood urinate.

Appendix 2. Major cattle production constraints in the study areas.

Constraints	Agro-ecology															
	Dega				*Woyna-dega*				*Kolla*				Over all			
	R1	R2	R3	Index	R1	R2	R3	Index	R1	R2	R3	Index	R1	R2	R3	Index
Feed shortage	53.3	0	33.3	0.322	60	40	0	0.433	66.7	13.3	13.3	0.400	60	17.8	15.6	0.385
Disease	20	73.3	6.7	0.356	40	60	0	0.400	20	66.7	13.3	0.344	26.7	66.7	6.7	0.367
Water scarcity	0	0	40	0.067	0	0	60	0.100	13.3	6.7	46.7	0.167	4.4	2.2	48.9	0.111
Poor genotype	26.7	26.7	6.7	0.234	0	0	0	0.000	0	13.3	13.3	0.066	8.9	13.3	6.7	0.100
Shortage of Initial capital	0	0	0	0.000	0	0	40	0.067	0	0	0	0.000	0	0	13.3	0.022
Lack of knowhow	0	0	13.3	0.022	0	0	0	0.000	0	0	0	0.000	0	0	8.9	0.015
Total	100	100	100	1.00	100	100	100	1.00	100	100	100	1.00	100	100	100	1.00

Index = [3 for rank 1) + (2 for rank 2) + (1 for rank 3)] for each of the factor divided by sum of all of the factors.

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Full Length Research Paper

Phosphorus release from poultry litter to the soil due to the management

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The study aimed to evaluate phosphorus release (P) from poultry litter (composted and uncomposted poultry litter) to the soil under different pH and depth conditions of application in typical Red Distroferric Oxisolin the city of Toledo, western Paraná state. The experiment was conducted under field conditions, in a randomized block design with treatments arranged in a 2x2x3 factorial scheme, consisting of two soil pH adjustments (5.5 and 6.0), two types of poultry litter (composted and uncomposted), and three different application depths (0, 0.05 and 0.10 m), with four replications. Regarding the assessment, P levels were determined from soil samples collected at the time of experiment implementation, followed by three other collections with 15days intervals. The largest P release into the soil at all depths of application and types of poultry litter was observed at pH 6.0 respect of pH 5.5. The application of uncomposted poultry litter onto the surface under pH 6.0 and during 45 days of evaluation released more P 45 days after application, followed by those at depths of 0.05 and 0.10 m. Uncomposted poultry litter was more efficient that composted in providing P, as evaluated by Mehlich-1 extractor.

Key words: Decomposition, organic fertilizer, nutrient availability.

INTRODUCTION

Brazilian agriculture can be considered the major world supplier of food, whether of plant or animal origin and at the same time it has become an important focus of studies and potential supplier of renewable energy. Among the energy recycling forms there is the use of residue from agricultural activities such as poultry litter, which can be used by farmers as a source of nutrients infertilization (Zhang et al., 2002), thus providing an increase of total carbon and organic matter content to the soil (Adeli et al., 2008; Singh et al., 2009), improving the physical, chemical and biological quality of the soil (McGrath et al., 2009) and increasing crop productivity (Sistani etal., 2004).

The use of poultry litter as fertilizer is the most common method and generally the most desirable form of organic fertilizer use as it provides essential nutrients to the plants (Costa et al., 2009). Manure from the intensive farming of chickens and hens fed with food rich in nutrients, especially phosphorus (P), but low in cellulose. That is why, its decomposition is faster, rapidly releasing the nutrients contained therein (Souza and Resende, 2003). Fertilization with poultry litter correctly performed, provides a greater potential yield and it can be used in different cultures and in the recovery of degraded areas due to their chemical, physical and microbiological benefits to the soil (Correa and Miele, 2011).

Poultry litter is considered as an excellent P source for plant, with 24% more P when compared to swine manure, and it has the ability to provide increases extractable phosphorus content with increasing doses (Fioreze and Ceretta, 2006).

P has a fundamental role inplant metabolism, as part of the rich energy compounds (Novais and Smyth, 1999), making it one of the most essential elements for plants survival, being present in the structural components of cells such as nucleic acids and phospholipids of the biomembranes, the second most limiting element to the crops productivity in tropical soils (Taiz and Zeiger, 2013).

However, the availability of most nutrients in the soil is affected by several factors, including soil pH, becoming one of the limiting factors the cultures development (Nachtigall et al., 2009). Brazilian soils are generally acid with low availability of nutrients needed for higher crop yields. Therefore, a practice that is needed is the correction of this acidity creating favorable conditions for the growth and development of plants (Silva, 2010).

With regard to poultry litter management, once removed from the shed it can be applied directly to the soil or temporarily stored in outdoor windrows for composting. Its storage, prior to application to the soil, allows flexibility at the time of application and a consequent synchronization between the liberation of nutrients starting from the needs of the plant, which reduces the risk of environment contamination (Gil et al., 2008). During the storage period, it is possible to perform poultry litter composting, with a combination of organic material, water, and oxygen. Composting reduces the volume and weight of the original organic substrate and in the end, results in a material which is biologically stable, odorless, and useful to fertilization of the soil (Moore Jr. et al., 1995a). On the other hand, a strategy that could improve the availability of P would be its incorporation into the soil, thus favoring the decomposition and minimizing P losses by fixing to colloids (iron and aluminum oxides) from highly weathered tropical soils.

Accordingly, because of the high growth of poultry activity in western Paraná, generating large amounts of organic fertilizer (poultry litter), it could become a way to obtain good-quality organic fertilizer at a reduced cost. However, experimental studies that demonstrate such efficacy of using poultry litter as fertilizer are scarce in the region.

The objective of this study was to evaluate P release from the poultry litter of the soil at different pH conditions and application depths of poultry litter (compost and composted) in typical Red Distroferric Oxisol in the city of Toledo, western Paraná state.

MATERIALS AND METHODS

The experiment was conducted in the Agronomy course's experimental farm, at the Agricultural Sciences and Veterinary Medicine School of the Pontifical Catholic University of Paraná (Pontifícia Universidade Católica do Paraná - PUCPR), Toledo campus-Paraná, situated in the geographical coordinates 24º 43'40 40" S and 53º 46'01 68" W, with an average altitude of 581 m. According to the Köppen climate classification, the climate of the region is humid subtropical mesothermal (Cfa), characterized by hot summers with average temperatures above 22°C, and winters with average temperatures of 18°C or below and an average annual rain fall of from 1600 to 1800 mm (Iapar, 2003). Climatic data on temperature and precipitation for the period of November 27, 2012 to January 28, 2013 were collected daily by the weather station installed in the campus of PUCPR and are presented in Figure 1.

The soil of the experimental unit was classified as typical Red Distroferric Oxisol, a loamy soil, slightly hilly relief (Embrapa, 2006). The experimental area used has become degraded due to the superficial horizon removal, which was used in an embankment and further construction of the administrative block of the university campus, leaving horizon B exposed. Prior to the implementation of the experiment, soil sample collection was carried out at 0– 0.20 m depth for the determination of chemical characteristics, with the following results: pH at $CaCl_2$of5.6, 15.63gdm^{-3}M.O., 8.23mgPdm^{-3}, 3.23; 2.78; 0.30; 0.0;4.54cmol^c dm^{-3}, respectively, Ca^{2+}, Mg^{2+}, K^+, Al^{3+} e H^+ + Al^{3+}; and determination of the granulometric proportion of this soil, presenting 720, 160, and 120g kg^{-1} of clay, silt, and sand, respectively, as the method proposed by Embrapa (1997).

The experimental design adopted was a randomized block in a 2x2x3 factorial scheme, with two pH adjustments (5.5 and 6.0), two types of poultry litter (with and with out composting) and application of the bed in three deep in the soil (0, 0.05, and 0.10 m), with four replications, each portion measuring 3.15 x 5.75 m. The poultry litter used in the experiment was acquired from farm of the region, coming from 14 production batches of broilers. Chemical analyses

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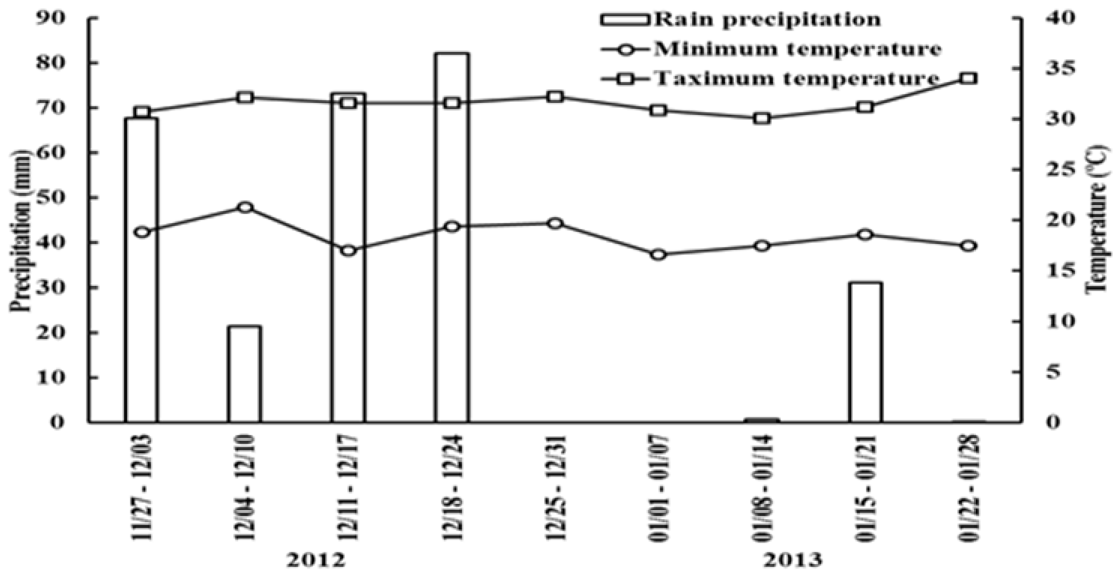

Figure 1. Weekly average rainfall and maximum and minimum temperatures during the period of November 27, 2012 to January 28, 2013.The accumulated rainfall was 276.4 mm. Source: Information collected by the weather station of the Pontifical Catholic University of Paraná, Toledo Campus -PR.

were performed to determine their composition, as shown in Table 1.

With this, it was found that the P content in the compost bed with avian was 14.70 g kg^{-1} at least as compared to avian without composting bed. As for the copper content, zinc, iron, manganese and boron, they were much higher than in poultry manure with compost. This was possibly due to the composting process because addition of the nutrient levels vary depending on the type of material used in the bed, the particle size, batch number, production system (Kiehl, 2010), feed composition, amount of material used in the shed floor covering, season, bird stocking density, the shed ventilation and characteristics of excreta of birds (Aires, 2009; Eghball, 2002) reports that the storage form also influence the levels of nutrients which make up the poultry litter.

The material collected was separated into two parts, the first being intended for the composting process, for a period of 90 days, according to the methodology described by Kiehl (2004), for use in the treatment of composted poultry litter. The other part was stored in a dry place, aiming at preserving their natural characteristics for subsequent use in the treatment of uncomposted poultry litter. As for poultry litter dose, it was applied 10 Mg ha^{-1} based on dry matter. This dose was established in an experiment in a green house, which was efficient for providing nutrients to corn crop.

A calibration curve was performed for pH adjustment, which consists of obtaining neutralization curves of soil acidity by incubation with $CaCO_3$. For this, we used the methodology described by Lana et al. (2010), in which soil samples were incubated with increasing doses of $CaCO_3$ p.a., keeping its humidity near field capacity for a period of approximately 30 days in order to determine the required amount of $CaCO_3$ for increasing the soil pH to the pre-established values.

Every two weeks, samples were collected from the incubated soil for measuring $CaCl_2$pH and SMPpH. After the occurrence of the overall reaction, the relevant data to pH values were subjected to analysis of variance and subsequent polynomial regression analysis using Sisvar software (Ferreira, 2011). By applying the equation: 5.239286+0,001345x-0,0000002x^2 and R^2=0.98, we determined the limestone dosage (kgha^{-1}) required to raise soil pH values to 5.5 and 6.0.

Subsequently, in September 2011, application of limestone in each plot was carried out and incorporated into the soil with subsoiler. After a year of application of the calcitic limestone, anew soil sampling at 0–0.20 m depth was made in all plots to check soil pH. The soil samples were sent to the Laboratory of Soil Fertility at PUCPR, dried and sieved for further determination of pH in $CaCl_2$0.01 mol L^{-1} according to the methodology described by Lana et al. (2010). In the results obtained, it was found that both soil pHs were according to the levels desired for developing the present study (soil pH 5.5 and 6.0), thus enabling the conduct of the experiment.

Prior to the application of poultry litter, soil samples were collected for the determination of P content. We collected approximately 0.5kg of soil in each experimental unit, which were packed in plastic bags and sent to cold chamber, where they remained refrigerated (between 4 and 5°C) for several days until the determination of the content of this nutrient.

To perform the application of poultry litter into the soil, we opened grooves aided by a tractor anda seeder, equipped with a furrow opener in seven lines, thus performing the marking of the lines. Further, with a two-rod rake made of wood (spaced 0.45 m between the rods, which were adjusted to depths of 0.05 and 0.10 m),the opening of the grooves in the respective depths was performed manually. After the grooves were opened,the litter was applied as the established treatments, and the groove closure was then made by using a hoe.

Three soil samples collection were performed at intervals of 15 days for evaluation. The first collection was performed before the application Poultry litter into the soil and the others occurred at 15, 30 and 45 days after addition of the bed. In each plot, six sub-samples were collected through a dutch auger, putting them together to form a composite sample and storing the min plastic bags, then stocking in a cold chamber at the PUCPR Veterinary

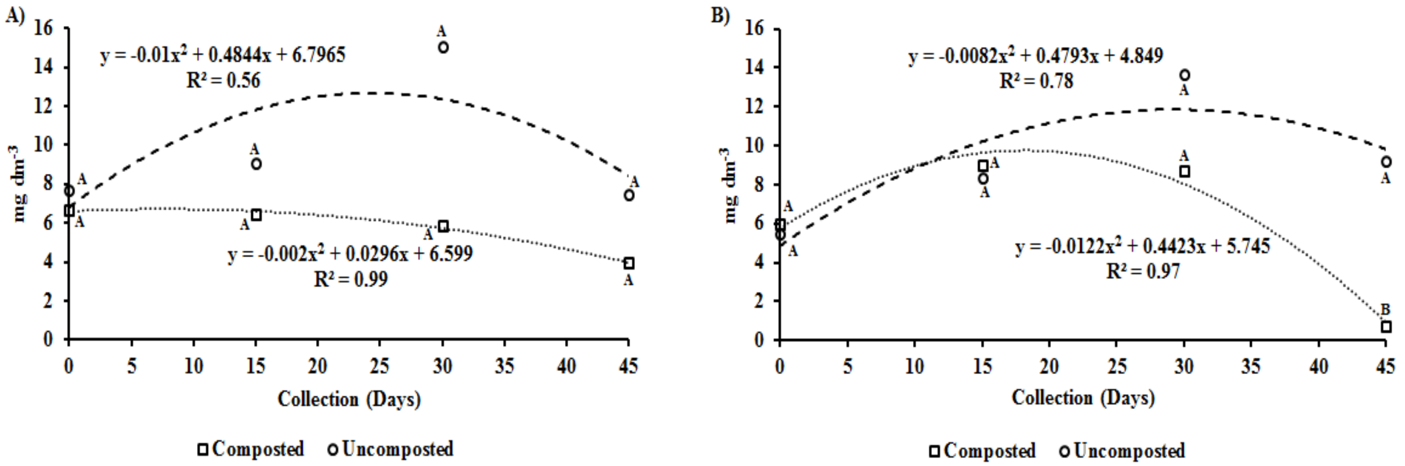

Figure 2. Average results for P availability due to the type of poultry litter (composted and uncomposted) and the number of days in each pH range 5.5 (A) and 6.0 (B) of a typical Red Distroferric Oxisol in the city of Toledo-PR. Averages followed by the same uppercase letter, in the column, do not differ between them by Tukey test at 5% probability.

Hospital. To determine P content, these samples were sent to the Laboratory of Soil Fertility, where drying was carried out, followed by their homogenization through a strainer with a 2 mm mesh. P extraction was conducted by using Mehlich-1 extraction solution, and subsequent determination of P in spectrophotometry was done, according to the methodology described by Lana et al. (2010).

Data obtained were subjected to analysis of variance,and when significant, the averages were compared with a Tukey test at 5 and 10% probability by using the Sisvarstatistical software (Ferreira, 2011).

RESULTS AND DISCUSSION

Analysis of variance revealed significant differences ($p<0.05$) for pH x poultry litter interaction among the soil sample collected, as shown in Figure 2. P levels for pH 5.5 ranged from 3.93 to 15.10 mg dm^{-3}, where as P levels for pH 6.0 were from 0.73 to 13.68 mg dm^{-3}. We can observe that the highest values were obtained for uncomposted poultry litter at pH6.0. Regarding the types of poultry litter (composted and uncomposted) in pH 5.5, there were no significant differences for P release ($p>0.05$) among the samples taken; however, significant responses were found ($p<0.05$) for soil pH 6.0, significant differences were observed in the collection at 45 days.

This is probably due to the fact that immobilization of inorganic P occurred with composted poultry litter, which started at 30 day sand extended, increasing the immobilization until 45 days after application. Alleoni and Melo (2009) found that when the C/P ratio is below 200:1, mineralization predominates, and over 300:1, immobilization predominates. Possibly with composted poultry litter, this balance has not occurred due to the composting process, which has probably reduced the concentration of P in the poultry litter. According Hartz et al. (2000), the decrease in mineralization process of organic compounds over time is related to its C/N ratio. It is initially faster in the compounds of lowest C/N ratio.

Due to this characteristic, a smaller amount of P was released to the soil by composted poultry litter, while the uncomposted poultry litter reached this C/P ratio due to its intense P release to soil at the beginning of the study. It started an inorganic P immobilization process which can be observed in the collection after 45 days from the application of poultry litter. Results similar to these were found in Araujo (2011), which reported finding higher P content available in the soil with the natural organic material, than with the addition of composted organic material, corroborating this study.

With regard to the application of poultry litter at different depths the soil (0, 0.05, and 0.10 m) in pH 5.5 and 6.0, we can see that the collection occurred 45 days after this application showed significant differences ($p<0.10$). The application at 0 m under pH 6.0 resulted in the highest P release to soil, followed by the application at 0.05 m, which was higher than the application at 0.10 m, corresponding to the values of 8.57, 5.72, and 0.60 mg dm^{-3} (Figure 3). However, the application of poultry litter at 0 and at 0.05 m were not statistically different ($p>0.10$) as well as the application of poultry litter at 0.05 and at 0.10 m.

These results indicate that mineral P release in to the soil collected at 45 days was only higher at 0 m compared to the application depth at 0.05 m, possibly due to the mineral P immobilization process in this collection. Such immobilization is also observed in pH 5.5 of the soil, due to the intense release of the mineral P in the previous samples (15 and 30 days) after the application of poultry litter in to the soil. That possibly

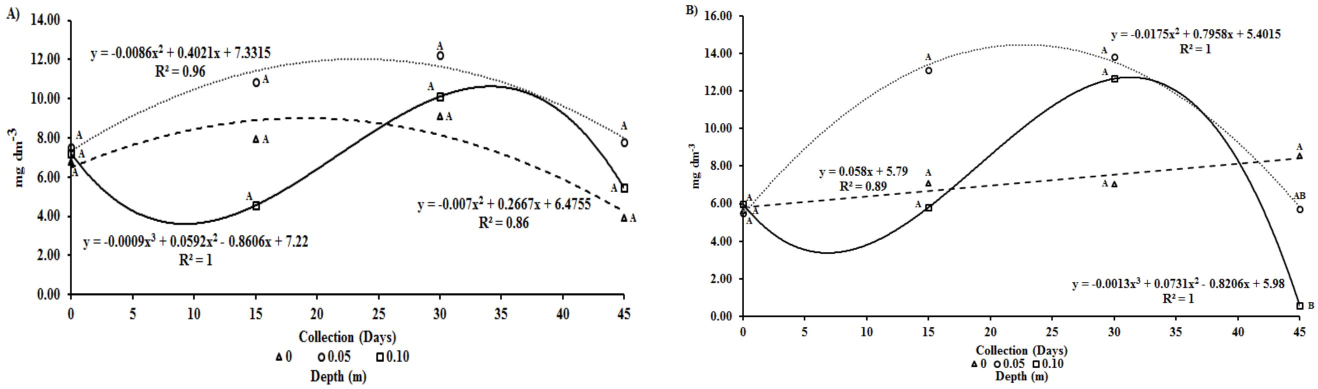

Figure 3. The average results of mineral P available according to the depth of the application of poultry litter (0, 0.05 and 0.10 m) and according to the days of collection at pH 5.5 (A) and 6.0 (B) soil. Averages followed by the same uppercase letter, in the column, do not differ between them by Tukey test at 10% probability.

happened because the condition that each of the depths provided for a higher or lower litter decomposition rate and also for mineralization of organic P released in the decomposition process.

With the application process of the poultry litter at the 0.05 m depth, it is possible that the soil conditions were more favorable for the litter decomposition process and mineralization of organic P, such as those conditions involving temperature, humidity, and oxygenation, since humidity and oxygen are the most limiting factors for organic material decomposition and there for the mineralization of organic P. Table 1 showed that precipitation was very favorable in relation to soil moisture, with heavy rains during the beginning of the study, except during the period 12/25/2012 to 07/01/2013 when there was no rain fall, with its return only after this period. It was also noted that the temperatures were always high, which were favorable to the process of poultry litter decomposition and mineralization of organic P duringall periods of implementation of this work.

However, with the high temperature, moisture reduction occurs on the ground surface, which explains the lower amount of inorganic P at 0 m in relation to litter application at 0.05 m depth. With the deep litter application we also have the location factor because when it is incorporated, its particles are in closer contact to the ground and the microorganisms, which accelerate the decomposition and mineralization processes. The efficiency of the incorporation process was studied by Freitas et al (2006), who found that the incorporation of organic waste decreases the amount of P in the organic residue, thus increasing the amount of P released and mineralized into the soil.

As for the application of poultry litter at the 0.10 m depth, we can see that P release to the ground was higher in the collection performed 30 days after the application for both soil pH levels (5.5 and 6.0). This was possibly due to the lower poultry litter decomposition and organic P mineralization rate in addition to a possible immobilization of inorganic P caused by the elevation of the C/P.

Decomposition and mineralization processes are possibly not very suitable for such depth because they present a very limited amount of oxygen, and this limitation may have been enhanced by the large amount of rainfall that occurred during the study period. This explains the higher P concentration at 0 m than at 0.10 m depth. These results disagree with the study presented by Souto et al. (2005) who found higher decomposition and mineralization rates at depths of 0.10 m. However, Rocha et al. (2005) observed that P availability is in greater quantity on the ground surface (the first 0.05 m) because the climatic conditions favor the decomposition and mineralization processes, besides P being a virtually immobile nutrient in the soil, results that corroborate the results found in the present work.

As noted above in Figure 2, for both soil pH levels(5.5 and 6.0), we can see that the collection 30 days after the application was the one that presented the higher P released into the ground for composted poultry litter, possibly due to P immobilization. Similar availability occurred in Figure 3, where both soil pH levels (5.5 and 6.0) showed the highest P availability level in the soil 30 days after the litter application, where as the only depth which did not have a higher release after 30 days was applying at 0 m in the soil at pH 6.0, possibly because of the P immobilization process caused by its intense initial release. These increases in P level the soil over time were observed and reported by Silva et al. (2011).

Similar results to those of the present study were found by Singh et al. (2009) who found that P release occurred mainly during the first 20 days after hatching, accounting for 15 to 17% of the total P. Similar results were also found by Adami (2012), who studied P release through

Table 1. Results from chemical analyses of the poultry litter (composted and uncomposted) used in the experiment.

Determination	Poultry litter	
	Composted	Uncomposted
Nitrogen (g kg^{-1})	27.90	42.60
Phosphorus (g kg^{-1})	37.70	98.60
Potassium (g kg^{-1})	18.20	42.80
Calcium (g kg^{-1})	76.70	32.40
Magnesium (g kg^{-1})	16.70	10.00
Sulfur (g kg^{-1})	8.60	7.50
Carbon (g kg^{-1})	264.60	410.70
Organic Matter (g kg^{-1})	454.90	706.40
Copper (mg kg^{-1})	240.70	76.28
Zinc (mg kg^{-1})	1,452.00	671.10
Iron (mg kg^{-1})	21,770.00	1,654.00
Manganese (mg kg^{-1})	1,805.00	637.40
Boron (mg kg^{-1})	209.70	73.06
pH ($CaCl_2$ 0,01mol L^{-1})	7.58	8.05
C/N Ratio	9.47	9.65
C/P Ratio	7.02	4.16
Humidity (%)	2.51	6.19

Source: Analyses performed at Laborsolo Analysis Lab.

poultry litter incubation in the field and found that, after 30 days, 23% of P had been released, which corroborates the present work. This is because the release of nutrients in poultry litter is slower, particularly P due to its low mobility, and due to be in organic form, which needs to go through an incorporation and mineralization process by the microorganisms, beyond being P incomplex forming the organic material.

Regarding the type of manure (with and without compost) at each level of soil application (0, 0.05, 0.10 m) in the pH range of 5.5 solo, you can see that there has been no significant difference (p>0.05), as well as each type of bed within each level of depth, as shown in Table 2. However, if we look at the range of pH 6.0 soil in Table 3, it can be seen with regarding the type of manure (with and without composting) in each application of the ground level (0, 0.05, 0.10 m) had significant difference (p<0.05), in which the collection at 45 days after application of the bed to 0 m, the composting bed showed no release of P exceeding bed composted.

As for the evaluation of each poultry litter type (composted and uncomposted) within each level of depth (0, 0.05 and 0.10 m) at a soil pH of 6.0, we can see that it also showed a significant difference (p<0.05), in which the uncomposted poultry litter in the collection performed 45 days after application released more P when applied to soil at 0 m, followed by the application at 0.05 m and lastly by the application at 0.10 m. However, the application of the uncomposted litter at 0 and at 0.05 m, as well as the application at 0.05 and 0.10 m, did not differ statistically. These results can be verified in Table 3. They possibly occurred because of the soil pH.

Regarding the higher mineral P content released by applying at 0 m, this was possibly due to the mineral P immobilization process at the 0.05 m depth of application. Possibly this immobilization was due to the large amount of P released in to the soil, and this release can be seen in the Table 3 on collections related to15 and 30 days after application of the poultry litter into the soil. This large amount released is due to the processing that this depth provides, and also due to the higher soil pH.

With the intense P release to soil, the C/P ratio of the poultry litter rose, which induced the immobilization process of the mineral P, there by reducing the amount of P released in to the soil in the collection at 45 days after the application.The same situation occurred at the 0.10 m depth of litter application, and results were similar to those found by Caires et al. (2003) and Tirloni et al. (2009).

With respect to the soil pH, we can see in Tables 2 and 3 that P release values were higher at pH 6.0 compared to at pH 5.5, which serve as references that the soil pH was possibly the factor that influenced the increased release of P in to the ground collected at 45 days, since both soils under went the same climatic, environmental influences, and the same processes (surface application

Table 2. Average results of mineral P availability due to the type of poultry litter (composted and uncomposted) and depth application(0; 0.05 and 0.10 m) at a soil pH level of 5.5.

Depth (m)	Poultry litter	
	Composted	Uncomposted
	mg dm^{-3}	
	Collection at the application	
0	6.20 ^{Aa}	7.40 ^{Aa}
0.05	6.55 ^{Aa}	8.48 ^{Aa}
0.10	7.19 ^{Aa}	7.24 ^{Aa}
	Collection at 15 DAA	
0	5.00 ^{Aa}	10.84 ^{Aa}
0.05	8.15 ^{Aa}	13.58 ^{Aa}
0.10	6.28 ^{Aa}	2.84 ^{Aa}
	Collection at 30 DAA	
0	6.37 ^{Aa}	11.86 ^{Aa}
0.05	6.80 ^{Aa}	17.62 ^{Aa}
0.10	4.40 ^{Aa}	15.82 ^{Aa}
	Collection at 45 DAA	
0	2.98 ^{Aa}	4.84 ^{Aa}
0.05	4.60 ^{Aa}	11.00 ^{Aa}
0.10	4.22 ^{Aa}	6.66 ^{Aa}

Averages followed by the same uppercase letter, in the column, and lower case letter, in the line, do not differ between them by Tukey test at 5% probability.

Table 3. Average results of mineral P availability due to the poultry litter type (composted and uncomposted) and application depth (0; 0.05 and 0.10 m) at a soil pH level of 6.0.

Depth (m)	Poultry litter	
	Composted	Uncomposted
	mg dm^{-3}	
	Collection at the application	
0	5.60 ^{Aa}	5.70 ^{Aa}
0.05	5.58 ^{Aa}	5.42 ^{Aa}
0.10	6.70 ^{Aa}	5.26 ^{Aa}
	Collection at 15 DAA	
0	5.97 ^{Aa}	8.24 ^{Aa}
0.05	15.31 ^{Aa}	10.91 ^{Aa}
0.10	5.68 ^{Aa}	5.93 ^{Aa}
	Collection at 30 DAA	
0	4.13 ^{Aa}	9.97 ^{Aa}
0.05	7.40 ^{Aa}	20.28 ^{Aa}
0.10	14.51 ^{Aa}	10.80 ^{Aa}
	Collection at 45 DAA	
0	0.77 ^{A}b	16.37 ^{Aa}
0.05	1.13 ^{Aa}	10.31 ^{ABa}
0.10	0.30 ^{Aa}	0.91 ^{Ba}

Averages followed by the same uppercase letter, in the column, and lower case letter, in the line, do not differ between them by Tukey test at 5% probability.

of uncomposted poultry litter), differing only in their pH levels.

By comparing there sults in Figures (2 and 3) and Tables (2 and 3), we can see that the P released into the soil was higher at pH 6.0 in the composted poultry litter as well as in the uncomposted poultry litter. That is due to the P availability and o their nutrients occurring in the soil pH range of 6.0 to 7.0, which is recommended for most cultures because of the higher release of nutrientes (Lopes and Guilherme, 2000).

In a study, Ernani et al. (2001) reported that soil pH close to neutral (pH 7.0) influenced the application of methods (embedded and superficial), providing for a higher P content availability for plants. These results were similar to those of this study.

The largest increase in the amount of P which was released by the poultry litter was provided at pH 6.0 levels. The rise in pH increases negative charges to the ground and decreases iron and aluminum solubility, thus increasing the amount of available inorganic P for plants. A reduction of this reaction occurs according to the acidification of the soil; that is, as soil pH is reduced. However, pH 5.5 is more acidic, and most P present in the soil is strongly retained in the positive charges of the solid phase and in the form of iron and aluminum phosphate precipitates. Similar results were found by Souza et al. (2006), who observed that when soil pH is close to 4.1, P availability for the plant was very low, but when it got close to 6.5, the release of P for plants was enough to meet their needs, corroborating this study.

Conclusion

The largest P release into the soil at all depths of application and types of poultry litter was observed at pH 6.0 respect of pH 5.5. The application of uncomposted poultry litter onto the surface under pH 6.0 and during 45 days of evaluation released more P 45 days after application, followed by those at depths of 0.05 and 0.10 m. Uncomposted poultry litter was more efficient that Composted in providing P, as evaluated by Mehlich-1 extractor.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Adami PF (2012). Grazing intensities and poultry litter levels in crop-livestock integration system. Thesis (Doctorate in Science) - Federal University of Paraná, Curitiba. P. 111.

Adeli A, Shankle MW, Tewolde H, Sistani KR, Rowe DE (2008). Nutrient dynamics from broiler litter applied to no-till cotton in an upland soil. Agron. J. 100:564-570.

Alleoni LRF, Melo VF (2009). Chemistry and mineralogy of soils: Part II - Applications. Viçosa: Editora Brazilian Soc. Soil Sci.2:685.

Araujo FF (2011). Phosphorus availability, soil amendment, leaf content and yield of maize after incorporation of phosphates and natural tannery sludge and composted. Acta Sci. Agron. 33(2):355-360.

Aires AM (2009). Anaerobic digestion of broiler bed with or without separation of the solid and liquid fractions. Dissertation (master's degreein Animal Science) - Faculty of Agriculture and Veterinary Sciences, Universidade Estadual Paulista, Jaboticabal. P. 134.

Caires EF, Blum J, Barth G, Garbuio FJ, Kusman MT (2003). Chemical soil amendments and soybean response to lime and gypsum applications in the implementation of tillage. J. Soil Sci. 27(2):275-286.

Correa JC, Miele MA (2011). Bed birds and the agronomic, environmental and economic aspects. In: PALHARES JCP, KUNZ A. (Ed.). Environmental Management in Poultry, Concord: Publisher Embrapa Swine and Poultry. pp. 125-152.

Costa AM, Borges EM, Silvaade A, Nolla, Guimarães EC (2009). Physical recovery potential of an Oxisol under degraded pasture, influenced by the application of poultry litter. Sci. Agrotecnol. 33:1991-1998.

Eghball B, Wienhold BJ, Gilley JE, Eigenberg RA (2002). Mineralization of manure nutrients. J. Soil Water Conserv. 57:469-473.

Embrapa (1997). EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA –Manual methods of soil analysis. 2.ed. Rio de Janeiro: Editora Embrapa. P. 212.

Embrapa (2006). EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA –. Brazilian system of soil classification. Brasilia: Editora Embrapa. P. 306.

Ernani PR, Steckling C, Bayer C (2001). Chemical characteristics of soil and yield of dry corn dough according to the method of application of phosphates in two levels of acidity. J. Soil Sci. 25(4):939-946.

Ferreira DF (2011). Sisvar: A computer statistical analysis system. Ciênc. Agrotecnol. 35(6):1039-1042.

Fioreze C, Ceretta CA (2006). Organic sources of nutrients in potato production systems. Rural Sci. 36:1788-1793.

Freitas MSC, Araújo CAS, Silvag GB, SILVA DJ (2006). Manure decomposition rate as function of time and depth incorporation in micro-sprinkler irrigation. In: I production day cietífica professional and technical education. brasília, 2006. Abstracts. Brasilia: setec/mec P. 154.

Gil MV, Carballo MT, Calvo LF (2008). Fertilization of maize with compost from cattle manure supplemented with additional mineral nutrients. Waste Manag. 28:1432-1440.

Hartz TK, Mitchell JP, Giannini C (2000). Nitrogen and carbono mineralization dynamics of manures and composts. Hortic. Sci. 35:209-212.

INSTITUTO AGRONÔMICO DO PARANÁ – IAPAR (2003). Agricultural zoning of Paraná. London: Publisher Agronomic Institute of Paraná. P. 76.

Kiehl EJ (2004). Composting guide: Maturation and quality of the compost. 4.ed. Piracicaba. P. 171.

Kiehl EJ (2010). New organic fertilizers. Piracicaba P. 248.

Lana MC, Fey R, Frandoloso JF, Richart A, Fontaniva S (2010). Chemical Analysis of Soil and Plant Tissue: Laboratory Practices.Cascavel. Editora: EDUNIOESTE. P. 129.

Lopes AS, Guilherme LRG (2000). Efficient use of fertilizers and agricultural correctives: agronomic aspects. 3ªrevised edition and updated – São Paulo, ANDA.

McGrath S, Maguire RO, Tacy BF, Fike JH (2009). Improving soil nutrition with poultry litter application in low input forage systems. Agron. J. 102:48-54.

Moore Júnior PA, Daniel TC, Sharpley NA, Wood CW (1995a). Poultry manure management. Environmentally sound aptions. J. Soil Water Conserv. 50:321-327.

Nachtigall GR, Nogueirol RC, Alleoni LRF (2009). Sequential extraction of Mn and Zn in soil as a function of pH and addition of poultry litter. Braz. J. Agric. Environ. Eng. 13(3):240-249.

Novais RF, Smyth TJ (1999). Phosphorus in soil and plant in tropical conditions. Viçosa: Editora: UFV. P. 399.

Rocha AT, Duda GP, Nascimento CWA, Ribeiro MR (2005). Phosphorus fractionation and evaluation of P-extractors available in soils in Fernando de Noronha. J. Agric. Environ. Eng. 9:178-184.

Silva FMF (2010). Organic matter in coffee. Work Completion of course (Degree in Technology in Cafeicultura) - Federal Institute of Education, Science and Technology South of Minas Gerais, Muzambinho. P. 49.

Silva TR, Menezes JFS, Simon GA, Assis RL, Santos CJL, Gomes GV (2011). Maize cultivation and phosphorus availability in fertilization with poultry litter. J. Agric. Environ. Eng.15(9):903-910.

Singh Y, Gupta RK, Thind HS (2009). Poultry litter as a nitrogen and phosphorus source for the rice–wheat cropping system. Biol. Fertil. Soils 45:701-710.

Sistani KR, Brink GE, Adeli A, Tewolde H, Rowe DE (2004). Year-round soil nutrient dynamics from broiler litter application to three bermudagrass cultivars. Agron. J. 96:525-530.

Souto PC, Souto JS, Santos RV, Araújo GT, Souto LS (2005). Manure decomposition arranged at different depths in the area degraded in the Paraíba semiarid. J. Soil Sci. 29:125-130.

Souza AG, Amarante CVT, Deschamps FC, Ernani PR (2006). Liming and phosphate fertilization promote early growth and production of hypericin in hypericum perforatum. Braz. Hort. 24(4):421-425.

Souza JL, Resende P (2003). Manual of organic gardening. Viçosa: Editora Aprenda Fácil. P. 564.

Taiz L, Zeiger E (2013). Plant Physiology. Porto Alegre: Artmed. 5ª Ed.

Tirloni C, Vitorino ACT, Novelino JO, Tirloni D, Coimbra DS (2009). Phosphorus availability depending on the setting of additions and a ground bioactivator. Sci. Agrotecnol. 33(4):977-984.

Zhang H, Smolen ME, Hamilton D (2002). Poultry litter quality criteria. Production technology. Department of Plant and Soil Sciences 14(24).

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Full Length Research Paper

Agronomic performance of RR® soybean cultivars using different pre-sowing desiccation periods and distinct post-emergence herbicides

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The current study aims to measure the effect of pre-sowing desiccation period and verify the influence of post-emergence herbicide on soybean agronomic traits and grain yield. The experiments were carried out according to a randomized complete block design with three replications during two crop seasons (2012/13 and 2013/14), using split plot design. Five soybean cultivars were used (BRS Favorita RR®, TMG 1179 RR®, TMG 1176 RR®, Anta 82 RR®, NS 7100 RR®). Two desiccation periods were adopted 7 days before sowing and just before sowing. Two types of weed management were tested in post-emergence - using glyphosate (Roundup Ready®) and a soybean selective herbicide (Robust®). During the 2013/2014 crop season, manual weeding was also used. The evaluated traits were plant height, first pod insertion, number of pods per plant and number of seeds per pod, 1,000-grain weight and grain yield. Considering the distinct post-emergence herbicides, there was no significant difference between glyphosate and Robust®. Nevertheless, the desiccation period showed significant differences in plant height, number of pods per plant and grain yield. The soybean grain yield was higher when desiccation was done 7 days before sowing. Therefore, an association between desiccation period and soybean performance was assumed.

Key words: *Glycine Max* (L.) Merril, inhibitors of the 5-enolpyruvylshikimate-3-phosphate synthase enzyme, Roundup Ready®, Robust®.

INTRODUCTION

After the emergence of biotechnology and the transgenic development of Roundup Ready (RR®) soybean cultivars, there was an alleged gain in easing weed management in this crop. The amount of glyphosate used for weed control was already big before the release of soybean transgenic cultivars (Petter et al., 2007). After the approval of RR® soybean cultivars in Brazil, the intensity of glyphosate consumption became even higher due to the possibility of carrying out post-emergence applications.

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Table 1. Soil chemical properties of dystroferric Red Latosol (0-0.20 m). Lavras – MG, in the 2012/2013 and 2013/2014 crop seasons.

Crop season	pH	Ca^{2+}	Mg^{2+}	Al^{3+}	$H^{+}+Al^{3+}$	SB	CEC	P	K	OM	V
	H_2O	cmol$_c$ dm^{-3}						mg dm^{-3}		dag/kg^{-1}	%
2012/13	5.9	4.7	1.3	0	2.9	6.3	9.2	7.21	118	2.61	68.51
2013/14	6.4	5.0	1.4	0	2.9	6.7	9.6	11.46	118	3.41	69.82

H + Al: Potential acidity; SB: sumo of basis; CEC: Cation Exchange capacity (pH 7.0); OM: Organic matter content; V: Base saturation

Glyphosate is the most consumed herbicide in Brazil with approximately 250 million liters annually sold (Londres, 2011), thus accounting for 30% or more of the entire amount of active ingredients consumed in the country (AENDA 2011). It confirms the importance of this active ingredient to weed management and, consequently, to the pesticide market.

The glyphosate action mechanism is quite unique, since it is the only herbicide able to specifically inhibit the 5-enolpyruvylshikimate-3-phosphate synthase (EPSPs) enzyme, which catalyzes the condensation of both shikimic acid and pyruvate phosphate, thus preventing the synthesis of three essential amino acids - tryptophan, phenylalanine and tyrosine (Zablotowicz and Reddy, 2004). In other words, the RR® soybean tolerance to glyphosate due to its EPSPs isoform, which is resistant to glyphosate.

However, the immoderate glyphosate use at high doses or the excessive number of applications may cause phytotoxic effects (Santos el al., 2007a) and unbalance the absorption of nutrients, water use and photosynthesis (Zablotowicz and Reddy, 2007; Albrecht et al. 2011; Serra et al., 2011). It may also be harmful to the microbial activity and to the nitrogen-fixing bacteria (Santos et al., 2007b; Zobiole et al., 2010; Serra et al., 2011; Zuffo et al., 2014).

Weed management in soybean fields has been done in three ways: just before sowing, 7 to 10 days before sowing or earlier (Oliveira Jr. et al. 2006). Reports indicate that the desiccation performed just before sowing, known as "Apply and Sow", is the most popular method among farmers, since it allows saving time and maximizing machinery use.

The current study aims to measure the effect of different pre-sowing desiccation periods using glyphosate and to verify how post-emergence herbicides affect soybean agronomic traits and grain yield.

MATERIAL AND METHODS

The experiments were conducted during 2012/2013 and 2013/2014 crop seasons at the Federal University of Lavras, in the Center for Scientific and Technological Development in Agriculture – “Muquém” Experimental Farm (located at 21°12 ’S, 45°58 ’W and 918 m altitude), in Lavras County, Minas Gerais State, in a clayey-texture soil classified as dystroferric Red Latosol – LVdf, with the following textural values: Clay: 640 g kg^{-1}; Silt: 200 g kg^{-1}; Sand: 160 g kg^{-1}. The chemical composition of the soil from the experimental area is presented in Table 1.

According to Koppen classification, the local climate conditions can be classified as Cwa, with mean annual temperature of 19.3°C and normal annual rainfall of 1,530 mm (Dantas et al., 2007). Climatic data were collected at the weather station of National Institute of Meteorology (INMET) located at Federal University of Lavras-UFLA and they are shown in Figure 1. In the previous season, the experimental area was cultivated with corn. After harvesting, the area was fallowed. The area had high weed infestation before the experiment setup. Among them, *Bidens subalternans* DC., *Ipomoe anil* (L.) Roth., *Brachiaria decumbens*.

The experiments were conducted in a split plot design with three replications. The experimental plot consisted of four 5 m-long rows, the two central rows were considered to be the effective area. Two plots were taken under consideration in order to evaluate the effect from the desiccation period – the first plot, which was subjected to desiccation 7 days before sowing, and the second one, in which desiccation was performed just before sowing. The subplots were five RR® soybean cultivars (BRS Favorita RR®, TMG 1179 RR®, TMG 1176 RR®, Anta 82 RR®, NS 7100 RR®).

The effect of two post-emergence herbicides was evaluated in distinct plots: Glyphosate (1.080 g a. i. ha^{-1}) and Robust® (Fluazifop-P-Butil 250 g a. i. ha^{-1} and Fomesafen 200 g a. i. ha^{-1}). The subplots were five RR® soybean cultivars. During the 2013/2014 crop season, plots under manual weeding were used as control. The crop management either before or after sowing was that recommended for our conditions, according to the crop demand.

By the time plants were ready to be harvested, plant height and first pod insertion were measured using metric ruler. In addition, 5 plants per plot were collected to determine the number of pods per plant, and the number of seeds per pod by manual counting. The 1000-grain weight was determined according to the methodology described by Brasil (1992). Seed moisture was standardized at 13% and grain yield was estimated in Kg/ha.

The results were subjected to variance analysis (ANOVA), and the means were grouped by Scott-Knott test (1974), at 5% probability. Statistical analysis was performed using the SISVAR® statistical package (Ferreira, 2011). The statistical model and analysis procedure were similar to those presented by Ramalho et al. (2012).

RESULTS AND DISCUSSION

The results from the desiccation periods indicated that the number of pods per plant, number of seeds per pod and the 1.000-grain weight presented significant differences ($p \leq 0.01$) regarding the crop season effect (Table 2).

All the evaluated traits were significantly ($p \leq 0.01$) influenced by the cultivars (Table 2). It was expected,

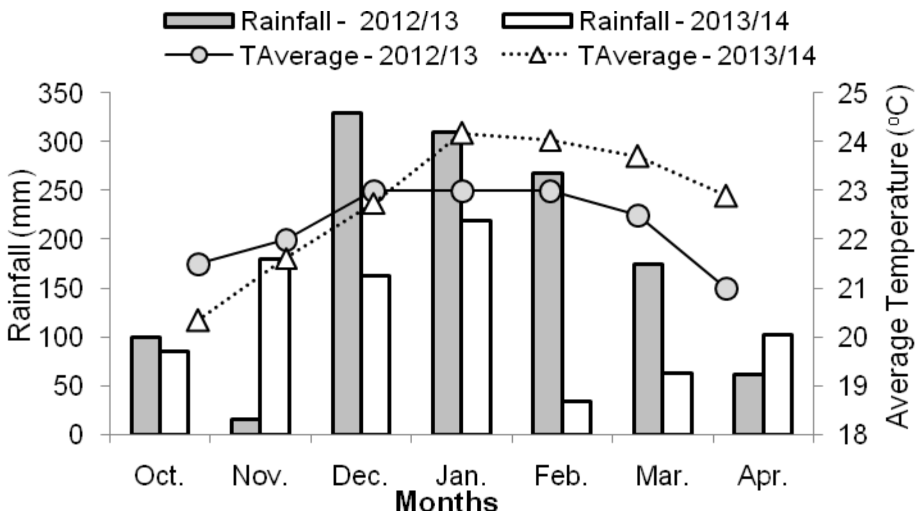

Figure 1. Monthly mean rainfall and mean temperature in Lavras– MG, during the 2012/2013 and 2013/2014crop seasons. Source: National Institute of Meteorology (INMET).

because cultivars have distinct genetic backgrounds, growth habits, maturity groups and other features that lead to such variation. These results corroborate those by Stulp et al. (2009) who also found differences in cultivar performances in different crop seasons.

Regarding the desiccation period, these results indicated that plant height, number of pods per plant and grain yield were significantly influenced by the desiccation method (Table 2). These results were also reported by Oliveira Jr. et al. (2006), who described the influence of glyphosate desiccation timing on soybean plant height and yield, thus reinforcing results found in the current study.

Except for the number of seeds per pod, the other agronomic traits and grain yield presented significant difference ($p \leq 0.01$) in the season x cultivar interaction (Table 2). Regarding the season x desiccation period interaction, only plant height and number of pods per plant presented significant differences ($p \leq 0.05$). As for the cultivar x desiccation period interaction, no significant difference was found in the evaluated parameters. The season x cultivars x desiccation period interaction showed significant difference in seed number per pod and grain yield; it shows that the cultivars have unequal performances regarding distinct desiccation methods and different crop seasons.

The differences in the pattern of production components among crop seasons did not affect grain yield (Table 2). The number of pods per plant was higher in the 2013/2014 crop season, and. the number of seeds per pod and the 1,000-grain weight were lower.

This fact may be attributed to the higher mean temperature observed during soybean pod formation in January and February (Figure 1). According to Castro et al. (2008), the soybean plant reaches better development in temperatures between 20 and 30°C, and the optimal temperature is approximately 30ºC. Increase in the number of pods per plant led to decrease in the amount of photoassimilates available for each pod, and consequently, to a smaller number of seeds per pod and 1,000-grain weight value.

By comparing the desiccation periods, the current study results indicated that the “Apply and Sow” method led to 10.56, 12.34 and 7.61% reduction in plant height, number of pods per plant and grain yield, respectively (Table 2). Oliveira Júnior et al. (2006) and Santos et al. (2007b) also described the negative effect caused by the “Apply and Sow” method on soybean yield. Data provided by these studies corroborated the results found in the current study.

The differences among management systems have been taken under consideration due to the shading effect caused by the weed population, which affects the growth of soybean seedlings. Therefore, Constantin et al. (2007) reported that the “Apply and Sow” system leads to grain yield decrease due to the shading effect. Thus, the current study assumes that the significant difference between desiccation periods probably due to the largest weed population found in the “Apply and Sow” method. This largest population accounts for the stronger shading effect at earlier soybean growth stages.

According to the economic point of view, grain yield is the most important production component. Therefore, a difference of 301.0 $Kg.ha^{-1}$ among yield averages was observed, thus suggesting the reductive effect of “Apply and Sow” method on the soybean yield.

The desiccation 7 days before sowing led to increase in plant height and in the number of pods per plant, in

Table 2. Variance and mean value analyses of plant height (PH), first pod insertion (FPI), number of pods per plant (NPP), seeds per pod (SPP), 1,000-grain weight (TGW) and grain yield (GY), by taking under consideration the study on different desiccation periods in RR® soybean cultivars during the 2012/13 and 2013/14 crop seasons, Lavras – MG.

Source of variation	DF	ANOVA (Mean squares - MS)¹					
		PH	FPI	NPP	SPP	TGW	GY
		cm		unit		g	Kg ha^{-1}
Blocks	2	437.60	0.074	12.82	0.029	0.82	1818849.03
Seasons (A)	1	55.29^{ns}	0.032^{ns}	11768.40**	0.23**	328.30**	34879.93^{ns}
Cultivars (C)	4	253.37*	141.64**	3214.15**	0.26**	65.34**	2678304.52*
Desiccation (D)	1	1332.93*	17.28^{ns}	1644.31*	0.007^{ns}	0.65^{ns}	1359481.59*
A x C	4	301.25**	40.57**	2026.39**	0.17^{ns}	8.23*	1188135.99**
A x D	1	209.06*	2.32^{ns}	2.68*	0.005^{ns}	0.80^{ns}	581435.86^{ns}
C x D	4	29.09^{ns}	4.16^{ns}	413.99^{ns}	0.009^{ns}	3.06^{ns}	1199762.62^{ns}
A x C X D	4	18.77^{ns}	12.81^{ns}	711.39^{ns}	0.04*	0.69^{ns}	1393195.62**
Error 1	2	122.16	3.53	68.04	0.01	10.82	254365.61
Error 2	8	57.62	4.61	222.50	0.02	9.83	365315.12
Error 3	28	47.12	10.67	472.50	0.01	9.68	270150.09
Mean		85.3	13.8	79.5	2.2	15.0	3728.1
CV 1 (%)		12.96	13.61	10.37	6.02	10.82	13.53
CV 2 (%)		8.90	15.55	18.75	6.89	9.83	16.21
CV 3 (%)		8.05	23.65	27.32	5.30	9.68	13.94
Factors		Mean values²					
Crop season							
2012/13		84.3^{a}	13.8^{a}	65.5^{b}	2.3^{a}	173.8^{a}	3704.0^{a}
2013/14		86.2^{a}	13.7^{a}	93.5^{a}	2.2^{b}	127.0^{b}	3752.2^{a}
Herbicides							
“Apply and Sow”		80.5^{b}	13.2^{a}	74.3^{b}	2.2^{a}	149.3^{a}	3577.5^{b}
7 days		90.0^{a}	14.3^{a}	84.7^{a}	2.3^{a}	151.4^{a}	3878.6^{a}
Cultivars							
BRS Favorita RR®		80.5^{b}	14.6^{b}	99.0^{a}	2.2^{a}	184.3^{a}	3888.7^{a}
Anta 82 RR®		90.6^{a}	14.0^{b}	65.2^{b}	2.2^{a}	151.4^{b}	3657.2^{a}
NS 7100 RR®		81.6^{b}	10.2^{c}	63.9^{b}	2.0^{b}	147.1^{b}	2943.0^{b}
TMG 1179 RR®		84.0^{b}	11.2^{c}	94.5^{a}	2.4^{a}	118.5^{c}	4031.9^{a}
TMG 1176 RR®		89.6^{a}	19.0^{a}	75.1^{b}	2.3^{a}	150.5^{b}	4119.5^{a}

¹ ** and *, significant at 1 and 5% probability by F test, respectively. ^{ns}, Non-significant; DF, degrees of freedom; CV, coefficient of variation. ² Means followed by the same letter in columns belong to the same group by Scott Knott test (1974), at 5% probability.

comparison to the “Apply and Sow” method. Such differences appear to be related to root dry weight decrease or to nodule dry weight decrease in soybean plants when the “Apply and Sow” method is adopted, as reported by Santos et al. (2007b) who described the low development of soybean plants resulting from weakened root systems.

There was high variation range between the mean yields, from 2943 to 4120 Kg.ha^{-1} in the NS 7100 RR® and TMG 1176 RR® cultivars, respectively (Table 2). However, all cultivars showed satisfactory performances, and the yield values above the average presented by this crop in the state of Minas Gerais were obtained in the 2013/2014 crop season - 2687 Kg.ha^{-1} (CONAB, 2014). Generally speaking, Anta 82 RR® and NS 7100 RR® cultivars reached higher yields in the “Apply and Sow” method (Figure 2). The other cultivars and crop seasons showed a distinct pattern. Nevertheless, no significant difference was found in grain yield. This fact is probably correlated to the individual features of each cultivar and to the genotype x environment interaction. Santos et al. (2007b) recommend that the pre-sowing desiccation in soybean fields should be done at least 7 days before sowing. Thereby, the current study assumes that Anta 82 RR® and NS 7100 RR® cultivars are not affected by glyphosate application just before sowing. Except for

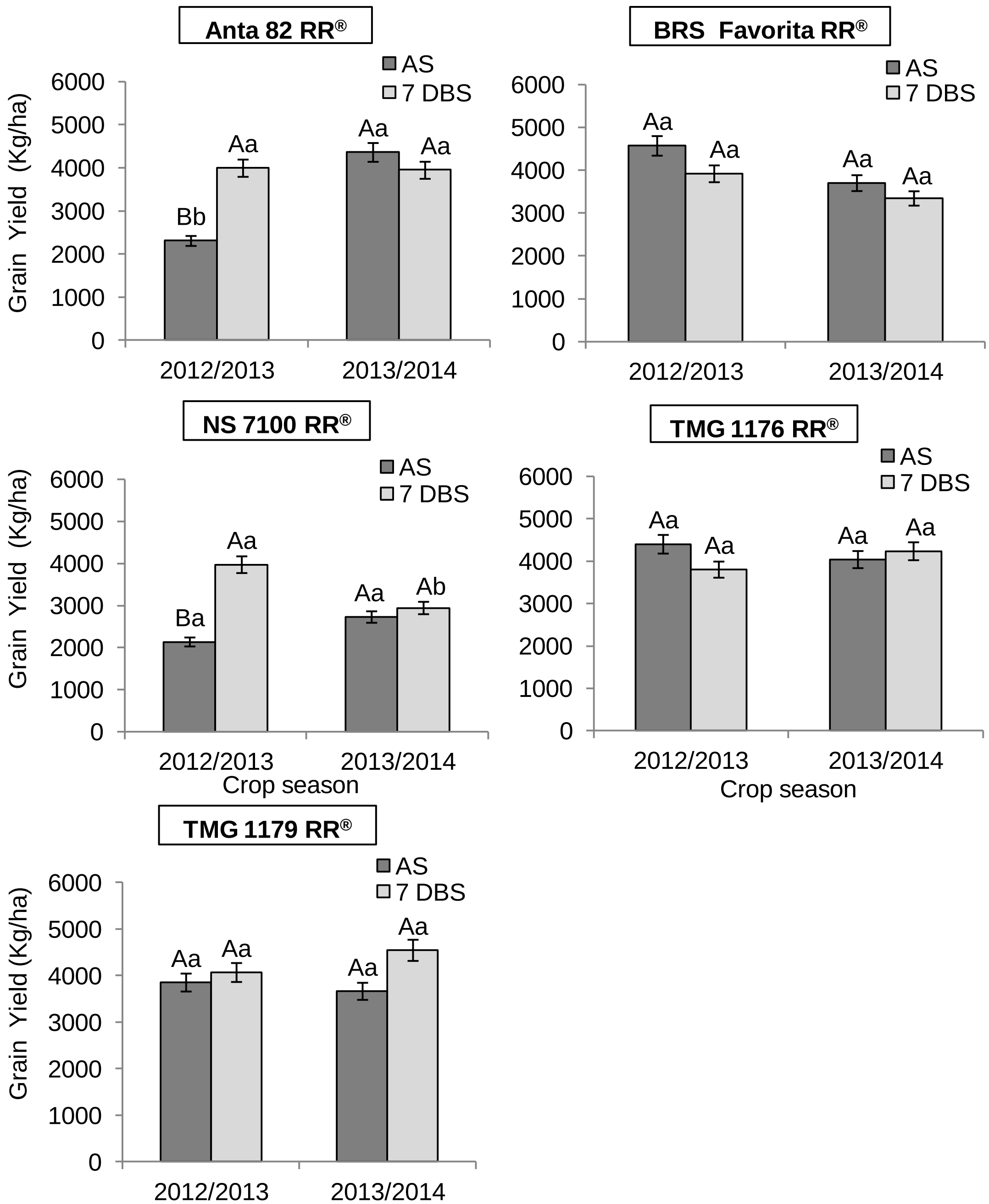

Figure 2. Grain yield (Kg/ha) in RR® soybean cultivars in different desiccation periods (AS, "Apply and Sow"; 7 DBS, 7 days before sowing), during the 2012/2013 and 2013/2014 crop seasons, in Lavras, MG, Brazil. Averages followed by the same capital letter in the same crop season and lower case in the same desiccation period belong to the same group according to the Scott-Knott test (1974) at 5% probability.

plant height and grain yield, the other variables were significantly ($p \leq 0.01$) influenced by crop seasons (Table 3). Regarding the different weed management systems, a significant difference was found among cultivars ($p \leq 0.01$) in all the evaluated traits, which is consistent with the genetic diversity among cultivars.

However, the different types of post-emergence weed control did not present significant differences in the evaluated traits, as well as season x herbicide interaction, cultivar x herbicide interaction and season x cultivars x herbicide interaction.

As for the season x cultivar interaction, there was

Table 3. Variance and mean value analyses of plant height (PH), first pod insertion (FPI), number of pods per plant (NPP), seeds per pod (SPP), 1,000-grain weight (TGW) and grain yield (GY) by taking under consideration the study on different herbicides in RR® soybean cultivars, during the 2012/13 and 2013/14 crop seasons in Lavras – MG.

Source of Variation	DF	ANOVA (Mean Squares - MS)¹					
		PH	FPI	NPP	SPP	TGW	GY
		cm		unidade		g	Kg ha^{-1}
Blocks	2	580.14	17.04	989.01	0.04	1.02	576326.77
Seasons (A)	1	91.26^{ns}	76.61**	11043.26**	0.18*	280.41**	762913.86^{ns}
Cultivars (C)	4	464.04**	93.75**	6130.34**	0.32**	73.93**	5057549.21**
Herbicides (H)	1	25.61^{ns}	9.44^{ns}	989.01^{ns}	0.87^{ns}	3.19^{ns}	24485.22^{ns}
A x C	4	2343.32**	78.80**	1281.70^{ns}	0.06^{ns}	4.81^{ns}	2044430.98**
A x H	1	11.97^{ns}	1.23^{ns}	1492.01^{ns}	0.0008^{ns}	0.87^{ns}	863057.05^{ns}
C x H	4	18.28^{ns}	5.90^{ns}	226.11^{ns}	0.03^{ns}	5.29^{ns}	411709.03^{ns}
A x C X H	4	63.03^{ns}	6.23^{ns}	417.21^{ns}	0.01^{ns}	0.46^{ns}	49578.20^{ns}
Erro 1	2	41.20	3.20	303.36	0.006	1.67	30657.73
Erro 2	8	38.00	3.75	426.87	0.021	1.79	413572.30
Erro 3	28	29.44	6.94	505.37	0.03	2.31	459597.01
Mean		90.0	14.1	80.5	2.3	15.9	3865.4
CV 1 (%)		7.13	12.63	21.63	3.54	8.09	4.53
CV 2 (%)		6.85	13.61	25.66	6.22	8.39	16.64
CV 3 (%)		6.03	18.58	27.92	7.45	9.52	17.54
Factors		Mean values²					
Crop season							
2012/13		91.2^{a}	15.3^{a}	66.9^{b}	2.4^{a}	181.5^{a}	3752.7^{a}
2013/14		88.7^{a}	13.0^{b}	94.0^{a}	2.3^{b}	138.2^{b}	3978.2^{a}
Herbicides							
Roundup®		90.6^{a}	14.5^{a}	76.4^{a}	2.3^{a}	162.1^{a}	3845.2^{a}
Robust®		89.3^{a}	13.7^{a}	84.5^{a}	2.3^{a}	157.5^{a}	3885.6^{a}
Cultivars							
BRS Favorita RR®		85.7^{b}	15.2^{b}	111.5^{a}	2.2^{b}	197.6^{a}	4134.2^{a}
Anta 82 RR®		97.2^{a}	13.0^{c}	55.6^{b}	2.3^{b}	160.1^{b}	3836.4^{a}
NS 7100 RR®		84.4^{b}	11.7^{c}	63.8^{b}	2.1^{b}	164.3^{b}	2760.7^{b}
TMG 1179 RR®		86.2^{b}	12.3^{c}	93.8^{a}	2.4^{a}	132.2^{c}	4393.8^{a}
TMG 1176 RR®		96.2^{a}	18.5^{a}	77.6^{b}	2.5^{a}	144.9^{c}	4201.9^{a}

¹ ** and * significant at 1 and 5% probability by F test, respectively. ns, Non-significant; df, degrees of freedom; CV, coefficient of variation.² Means followed by the same letter in columns belong to the same group by Scott Knott test (1974), at 5% probability

significant difference ($p \leq 0.01$) in plant height, first pod insertion and grain yield (Table 3). These results are similar to those reported by Correa and Alves (2009). By evaluating the efficiency of herbicides applied in conventional and transgenic soybean cultivars, no significant difference was found in first pod insertion and grain yield when comparing selective herbicides, glyphosate and the mix between them.

As for the differences found among evaluated traits, it is possible to notice that the range of yield variation between TMG 1179RR® (4394 kg.ha^{-1}) and NS 7100 RR® (2761 kg.ha^{-1}) cultivars is considerably high.

In addition to grain yield, other agronomic traits, such as plant height and first pod insertion height, are extremely important and desirable to a cultivar. These features are linked to the cultivar genetic profile, and they are also influenced by environmental factors such as soil fertility, climate, crop season, humidity, among other factors (Lambert et al., 2007).

Regarding plant height, Rezende and Carvalho (2007) recommended an optimal soybean plant height to improve harvest efficiency, and described the ideal height between 60 and 120 cm. All the tested cultivars in both crop seasons reached mean plant heights consistent with the recommended optimal height.

As for the first pod insertion, the current results indicate difference of 18.56cm in TMG 1176 RR® cultivar and 1175cm in the NS 7100 RR® one. Despite the consistent

Table 4. Variance and average value analyses of plant height (PH), first pod insertion (FPI), number of pods per plant (NPP), seeds per pod (SPP), 1,000-grain weight (TGW) and grain yield (GY) taken under consideration of the study on different kinds of weed management in RR® soybean cultivars during the 2013/14 crop season in Lavras – MG.

Source of variation	DF	ANOVA (Mean Squares - MS)¹					
		PH	FPI	NPP	SPP	TGW	GY
		cm		unidade		g	Kg ha^{-1}
Blocks	2	1149.51	3.73	1938.73	0.06^{ns}	1.32	827761.22
Cultivars (C)	4	901.62**	172.64**	3236.00**	0.50**	56.94**	4882692.59**
Management (M)	2	0.64^{ns}	1.43^{ns}	1404.05^{ns}	0.02^{ns}	4.75^{ns}	362579.36^{ns}
C x M	8	41.33^{ns}	6.77^{ns}	619.93^{ns}	0.01^{ns}	1.90^{ns}	133496.77^{ns}
Error 1	4	126.75	5.61	128.50	0.02	3.40	185959.93
Error 2	24	14.37	3.22	626.36	0.04	2.67	213033.47
Mean		88.7	13.1	92.0	2.2	135.7	3939.3
CV 1 (%)		6.34	18.01	12.31	6.21	13.59	10.95
CV 2 (%)		4.27	13.65	27.18	8.71	12.05	11.72
Factors				Mean values²			
Management							
Roundup®		88.9^a	13.3^a	85.0^a	2.3^a	141.7^a	3838.1^a
Robust®		88.5^a	12.8^a	103.1^a	2.2^a	134.7^a	4118.3^a
Capina		88.7^a	13.3^a	88.1^a	2.2^a	130.6^a	3861.6^a
Cultivars							
BRS Favorita RR®		79.6^b	10.2^c	120.9^a	2.1^b	170.4^a	3483.0^b
Anta 82 RR®		103.2^a	13.7^b	71.9^b	2.2^b	134.5^c	4476.8^a
NS 7100 RR®		81.8^b	11.0^c	82.3^b	1.9^c	149.4^b	2856.9^c
TMG 1179 RR®		84.1^b	10.1^c	99.7^a	2.4^a	109.4d	4440.8^a
TMG 1176 RR®		95.0^b	20.5^a	85.4^b	2.6^a	114.6d	4439.1^a

¹ ** and * significant at 1 and 5% probability by F test, respectively. ^{ns}, Non-significant; DF, degrees of freedom; CV, coefficient of variation. ² Means followed by the same letter in columns belong to the same group by Scott Knott test (1974), at 5% probability.

variation, cultivars NS 7100 RR®, Anta 82 RR® and TMG 1179 RR® could be considered to be suitable for mechanical harvesting. Even belonging to a group with lower height of first pod insertion, only the NS 7100 RR® cultivar showed lower first pod insertion values, although they were still close to the desirable ones.

Regarding the production components, it was found distinct performance among cultivars under divergent edaphoclimatic conditions, fact that was already expected due to the unequal genotypic structure and to the intense environmental influence on plant phenotype.

There were significant differences ($p \leq 0.01$) among cultivars in all evaluated traits, except for the NS 7100 RR® cultivar, which presented no significant difference in grain yield among cultivars. Furthermore, it was also found that there was no difference between the types of weed management tested in post - emergence, as well as in the season x herbicide interaction (Table 4).

Differently, Zadinello et al. (2012) reported results that do not meet those in the current study. They found 15% yield reduction as the result from herbicide application in the R_2 stage. Such reduction was caused by glyphosate application in post-emergence stage and it was also described by Albrecht and Ávila (2010) and by Santos et al. (2007a, 2007b).

By analyzing the averages from the evaluated traits related to post-emergence weed management, it is possible to notice that the management using manual weeding or herbicides (Roundup® or Robust®) do not affect soybean agronomic traits and yield (Table 4). It is possible to assume that these herbicides do not affect the evaluated soybean cultivars, fact that makes them suitable due to their high efficiency.

According to the herein found results, it is possible to see the relation between desiccation management and soybean agronomic performance. The desiccation 7 days before sowing appears to be responsible for higher soybean yield in comparison to the “Apply and Sow” method. It seems that the different types of post-emergence weed management (Glyphosate, Fluazifop-P-Butil and Fomesafen or manual weeding have no effect on soybean agronomic traits and grain yield.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Albrecht LP, Ávila MR (2010). Manejo de glyphosate em soja RR® e a qualidade das sementes. Inf. Abrat. 20(2):45-54.

Albrecht LP, Barbosa AP, Silva AFM, Mendes MA, Maraschi-Silva LM, Albrecht AJP (2011). Desempenho da soja Roundup Ready sob aplicação de glyphosate em diferentes estádios. Planta daninha 29(3):585-590.

AENDA – Associação das Empresas Nacionais de Defensivos Agrícolas (2011). Quando 15% é maior 85%. Disponível em: http://www.aenda.org.br. Acesso em: 10 out. 2013.

BRASIL (1992). Ministério da Agricultura. Regras para análises de sementes. P. 365.

Castro PRC, Klyge RA, Sestari I (2008). Manual de fisiologia vegetal: Fisiologia de cultivos. Piracicaba: Editora Agronômica Ceres, P. 864.

CONAB - Companhia Nacional de Abastecimento (2014). Acompanhamento de safra brasileira: grãos, décimo primeiro levantamento, Agosto 2014. Companhia Nacional de Abastecimento, Brasília: CONAB, P. 87.

Constantin J, Oliveira JR RS, Cavalieri SD, Arantes JGZ, Alonso DG, Roso AC, Costa JM (2007). Interação entre sistemas de manejo e de controle de plantas daninhas em pós-emergência afetando o desenvolvimento e a produtividade do milho. Planta Daninha, 25(3):513-520.

Corrêa MJP, Alves PLA (2009). Eficácia de Herbicidas Aplicados em Pós-Emergência na Cultura da Soja Convencional e Transgênica. Planta Daninha, 27(spe):1035-1046.

Dantas AA, Carvalho LG, Ferreira E (2007). Classificação e tendências climáticas em Lavras, MG. Ciênc. Agrotec. 31(6):1862-1866.

Ferreira DF (2011). Sisvar: A computer statistical analysis system. Ciênc. Agrotec. 35(6):1039-1042.

Petter FA, Procópio SO, Cargnelutti Filho A, Barroso ALL, Pacheco LP (2007). Herbicide management in Roundup Ready® soybean crop. Planta Daninha 25(3):557-566.

Lambert ES, Meyer MC, Klepker D (2007). Cultivares de soja 2007/2008 Região Norte e Nordeste. Embrapa Soja, Documento 284:36.

Londres F (2011). Agrotóxicos no Brasil um guia para ação em defesa da vida. Rio de Janeiro: Assessoria e Serviços a Projetos em Agricultura Alternativa, P. 190.

Oliveira Junior RS, Constantin J, Costa JM, Cavalieri SD, Arantes JGZ, Alonso DG, Roso AC, Biffe DF (2006). Interação entre sistemas de manejo e de controle de plantas daninhas em pós-emergência afetando o desenvolvimento e a produtividade da soja. Planta Daninha 24(4):721-732.

Ramalho MAP, Ferreira DF, Oliveira AC (2012). Experimentação em genética e melhoramento de plantas. 2.ed. Lavras: UFLA, P. 322.

Rezende PM, Carvalho EA (2007). Avaliação de cultivares de soja [Glycine max (L.) Merrill] para o sul de Minas Gerais. Ciênc. Agrotec. 31(6):1616-1623.

Santos JB, Ferreira EA, Reis MR, Silva AA, Fialho CMT, Freitas MAM (2007a). Avaliação de Formulações de Glyphosate Sobre Soja Roundup Ready. Planta Daninha 25(1):165-171.

Santos JB, Santos EA, Fialho CMT, Silva AA, Freitas MAM (2007b). Época de dessecação anterior à semeadura sobre o desenvolvimento da Soja Resistente ao Glyphosate. Planta Daninha 25(4):869-875.

Scott AJ, Knott MA (1974). A Cluster Analysis Method for Grouping Means in the Analysis of Variance. Biometrics 30(3):507-512.

Serra AP, Marchetti ME, Candido AC da S, Dias ACR, Christoffoleti PJ (2011). Glyphosate influence on nitrogen, manganese, iron, copper and zinc nutritional efficiency in glyphosate resistant soybean. Cienc. Rural 41(1):77-87.

Stülp M, Braccini AD, Albrecht L, Ávila MR, Scapim, CA, Schuster I (2009). Desempenho agronômico de três cultivares de soja em diferentes épocas de semeadura em duas safras. Cienc. Agrotec. *33*(5):1240-1248.

Zablotowicz RM, Reddy KN (2004). Impact of glyphosate and *Bradyrhizobium japonicum* symbiosis; with glyphosate-resistant transgenic soybean: a minireview. J. Environ. Qual. 33(3):825-831.

Zablotowicz RM, Reddy KN (2007). Nitrogenase activity, nitrogen content, and yield responses to glyphosate in glyphosate-resistant soybean. Crop Prot. 26(3):370-376.

Zadinello R, Chaves MM, Santos RF, Bassegio D, Werncke I (2012). Influência da aplicação de Glifosato na produtividade da soja. Act. Iguaz. 1(4):1-8.

Zobiole LHS, Kremer R, Oliveira R, Constantin J (2010). Glyphosate affects micro-organisms in rhizospheres of glyphosate-resistant soybeans. J. Appl. Microbiol. 110:118-127.

Zuffo AM, Petter FA, Nóbrega JCA, Pacheco LP, Alcântara Neto F, Andrade FR (2014). Microbiological attributes in a latosol in glyphosate application under water deficit conditions. Afr. J. Agric. Res. 9(32):2495-2505.

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Full Length Research Paper

Greenhouse evapotranspiration and crop factor of *Amaranthus cruentus* grown in weighing lysimeters

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Actual evapotranspiration and crop coefficient (K_c) of *Amaranthus cruentus* grown in weighing lysimeter was determined under a screen house. The weighing lysimeter was made of a cylindrical plastic of circular cross-sectional area of 0.076 m^2 and diameter 0.3 m. Climatic variables such as solar radiation, relative humidity, air temperature and wind speed were collected for the estimation of reference evapotranspiration (ET_r) using the FAO-Penman Monteith model. Actual crop evapotranspiration (ET_c) was measured directly from the daily drop in the level of water in the burette that was connected to the lysimeter. Crop factor (K_c) was estimated from the ratio of ET_c /ET_o. The ET_c of the crop rose gradually from the period of emergence (4.5 mm $week^{-1}$) during the 1 week after planting (WAP) to a maximum value of 14.3 mm $week^{-1}$ during the 7 WAP. K_c for the emergence and maturity stages of *Amaranthus cruentus* were 0.15 and 0.36, respectively. The highest leaf area index (LAI) and leaf coverage area were 11.39 and 0.866. The optimum soil moisture content for the highest K_c value (0.36) was 11.7%. The output of this research will be useful for farmers who are into vegetable production for enhanced productivity at farm levels.

Key words: Lysimeter, *Amaranthus cruentus*, crop factor, soil water content, leave area index.

INTRODUCTION

A detailed knowledge of crop evapotranspiration from the period of crop emergence to maturity is essential for the assessment of water resources and storage requirements, the capacity of irrigation systems, optimal allocation of water to crops and for the decision making in agriculture (Oguntunde, 2004). Knowing the crop's evapotranspiration is very much essential in determining the crop's irrigation requirement. It helps to save water by controlling water supply through better determination of crop water requirements and development of biological and physical criteria (Katerji et al., 1997) leading to precise determinations of irrigation schedules for efficient performance of irrigation systems supplying water to field (Pereira et al., 2002; Ramirez and Harmsen, 2011); and also to improve the water use efficiency of species and plant varieties that are cultivated. Knowing the ET helps to understand the magnitude of gas interchanges between the eco and agro systems with the atmosphere (Ramirez et al., 2011).

Evapotranspiration is directly measured using weighing

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lysimeters (Howell et al., 1991). Lysimeter measurements are adopted for hydrological balances of crops as it provides a convenient and a practical way of monitoring soil water content and the soil water balance under controlled environments of which ET is a component (da Silva et al., 2005; Liu et al., 2007, Ceccon et al., 2008), or to determine crop coefficient (K_c) values (Tyagi et al., 2000). Recent studies around the world have been reported on the use of lysimeters to develop crop-coefficient for a variety of crops, such as pulse crops in India (Pandey and Pandev, 2011), Corn in Spain (Martinez, 2008), Rice and Sunflower in India (Tyagi et al., 2000), wheat and maize in China (Liu and Luo, 2010), and Cotton and Wheat in the USA (Ko et al., 2009).

Leafy Amaranth (*Amaranthus cruentus*) has so many health and nutritional benefits. *A. cruentus* is high in protein, lysine, calcium, iron and fibre; all of which are useful as functional ingredient in cereal products. Amaranth oil is high in "squalene", a powerful antioxidant used as a dietary supplement for diabetes and those suffering from hypertension and metabolic disorders (Makus and Davis, 1984; Pal and Khoshoo, 1974; Teutonico and Knorr, 1985). Amaranth oil has been used for strengthening immunizing function in the body, improves resistance to diseases, radioactive and x-ray irradiation, improves mental performance and memory functions, helps to regulate the conversion of fats, especially cholesterol and also helps to fight against bacteria, fungi, herpes and other viruses, and improve auto-immune disorders (Fasinmirin, 2007). The vegetable is very rich in vitamin A and it contributes to a balance diet a significant amount of bet-carotene and ascorbic acid (Vitamin C), iron and calcium (Early, 1997). Efforts to improve the production of this very important crop have been hampered by inadequate knowledge on how best to manage the increasingly scarce water resource, especially during dry season (Fasinmirin et al., 2009). Therefore, efforts should not be spared at quantifying the actual water need of *A. cruentus*, so as to effectively manage the scarce resource for optimum production of the crop. Despite these breakthroughs, limited data is available on the water requirement of *A. cruentus* from the period of its establishment to maturity in order to prevent water stress or over irrigation of the crop on the field. Therefore, this research was aimed at determining the actual evapotranspiration and crop coefficient for *A. cruentus* grown in weighing lysimeters.

MATERIALS AND METHODS

Study site

The study was conducted in a screen house at the Department of Agricultural Engineering, Federal university of technology, Akure, Ondo state, Nigeria. Akure is in the south-western part of Nigeria (latitude 7°14'N and longitude 5°08'E) and is located within the humid region of Nigeria. Akure lies in the rain forest zone with a mean annual rainfall of between 1300 and 1600 mm and with an average temperature of 27.5°C. The relative humidity ranges between 85 and 100% during the rainy season and less than 60% during the dry season period. Akure is about 351 m above the mean sea level (Fasinmirin et al., 2009) (Figure 1).

The screen house was made of galvanized iron pipes, 51 mm in diameter and 4 m high. Transparent ethylene (nylon) was used as cover for the entire screen house to aid the reception of solar radiation and to prevent rain water and dew from getting to the crop. Circular perforations of about 6 mm in diameter were made at the sides of the screen and below the platform where lysimeter containing the growing crop was placed, in order to allow for convectional movement of air into and outside the screen house.

Lysimeter configuration and water application

The lysimeter was made of a cylindrical plastic bucket, having a circular cross-sectional area of 0.076 m^2 and a diameter of 0.3 m. The thickness and depth of the lysimeter were 0.003 and 0.3 m, respectively. The lysimeter depth was enough to permit normal root development. The plastic material of which the lysimeter was made helped to minimize heat conduction down the lysimeter walls (Pruitt and Angus, 1960).

Soil was collected from a nearby, previously cultivated field at depths of 0 - 200, 200 - 400 and 400 - 600 mm. The soil was carefully collected and placed into the lysimeter to minimize disturbance. Gravel was first placed at the bottom of the lysimeter, followed by the soil obtained from soil depth of between 400 - 600 mm, then the soil at 200 - 400 mm and finally the soil at 0 - 200 mm (the top soil). The weighing mechanism comprised of a water filled float, which was connected to a calibrated burette (0.1 mm accuracy) via a mercury filled manometer. The burette was also filled to the zero point with water. The change in water level in the burette was taken as the ET for the day. A hose pipe was used to connect the water-filled tube to one end of the manometer, while another hose connected the burette to the other end of the manometer. This system measures changes in weight of the lysimeter system.

A. cruentus seeds obtained from the National Institute of Horticulture (NIHORT), Ibadan, Nigeria were mixed with dry sand, such that the sand to seed ratio was 80:20. The mixture was broadcasted on the top soil in the lysimeter. The germinating plants were prunned down to two viable stands after the 1 week after planting (1 WAP). The quantity of water added to the crop was measured using a measuring cylinder. The time to irrigate the crop was determined by a tensiometer that was installed at the 15 cm depth of soil in the lysimeter. The soil in the lysimeter was irrigated to field capacity based on the tensiometer reading (40 centibars) (James, 1994).

Measurements

Reference and actual crop evapotranspiration

Climate parameters such as daily maximum and minimum air temperature and daily maximum and minimum relative humidity, wind speed, solar radiation, sunshine hours and rainfall were collected at the Meteorological station of the Federal University of Technology, Akure, Nigeria, located some 120 m away from the site of experiment. The data collected were used to estimate the reference evapotranspiration using the FAO-Penman Monteith model as defined by Allen et al. (1998) and Fasinmirin et al. (2009) as:

$$ET_o = \frac{0.408\Delta(R_n - g) + 900\gamma u_2 (e_s - e_a)/(t+273)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

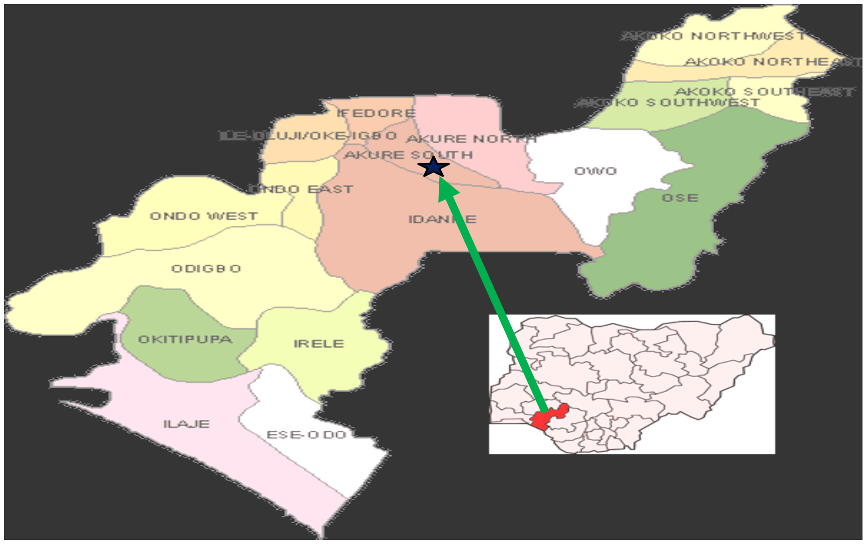

Figure 1. Maps showing the location of the experiment.

where: ET_o = Reference evapotranspiration [mm day^{-1}]; R_n = Net radiation [MJ m^{-2} day^{-1}]; G = Soil heat flux density [MJ m^{-2} day^{-1}] = 0 (In general G is negligible in the daily calculation of reference ET because g is small on daily basis (Allen et al., 1998)); t = Mean daily air temperature at 2 m height [°C]; u_2 = Wind speed at 2 m height [m s^{-1}]; e_s = Saturation vapour pressure [kPa]; e_a = Actual vapour pressure [kPa]; e_s-e_a = Saturation vapour pressure deficit [kPa]; Δ = Slope of the vapour pressure curve [kPa °C^{-1}], and γ = Psychrometric constant [kPa °C^{-1}].

The daily evapotranspiration of the crop (ET_C) was measured by determining the daily drop in water level of the burette. The amount of water lost from the lysimeter through evapotranspiration causes a drop in water level in the burette. The initial and final readings were recorded and the difference between the two gave the crop evapotranspiration on daily basis. The crop coefficient (K_c) of the crop was determined using equation 2 as stated in Fasinmirin et al. (2009).

$$K_c = \frac{crop\ evapotranspiration}{reference\ evapotranspiration} \frac{ET_C}{ET_O} \quad (2)$$

Soil parameters such as soil water content was determined weekly at a depth of 20 cm using a digital soil moisture meter on weekly basis.

Percentage soil water content was recorded during infiltration using a hand-held digital soil moisture meter-Lutron PMS - 714, IP - 65 for soil moisture ranging from 0 to 50%. The meter recorded the soil moisture content on wet basis. The soil bulk density (g.cm^{-3}) was determined by the core method using a 5 cm long by 4 cm diameter cylindrical metal core. The corer was rammed into the soil to ensure little soil disturbance and to ensure nearly insitu soil condition was maintained. Samples were dried at 105°C for 24 h in a forced air oven, weighed and density calculated as sample dry weight (g) divided by sample volume (cm^3) as described by Blake and Hartge (1986).

Measured agronomic parameters include number of leaves of *A. cruentus,* which was counted on a weekly basis from the 1 WAP to the 9 WAP. The leaf area (m^2) was determined using graphical (approximate) method. The leaf area was recorded weekly from the 2 WAP to crop maturity. Leaf area index according to Gong et al. (1995) was estimated from the relationship (Equation 3):

$$Leaf\ area\ index\ (LAI) = \frac{Area\ of\ leaf\ coverage\ per\ plant}{Area\ of\ soil\ covered\ per\ plant} \quad (3)$$

The Leaf coverage area (LCA) was calculated using the Equation 4:

Leaf coverage area =

$$(Total\ number\ of\ leaves\ per\ plot) \times \frac{Leaf\ area}{Plot\ size} \quad (4)$$

The plant height was measured using a metre rule from the soil surface to the apex leaf on the plant before the growth of flowers and to the flower tip when flowers started to appear on the crop. This was recorded on a weekly basis and error due to parallax was well avoided by taking the readings at eye level. The root depth was recorded weekly by carefully removing the soil by a hand trowel and measuring the root depth using a steel rule.

Statistical analysis

Soil and crop data were subjected to statistical analysis such as mean and standard deviation. Also, graphical analysis of the climate parameters, soil water content, evapotranspiration and crop factor were presented to enhance interpretation of trends and characteristics of the data collected.

RESULTS AND DISCUSSION

Micro-climate of the screen house

The mean weekly temperature during the 10 week The mean weekly temperature during the 10 week period of the experiment is shown in Figure 2 The highest temperature value was recorded in the 1 Week after Planting (1 WAP) with value 26.7°C (± 0.63), while the lowest temperature figures was recorded during the 10

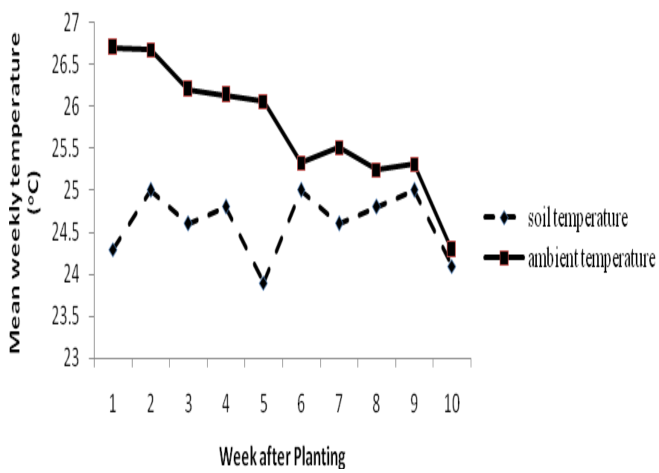

Figure 2. Mean weekly ambient and soil temperature during the research period.

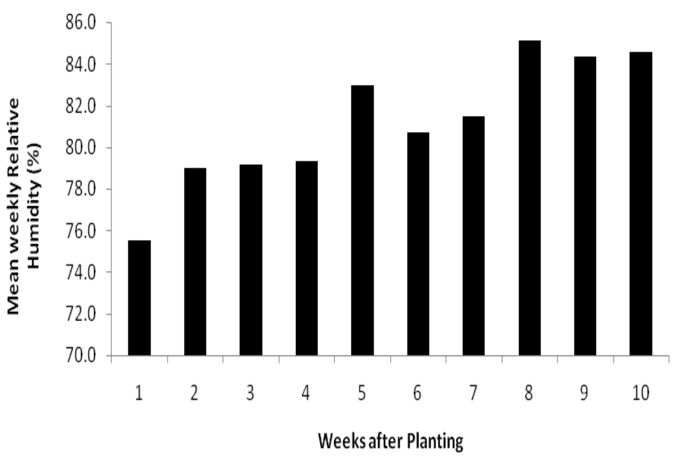

Figure 3. Ambient Relative humidity of the site during the research period.

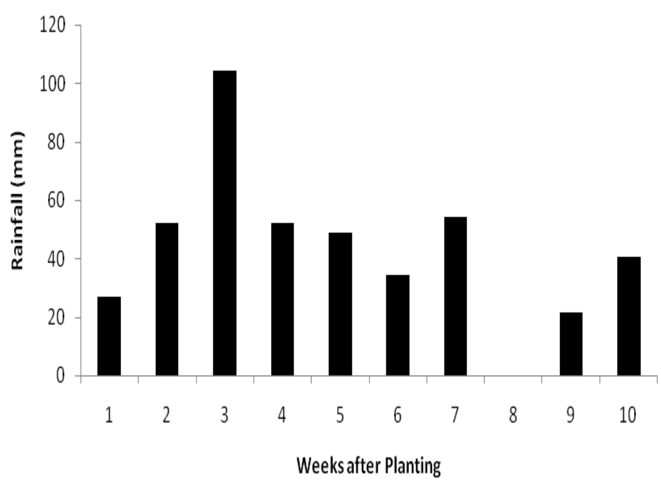

Figure 4. Average weekly rainfall during the period of the experiment.

WAP, with mean weekly temperature of 24.3°C (± 0.49). The measured soil temperature values were lower comparatively with ambient temperature and this could be as a result of the presence of the screen which shields the soil from direct solar radiation. Even at the highest ambient temperature of 26.7°C (± 0.63), the corresponding mean weekly soil temperature was 24.5°C (± 0.12). The Figure shows a steady decline in average weekly temperatures from the 1 to the 10 WAP. The decline in weekly temperature must have been caused by gradual rise in the frequency of rainfall.

Akure is known to have high relative humidity values. Throughout the course of the research (April to June), the relative humidity had a minimum value of 75.5% (± 4.73) which was recorded in the 1 WAP and highest relative humidity was recorded in the 8 WAP with a value of 85.1% (± 2.47) (Figure 3). Analysis of the rainfall data during the experiment period shows a gradual increase from 26.7 mm in the 1 WAP to a peak of 104.1 mm in the 3 WAP. A steady decline in rainfall occurred from the 4 to 6 WAP and increased again in the 7 WAP. Zero value of rainfall was recorded during the 8 WAP as a result of temporal cessation of precipitation (Figure 4).

The wind speed data is shown in Figure 5. The total weekly values of the wind speed rose from 2 ms^{-1} (± 0.39) during the 1 WAP to 2.4 ms^{-1} (± 0.21) in the 3 WAP. It declined in the 4 WAP to 2 ms^{-1}(± 0.34) and rose to a peak, 2.6 ms^{-1} (± 0.26) in the 9 WAP and declined again in the 10 WAP.

Reference evapotranspiration

Figure 6 shows the weekly reference evapotranspiration during the period of the growing season of *A. cruentus*. There was a sharp rise in the ET_o value from the 1 WAP to the 2 WAP, after which there was a gradual decline in reference evapotranspiration up to the 10 WAP. The highest ET_o value of 37.79 $mm.wk^{-1}$ occurred in the 3 WAP, an indication of highest value of 5.40 $mm.day^{-1}$ and the lowest value of 25.69 $mm.week^{-1}$ (3.67 $mm.day^{-1}$) occurred during the 10 WAP. Statistical analyses of the reference crop evapotranspiration (ET_o) values obtained from the Penman – Monteith model showed a high correlation coefficient (r = 0.81). Rise in ET_o was observed during the month of March (1 to 2WAP), which was in the dry season. The ET_o took a gradual downward trend from the month of April to May, which was in the wet season of the year. The rise in ET_o observed in March must have been caused by high solar radiation, which was accompanied by high temperature that often results in quick evaporation of water from soil and water surfaces (Fasinmirin et al., 2009).

Soil water content and crop evapotranspiration

Result of percentage soil water content at depths of 10

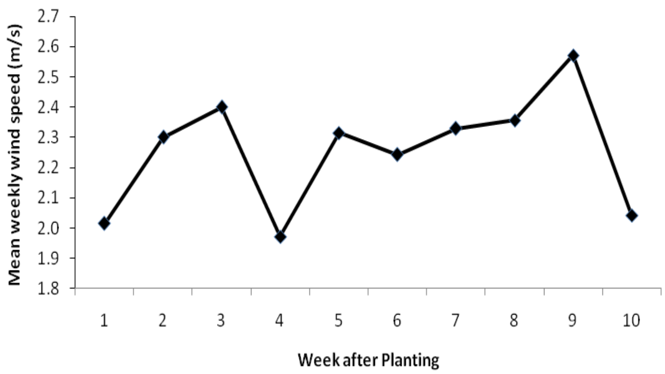

Figure 5. Mean weekly wind speed during the research period.

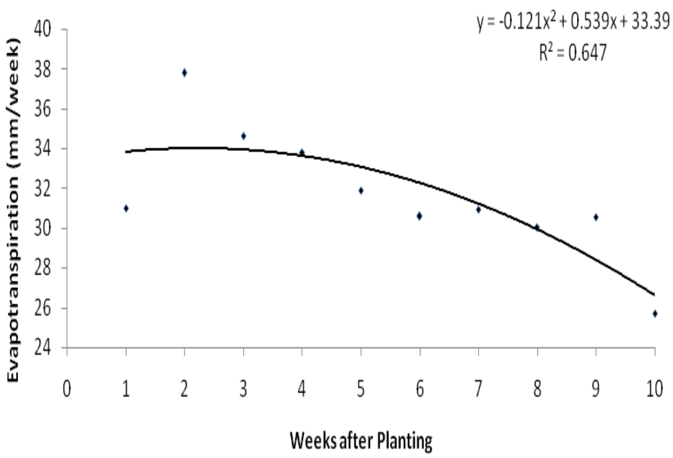

Figure 6. Reference evapotranspiration (ET_o).

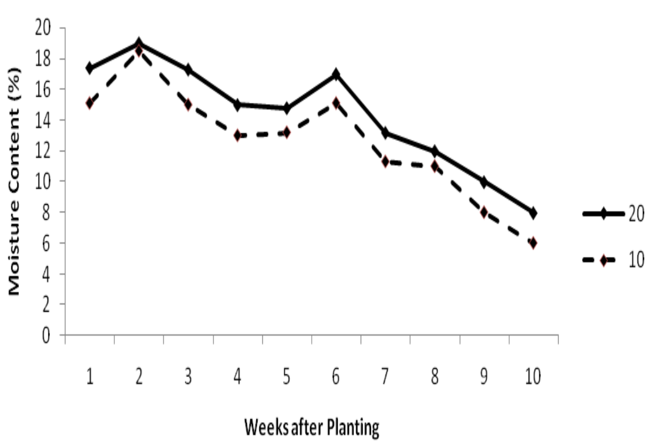

Figure 7. Percentage soil water content against weeks after planting**.**

and 20 cm is presented in Figure 7. Higher moisture was observed at the 20 cm soil layer when compared to the 10 cm soil layer throughout the period of the experiment. This could be attributed to gravitational pull of water from the soil superficial layer to the root zone depth of the crop, where the moisture was optimally utilized. At the early growth stage (emergence stage) of *A. cruentus*, moisture removal was largely due to evaporation from the soil surface. Advances in crop growth (vegetative stage) and root development led to increase in moisture loss through evaporation from soil surface and transpiration from plant surface. The increase in leaf coverage area during the crop vegetative and flowering stages lead to rapid moisture loss from the soil and thus, the decline in the trend of percentage soil water content.

Figure 8 shows the crop evapotranspiration (ET_c) in $mm.week^{-1}$ throughout the growing season of the crop. The weekly ET_c value of evapotranspiration during the emergence stage of the crop, that is, 1 WAP was 4.5 mm, that is, 0.6 $mm.day^{-1}$ (± 0.24)). The ET_c rose gradually from the 2 WAP with value of 6.5 $mm.week^{-1}$, that is, 0.9 $mm.day^{-1}$ (± 0.19)) to the maximum at the 7 WAP with value 14.3 $mm.wk^{-1}$ is 2.0 $mm.day^{-1}$ (± 0.51)). The highest ET_c at the 7 WAP had corresponding high values of LAI and LCA, which were 10.65 and 0.81, respectively. The lowest ET_c value of 5 mm. $week^{-1}$ (0.7 $mm.day^{-1}$ ± 0.27), which was observed during the 10 WAP with corresponding decline in LCA and LAI implies that the crop water use was highest during the vegetative growth stage of the crop. Amaranth inflorescence development implies the crop passed through a significant change in its physiological stage, which were accentuated in the pattern of water use.

The lower ET_c values observed during maturity and senescence stages of the crop must have been caused by leave drops and a reduction in LCA and LAI. This agrees with the findings of Fasinmirin et al. (2009). They documented an increase in evapotranspiration of *A. cruentus* during the flowering/fruiting stage of the crop using the water balance method. However the ET values obtained from the lysimeter experiment was significantly lower than the ET values obtained from field experiment. This observation was also reported by Montero et al. (1985) and Rosenberg et al. (1989), who stated that usually, evapotranspiration inside a greenhouse/screen house is around 60 to 80% of that verified outside. The polynomial correlation between the ET_c and WAP was high (r = 0.92), an indication of a normal trend of crop behaviour during its growth stages.

Crop coefficient

The average K_c value for the emergence, vegetative, maturity and senescence growth stages are 0.15, 0.26, 0.36 and 0.19, respectively over the duration of the experiment (Figure 9). The crop factor K_c appears to be constant at the early stage of crop growth but rose sharply during the vegetative and flowering stages of the crop. At late season when the crop reaches senescence, the crop factor K_c declined. Similar observation was made

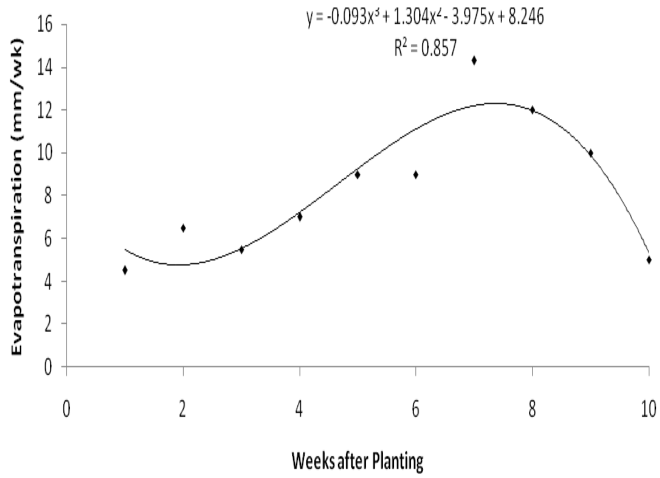

Figure 8. Crop evapotranspiration (ET_c) against weeks after planting.

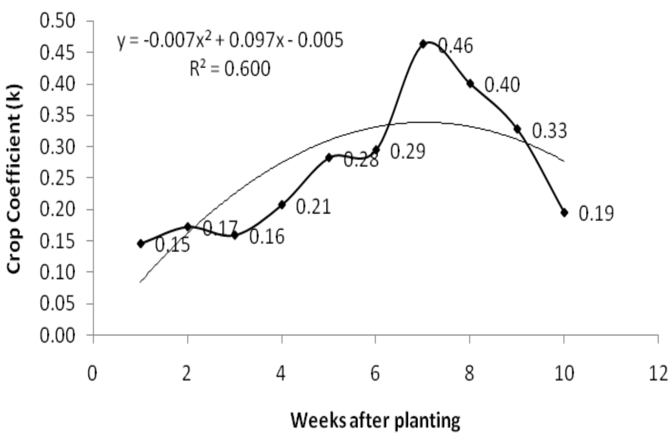

Figure 9. Variation of crop coefficient with weeks after planting.

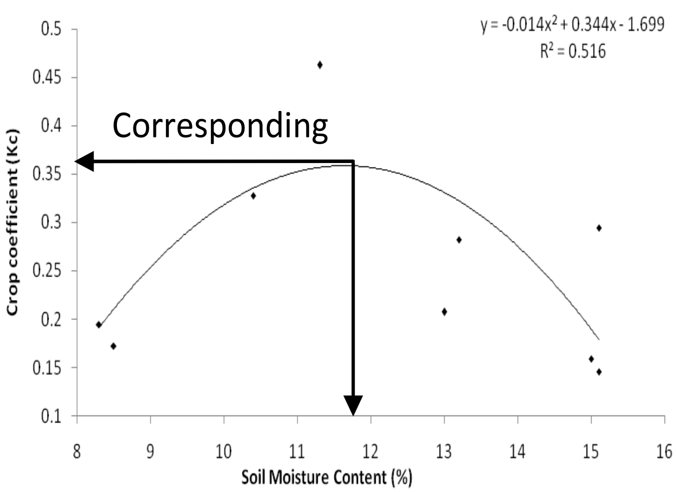

Figure 10. Relationship between crop coefficient and soil water content.

by Faust (1989) who stated in his work on pears that declining K_c values during fall might be due to reduced sensitivity of the stomata as leaves begin to senescence or due to water stress due to reducing rainfall/irrigation. The sharp rise observed during the vegetative/flowering stage is an indication that the crop requires water than other stages of its development. The high LAI (11.39 and 10.48) and LCA (0.866 and 0.797) values obtained during 8 WAP and 9 WAP respectively must have been responsible for the corresponding increase in K_c value during maturity. Same observation was made by Tyagi et al. (2000) who reported that highest K_c values occurred in sunflower during the vegetative and maturity growth stages with corresponding high mean LAI value. Also, Ayars et al. (2003) observed that K_c was a linear function of the amount of light intercepted by the leaves of peach (*Prunus persica L.*) trees. It could be assumed that as leaf area increases so would the amount of solar radiation intercepted and the amount of ET_c. A polynomial regression correlation (r = 0.77) was obtained from the plot of K_c against WAP and an expression was derived between Kc and WAP, that is, $y = -0.007x^2 + 0.097x - 0.005$.

The relationship between crop factor (K_c) and percentage soil water content (MC) is presented in Figure 10. The optimum percentage of soil water content of 11.7% was obtained from the relationship and the corresponding K_c value of 0.36 was derived for *A. cruentus* from the lysimeter experiment. Percentage water content above this optimum value will lead to decreased K_c, and consequently a decrease in crop ET. The coefficient of correlation between the crop coefficient and the percentage soil water content (r = 0.72) is sufficiently high for adoption in the study area and for soils of similar physical characteristics.

Yield parameters of *A. cruentus*

Figure 11 shows the weekly number of leaves throughout the period of the experiment. The number of leaves on the plant rose to its highest value of 21 during the 7 WAP (vegetative stage of *A. cruentus*). The polynomial correlation of regression between the number of leaves and the Weeks after Planting was high (r = 0.93).

The plant height increased throughout the period of the experiment (Figure 12). Increases in plant height were however greatest in the vegetative and maturity stage. It however tended to flatten out at crop senescence. The crop rooting depth data is shown in the Figure 13. It was observed that the root depth was shallow and had buttress and tap root formations. This could have been due to the screen house preventing enough sunlight from getting to the plant and as such causing the plant to have buttress root and shallow tap root formations. The root depth increased well from the emergence into the flowering/fruiting stage. Little change in the root depth

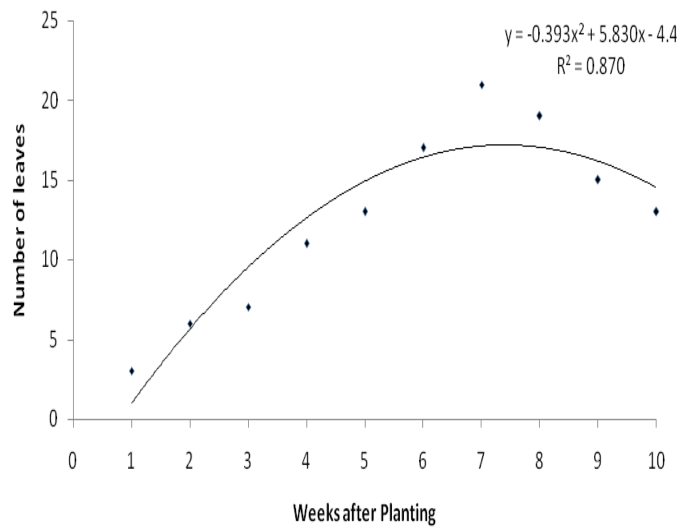

Figure 11. Number of leaves against weeks after planting.

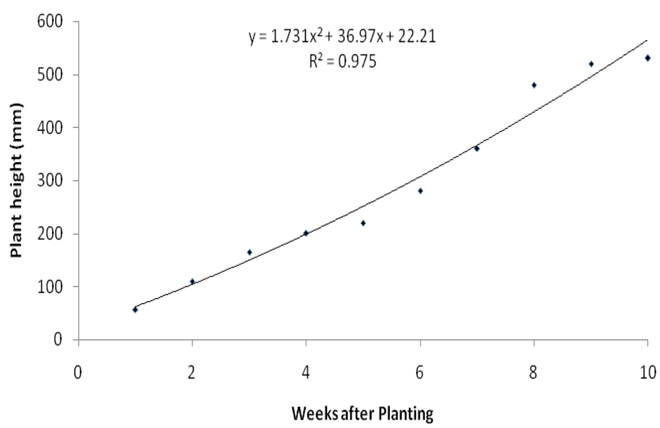

Figure 12. Plant height against weeks after planting.

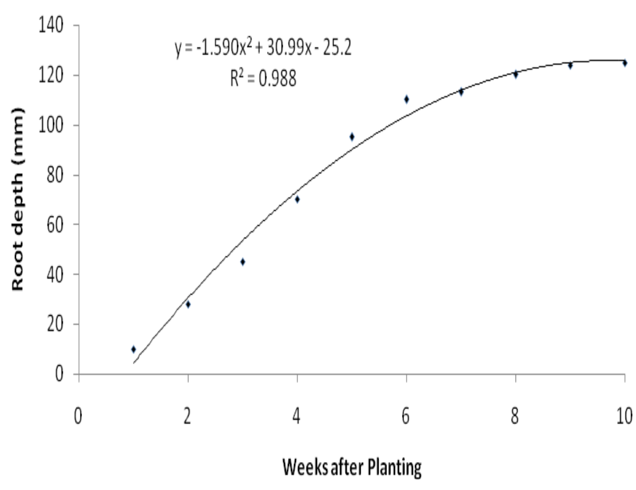

Figure 13. Variation of root depth with weeks after planting.

Table 1. Leaf area, leaf coverage area and leaf area index.

WAP	NOL	PS (m^2)	LA (m^2)	LCA	LAI
2	6	0.076	0.00046	0.036	0.48
3	7	0.076	0.00087	0.080	1.05
4	11	0.076	0.00095	0.137	1.81
5	13	0.076	0.00104	0.178	2.34
6	17	0.076	0.00242	0.541	7.12
7	21	0.076	0.00293	0.810	10.65
8	19	0.076	0.00346	0.866	11.39
9	15	0.076	0.00404	0.797	10.48
10	13	0.076	0.00411	0.703	9.25

WAP, Week after planting; NOL, Number of leaves; LA, leaf area, PS, plot size.

was observed during the maturity and senescence stages of the crop.

Leaf coverage area and leaf area index

Table 1 shows the leaf area, leaf area index (LAI) and the leaf coverage area (LCA) of *A. cruentus* throughout the period of experiment. Steady increase in LAI was observed during the vegetative stage of the crop, that is, 2 to 7 WAP with corresponding values of 0.48 and 10.65, respectively. Similarly, LCA values of 0.036 and 0.810 were recorded during the 2 and 7 WAP, respectively. However, the peak values of LAI and LCA were recorded during the 8 and 9 WAP and thereafter declined during crop senescence. Similar observation was reported by Fasinmirin et al. (2009). These researchers reported that leaf droppings at crop full maturity affects significantly the leaf area index.

Conclusion

This study shows the crop evapotranspiration (ET_c) and the crop coefficient (K_c) of *Amaranthus cruentus* growing in a lysimeter placed in a screen house. Results obtained showed that the ET_c increases rapidly during the vegetative and flowering stages, indicating that crop water requirement was highest during this crop growth stages. The ET_c values varied from 0.6 $mm.day^{-1}$ in the emergence stage to peak values of 2.0 $mm.day^{-1}$ during the vegetative and flowering stages. Also, crop coefficient (K_c) values obtained shows that *A. cruentus* requires much more application of water during the vegetative and flowering stages than at emergence and senescence. Also, the optimum percentage soil water content (11.7%) required to obtain maximum K_c value was derived from the experiment. The results obtained presents local farmers in the study area the opportunity to grow *A. cruentus* all year round, especially in areas of water scarcity, thus saving water to obtaining optimum yield, which is realizable with half the crop water requirement.

REFERENCES

Allen RG, Pereira LS, Raes D, Smith M (1998). Crop Evapotranspiration, Guidelines for Computing Crop Water Requirements. FAO Irrig. Drain. 56:356.

Ayars JE, Johnson RS, Phene CJ, Trout TJ, Clark DA, Mead RM (2003). Water use by drip-irrigated late-season peaches, Irrig. Sci. 22:187-194. http://dx.doi.org/10.1007/s00271-003-0084-4

Blake GR, Hartge KH (1986). Bulk density. In: A. Klute (Ed.). Methods of Soil Analysis. Part I. Physical and Mineralogical Methods. 2nd. Ed., Agronomy No. 9 (part I). ASA-SSSA. Madison, Wisconsin, USA, pp. 363-375.

Ceccon P, Dalla Costa L, Giovanardi R, Rogger C (2008). The Interaction of Sowing Date and Water Availability in Determining Plant Architecture, Fruiting Pattern and Yield Components of Soybean (*Glycine max* L. Merr.), J. Agron. Crop Sci. 173(3-4):172-183. http://dx.doi.org/10.1111/j.1439-037X.1994.tb00552.x

da Silva RC, Folegatti MV, Araújo da Silva TJ, Júnior JA, Fonseca SC, Vasconcelos RR (2005). Water relations and photosynthesis as criteria for adequate irrigation management in 'Tahiti' lime trees. Sci. Agric. (Piracicaba, Braz.), 62(5):415-422.

Early IK (1997). Cultivation and Uses of Amaranth in Contemporary Mexico. In "Proceedings of the First Amaranth Seminar" Rodale Press, Bumaus, PA. P. 39.

Fasinmirin JT (2007). The Response of *Amaranthus cruentus* L. to Water Application Using Drip and Sprinkler Irrigation Systems. Unpublished Ph.D. Thesis. Federal University of Technology, Akure. Nigeria, pp. 22-105.

Fasinmirin JT, Olufayo AA, Oguntunde GP, Oguntuase MA (2009). Parametrizing Simple Model between Yield and Evapotranspiration for *Amaranthus cruentus* under Drip and Sprinkler Irrigations. Int. J. Plant Prod. 3(1):1735-8043.

Faust M (1989). Physiology of Temperate Zone Fruit Trees. Wiley, New York, USA. PMCid:PMC202953

Gong P, Ruiliang PU, Miller JR (1995). Coniferous Forest Leaf Area Index Estimation along the Oregon Transect Using Compact Airborne Spectrographic Imager Data, PE & RS, 61(9):1107-1117.

Howell TA, Schneider AD, Jensen ME (1991). History of lysimeter design and use for evapotranspiration measurement, In R.G. Allen, T.A. Howell, W.O. Pruitt, I.A. Walter, M.E. Jensen, Proceeding of International symposium on lysimetry, July 23-25, 1991, Honolulu, Hawaii, pp. 1-9.

James HG (1994). Irrigation scheduling: advantages and pitfalls of plant based methods. J. Exp. Bot. 55:2427-2436.

Katerji N, van Hoorn JW, Hamdy A, Mastrorilli M, Mou Karzel E (1997). Osmotic adjustment of sugar beets in response to soil salinity and its influence on stomatal conductance, growth and yield. Agric. Water Manage. 34:57–69.

http://dx.doi.org/10.1016/S0378-3774(96)01294-2
Ko J, Piccinni G, Marek T, Howell T (2009). Determination of growth-stage-speciffic crop coefficients (Kc) of cotton and wheat. Agric. Water Manage. 96:1691-1697.
http://dx.doi.org/10.1016/j.agwat.2009.06.023
Liu F, Savi S, Jensen CR, Shahnazari A, Jacobsen SE, Stiki R, Andersen MN (2007). Water relations and yield of lysimeter grown strawberries under limited irrigation. Scientia Horticulturae 111(2):128-132. http://dx.doi.org/10.1016/j.scienta.2006.10.006
Liu Y, Luo Y (2010). A consolidated evaluation of the FAO-56 dual crop coefficient approach using the lysimeter data in the North China Plain. Agric. Water Manage. 97:31-40.
http://dx.doi.org/10.1016/j.agwat.2009.07.003
Makus DJ, Davis DR (1984). A mid-summer crop for fresh greens or canning – vegetable amaranth. Ark Farm Res. 33:10.
Martinez CA (2008). Use of thermal units to estimate corn crop coefficients under semiarid climatic conditions. Irrig. Sci. 26:335-345. http://dx.doi.org/10.1007/s00271-007-0097-5
Montero JI, Castilla N, Gutierrez de ravé E, Bretones F (1985). Climate under plastic in the Almeria. Acta Horticulturae 170:227-234.
Oguntunde PG (2004). Evapotranspiration and complimentary relations in the water balance of the Volta Basin: Field measurement and GIS – based regional estimate. Ecol. Dev. Ser. 22:16-91.
Pal M, Khoshoo TN (1974). Grain Amaranths. In: Evolutionary studies in world crop (ed.) J. Hutchinson, Cambridge University Press. Cambridge, England. P. 129.
Pandey P, Pandey V (2011). Lysimeter based crop coefficients for estimation of crop evapotranspiration of black gram (*Vigna Mungo* L.) in sub-humid region. Int. J. Agric. Biol. Eng. 4:50-58.
Pereira LS, Oweis T, Zairi A (2002). Irrigation management under water scarcity. Agric. Water Manage. 57:175-206.
http://dx.doi.org/10.1016/S0378-3774(02)00075-6
Pruitt RO, Angus DE (1960). Large weighing lysimeters for measuring evapotranspiration. Trans. ASAE 3:13-18.
http://dx.doi.org/10.13031/2013.41105
Ramirez VH, Harmsen WE (2011). Water vapor flux in agroecosystems: methods and models review. In: Labedski, L. (ed.), Evapotranspiration. INTECH Open Access Publisher: 3-48.
Ramirez VH, Mejia A, Marin EV, Arango R (2011). Evaluation of models for estimating the reference evapotranspiration in Colombian Coffee Zone. Agronomía Colombiana 29(1):107-114
Rosenberg NJ, Mckenney MS, Martin P (1989). Evapotranspiration in a greenhouse-warmed world: a review and a simulation. Agric. Forest Meteorol. 47:303-320. http://dx.doi.org/10.1016/0168-1923(89)90102-0
Teutonico RA, Knorr D (1985). Amaranth: Composition, Properties, and Applications of a Rediscovered Food Crop. Food Technol. 39:49-60.
Tyagi NK, Sharma DK, Luthra SK (2000). Determination of evapotranspiration and crop coefficients of rice and sunflower with lysimeter. Agric. Water Manage. 45:41-54.
http://dx.doi.org/10.1016/S0378-3774(99)00071-2

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