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Full Length Research Paper

Determinants of small-scale farmers' adaptation decision to climate variability and change in the North-West region of Cameroon

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Small-scale farmers' adaptation decision in the face of climate variability and change (CVC) depends largely on their ability to perceive the impacts of CVC as well as their degree of vulnerability to these impacts. This research looks at the factors that influence small-scale farmers' adaptation decision faced with climate variability and change, with particular focus on Mbengwi Central Sub-Division, North-West Region of Cameroon. The study made use of household surveys to identify the impacts, determine vulnerability and assess the factors influencing small-scale farmers' adaptation decision. Data obtained from household surveys was analyzed using descriptive statistics (bar charts, percentage indices) and inferential statistics (Mann-Whitney test, Chi-Square, and the Binomial Logistic (BNL) regression model). Data analysis was done on Microsoft Excel 2007 and the Statistical Package for Social Sciences (SPSS) 17.0. Results showed that, following small-scale farmers' perceptions, crop productivity decline was the main impact of CVC (96.7%) and poverty the principal cause of vulnerability to CVC (98.3%). Mann-Whitney test results revealed that there was a significant difference between farmers' adaptation decision and six hypothesized continuous explanatory variables (age, household size, farm size, number of farms, annual family income, farm experience) (p<0.01). Chi-square test results revealed that there was a significant difference between farmers adaptation decision and some hypothesized discontinuous explanatory variables (perception of extreme weather events, access to weather information, access to extension services, access to credit, membership in farming groups and distance to markets) (p<0.01). Results of the BNL regression model showed that the main determinants of small-scale farmers' adaptation decision in the study area were age of household head, farm size and access to weather information (p<0.05).

Key words: Climate variability and change, small-scale farmers, impacts, vulnerability, adaptation decision, North-West Region of Cameroon.

INTRODUCTION

Africa is already experiencing the devastating impacts of climate variability and change especially on its small-scale farmers' population which make up the largest proportion of the economically active population (FAO,

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2016). This situation is expected to worsen in the coming decades owing to even greater variability and change in climate across the continent with scanty and erratic rainfall coupled with high temperatures to take precedence (IPCC, 2001). Africa is predicted to experience temperature changes of between 0.2 to 0.5°C per decade with the interior regions of Africa to bear the brunt of adverse variations and changes in rainfall and temperature patterns (IPCC, 2007).

Sub-Saharan Africa in particular is expected to experience decreased precipitation and increased temperatures in future predicted climate scenarios which will cause production instability amongst small-scale farmers (Morton, 2007; Challinor and Wheeler, 2008). With rain-fed agriculture being the most practiced form of agriculture in sub-Saharan Africa, variations and changes in temperature and rainfall in particular will pose a serious problem to the mostly agriculture dependent economies of this region (World Bank, 2013). Smallholder farmers in sub-Saharan Africa are therefore highly vulnerable to the nefarious impacts of climate variability and change. According to the Inter-Governmental Panel on Climate Change (IPCC), vulnerability to climate variability and change is a function of exposure to extreme climate events, sensitivity to the events and adaptive capacity of the affected community (IPCC, 2007). The high vulnerability of these small-scale farmers completely wears away their resilience faced with an increasingly variable and changing climate (FAO, 2010).

Cameroon is a predominantly agriculture dependent economy with small-scale farmers constituting the bulk of the farming population (Molua and Lambi, 2007). These small-scale farmers live mainly in the rural areas where they practice farming as a means of livelihood. With the average temperature in Cameroon predicted to increase by 0.7 to 0.8°C by the 2020s as a result of global warming according to transient General Circulation Models (GCMs), small-scale farmers in particular are expected to bear the brunt of these predicted variations and changes owing to their limited adaptive capacity (Gordon et al., 2000; Johns et al., 2003; Tingem et al., 2007). Some studies carried out in Cameroon have already proven that extreme climate events like rising temperatures lead to production instability amongst small-scale farmers due to their economic impoverishment (Molua, 2006; Molua and Lambi, 2007; Tingem et al., 2008a, b, c; Ngondjeb, 2013).

The North-West Region of Cameroon in particular is dominated by small-scale farmers who grow crops that are highly sensitive to variations and changes in temperature and precipitation. These crops have a narrow threshold for production success, such that variations and changes in temperature and rainfall that occur during key developmental phases of the crop can lead to production failure. Some of these highly sensitive crops are: cereals like beans, groundnuts, maize and soybeans; market gardening crops like tomatoes, condiments, cabbages, lettuce, huckleberry and carrots as well as tubers like yams, cocoyams and cassava. Hence the continuous dependence on rainfall in order to cultivate these highly sensitive crops makes smallholder farmers vulnerable to the negative impacts of climate variability and change. Studies conducted in the North-West Region of Cameroon have shown that climate variability and change is already impacting negatively on agriculture especially on small-scale farmers (Tingem et al., 2008a; Sunjo et al., 2012; Kimengsi et al., 2015).

With climate variability and change impacting nefariously on small-scale farmers, adaptation therefore becomes incumbent. From the foregoing, it is noticed adaptation to climate variability and change by small-scale farmers is not just straight forward as small-scale farmers' adaptation decisions vary. It is for this reason that this paper sought to provide answers to the following burning questions: what are the impacts of climate variability and change on small-scale farmers? What are the causes of small-scale farmers' vulnerability to the impacts of climate variability and change? What are the factors influencing small-scale farmers' adaptation decision to climate variability and change? The answers to the aforementioned questions aided in the attainment of the objectives of the study which were:

1. To identify the impacts of climate variability and change on smallholder farmers.
2. To identify the causes of smallholder farmers' vulnerability to the impacts of climate variability and change.
3. To analyze the factors affecting smallholder farmers' adaptation decision in the face of climate variability and change.

MATERIALS AND METHODS

Description of the study site

This study was carried out in the North-West Region of Cameroon, specifically in Mbengwi Central Sub-Division (Latitude 6° 02' N and Longitude 10° 01' E). It was conducted in four villages: Tugi (Lat. 6° 01' N; Long. 10° 02'E), Ngyen-Mbo (Lat. 6° 01' N; Long. 10° 02' E), Ku-Bome (Lat. 6° 00' N; Long. 10° 03' E) and Njah-Etu (Lat. 5° 87' N; Long.10° 20' E). The dry season which stretches from mid October to mid March and the rainy season which stretches from late March to late October constitute the two main distinct seasons of the area. The long-term average temperature in Mbengwi central sub-Division is 26°C and the long-term annual average rainfall is 1450 mm with major variability in the past three decades (Awazi, 2016). It is a very hilly area characterized by a rolling topography. The principal vegetation type is the savannah grassland. Agriculture predominates with small-scale farmers doing most of the farming. The main food crops grown are maize, groundnuts, okra, beans, cocoyams, yams, plantains and cassava. Cash crops cultivated include: coffee, oil palms, and banana. Market gardening crops grown include: tomatoes, cabbages, lettuce, carrots, huckleberry and watermelon. Fruits grown are: oranges, pineapples, avocado, guava, plums, paw-paw and mangoes. Animal husbandry is equally

Table 1. Description of hypothesized explanatory variables.

Variable	Description
Household size	Continuous
Sex	Dummy, takes the value of 1 if male and, 0 otherwise
Noticed extreme sunshine	Dummy, takes value of 1 if Yes and 0 otherwise
Age	Continuous
Number of farms	Continuous
Farm size in hectares	Continuous
Noticed high temperatures	Dummy, takes value of 1 if Yes and 0 otherwise
Annual family income	Continuous
Farm experience	Continuous
Access to weather information	Dummy, takes value of 1 if Yes and 0 otherwise
Noticed highly inconsistent rainfall	Dummy, takes value of 1 if Yes and 0 otherwise
Access to extension services	Dummy, takes value of 1 if Yes and 0 otherwise
Education	Dummy, takes value of 0 No education, 1 primary, 2 secondary, 3 tertiary
Access to credit	Dummy, takes value of 1 if Yes and 0 otherwise
Noticed reduced rainfall	Dummy, takes value of 1 if Yes and 0 otherwise
Distance to market	Dummy, takes value of 1 near, 2 moderate, 3 far
Land ownership	Dummy, takes value of 1 if owned, 0 otherwise
Noticed storms	Dummy, takes value of 1 if Yes and 0 otherwise
Membership in farming group	Dummy, takes value of 1 if Yes and, 0 otherwise

widespread (goats, pigs, sheep, poultry, and cattle).

Data collection and analysis

This study made use of the stratified random sampling procedure wherein smallholder farmer household heads were stratified based on age. And then, only small-scale farmers whose ages were greater than 30 years were randomly selected for the survey. All this was done with the help of agricultural extension officers found in the different study villages. Mainly old small-scale farmers were surveyed in order to get more reliable information pertaining to the degree of variability and change in climate elements. Following sampling, household survey of small-scale farmer household heads was then conducted in the four villages under study (Tugi, Ku-Bome, Ngyen-Mbo and Njah-Etu). This was done through the administering of structured and semi-structured questionnaires. A total of 120 small-scale farmer household heads were interviewed during the survey with a 100% respondents' rate. Household surveys provided information on the impacts, vulnerability and adaptation to climate variability and change as perceived by small-scale farmers. The data collection method used for this study was similar to those of other related studies (Tabi et al., 2012; Harvey et al., 2014; Rurinda, 2014; Rurinda et al., 2014).

Variables of the study

This study made use of the explanatory or independent variables as shown in Table 1. Data analysis for this study was done using descriptive and inferential statistics on Microsoft Excel 2007 and SPSS 17.0. Famer identified impacts of and causes of vulnerability to climate variability and change were analyzed through descriptive statistics only (bar charts and percentage indices).

Meanwhile, factors influencing small-scale farmers' adaptation decision in the face of climate variability and change were analyzed through inferential statistics. In order to test whether there was a significant difference between farmers' adaptation decision and various hypothesized continuous and discontinuous explanatory variables (Table 1), the Mann-Whitney test (U-test) and Chi-Square test (X^2 test) were used respectively. A similar approach was followed by Temesgen et al. (2014). As a rule of thumb, the normality of the continuous variables was tested using: histogram with normal curve, PP and QQ plots and most importantly the one sample Kolmogorov-Smirnov test, before choosing the suitable statistical tool for the analysis. For non-normal categorical variables, non-parametric tests such as the U-test (Mann-Whitney test) and H-test (Kruskal-Wallis test) were used. The Kruskal-Wallis test (H-test) in particular was used to test whether smallholder farmers' adaptation decision differed significantly across the four villages studied.

The Binary Logistic (BNL) Regression model on its part was used to examine the causal relationship between farmers' adaptation decision (binomial dependent variable) and several hypothesized continuous and discontinuous explanatory variables (Table 1). The Binary Logistic (BNL) regression model (Equation 1) predicts the log odds of having made one decision (adaptation) or the other (non-adaptation). This model therefore permits the analysis of decisions across two categories (adaptation and non-adaptation). This model is expressed as:

$$\ln(\text{odds}) = \ln\left(\frac{\hat{Y}}{1-\hat{Y}}\right) = \propto +\beta X \qquad (1)$$

Where
$\hat{Y}$ is the predicted probability of the event (adaptation);
$1-\hat{Y}$ is the predicted probability of the other decision (non-adaptation);
X is the independent variable.

In order to run the BNL model, the Box-Tidwell Test was carried out. The Box-Tidwell Test was used to test if the relationship between the continuous predictors and the logit (log odds) was linear before running the model. This assumption was tested by including in the model, interactions between the continuous predictors and their logs. The aforementioned assumption and the BNL regression proper were done on SPSS version 17.0. The Binary logistic regression (BNL) model has also been used by other authors in order to decipher the factors influencing farmers' adaptation in the face of climate variability and change (Di Falcao et al., 2011; Belay et al., 2017).

RESULTS AND DISCUSSION

Farmer identified impacts of climate variability and change

Smallholder farmers in the study area increasingly perceive the negative impacts of climate variability and change. As revealed by household surveys, smallholder farmers generally perceive more than one impact of climate variability and change which were all negative (Table 2).

As shown on Table 2, the most recurrent negative impacts perceived by smallholder farmers were crop productivity decline (96.7%), increased poverty (80.8%), food insecurity (67.5%) and shortage of water (52.5%) while the least recurrent negative impacts perceived by farmers were death of animals (18.3%), increase in bushfires (13.3%) and "No Impact category" with 0%. Studies conducted by Molua and Lambi (2007) in Cameroon; IPCC (2007); Morton (2007); Mary and Majule (2009) in the Singida Region of Tanzania; Herrero et al. (2010) in Kenya; FAO (2011); Tabi et al. (2012) in the Volta Region of Ghana; Mbilinyi et al. (2013) in Tanzania; Ngondjeb (2013) in the Sudano-Sahelian Area of Cameroon; FAO (2016); The Global Risks Report (2016); Shumetie and Alemayehu (2017) in the Western Hararghe Zone of Ethiopia; and Fadina and Barjolle (2018) in the Zou Department of South Benin, showed that the impacts of climate variability and change on smallholder farmers are essentially negative and farmers always perceive a combination of several negative impacts. Hence CVC generally impacts negatively on smallholder farmers in MCSD.

Direct observations through transect walks vindicated farmers' perception that there has been an increase in crop diseases which reduces crop productivity.

Farmer identified causes or sources of vulnerability

Smallholder farmers in the study area are increasingly conscious of the sources or causes of their vulnerability in the face of climate variability and change. Household surveys conducted in the study area showed that smallholder farmers often perceived varied causes of vulnerability (Table 3).

Farmers identified a combination of causes from the twelve causes of vulnerability cited by smallholder farmers in the study area (Table 3). Hence the most recurrent sources or causes of vulnerability identified by farmers were poverty (98.3%), inadequate rainfall (85.8%), limited weather information (55.8%), and biased land tenure system (55%) while the least recurrent causes of vulnerability perceived by farmers were limited access to credit facilities (20.8%) and soil infertility (15.8%). Similar studies conducted by Tabi et al. (2012) in the Volta Region of Ghana; Lema et al. (2014) in the Hai District, Kilimanjaro Region, Tanzania; Rurinda (2014); Rurinda et al. (2014) in the smallholder farming systems of Zimbabwe; Harvey et al. (2014) in Madagascar and the FAO (2016) showed that there are several causes of smallholder farmers' vulnerability and small-scale farmers themselves always cite a combination of factors responsible for their vulnerability in the face of climate variability and change.

Factors influencing smallholder farmers' adaptation decision

Even though climate variability and change is a reality in the study area, some farmers are adapting while others do not. This study found out that smallholder farmers' adaptation or non-adaptation is influenced by several socio-economic, institutional and environmental factors (Tables 4 and 5).

Mann-Whitney test (U-test)

The U-test was used to test if there was a significant difference between farmers' adaptation decision and various hypothesized continuous variables and the following results were found (Table 4).

Age of household head: Many studies have shown that age of household head has a positive effect on farmers' adaptation decision (Temesgen et al., 2014; Belay et al., 2017). In this study, the ages of the sampled household heads ranged from 30 to 65 years with an average of 43.98 and a standard deviation of 8.89. A U-test was conducted to see if there is a difference between farmers' adaptation decision with respect to age of household head was statistically significant. The test results revealed that there was a significant difference between farmers' adaptation decision with respect to age ($Z=-7.598$, $p<0.01$). This means that the older the household head, the greater the propensity to adapt to climate variability and change in the study area.

Household size: Several studies have also shown that household size has a significant influence on farmers' adaptation decision (Temesgen et al., 2014; Belay et al., 2017). In this study, the household size of the sampled households ranged from 1 to 12 persons with an average of 5.86 and a standard deviation of 2.22. The U-test was conducted order to see if the difference between farmers' adaptation decision with respect to household size was

Table 2. Impacts of climate variability and change**.**

Impact	Number of respondents	%
Crop productivity decline	116	96.7
Increased poverty	97	80.8
Food insecurity	81	67.5
Shortage of water	63	52.5
Surge in crop and livestock diseases	48	40
Surge in farmer-grazier conflicts	36	30
Surge/resurgence of new pests	31	25.8
Surge in disease attack on farmers	27	22.5
Death of animals	22	18.3
Increase in bushfires	16	13.3
No impact	0	0

n = 120.
Source: Own Survey (2015).

Table 3. Causes or sources of vulnerability (farmers perceived a combination of causes).

Sources or causes of vulnerability	Number of respondents	%
Poverty	118	98.3
Inadequate rainfall	103	85.8
Limited or no weather information	67	55.8
Limited access to land	66	55
Limited off-farm jobs	53	44.2
Limited or no advice from extension agents	48	40
Low prices of farm products	43	35.8
Rolling topography	41	34.2
Distant markets	33	27.5
Limited or no credit facilities	31	25.8
Limited farm-to-market roads	27	22.5
Soil infertility	19	15.8

n = 120.
Source: Own Survey (2015).

Table 4. Descriptive statistics and U-test results for continuous variables.

Variable	Unit	Min.	Max.	Mean	Std. Dev	*Z (U-test)*	P-level
Age	Years	30	65	43.98	8.89	-7.598	0.000***
Household size	Number	1	12	5.86	2.22	-6.563	0.000***
Farm size	Hectare	0.2	6	1.29	1.08	-7.721	0.000***
N^o of farms	Number	2	17	7.09	3.21	-7.454	0.000***
Ann. family income	FCFA$^+$	30000	700000	184291.7	118400.2	-6.761	0.000***
Farm experience	Years	7	45	23.43	8.81	-6.807	0.000***

$^+$ 1 US$= 580 FCFA, *** Significant at 1% (df=2; p< 0.01).

statistically significant. The U-test result showed that there was a significant mean difference between farmers' adaptation decision with respect to household size (Z= -6.568, p<0.01). This implies that larger households have a higher propensity to adapt in the face of climate variability and change than smaller households.

Table 5. Summary of Chi-square test results for discontinuous explanatory variables.

Variable	Description	Frequency (N)		%		Chi-Square	p-level
		Adapted	Not adapted	Adapted	Not adapted		
Education	No formal education	10	5	8.3	4.2	1.085	0.781NS
	Primary	65	25	54.2	20.8		
	Secondary	7	5	5.8	4.2		
	Higher	2	1	1.7	0.8		
Noticed extreme sunshine	No	3	25	2.5	20.8	61.127	0.000***
	Yes	81	11	67.5	9.2		
Access weather information	No	8	28	6.7	23.3	55.903	0.000***
	Yes	76	8	63.3	6.7		
Noticed high temperature	No	0	25	0	20.8	73.684	0.000***
	Yes	84	11	70	9.2		
Access extension services	No	9	24	7.5	20	39.570	0.000***
	Yes	75	12	62.5	10		
Sex of HH head	Male	41	13	34.2	10.8	1.642	0.200NS
	Female	43	23	35.8	19.2		
Access to credit	No	8	23	6.7	19.2	38.873	0.000***
	Yes	76	13	63.3	10.8		
Noticed highly inconsistent rainfall	No	3	24	2.5	20	57.532	0.000***
	Yes	81	12	67.5	10		
Land ownership	No	46	23	38.3	19.2	0.859	0.354NS
	Yes	38	13	31.6	10.8		
Noticed decrease rainfall	No	1	21	0.8	17.5	54.959	0.000***
	Yes	83	15	69.2	12.5		
Membership in farming group	No	2	23	1.7	19.2	57.805	0.000***
	Yes	82	13	68.3	10.8		
Distance to market	Near	32	2	26.7	1.7	40.990	0.000***
	Moderate	39	7	32.5	5.8		
	Far	13	27	10.8	22.5		
Noticed storms	No	2	20	1.7	16.7	47.591	0.000***
	Yes	82	16	68.3	13.3		

Source: Own Survey (2015); *** Significant at 1% (df=1, p<0.01); NS= Not significant.

Farm size: The U-test was conducted to see if there is a significant difference between farmers' adaptation decision with respect to farm size. In this study the farm size ranged from 0.2 to 6 ha with an average of 1.29 and a standard deviation of 1.08. The U-test result showed that there is a significant mean difference between farmers' adaptation decision with respect to farm size (Z= -7.721, p<0.01). This implies that farmers with larger farm sizes have a higher ability to adapt than those with smaller farms.

Number of farms: In this study the number of farms ranged from 2 to 17 farms with an average of 7.09 and a standard deviation of 3.21. The U-test was conducted to see if there was a significant difference between farmers' adaptation decision with respect to number of farms. The U-test result showed that there was a very significant mean difference between farmers' adaptation decision with respect to number of farms (Z= -7.454, p<0.01). This implies that smallholder farmers with many farms have a higher propensity to adapt than those with few farms.

Farm experience: Farm experience generally increases with age and this has been identified by various studies and found to have significant influence on farmers' adaptation decision (Temesgen et al., 2014; Belay et al., 2017). In this study, farm experience ranged from 7 to 45 years with a mean of 23.43 and a standard deviation of 8.81. The U-test was used to see if there was a significant difference between farmers' adaptation decision with respect to farm experience. The U-test result showed that there was a significant mean difference between farmers' adaptation decision with respect to number of farms (Z= -6.807, p<0.01). This

Table 6. Logistic regression predicting adaptation decision from explanatory variables.

Predictor variable	Coefficients	Wald X^2	p-level	Odds Ratio (Exp B)	95% C.I. for Exp (B)	
					Lower	Upper
Intercept	–27.611	7.749	0.005	0.000		
Age of Household head	0.367**	5.564	0.018	1.443	1.064	1.957
Number of farms	0.710	2.128	0.145	2.035	0.783	5.285
Household size	–0.619	1.167	0.280	0.538	0.175	1.656
Annual family income	0.000	1.290	0.256	1.000	1.000	1.000
Farm size	8.678*	3.161	0.075	5871.514	0.411	8.383E7
Access_weather_ infos	4.958**	4.098	0.043	142.372	1.171	17313.038
Number of observations	120					
-2 Log Likelihood	146.664					
Likelihood Ratio X^2	123.716***					
Nagelkerke R Square	0.912					

*, **, *** Significant at 10, 5 and 1% probability levels respectively.

implies that the greater the experience of the farmer, the more likely the farmer will adapt in the face of climate variability and change.

Annual family income: Studies have equally found out that annual family income has a significant influence on smallholder farmers' adaptation decision (Temesgen et al., 2014; Belay et al., 2017). In this study, annual family income of the smallholder farmer households censored ranged from 30 000 FCFA (US$ 52) to 700 000FCFA (US$ 1 207) with an average of 184 291.67FCFA (US$ 323.5) and a standard deviation of 118 400.218FCFA (US$ 201.63). The U-test was used to test if there was a significant difference between farmers' adaptation decision with respect to annual family income. The U-test result showed that there was a significant difference between farmers' adaptation decision with respect to annual family income (Z= -6.761, p<0.01). This implies that adaptation is highly affected by the income of the household and households with higher family income have a greater likelihood to adapt.

Chi-Square test result

In order to test whether there was a significant difference between farmers' adaptation decision and several hypothesized qualitative explanatory variables, the chi-square test was used. The chi-square test results showed that there was a significant difference between farmers' adaptation decision with respect to perception of extreme sunshine, access to weather information, perception of high temperature, access to extension services, access to credit, perception of highly inconsistent rainfall, membership in farming groups, perception of decreased rainfall, distance to markets and perception of storms (p<0.01) with Chi-square values of 61.127, 55.90, 73.68, 39.57, 38.87, 57.53, 57.81, 54.96, 40.99, and 47.59 respectively (Table 5). This implies that the more farmers have better access to weather information, good extension services and credit facilities as well as belonging to farming groups and having easy accessibility to markets as well as perceiving extreme climatic events, the higher their likelihood to adapt to climate variability and change. With the p-levels being very statistically significant (p<0.01), it implied that there was a 99.99% probability that these events did not occur by chance.

However, the chi-square test did not show any high statistical significance between farmers' adaptation decision and educational status, sex, and land ownership. This implies that these variables have no significant influence on smallholder farmers' adaptation decision.

Binary logistic regression model

In order to determine the causal relationship between farmers' adaptation decision and various hypothesized explanatory variables, the binary logistic regression model was used and the following results were found (Table 6).

This regression model was run to ascertain the effects of six predictors namely; age of household head, number of farms, household size, annual family income, farm size, and access to weather information on smallholder farmers' adaptation decision in the face of climate variability and change. Several other predictor variables were dropped either because of high levels of multicollinearity with other predictor variables or because they were redundant and did not contribute significantly when added to the model. The model was statistically significant, Likelihood Ratio X^2 (6, n = 120) = 123.72, p<0.01. The likelihood ratio statistics from the BNL model therefore indicated that X^2 statistics was highly significant

Table 7. Classification table for predictor variables.

Observed		Predicted		
		Decision		Percentage correct
		No adaptation	Adaptation	
Decision	**No adaptation**	33	3	91.7
	Adaptation	2	82	97.6
Overall percentage				95.8

(X^2 = 123.72, p<0.01) signifying that the model has a strong explanatory power. The model explained 91.2% (Nagelkerke R^2 or Pseudo R^2 = 0.912) of the variance in farmers' adaptation decision and correctly classified 95.8% of the cases. Pseudo R^2 (0.912) therefore showed that the weighted combination of predictor variables was jointly significant in explaining smallholder farmers' adaptation to CVC.

The model results showed that age of household head (p<0.05), farm size (p<0.10), and access to weather information (p<0.05) added significantly to the model/prediction, meanwhile number of farms, household size and annual family income (p>0.10) did not add significantly to the model. This indicated that the older the farmer, the greater the likelihood to adapt to climate variability and change. Similarly, the bigger the farm size, as well as easy access to weather information the greater the likelihood of the farmer to adapt to climate variability and change. However, number of farms, household size and annual family income did not contribute significantly in influencing smallholder farmers' adaptation decision (p>0.10). Household size in particular had a negative influence on adaptation which is unprecedented because most studies have shown that the bigger the household size, the greater the capacity to adapt to climate variability and change. This could be due to the presence of a high dependent population (infants and very old people) or sheer laziness and lukewarm attitude towards farming activities. The BNL regression model has also been followed by Di Falcao et al. (2011) and Belay et al. (2017) whose studies found that access to credit, extension services and information are the main drivers of farmers' adaptation decision in the face of climate variability and change.

The classification table of this model (Table 7) portrayed the sensitivity (% of occurrences correctly predicted); specificity (% of non-occurrences correctly predicted); false positive rate (% of predicted occurrences which are incorrect); false negative rate (% of predicted non-occurrences which are incorrect) and the overall success rate of the model.

Cut value is 0.5

The sensitivity of the prediction was 82/84 = 97.6%; the specificity of the prediction was 33/36 = 91.7%; the false positive rate was 3/85 = 3.53%; the false negative rate was 2/35 = 5.7%. Overall, the predictions were correct 115 out of 120 times, with an overall success rate of 115/120 = 95.8%.

The Kruskal-Wallis test (H-test) which sought to portray the degree of variation in smallholder farmers' likelihood to adapt to CVC across the four villages studied (Tugi, Ngyen-Mbo, Ku-Bome, and Njah-Etu) revealed that farmers' adaptation to CVC did not vary across the four villages [X^2 (1, n= 120) = 0.031, p> 0.10]. This therefore means that adaptation decision amongst smallholder farmers across the four villages were the same.

Conclusions

The study found that all the small-scale farmers interviewed, perceived the impacts of climate variability and change but some adapted while others did not. Farmers generally perceived a combination of impacts which were all negative. The most recurrent negative impacts identified by farmers were crop productivity decline (96.7%), increased poverty (80.8%), food insecurity (67.5%) and shortage of water (52.5%), while the least recurrent negative impacts perceived were death of animals (18.3%) and increase in bushfires (13.3%). The "No Impact category" had 0% meaning all the respondents perceived the negative impacts of climate variability and change. Pertaining to the causes of vulnerability, farmers perceived a combination of causes or sources of vulnerability with the most recurrent ones being poverty (98.3%), inadequate rainfall (85.8%), limited weather forecast (55.8%), and biased land tenure system (55%) while the least recurrent causes of vulnerability perceived by farmers were limited access to credit facilities (20.8%) and soil infertility (15.8%). BNL regression analysis revealed that age of household head, access to weather information and farm size (p<0.05) significantly influenced small-scale farmers' adaptation decision while household size, annual family income and number of farms (p>0.10) had limited influence on smallholder farmers' adaptation decision. Thus, more small-scale farmers will take to adaptation if younger farmers get advice from their older counterparts, if weather information is made accessible, and if more land is made available to farmers through better land tenure systems.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Planting density and number of stems for ecological crop determinate growth tomato

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Tomato growers adopting an ecologically based system have opted for determinate growth varieties due to their ease of staking and sprouting, and due to the fact that they have a shorter cycle, which reduces phytosanitary problems that usually occur towards the end of the growing season. This study aimed to evaluate yield components and fruit quality of 'Floradade' determinate growth tomato in an ecologically based production system with regard to plant density and number of stems per plant in two growing seasons, spring-summer (SS) and summer-fall (SF). Two experiments were conducted in Pelotas in the years 2010/2011 under open field conditions. Plants were trained with two or four stems and four plant densities were evaluated: 2.0; 2.5; 3.0 and 3.6 plants m^{-2} in SS, and 1.5; 2.0; 2.5 and 3.0 plants m^{-2} in SF. The fruit number, fruit average weight, fruit yield, ascorbic acid content, total soluble solids and fruit pH were evaluated. The average fruit yield obtained in SF was on average 80% lower than that in SS. The increase of plant density and number of stems per plant led to an increase in fruit number and fruit yield in the two crop seasons. There was an increase in total soluble solids and reduction in the ascorbic acid content of the fruit. Two stems per plant and plant density of 3.0 plants m^{-2} are recommended for the 'Floradade' tomato crop under an ecological production system and SS crop conditions.

Key words: *Solanum lycopersicum*, organic production, crop management, crop season.

INTRODUCTION

The growth of tomatoes can be a diversification strategy for family farms, as it allows high economic yield, especially when produced in ecologically-based systems. The use of open pollinated varieties in these systems allows farmers to select and produce their own seeds (Vizcayno et al., 2014).

In the State of Rio Grande do Sul, Brazil, two tomato crops are grown every year in the spring-summer (SS) and summer-fall (SF) seasons. In the SS season, there is growing availability of solar radiation and increasing air temperature averages; in the SF season, the opposite occurs (Pereira et al., 2002).

In addition to environmental factors and genetic characteristics of tomato varieties, other factors associated with plant management, such as planting density, may interfere with tomato growth and yield. Fruit yield is determined by a combination of number and average fruit mass components, whose association results in the total production per plant (Rocha et al., 2010). As these components are associated with planting density, they define the yield per area unit, which is a consequence of the balance between vegetative growth (source) and generative growth (drainage) for a given photoassimilate supply.

The appropriate balance between photoassimilate supply and demand can be obtained through a good source/drainage ratio, which is connected with the appropriate potential fruit load per area unit (Peil and Galvez, 2005). This adjustment should be made by varying planting density and number of stems per plant in accordance with available solar radiation and soil fertility.

The correct planting density choice provides greater efficiency in the interception and use of solar radiation on the canopy and, consequently, higher yield per area. However, higher planting density decreases average fruit mass (Candian et al., 2017), as it reduces solar radiation penetration in the canopy. Thus, lower planting densities would provide an increase in photoassimilate production in the plant, resulting in greater fruit number and size.

Planting density can also affect the ascorbic acid and soluble solid contents of the tomato (Borraz et al., 1991). The recommended ascorbic acid content is 23 mg/100 g of pulp (Crawford, 1996), but values between 10 and 30 mg/100 g of ascorbic acid in fresh fruit have been found (Davies and Hobson, 1981). For soluble solids, the average is 4.5° Brix. However, soluble solid content is inversely proportional to tomato production (Agbna et al., 2017).

Tomato growers adopting an ecologically based system have opted for determinate growth varieties due to their ease of staking and sprouting, and due to the fact that they have a shorter cycle, which reduces phytosanitary problems that usually occur towards the end of the growing season. However, there are few studies available aiming at the analysis of plant density management and the number of determinate growth tomato stems in ecologically based production systems.

This study aimed to evaluate yield components and the fruit quality of Floradade determinate growth tomato with regard to planting density and number of stems per plant in an ecologically based production system.

MATERIALS AND METHODS

Two experiments were conducted at *Embrapa Clima Temperado / Estação Experimental Cascata* (latitude 31º37'S, longitude 52º31'W and altitude 181 m), located in the municipality of Pelotas, Rio Grande do Sul State, Brazil. Field cultivation was carried out using the determinate growth habit Floradade® (Feltrin) variety which bears persimmon-shaped fruit, with fruits of very attractive physical and organoleptic characteristics, possessing determined growth habits and it is indicated for organic crops in Rio Grande do Sul for resistance to fungus and insect attack.

Seedlings were grown in expanded polystyrene trays (128 cells) filled with Germina Plant® commercial substrate. Sowing was done on September 17, 2010 for the spring-summer (SS) cycle and transplanting to the field at 32 DAS (days after sowing). Sowing for the summer-fall (SF) crop was carried out on December 17, 2010 and seedling transplant to the field was performed 27 DAS. The culture cycle was 111 days for the SS crop, and 81 days for the SF counting from transplant.

The incident global solar radiation and air temperature were obtained by an automatic agro-climatic station located in a meteorological shelter close to the experiment location.

The local soil was the Acrisol type (Embrapa, 2006), having been ecologically managed for ten years, showing the following chemical and physical characteristics: pH water = 5.5; Ca = 2.6 $cmol_c\ dm^{-3}$; Mg = 0.9 $cmol_c\ dm^{-3}$; exchangeable H + Al = 3.5 $cmol_c\ dm^{-3}$; Base saturation = 52%; SMP index = 6.2; Organic matter = 1.9%; Clay = 25%; P (Mehlich) = 11.9 mg dm^{-3}; $CTC_{pH\ 7.0}$ = 7.3 $cmol_c\ dm^{-3}$ and K = 119 mg dm^{-3} in the SS cycle experimental area; and water pH = 5.5; Ca = 2.3 $cmol_c\ d^{-3;}$ Mg = 1 $cmol_c\ dm^{-3}$; exchangeable H + Al = 3.5 $cmol_c\ dm^{-3}$; Base saturation = 51%; SMP index = 6.2; Organic matter = 1.9%; Clay = 24%; P (Mehlich) = 20.2 mg dm^{-3}; $CTC_{pH\ 7.0}$ = 7.1 $cmol^c\ dm^{-3}$ and K = 121 mg dm^{-3} in the SF cycle experimental area.

Soil correction based on chemical analysis was performed in its entirety prior to transplant using 28 g limestone, 5 kg earthworm humus, 5 kg avian bed, 14 g natural phosphate, 10 g bone meal and 3 g boron micronutrient (Borax) per linear meter. Drip irrigation was used.

The plants were staked vertically with bamboo from 30 days after transplant (DAT) onwards by using the so-called "Mexican" system (Wamser et al., 2007), in which all shoots below the first inflorescence are removed. Pest and disease control were carried out by means of curative and preventive methods with the application of Bordeaux mixture and lime sulfur spray, *Bacillus thuringiensis* based products, the use of yellow and blue adhesive baits, light trap, attraction pheromones for the tomato moth (*Tuta absoluta*) and the release of butterfly egg parasitoids (*Trichogramma pretiosum*). Manual weeding was performed for spontaneous plant control.

The plants were conducted with two or four stems. After the first inflorescence, the development of a lateral stem or three lateral stems was allowed, thus maintaining two stems or four stems per plant. All other stems and shoots were removed.

Four planting densities were also evaluated: 2.0. 2.5. 3.0 and 3.6 plants m^{-2} in the SS experiment, corresponding to 0.50. 0.40. 0.33 and 0.28 m plant spacings; and 1.5. 2.0. 2.5 and 3.0 plants m^{-2} in the SF experiment, corresponding to 0.65. 0.50. 0.40 and 0.33 m plant spacing in the planting row. Spacing between rows as 1 m.

Thus, the experiments had a factorial design (2×4), with treatments resulting from the combination of levels of two factors: number of stems per plant and planting density. The experiment had a randomized block design, with three replications. Each block consisted of three cultivation rows, and only the central row was considered useful for evaluation. Each experimental plot included

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51 plants.

Five plants per experimental plot were selected for data collection. The harvest started on 68 DAT for the SS crop and 62 DAT for the SF crop, and was performed once a week until the end of the cycle, when ripening and fully ripened fruit were collected (Ceagesp, 2003). Next, counting, fresh mass (FM) determination and fruit categorization were carried out (Ceagesp, 2003). Fruit with mild or severe defects were considered non-marketable. The analyzed variables were number of fruit, average mass and total production (commercial and non-commercial) by area.

A sample of eight fully ripened tomatoes was randomly collected from each treatment in the middle of the productive period for chemical analysis in the Food Technology Laboratory of Embrapa Clima Temperado, and three technical analyzes of ascorbic acid (official 967 method), soluble solid total (refractometry) and pH (digital parameter) were performed.

The results were submitted to analysis of variance and tests of hypotheses by means of factorial analysis, aiming to obtain main effects of factors involved and their interaction. Levels of the number of stems factor were interpreted by comparison of means by the Fisher's Least Significant Difference (LSD) test at a 5% error probability and the plant density factor by means of regression analysis.

RESULTS

The solar radiation, relative humidity and temperature obtained during the experiment are shown in Figure 1. There was no interaction between the number of stems and planting density for most response variables in both crop cycles ($p>0.05$). Results referring to the isolated effects of factors are shown in Tables 1 and 2 and Figure 2. Results concerning response variables in which there was interaction between factors are shown in Figure 3.

For both crop cycles, the number of commercial fruit produced by area as well as commercial productivity increased proportionally to planting density as a consequence of the higher number of plants per area unit (Figures 2a and 2b). It was also observed that fruit yield was very similar in higher densities in the SS cycle (3.0 and 3.6 plants per m^{-2}), 101.2 and 101.0 t ha^{-1}, respectively. In the SF cycle, the increase from 2.5 to 3.0 plants m^{-2} led to a 22% increase in productivity, from 18.6 to 22.8 t ha^{-1} (Figure 2b). Yields obtained in the SF crop cycle were on average 80% lower than those obtained in SS cultivation - below 25 t ha^{-1}, being considered low. Nevertheless, during the latter period the farmer is able to market the product at much higher prices, which compensates low productivity financially-wise.

The number of stems per plant affected the number of fruit and crop productivity in the SS cycle; this effect, however, was not observed in the SF cultivation. The plants with four stems showed higher fruit number and higher commercial fruit yield than those with two stems in the SS cycle (Table 1).

In the SS crop, there were more non-commercial fruits per area in four-stemmed plants (Table 1). There was interaction between factors for the ascorbic acid (AA) content variable in the SS fruit crop (Figure 3a). In two-stemmed plants, the increase in planting density proportionally decreased the AA fruit content. In four-stemmed plants, the AA content responded to the increase in crop density in a quadratic way, with higher initial values for the 2.0 plant m^{-2} density. Upon comparing the number of stems within the same planting densities in the SS cycle, it was noticed that the increase in the number of stems per plant caused a decrease in the fruit AA content (Figure 3a). In the SF cycle, planting density and number of stems per plant did not affect the fruit AA content, with an average of 19.8 mg/100 ml of fruit pulp.

Increased planting density in the SS crop affected the soluble solids (SS) content in the fruit quadratically, with maximum values of 4.75 and 4.70, respectively, at 3.0 and 3.6 m^{-2} plant densities (Figure 3b). The SS content was also higher when there was a lower number of stems per plant (Table 2), and when there was higher plant density and productivity (Figure 2b) in the SS cycle.

There was an inverse relation between the AA and SS content in fruit in the SS crop (Figures 3a and b). Fruit acidity (pH) was not influenced by experimental factors, showing an average of 4.3 in both crop cycles. The pH values found in this study were similar to those found in an organic production system (Carvalho et al., 2017; Candian et al., 2017), and within a range that is thought to be desirable for *in natura* tomato consumption, with values higher than 3.7. As a rule, overly acidic tomatoes are rejected by consumers (Borguini and Silva, 2007).

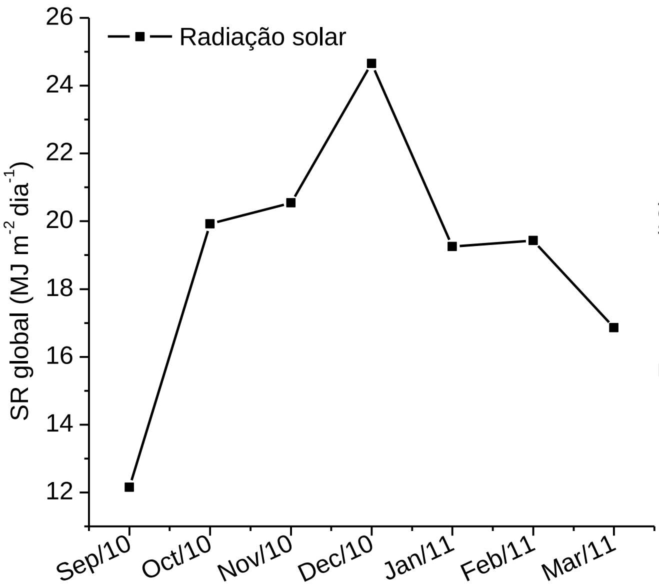
In the SS crop, for plants with two stems, the increase in planting density did not affect the average fruit mass, which remained at 222.94 g $fruit^{-1}$ (Figure 3c). There was a linear fruit average mass reduction as planting density increased with reference to four-stemmed plants in SS crop (Figure 3c).

In the SF crop, neither factor affected the average fruit mass, showing an average of 139.7 g $fruit^{-1}$. In this experiment, the low radiation availability prevented the occurrence of differences between treatments. The average fruit mass in the SF cycle was much lower than that for the salad-type fruit, which is at least 250 g, that is, 90 g below the lowest value.

DISCUSSION

The higher fruit yield in higher planting density treatments occurred due to the greater interception of photosynthetically active light and, consequently, greater canopy photosynthesis, leading to a higher production of photoassimilates that were made available for the growth of the fruit (Jiang et al., 2017).

The productivity obtained in the SS crop - between 82 and 101 t ha^{-1} - can be considered excellent, since it is similar to that obtained by indeterminate hybrids in conventional crop (Mueller et al., 2013; Heine et al., 2015). Also, it exceeds the national average productivity of the fruit, which is 60 t ha^{-1} (IBGE, 2012). Yields obtained in SF cultivation were on average 80% lower



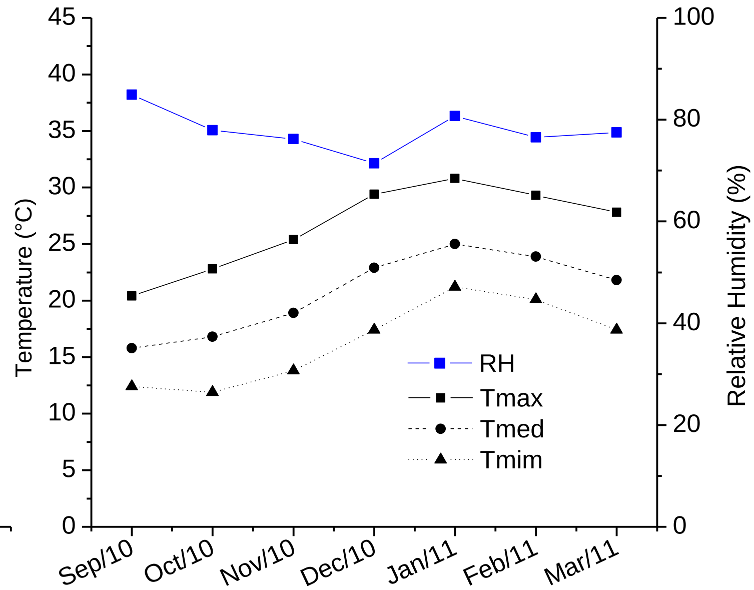


Figure 1. Solar radiation (SR), relative humidity (%) and maximum, medium and minimum air temperature throughout crop cycles.

Table 1. Number of fruits (NF) and commercial (COM) and non-commercial (NCOM) yield of tomato 'Floradade' in two crop seasons as a function of number of stems per plant in ecological production system.

Stems/plant	Spring-summer2010/2011				Summer-fall2011			
	NF m^{-2}		Yield ($t\ ha^{-1}$)		NF m^{-2}		Yield ($t\ ha^{-1}$)	
	COM	NCOM	COM	NCOM	COM	NCOM	COM	NCOM
02	39.8^{b}*	2.8^{b}	88.7^{b}	4.1^{ns}	12.4^{ns}	3.1^{ns}	18.7^{ns}	2.5^{ns}
04	46.2^{a}	5.2a	99.1^{a}	6.4	11.1	3.8	17.1	3.7
CV (%)	11.0	24.8	11.6	24.3	32.8	24.0	26.0	23.2

*Means followed by the same letter per column do not differ by Fisher's LSD test (p<0.05), ns, not significant.

Table 2. Soluble solids (as 0Brix) of tomato 'Floradade' fruits in two crop seasons as a function of number of shoots per plant in ecological production system.

Stems/plant	Spring-summer (2010/2011)	Summer-fall (2011)
02	4.63^{a}	4.0^{ns}
04	4.43^{b}	4.1
CV (%)	2.77	6.8

*Means followed by the same letter per column do not differ by Fisher's LSD test (p<0.05), ns, not significant.

than those obtained in SS - below 25 t ha^{-1} - being considered low. However, during this period the farmer is able to market the product at higher prices, which compensates low productivity financially-wise.

The highest fruit production in the SS cycle was due to a greater solar radiation accumulation, since the global solar radiation flux in this period totaled 2333 MJ m^{-2}, whereas in SF it was only 1368 MJ m^{-2}. In addition, in the SS period, there is a growing evolution of available solar radiation, which increases considerably along this crop cycle under Rio Grande do Sul State climatic conditions. Taking into consideration healthy plants having an adequate supply of water and nutrients, liquid photosynthesis and phytomass production are proportional to the amount of radiation absorbed by the canopy, (Monteith, 1972) increasing production (Hachmann et al., 2014). On the other hand, in the SF period, solar radiation decreases along the culture cycle; also, the high temperatures at the beginning of the cycle have a negative impact on the number of flowers per

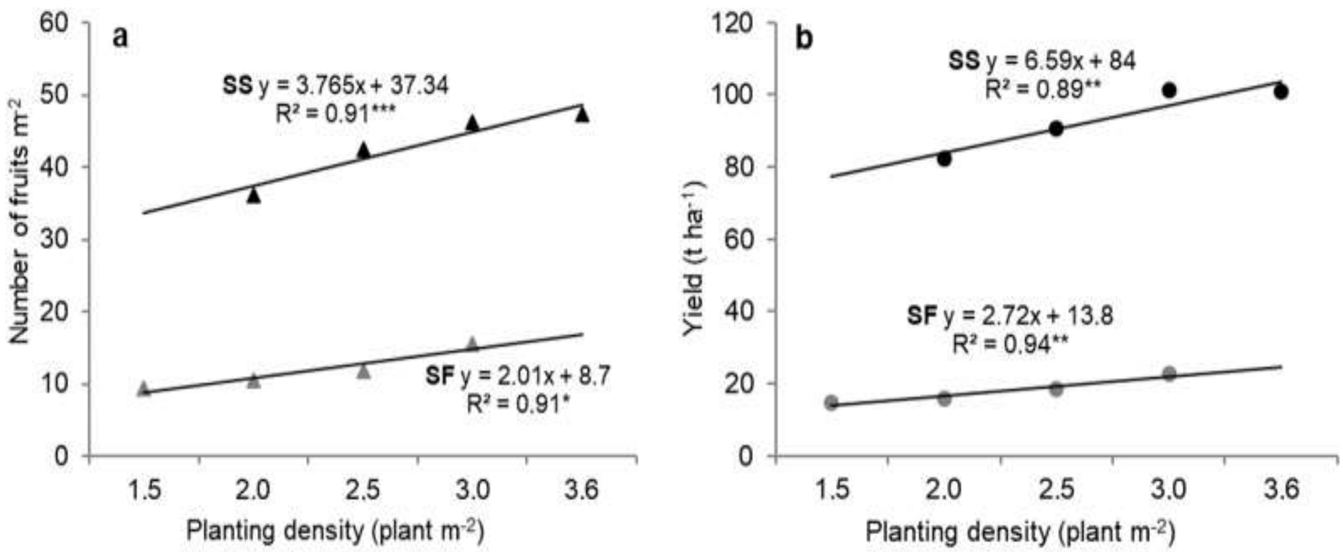


Figure 2. Number of fruits (a) and commercial yield (b) of tomato Floradade in Spring-summer (SS) and Summer-fall (SF) crop seasons and ecological production system.

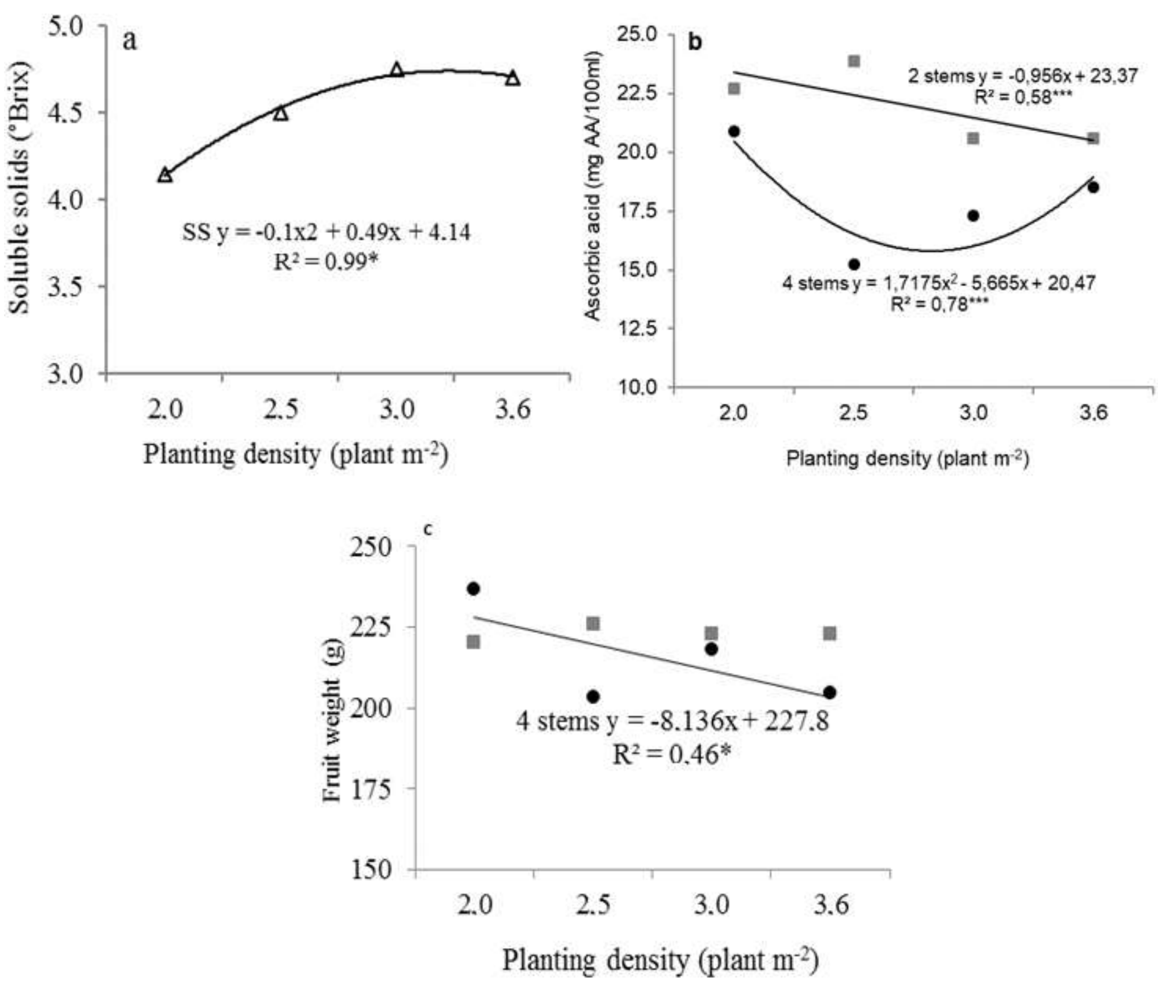


Figure 3. Soluble solids (a), ascorbic acid (b), and fruit weight (c) of tomato Floradade in Spring-summer crop season as a function of plant density and number of shoots per plant in ecological production system.

raceme.

In agreement with this information, it was observed that the plant leaf area index (LAI) in the SF period was 50% lower than that in the SS cultivation, when the same planting densities and number of stems per plant (2.47 for the SS cultivation and 1.21 for the SF cultivation) are compared. As light interception is an important plant productivity determinant, when the leaf area is reduced, there is solar radiation interception reduction and photoassimilate production which, together with the lower solar radiation of the period, contribute to reduced summer-fall cycle productivity. Furthermore, an aggravating factor in the SF cultivation was the late blight (*Phytophthora infestans*) occurrence in the plants at the end of the cycle, which caused fast plant leaf area loss. Lower LAI values for SF cultivation as compared to SS cultivation were found for this same variety under Rio Grande do Sul State conditions (Radin et al., 2003).

The number of stems did not affect the number of fruit and productivity of the tomato plant in the SF cycle due to the low solar radiation available and the great competition for photoassimilates between the stems under this condition, which resulted in a lower fruit fixation index. Therefore, there was four-stemmed plant superiority in relation to two-stemmed ones.

The higher number of fruit and higher yield per area with higher planting densities and the increase in the number of stems in the SS cultivation cycle are possibly related to an increase in LAI (on average 3.08 for a 3.6 m^{-2} plant density and 2.93 for 4 stemmed plants) and, consequently, a greater canopy efficiency at interception (Heuvelink, 1995; Papadopoulos and Pararajasingham, 1997) and the use of the abundant solar radiation available in the SS period. Candian et al. (2017) and Charlo et al. (2009) also found a higher number of fruit when the plants had a greater number of stems.

For both crop cycles, the density factor had no significant effect on the number of non-commercial fruit per area, 4.0 and 3.5 m^{-2} fruit on average in the SS and SF crops, respectively. Thus, there were no significant differences in fruit yield, with an average of 5.25 and 3.12 t ha^{-1} for the SS and SF crops, respectively.

The higher number of non-commercial fruit in four-stemmed plants was due to corn-earworm (*Helicoverpa zea*) and tomato pinworm (*Neoleucinodes elegantalis*) attack, in addition to soft rot occurrence. This bacterium (*Erwinia* sp) penetrates through wounds caused by insects that perforate the fruit. The greater damage by fruit borer caterpillars in four-stemmed plants may be related to the greater difficulty of natural enemies, such as egg parasitoids and *B. thuringiensis* applications, in reaching the target, due to a greater stem density per area.

Fruit of four-stemmed plants showed AA levels below 23 mg/100 ml, believed to be the minimum value of this acid in the fruit, whereas fruit of two stemmed plants showed AA levels above 20 mg/100 ml pulp, which was close to ideal levels (Crawford, 1996). A higher two-stemmed plant density, in spite of increasing light interception and the canopy photosynthetic rate, also reduces the penetration of light inside, decreasing the plant individual photosynthetic rate and, consequently, the ascorbic acid biosynthesis.

The total soluble solids content determines fruit taste, which is an important index for commercial tomato quality analysis (Jiang et al., 2017). The higher soluble solids content with higher planting density and the increase in productivity were due to the fact that the photosynthetic activity increase in the total plant set can be a way of obtaining high productivity without negatively affecting fruit quality, since a direct relation between fruit yield and soluble solids content is obtained (Guimarães et al., 2007). However, this is not in agreement with the results obtained by Agbna et al. (2017), who found that the soluble solid content and ascorbic acid is inversely proportional to tomato productivity under irrigation.

For both soluble solids (Figure 2b) and productivity (Figure 1b) variables, there were no numerical gains as the population increased from 3.0 to 3.6 plants m^{-2} in the SS cycle. In addition, one must consider the greater handling difficulty and the additional demand for labor as a consequence of a greater number of plants per cultivated area unit.

In both higher and lower plant density four-stemmed plants, there was an increase in ascorbic acid (Figure 1b). This can be attributed to stress caused by competition between plants in high densities and protection against UV radiation at low densities (Taiz et al., 2017). Previous research on the relationship between light irradiation and fruit ascorbic acid content has shown that ascorbate synthesis and metabolism in fruit are significantly affected by fruit irradiation in addition to leaf irradiation (Gautier et al., 2009).

The average fruit mass decrease in higher planting density four-stemmed plants can be attributed to the lower penetration of solar radiation in the canopy, the greater competition between plants for water and nutrients and, consequently, the lower production of photoassimilates, thus decreasing the average fruit mass (Wamser et al., 2009; Wamser et al., 2012). In the SS cycle, because of the high solar radiation availability, the average fruit mass was not altered for two-stemmed plants, even when planting density increased. This indicates that with two stems per plant, the increase in planting density did not affect the penetration of solar radiation in the canopy, without affecting fruit growth. The results of this study show that variations in plant and stem density per area alter solar radiation penetration in the canopy.

Conclusions

1. The yield components and chemical characteristics of

the tomato depend on the growing season for both planting density and the number of stems per plant.

2. In the spring-summer crop, the density of 3.0 plants m^{-2} with two stems per plant is recommended for 'Floradade' tomato in an ecologically based production system.

3. For summer-fall cycle crops, new studies should be carried out, testing other population arrangements and crop productive x economic feasibility under field conditions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Incidence and severity of maize streak disease: The influence of tillage, fertilizer application and maize variety

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Maize streak disease (MSD) is one of the most destructive diseases of maize (*Zea mays* L.) estimated to cause a yield loss of about 20% in Ghana. Field experiment was conducted at Nkwanta in the Volta Region of Ghana during the cropping seasons of 2015 to assess the effects of tillage practices, fertilizer application and maize variety on the incidence and severity of MSD. The MSD severity was assessed using 1 to 5 visual scale (1=no symptom and 5= very severe symptom). The relationship between total N, available P and exchangeable K contents of soils and maize leaves sampled at silking stage and MSD incidence and severity were elucidated with Pearson correlation coefficients. Although symptoms were observed in both fertilized and non-fertilized plants, fertilizer addition effectively reduced the MSD impact on growth and yield. Incidence and severity of MSD under no-tillage system were significantly lower than under conventional tillage. Severe MSD, particularly, of plants on the plots with no added nutrients led to stunted growth and reduced grain yield. The severity of MSD correlated positively with maize leaf N content, while increasing leaf K content resulted in reduced MSD severity. It can therefore be concluded that tillage and plant nutrition affect the severity of MSD in tropical soil.

Key words: *Zea mays*, grain yield, inorganic fertilizer, maize streak disease, maize varieties, tillage.

INTRODUCTION

Maize (*Zea mays* L.) is a major food security and cash crop for over 100 million people in Africa (Bosque-Perez, 2000) and also a major constituent in livestock feed (Romney et al., 2003). It accounts for 50 to 60% of total cereal production in Ghana (MiDA, 2010; Agyare et al., 2013). Diseases and pests, unpredictable rainfall and declining soil fertility are very critical biophysicalfactors contributing to decline in maize yields across sub-Saharan Africa including Ghana (Magenya et al., 2008; Obeng-Bio, 2010; MoFA, 2013). Maize streak disease

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(MSD) is one of the most destructive diseases of maize in terms of growth and yield loss in Africa (Magenya et al 2008; Karavina, 2014). The disease is caused by maize streak virus (MSV; genus *Mastrevirus*, family Geminiviridae) which is transmitted by various species of leafhoppers of the genus *Cicadulina* (Cicadilidae: Homoptera) in a persistent manner but the most important vector is *Cicadulina mbila (*Karavina, 2014*).* MSV has a wide host range, infecting over 80 other plant species in the family Poaceae (Shepherd et al., 2010). MSD is identified as yield declining factor of maize in Ghana with an estimated yield loss of about 20% (Oppong, 2013). Yield losses due to MSD reported elsewhere range from trace to almost 100% (Kyetere et al., 1999; Alegbejo et al., 2002).

One major challenge of MSD is its sporadic and unpredictable nature that makes it difficult to decide on how to apply any strategy to control it (Martin and Shepherd, 2009). In view of this, several methods, including the use of insecticides against the leaf hoppers (vector), plan planting to avoid the peak period of the vector infestation and the use of resistant varieties are employed to manage the disease (Magenya et al., 2008). These interventions however have not been very successful (Magenya et al., 2008).

Therefore, there is need to find alternative measures to control this disease in cost-effective and environmentally friendly manner to increase yield and to improve grain quality. Magenya et al. (2009) proposed that soil nutrient management provides a potential alternative measure to widening the scope of MSD management. The ability of a crop plant to resist or tolerate insect pests and diseases is tied to optimal physical, chemical and mainly biological properties of soils as well as soil management (Altieri and Nicholls, 2003). Soil nutrients are reported to affect the development of a disease by affecting plant physiology, the pathogen or both (Ownley et al., 2003). Again, modification of the soil environment through tillage practices can influence plant nutrient availability and hence plant growth, disease tolerance and yield (Dordas, 2009). The study was conducted to examine the effectiveness of different rates of inorganic nitrogen (N), phosphorus (P) and potassium (K) fertilizers on incidence and severity of MSD of two maize varieties (*Obatanpa* and *Domabin*) under no-tillage and conventional tillage systems.

MATERIALS AND METHODS

Study area

The field experiment was conducted at Nkwanta in the Volta Region of Ghana, which lies between latitudes 7° 30' and 8° 45'N and longitude 0° 10' and 0° 45'E. Nkwanta is found in the Forest-Guinea Savannah transition zone of Ghana. The average annual rainfall of the area ranges from 922 to 1,874 mm and the mean temperature is about 26.5°C (GSS, 2014). The dominant soil type was Acriosol (WRB, 2015). The field experiments were conducted under rain-fed conditions in both the major (June-September, 2015) and minor (September-December, 2015) cropping seasons. The monthly rainfall distribution of the experimental year is as shown in Figure 1.

Experimental design

The study was conducted using the split-split plot design with four replications, with tillage as the main plot, maize variety as sub-plots and fertilizer rates as sub-sub plots, respectively. The main treatments involved were: (1) Two tillage practices, No-tillage (T1) and Conventional tillage (T2); (2) Two local maize varieties; *Obatanpa* (V1) and *Domabin* (V2); and (3) Seven fertilizer application rates (N, P and K kg ha^{-1}), 0:0:0 (F1), 100:30:60 (F2), 100:80:60 (F3), 100:60:60 (F4), 100:60:30 (F5), 100:60:80(F6) and 60:60:60 (F7). These together make a total of 112 sub-sub plots.

On the no-tillage plots, the vegetation was first slashed and then followed by Glyphosate herbicide application at a rate of 1 L ha^{-1}. Three seeds were sown per hill at a spacing of 80 cm between rows and 40 cm within rows up to a depth of 5 cm. After emergence, the seedlings were thinned to two per hill.

The split fertilizer application method was adopted. In order to attain the different fertilizer application rates, NPK (15:15:15) was used for the basal application and supplemented with Urea (46% N), Triple Super Phosphate (TSP) (46% P_2O_5) and Muriate of Potash (MOP) (60% K_2O). The first fertilizer split was done 10 days after planting in a band about 5 cm away from the hills to a depth of 5 cm while the top-up application was done six weeks after planting, where necessary.

Data collection

Data collections were done in both major and minor cropping seasons. On each plot, 12 plants from middle rows were randomly selected and tagged for growth, disease and yield assessments. The plant height and disease incidence and severity were measured on 9th week after planting and yield data was collected at physiological maturity. Plant height was measured from the soil level to the tassel height using a meter rule. Grain yield was determined by measuring the total weight of maize per plot at 13% moisture content with a balance and expressed in tons per hectare. The incidence of MSD was determined by visually observing and recording the number of maize plants showing the disease symptoms and the percentage incidence was calculated as follows:

$$\text{Incidence (\%)} = \frac{Number\ of\ infected\ plants}{Number\ of\ plants\ assessed} \times 100$$

The plants were also scored for disease severity based on a scale of 1 to 5 adopted from Bosque-Perez and Alam (1992) with a modification by Oppong et al. (2014a, b) (Table 1).

In the study, soil sampling was done at two different periods. The initial soil sampling was done at the beginning of the study to characterize soils at the study site before treatments were applied whilst the second soil samples were taken at maize silking stage to determine the soil nutrient status after the period of maximum uptake by the maize. A composite sample for each plot was obtained by thoroughly mixing soil samples collected at a depth of 01 to 20 cm at six randomly selected points within each plot with an, using Auger. Leaf samples were collected from four plants in each plot at maize silking stage to determine the leaf nutrient content uptake by the maize. On each plant, leaves opposite and just below the uppermost ear (the second most fully expanded leaf) were sampled using a knife (Arnon, 1975). Maize grains were also sampled from each plot at the physiological maturity stage harvest

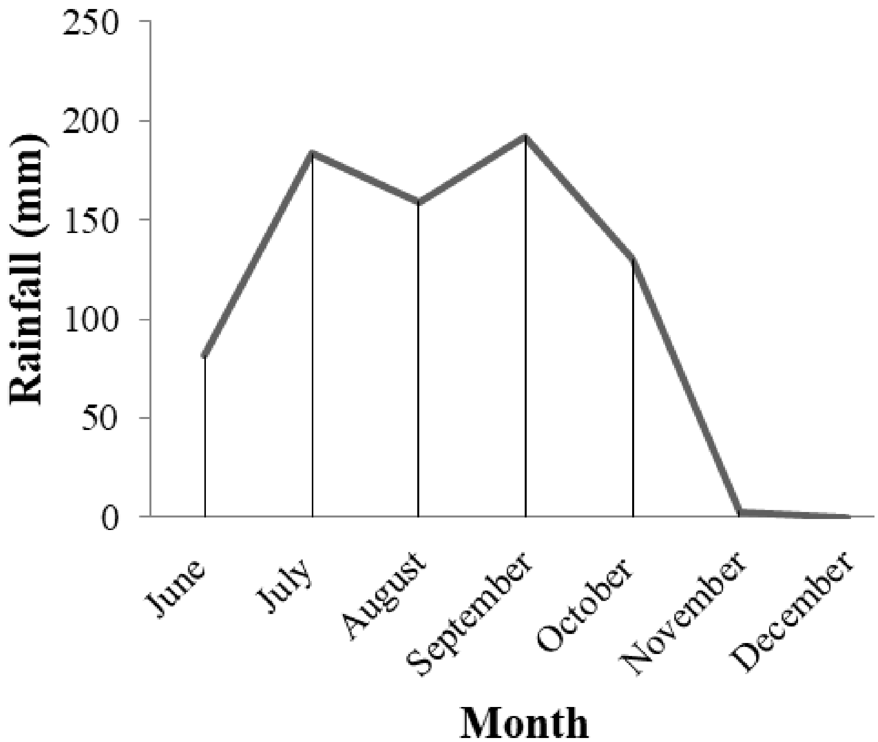

Figure 1. Mean monthly rainfall distribution during the 2015 cropping seasons at Nkwanta, Ghana.

Table 1. Visual rating scale for maize streak disease (MSD) severity.

Rating scale	Description	Expression in terms of severity
1	No symptoms	No infection
2	Very few streaks on leaves, light streaking on old leaves gradually decreasing on young leaves	Mild infection
3	Moderate streaking on old and young leaves, slight stunting	Moderate infection
4	Severe streaking on about 60-75% of leaf area, plants stunted	Severe infection
5	Severe streaking on more than 75% leafarea, plants severely stunted or dead	Very severe infection

Source: Bosque-Perez et al. (1992) and Oppong et al. (2014a, b).

for crude protein determination).

Soil and maize grain analyses

Soils of the experimental fields were characterized by the determination of the textural class, pH, bulk density, organic matter content, total nitrogen, available phosphorus, exchangeable bases ($Ca^{2+,}$ $Mg^{2+,}$ K^{+}, Na^{+}) and exchangeable acidity (H^{+} and Al^{3+}). The soil samples collected at maize silking stage were analysed for total N, available P and exchangeable K contents. Soil pH was measured in a 1:2.5 soil-water ratio using a glass electrode pH meter (Rowel, 1994). The particle size distribution of the soil was determined using the pipette sampling technique described by Rowel (1994). The organic carbon (C) content of the soil was determined using the Walkley-Black method and the organic matter content of the soil was estimated from the organic C content (FAO, 2008). The total N in the soil samples were determined by the Micro-Kjeldahl method as described by Rowel (1994), with a slight modification. The exchangeable cations were also determined using techniques described by Rowel (1994).

The grain N content was determined using protocol obtained from IITA (1985). The grain crude protein was then estimated by multiplying the percentage N by 6.25 (Galicia et al., 2009).

Data analyses

All data were analysed using GenStat Discovery Version 4 (VSN International). Data in percentages were normalized using angular transformation. Relationships between disease data (MSD incidence and severity scores) and plant height, grain yield, and soil total N, available P and exchangeable K were established by calculating Pearson's correlation coefficients. Analysis of variance

(ANOVA) was performed to test the treatments and their interaction effects for significance at 5% level of probability. The least significant difference (l.s.d) was used for means comparison.

RESULTS

Physicochemical properties of soils of the study area

The physicochemical properties of soils used for the field experiments are shown in Table 2. The soil had low pH and organic matter content as well as low total nitrogen, available phosphorus, exchangeable potassium and exchangeable calcium contents.

MSD incidence and severity

During the major season, the incidence and severity of MSD were both significantly greater ($P < 0.05$) in the conventionally tilled plots than in the no-till plot (Table 3). In the minor season, incidence did not differ among the tillage systems, but the severity was higher in the conventionally tilled plots than in the no-till plots.

In the major season, MSD incidence and severity were not significantly ($P>0.05$) different between the two maize varieties. In the minor season, MSD severity was significantly ($P < 0.05$) higher on *Domabin* as compared to *Obatanpa,* but the disease incidences were not significantly different ($P>0.05$).

The fertilizer treatments did not significantly ($P>0.05$) affect the overall MSD incidence and severity in the major season. However, in the minor season, the MSD severity in the control was significantly higher ($P<0.05$) than in the fertilizer amended plots, which did not differ significantly among themselves.

Plant height (cm), grain yield (kg ha^{-1}) and grain crude protein content (%)

The plant height and grain yield of the two maize varieties under different tillage operations and fertilizer treatments are shown in Table 4. The maize plants under conventional tillage generally had significantly higher heights than under no-tillage. The overall mean plant height for *Obatanpa* was not significantly different ($P>0.05$) from that of *Domabin*. Maize from the fertilized plots showed significantly higher plant heights than from the control but, the plant heights were not significantly different among the different fertilizer treatments.

Pooling all the data, conventional tillage resulted in significantly higher ($P<0.05$) grain yield than no-till. Also, *Obatanpa* had a significantly ($P> 0.05$) higher grain yield than *Domabin*. The mean grain yields recorded for the fertilized plots were not significantly different ($P>0.05$) among themselves but they were significantly higher than the control.

Table 2. Physicochemical properties of the soil used in the study.

Soil parameter	Value
Bulk density (g cm^{-3})	1.6
Soil pH	6.6
Organic matter (%)	1.20
Total N (%)	0.01
Available P (µg g^{-1})	8.20
Exchangeable bases (cmol$_c$ kg^{-1})	
Ca^{2+}	1.84
Mg^{2+}	3.08
K^+	0.12
Na^+	0.17
Exchangeable acidity(cmol$_c$ kg^{-1})	3.80
ECEC (cmol$_c$ kg^{-1})	6.08
Sand (%)	62.30
Silt (%)	24.80
Clay (%)	13.00
Textural class	Sandy loam

The results indicated a significantly positive interaction between tillage and fertilizer application on mean grain yield.

Soil total N, available P and exchangeable K status at maize silking stage

The nitrogen, phosphorus and potassium contents of soil under the different treatments at silking stage are shown in Table 5. Soil total N content at maize silking stage under conventional tillage was not significantly different ($P > 0.05$) from under no-tillage but available P and exchangeable K contents under no-tillage system were significantly higher ($P \leq 0.05$) than under the conventional tillage system

Fertilizer application did not significantly ($P > 0.05$) affect soil N content. Maize plots, which received fertilizer at a rate of 100:60:80 (F6) had both the highest available P and the highest exchangeable K contents. The total N and exchangeable P contents of soils were not significantly ($P > 0.05$) affected by interactions among the different treatment variables. However, but soil exchangeable K content was significantly affected ($P<0.05$) by both the tillage × fertilizer and variety × fertilizer interactions.

Maize leaves N, P and K contents at maize silking stage

The results indicated that plants under conventional tillage had significantly ($P\leq 0.05$) higher nitrogen (N) content in their leaves than those under no-tillage (Table 6). The two maize varieties did not differ significantly

Table 3. Mean MSD incidences and severity as affected by tillage systems, maize varieties and N, P, K fertilizer application rates.

Parameter	Major season		Minor season	
	Incidence (%)	Severity	Incidence (%)	Severity
Tillage system				
T1 (No- tillage)	17.9	1.21	88.80	2.58
T2 (Conventional tillage)	41.6	1.67	90.00	2.72
l.s.d	6.86*	0.215*	NS	0.1236*
Maize variety				
V1(Obatanpa)	29.8	1.42	89.40	2.62
V2(Domabin)	29.7	1.47	89.40	2.68
l.s.d	NS	NS	NS	0.0543*
Fertilizer rates (NPK kg ha^{-1})				
F1	33.2	1.61	88.95	2.86
F2	28.2	1.39	88.95	2.59
F3	28.2	1.40	88.95	2.62
F4	30.9	1.44	90.00	2.57
F5	33.1	1.46	88.95	2.66
F6	27.6	1.40	90.00	2.62
F7	26.9	1.40	90.00	2.64
l.s.d	NS	NS	NS	0.1208*
Mean	29.7	1.44	89.4	2.65
Treatment interactions				
T×V (P)	0.633	0.597	1.00	0.410
T×F (P)	0.479	0.342	0.826	0.317
V×F (P)	0.237	0.331	0.368	0.633
T×V×F (P)	0.237	0.526	0.368	0.860

*Significance at P ≤ 0.05, NS: Not significant, T: tillage, V: maize variety and F: fertilizer application.

(P>0.05) in terms of their leaf N contents. Fertilizer application significantly (P≤ 0.05) affected the N contents in the leaves of maize plants. Plot amended with fertilizer rate of 100:30:60 (F2) had the highest leaf N content whilst the unfertilized plot, F1 (0:0:0) had the lowest. Both tillage systems and maize varieties did not have significant influence (P>0.05) on mean leaf P content but tillage system × fertilizer rates and variety × fertilizer rates interaction effects were significant (P<0.005) (Table 6). Fertilizer application rates did not have significant influence on the mean leaf P contents.

The mean leaf K content recorded for no-tillage system was significantly higher (P<0.05) than that of conventional tillage. The improved maize variety *Obatanpa* had significantly higher mean K content than the local variety *Domabin* (Table 6).

Tillage and varietal interaction did not significantly (P>0.05) affect N and P but significantly (P≤ 0.05) affected K contents of maize leaves. Tillage and fertilizer application interactively affected leaf P and K but not leaf N content. Interaction between maize varieties and fertilizer application did not have a significant (P> 0.05) effect on the leaf N content but significantly (P≤ 0.05) affected leaf P and K contents.

Relationship between MSD incidence and severity and plant height, grain yield, N, P, K contents in the soil and leaves at silking

MSD incidence significantly correlated positively with plant height (r =0.595; P≤0.05) and grain yield (r =0.403; P≤ 0.05) as shown in Table 7a. MSD severity also significantly correlated positively with plant height (r =0.461; P<0.05) and grain yield (r=0.295; P≤ 0.05) (Table 7a).

Table 7b shows the correlation between the soil nutrient (NPK) content at maize silking stage and MSD incidence and severity. The soil total N content weakly correlated positively with MSD incidence (r = 0.041; P>0.05) and severity (r = 0.077; P>0.05) whiles soil available P weakly correlated negatively with MSD incidence (r = -0.233; P>0.05) and severity (r = -0.045; P>0.05) (Table 7b). Conversely, soil exchangeable K

Table 4. Plant heights and grain yields of maize as influenced by tillage, variety and fertilizer application.

Treatment	Plant height (cm)	Grain yield (kg ha^{-1})
Tillage		
T1 (No- tillage)	143.5	3127
T2 (Conventional tillage)	203.1	3941
l.s.d	12.87*	453.0*
Varieties		
V1(Obatanpa)	176.9	3759
V2(Domabin)	169.8	3309
l.s.d	NS	434.6*
Fertilizer rates (NPK kg ha^{-1})		
F1	150.6	2757
F2	178.5	3801
F3	171.8	3539
F4	171.3	3588
F5	180.7	3758
F6	177.4	3673
F7	182.9	3624
l.s.d	16.96*	653.2*
Mean	173.3	3534
Treatment interactions		
T×V (P)	0.460	0.658
T×F (P)	0.169	0.018*
V×F (P)	0.517	0.636
T×V×F (P)	0.760	0.032*

*Significance at P ≤ 0.05, NS: Not significant, T: tillage, V: maize variety and F: fertilizer application.

content significantly and negatively correlated with both MSD incidence (r = -0.439; P≤ 0.05) and severity (r = -0.319; P≤ 0.05).

Correlations between maize leaf N, P and K contents and MSD incidence and severity are shown in Table 7c. Correlations between leaf N content and MSD incidence (r=-0.057; P>0.05) and severity (r = -0.57; P>0.05) were not significant. Similarly, correlations between P content in the maize leaves and MSD incidence (r=-0.017; P>0.05) and severity (r= -0.20; P>0.05) were not significant. There was however positive and strong correlation between leaf P content and leaf K content (r = 0.501: P<0.05). There was a significant negative correlation (-0.296; P ≤ 0.05) between leaf K content and MSD severity.

DISCUSSION

Laboratory analyses of the soil at the experimental site (Table 2) revealed that the soil had a high bulk density, which is characteristic of sandy soils (Arthur, 2014). The soil pH was 6.6, which is slightly acidic and considered as good for plant growth (Yeboah et al., 2012). The organic matter content of soil was low (Table 2). Moreover, the soil was low in nitrogen, phosphorus, potassium and calcium, but had adequate magnesium content (Yeboah et al., 2012).

The significantly lower MSD incidence recorded under no-tillage than conventional tillage corroborated with the findings of Bowden (2015) who also reported lower incidence of barley yellow dwarf of wheat under no-tillage plots. Bowden (2015) attributed the situation to vector behaviour and explained that the aphids that carried barley yellow dwarf virus preferred tilled fields to fields with abundant crop residue on the soil surface. The finding of the present study suggests that no tillage can be a suitable method for managing MSD especially by resource-poor smallholder farmers. The result however contradicts the findings of Krupinsky and Tanaka (2001) who observed a higher incidence of leaf spot disease and Gilbert (2005) who also observed more severe net blotch of barley under no-till plots than conventional tillage.

The two maize varieties (*Obatanpa* and *Domabin*) differed significantly in terms of MSD severity when the disease pressure was high in the minor season. Similarly,

Table 5. Soil total N, available P and exchangeable K status at maize silking stage as affected by tillage systems, maize varieties and N,P, K fertilizer application rates.

Treatment	Total N (%)	Available P (μg g^{-1})	Exchangeable K ($cmol_c$ kg^{-1})
Tillage			
T1 (No- tillage)	0.036	45.4	0.489
T2 (Conventional tillage)	0.039	33.1	0.345
l.s.d	NS	6.73*	0.0564*
Maize variety			
V1(*Obatanpa*)	0.039	27.5	0.343
V2(*Domabin*)	0.041	38.1	0.395
l.s.d	NS	NS	NS
Fertilizer rates (NPK kg ha^{-1})			
F1	0.041	13.7	0.390
F2	0.043	25.0	0.430
F3	0.033	46.4	0.333
F4	0.037	37.6	0.402
F5	0.057	40.6	0.334
F6	0.029	77.0	0.637
F7	0.022	34.5	0.391
l.s.d	NS	28.42*	0.1144*
Treatment interactions			
T×V (P)	0.734	0.8I5	0.655
T×F (P)	0.117	0.877	0.004*
V×F (P)	0.406	0.209	0.018*
T×V×F (P)	0.878	0.586	0.103

*Significance at P ≤ 0.05, NS: Not significant, T: tillage, V: maize variety and F: fertilizer application.

Table 6. N, P and K contents of maize leaves at silking stage as affected by treatments.

Treatment	Leaf N	Leaf P	Leaf K
Tillage system			
T1 (No- tillage)	1.280	0.281	1.418
T2 (Conventional tillage)	1.637	0.285	1.294
l.s.d	0.2921*	NS	0.0442*
Maize variety			
V1 (Obatanpa)	1.403	0.287	1.394
V2 (Domabin)	1.515	0.280	1.219
l.s.d	NS	NS	0.0579*
Mean	1.459	0.283	1.356
Treatment interaction			
T× V (P)	0.673	0.619	0.023
T× F (P)	0.887	<0.001*	<0.001*
V×F (P)	0.920	<0.001*	<0.017*
T × V× F (P)	0.931	0.441	0.113

*Significance at P ≤ 0.05, NS: Not significant, T: tillage, V: maize variety and F: fertilizer application.

Bua et al. (2010) working with three maize varieties realized that MSD severity significantly varied among them. These differences in the degree of MSD severities among the maize varieties could be due to the differences in the genetic makeup of maize genotypes as reported by Aziz et al. (2008) when screening tomato germplasm for resistance to tomato yellow leaf curl virus. *Obatanpa* is an improved variety reported to be high yielding and tolerant to MSV infection (Twumasi-Afriyie et al., 1992) compared to *Domabin* which is a local cultivar (Asare-Bediako et al., 2017). The findings of the present study confirm the observations made by previous authors.

The disease incidence was not affected by fertilizer application. This could be attributed to the fact that fertilizer application does not necessarily affect MSD occurrence, especially as the virus could have infected the plants before the first fertilizer was applied (10 days after planting). The result does not agree with Magenya et al. (2009) who reported that the types and concentrations of nutrient elements in host plant tissues indirectly influence the population dynamics of leafhoppers and may therefore affect transmission of MSV. The impact of fertilizer application on MSD was realized only in the minor season. Though MSD incidence was not reduced, severity was significantly affected by NPK application. This result is in agreement with the findings of Huber et al. (2007) which state that take all disease of wheat is reduced when balanced nutrient is applied. The results thus suggest that fertilizer application may not necessarily affect MSD occurrence, but it can have significant impact on the ability of plant to limit penetration and development of the invading virus (Huber et al., 2007). Also, the fertilized plants obtained sufficient nutrients and hence grew stronger and healthier and so they compensated for any viral damage that would have occurred. The ability of the MSD affected plant to maintain its own growth in the presence of sufficient amounts of plant nutrients in spite of the MSV infection, possibly explains why MSD severity was reduced by fertilizer application.

The high MSD incidence and severity recorded in the control further supports this suggestion. The study has demonstrated that fertilizer application has beneficial effect against MSD severity. The results indicate that maize from fertilized plots potentially obtained sufficient nutrients and grew stronger and healthier. The capacity to grow faster enabled the fertilized plants to with stand any viral damage that would have occurred if their growth were slower.

In agreement with Bosque-Perez and Alam (1992), MSD incidence and severity were higher during the minor cropping season than during the major cropping season. Martin and Shepherd (2009) observed that droughts or irregular rains around the time that maize is planted tend to be associated with severe MSD. They argued that the number of viruliferous leaf hoppers is low in the major rainy season but increase in the minor season when the rainfall intensity reduces.

The low grain yields under no-tillage treatment can be attributed to slow early crop establishment which resulted in relatively shorter plant heights as compared to those under conventional tillage. The amounts of available P in the 0 to 20 cm layer indicate that there was probably less P fixation and uptake by plants under no-tillage. As the surface-applied nutrients often remain largely in the surface soil layer of soils under no-tillage (Arnon, 1975), they may not be readily accessible to the crop. This was evident in comparatively higher plant height and grain yield under conventional tillage than under no-tillage system.

Fertilized plots, gave 24.8% more grains than the unfertilized plots. Phosphorus application at 30 kg ha^{-1} yielded 6 and 7% more grains than at the 60 kg P, which is the recommended rate for the study site (Yeboah et al., 2012) and also at 80 kg P ha^{-1} respectively. Fosu-Mensah and Mensah (2016) also obtained a maximum yield of 4953 kg ha^{-1} at 120 kg ha^{-1} N and 30 kg P ha^{-1}. They explained that at soil available P levels beyond 30 kg ha^{-1}, plant growth and grain yield were adversely affected as excessive soil P induced deficiency of micronutrients such as Zn (Olusegun, 2015). Also, Kogbe et al. (2003) reported that P application rates beyond 40 kg ha^{-1} depressed plant yields, leading to low economic returns. In this study the yield response of *Obatanpa* was greater than that of *Domabin*, possibly due to the genotypic superiority of the former in terms of nutrient use efficiency and hence grain yield. This agrees with widely accepted assertion that plant genotypes differ in their responses to changing soil fertility and environmental conditions (Faisal et al., 2013).

The significant negative correlation between the soil exchangeable K concentration with both MSD incidence (r = -0.4393) and severity (r = -0.3189) agreed with the findings of Wang et al. (2013). They reported that increased K fertilizer application significantly reduced the incidence of stem rot disease and aggregate sheath spot of rice. Magenya et al. (2009) also observed a significant negative correlation between soil K concentration and number of *C. mbila* (vector of MSV) and noted that fields that exhibited low K contents had the highest numbers of *C. mbila*.

The MSD incidence and severity had positive correlation with the maize height and the grain yield (Table 6). The low mean MSD incidence and severity of 29.7% and 1.4, respectively in the major cropping season implied that although the disease incidence occurred, the plants were able to maintain their own growth and yield in spite of infection as reported by Dordas (2009). The findings however disagreed with that of Bosque-Perez et al. (1998) who reported a significant negative correlation of MSD incidence with plant height and grain weight. The disease also has been reported by Bua et al. (2010) to significantly reduce maize growth and yield. The lack of significant correlation between the MSD incidence and severity with grain crude protein content imply that the quality of maize grains is not affected by the MSD occurrence.

Table 7. Correlation matrices among MSD incidence and severity and **a**. plant height and grain yield **b**. soil N, P and K contents and **c**. leaf N, P and K contents**.**

Parameter	MSD incidence (%)	MSD severity	Plant height (cm)	
a				
MSD severity	0.905*	-	-	-
Plant height (cm)	0.595*	0.461*	-	-
Grain yield (kg ha^{-1})	0.403*	0.295*	0.507*	-
b	**Soil N**	**Soil P**	**Soil K**	**MSD incidence**
Soil P	- 0.041	-	-	-
Soil K	-0.177	0.5548*	-	-
MSD incidence	0.157	-0.233	-0.439*	-
MSD severity	0.077	-0.145	-0.319*	0.908*
c	**Leaf N**	**Leaf P**	**Leaf K**	**MSD Incidence (%)**
Leaf P	0.133	-	-	-
Leaf K	-0.173	0.501*	-	-
MSD Incidence (%)	-0.057	0.017	-0.110	-
MSD Severity	0.025	-0.020	-0.296*	0.141

*Significant at p<0.05.

The results showed that higher maize leaf N content was associated with higher MSD severity. MSD severity in the minor season was significantly higher on conventional tillage system (Table 7). Also, *Domabin* which was less tolerant to MSD showed higher leaf nitrogen content. Similar results were obtained by Zafar and Athar (2010) in their investigation to reduce disease incidence of cotton leaf curl virus (CLCUV) in cotton (*Gossypium hirsutum* L.) by potassium supplementation. A comparison of two cotton varieties showed that diseased leaves of susceptible variety had significantly greater concentration of N than the healthier leaves of both susceptible and resistant varieties.

A significantly higher K content in the leaf of *Obatanpa* than *Domabin* reflected in a significantly lower MSD severity and greater plant heights recorded for *Obatanpa* variety compared to the higher MSD severity and lower plant heights of the *Domabin* variety, especially during the minor season. Increased disease resistance in *Obatanpa* could be related to its ability to absorb greater amounts of the applied K. According to Wang et al. (2013), the presence of adequate plant K content decreases internal competition by pathogens for nutrient resources, and increases phenol concentrations which play a critical role in plant resistance. The significant negative correlation observed between leaf K content and MSD severity confirms this suggestion and was also evident in the higher grain yield produced by *Obatanpa.*

Conclusions

The study showed that no-tillage and fertilizer application, particularly K addition, are effective in minimizing the occurrence and severity of MSD. Furthermore, it was concluded that the use of improved varieties such as *Obatanpa* can reduce incidence and severity of MSD as compared to local varieties such as *Domabin*.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Screening for salinity tolerance of *Oryza glaberrima* Steud. seedlings

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Rice (*Oryza sativa*) is a salt-sensitive species and improvement of salt resistance is a major goal for plant breeders. Some species of *Oryza* genus may constitute an interesting source of genes involved in stress resistance for cultivated rice improvement. The African rice *Oryza glaberrima* is poorly described for its response to salt stress. Twenty-five accessions of *O. glaberrima* were exposed during 2 weeks to 0 or 60 mM NaCl in nutrient solution. Morphological and physiological parameters were recorded and used to perform principal component analysis allowing us to consider three contrasting groups (salt-resistant, medium, and salt-sensitive). Most of the tested lines appeared more salt-sensitive than the moderately salt-resistant cultivar I Kong Pao from *O. sativa*. Salt-sensitivity index was higher for roots than for shoots and *O. glaberrima* was poorly efficient for regulation of Na^+ translocation from the root to the shoot. Some accessions such as TOG5307 however were able to maintain a high net photosynthesis under salt conditions and exhibited a high level of tolerance to accumulated Na^+ ions and a high capacity for osmotic adjustment. It is concluded that these salt-tolerant accessions constitute a promising material for rice improvement through inter-specific crosses with *O. sativa*.

Key words: African rice, NaCl, *Oryza glaberrima*, salinity, salt stress.

INTRODUCTION

Rice is an important staple food for more than half of the human population. It provides 50% of the calories consumed in several areas of Asia and Africa (Khush, 2005). In numerous African countries, however, rice production is still not sufficient and the estimated rice import in Africa accounts for several millions of tones each year which represent more than one-fourth of its requirements (Nhamo et al., 2014). There is consequently an urgent need to increase rice production, especially considering that the world's population is predicted to reach around 10 billion people by 2050 (Hoang et al., 2016). Because of a very limited potential for future expansion of arable lands, such a goal implies to extend rice culture to marginal lands which are not used at the moment for rice culture.

Numerous environmental constraints are limiting rice production. Among them, drought and soil salinity are probably the most prevalent abiotic stresses hampering

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plant growth and development. Salinity affects more than 830 × 10^6 ha in the world. Of the 230 × 10^6 ha of the world's irrigated lands, 45 × 10^6 ha (20%) have already been affected by salt, and the problem is increasing due to sea level rise and to erratic irrigation (Munns, 2005). Salinity imposes a double constraint to plants: an osmotic stress and an ionic toxicity. Osmotic stress is related to the presence of a high external salt concentration which decreases the external water potential and thus compromises water uptake by the plant. The ionic component of salt stress is due to progressive accumulation of toxic ions such as Na^+, excess of Cl^- and salt-induced decrease in essential elements, mainly K^+ (Acosta-Motos et al., 2017).

Rice is very sensitive to salt stress (Hoang et al., 2016) and a NaCl dose as low as 50 mM in nutrient solution is considered to be lethal for salt-sensitive cultivars (Yeo and Flowers, 1986; Zhu et al., 2001). Salt-sensitivity in rice varies depending on the phenological stage with young seedlings and plants at the flowering stages being considered as the most sensitive ones (Lutts et al., 1995; Hakim et al., 2010). Despite a high number of available cultivars, *Oryza sativa* L. still performs poorly under salt stress conditions (Singh and Sengar, 2014). The most salt-tolerant genotypes are tall indica landraces which suffer from major agronomic drawback under West African conditions. Numerous evidences are now available regarding the loss of genetic diversity encountered by *O. sativa* since its domestication (Caicedo et al., 2007).

Some biotechnological tools may be used to improve salt-tolerance of existing cultivar (Lutts et al., 1999; Singh and Sengar, 2014) but both *in vitro* selection and transgenic approaches suffer from technical and/or social limitations. A promising alternative is to use other species of *Oryza* genus for breeding purposes in order to improve abiotic stress resistance in *Oryza sativa* (Atwell et al., 2014). The cultivated African rice *Oryza glaberrima* Steud. is receiving a considerable attention since several years. This species was domesticated 3000 years ago. Although it was progressively replaced by the high-yielding Asian rice *O. sativa*, this hardy species has qualities that make it superior to Asian rice as a subsistence crop (Linares, 2002). This species suffers from easy shedding of grains, resistance to milling, greater breaking of grains, red pericarp and lower yield (Nayar, 2010). However, it also presents a greater resistance to various biotic and abiotic stresses. Resistance to yellow mottle virus (Pidon et al., 2017) and to the nematode *Meloidgyne graminicola* (Cabasan et al., 2015) has been identified in this species. *O. glaberrima* produces extra-tillers allowing it to efficiently compete with weeds (Sarla and Mallikarjuna Swamy, 2005). It displays interesting properties for resistance to iron toxicity (Majerus et al., 1999; Dufey et al., 2015) and to submergence (Sakagami et al., 2009). It also possesses promising characters for drought resistance (Bimpong et al., 2011; Bocco et al., 2012; Ndjiondjop et al., 2012; Kijoji et al., 2013).

Numerous strategies have been efficiently used by breeder to overcome hybrid sterility between *O. sativa* and *O. glaberrima* (Shen et al., 2015). Several varieties issued from selected recombined plants obtained after interspecific crosses between the two species are now available and known as New Rice for Africa (NERICA) varieties. Most of them resemble *O. glaberrima* during early growth, displaying weed competitive ability and with *O. sativa* at the reproductive stage, allowing high yielding capacities (Jones et al., 1997; Sarla and Mallikarjuma Swamy, 2005). Despite the large set of data available for water stress resistance in *O. glaberrima*, information regarding salinity resistance in this species remains poorly documented. Awala et al. (2010) reported that *O. glaberrima* CG14 appeared rather salt-sensitive but the obtained hybrids after crossing this line with the *O. sativa* WAB56-104 cultivar produced hybrids exhibiting a high level of salinity resistance. Platten et al. (2013) quantified Na^+ accumulation in several salt-exposed lines of *O. glaberrima* and identified a specific gene (*OgHKT1;5*) which partly contribute to regulate Na^+ absorption and translocation.

Screening for salinity resistance in *O. glaberrima* is still required in order to identify the most promising material to integrate in interspecific crosses with *O. sativa*. The present study therefore screened 25 lines of *O. glaberrima* exposed to salinity at the seedling stage, and analyzed their overall behavior in terms of growth in relation to physiological properties influencing salt-stress resistance.

MATERIALS AND METHODS

Plant material and growing conditions

Twenty-five accessions of *O. glaberrima* Steud. and one genotype of *O. sativa* L. were used in the present study. Seeds of *O. glaberrima* were obtained from Africa Rice (Abomey-Calavi, Benin) (Table 1). The cultivar I Kong Pao (IKP) of *O. sativa* was used as a reference since this genotype exhibited a medium level of salt resistance and is well adapted to environmental conditions where *O. glaberrima* usually occurs (Lutts et al., 1995, 1999; Zhu et al., 2001). Seeds were germinated in glass vessels on 2 layers of Whatman (85 mm, Grade 1) filter paper moistened with 10 ml of deionized water. They were placed in a growth chamber at 25 to 21°C (day/night) under a 16 h daylight period (150 to 220 µmole m^{-2} s^{-1}). Illumination was provided by SYLVANIA fluorescent tubes (F36W/840-T8, cool white). For each genotype, 25 seeds were placed in each glass vessel.

Eleven-days old seedlings were transferred to a phytotron and maintained at 24°C/21°C (day/night). They were fixed on polystyrene plates floating on Yoshida et al. (1976) nutritive solution. For each genotype, seedlings were distributed among tanks containing 1.5 L of nutrient solution. Illumination was provided by PHILIPS metal iodide lamp (HPIT/400W) for 16 h d^{-1} at a photon flux density (PFD) of 180 to 200 µmoles m^{-2} s^{-1}. Daytime humidity was 65%. The nutrient solution was renewed every week and tanks were randomly rearranged in the phytotron. Salt stress was applied when plants were 33 days-old: sodium chloride (NaCl) was added

Table 1. List of accessions from *Oryza glaberrima* used on the current study and their corresponding salt-sensitivity index estimated for roots. shoots and a whole plant basis. I Kong Pao is a moderately salt-resitant variety from *Oryza sativa*.

Variety	Provenance	SI Root	SI Shoot	SI Total
IKP (I KONG PAO)	Thailand	67.1	34.8	38.8
CG17	Senegal	73.0	50.0	54.1
CG20	Senegal	77.7	49.6	55.7
TOG5293	Nigeria	84.9	47.9	55.1
TOG5307	Nigeria	47.0	9.7	16.1
TOG5385	Nigeria	74.6	44.2	49.6
TOG5390	Nigeria	85.7	56.0	62.0
TOG5420	Nigeria	75.7	48.6	53.2
TOG5440	Nigeria	82.0	42.1	49.3
TOG5442	Nigeria	72.6	52.4	55.7
TOG5456	Nigeria	78.8	50.1	55.2
TOG5479	Nigeria	86.1	52.1	58.3
TOG5482	Nigeria	65.3	46.1	49.8
TOG5500	Nigeria	72.3	43.2	46.3
TOG5566	Nigeria	76.3	60.1	62.8
TOG5588	Ghana	77.1	38.6	46.2
TOG5641	Nigeria	73.6	48.5	51.2
TOG5666	Nigeria	88.5	56.2	63.7
TOG5672	Nigeria	70.8	57.6	59.3
TOG5681	Nigeria	69.7	45.9	48.7
TOG5685	Nigeria	82.3	68.2	70.7
TOG5775	Libéria	35.6	25.4	26.9
TOG5885	Liberia	77.1	64.3	66.5
TOG5949	Nigeria	91.3	79.9	82.3
TOG5969	Nigeria	82.7	54.3	60.1
TOG5979	Nigeria	75.4	62.6	64.8

to nutrient solution in order to reach a final concentration of 60 mM to one half of the tanks, the other half being used as unstressed controls. Salt stress was applied for 2 weeks.

Morphological and physiological analysis

The length of the longest leaf (LHL), the number of tillers (NT) and the number of leaves (NL) were determined. The stomatal conductance (g_s) was estimated using porometer (type AP4-UM-3) (Delta T-devices, IK) on 6 plants per treatment. The net photosynthesis (*A;* net carbon assimilation rate; in mmoles CO_2 m^{-2} s^{-1}) was estimated under constant photosynthetic photon flux (500 µmoles m^{-2} s^{-1}), the instantaneous transpiration (*E*) (in mmoles H_2O m^{-2} s^{-1}) and the intercellular CO_2 content (*C*i; µmoles $mole^{-1}$) were measured on the youngest fully expanded leaf of 6 plants per treatment using a water vapor analyzer (LCA 2 8.7, ADC, Great Amwell, England) and an air supply unit (ASU 10.87, ADC, Hertfordshire, UK) mounted in series in an open system. All these measurements were performed at the time of stress imposition and after 2 weeks of treatment. Plants were then harvested at the end of stress exposure. Roots and shoots were separated, and roots were quickly rinsed for 30 s in deionized water to remove ions from the root surface and the free spaces. Shoots and roots were weighed for fresh weight determination (in g), then incubated in an oven at 72°C for 48 h until constant dry weight were reached. Water content (mL.g^{-1} WC) was estimated using the equation:

$$WC = (FW - DW)/DW$$

The sensitivity index (SI) that is, the difference between dry matter production of salt-treated plants and the control, expressed in % of the matter, was calculated according to the following expression:

$$SI = (100 \times (DW_{control} - DW_{treatment})) / DW_{control}$$

The mean tolerance index (TI_{Na}) to endogenous Na^+ was estimated for each physiological parameter as the ratio between the relative value of this parameter recorded in stress conditions expressed as a % of the mean value recorded in control conditions divided by the concentration of accumulated Na^+ in the considered organ:

$$TI_{Na} = ((X_{NaCl}/X_{control}) \times 100)/Na^+ \text{ content}$$

Ions measurement

For ion content determination, *c.a.* 100 mg DW was weighed. Samples were placed in flask of 10 ml and digested with nitric acid (68%) at 80°C. After complete evaporation, residues were dissolved with nitric acid (HNO_3) (68%) + HCl_{cc} (1:3, v/v). Solution was filtered using a layer of Whatman (85 mm, Grade 1). The filtrate was used to determine the cations concentration (K, Na, Mg, Ca and Fe) by flame emission using atomic absorption spectrometry (Thermo scientific S series model AAS4). The analysis was performed on 3 plants per treatment and each sample was analyzed in triplicate. Results are expressed in mg g^{-1} DW.

Osmotic potential measurement

For osmotic potential (*Ψ*s) measurement, roots and leaves of 3 plants per treatment were frozen in liquid nitrogen at harvest. After 3 cycles of frozen/thaw, samples were centrifuged at 15,000 g during 15 min at 4°C. The supernatant corresponding to the extracted sap was used to measure the osmolality (c) using a Wescor 5500 vapor pressure osmometer as previously detailed (Lutts et al., 1999). The *Ψ*s was then calculated according to:

Ψs (MPa) = - c (mosmoles.Kg^{-1}) $\times 2.58\times 10^{-3}$ according to the Van't Hoff equation.

Malondialdehyde and proline concentrations

Malondialdehyde (MDA) is a common indicator of oxidative stress. It was quantified on roots and leaves of 3 plants per treatment using the method of Heath and Packer (1968). Frozen 250 mg were homogenized in pre-chilled mortar with a solution of 0.5% thiobarbituric acid (TBA) in 20% trichloroacetic acid (TCA) and were heated to 95°C for 30 min. Then samples were cooled at room temperature. After centrifugation at 3000 rpm for 5 min the absorbance of supernatant was read at 532 nm, and the values of the non-specific absorbance were taken at 600 nm and subtracted from the original (532 nm). The MDA concentrations were calculated using the molar extinction coefficient of 155 mM cm^{-1}. Results are expressed as moles g^{-1} FW.

Proline content was measured as described by Bates et al. (1973). Frozen tissue (0.5 g) were homogenized in 10 ml of 3% sulphosalicylic acid and then centrifuged at 10,000 × g. The supernatant (0.5 ml) was mixed with 1 ml of glacial acetic acid and 1 ml of 2.5% acid ninhydrin (2.5 g of ninhydrin dissolved in a mixture of 60 ml glacial acetic acid and 40 ml 6 M phosphoric acid). The mixture was incubated for 1 h at 100°C and then the reaction was terminated by cooling in an ice bath. The reaction mixture was extracted with 2 ml of toluene, mixed vigorously with the test tubes stirrer for 15 s. The chromophore-containing toluene was warmed to room temperature and absorbance was read at 520 nm using toluene as a blank. Proline concentration was estimated on the basis of a standard curve. Results are expressed as moles g^{-1} FW.

Statistical analysis

The statistical analyses were performed with the "JMP Pro 12" software. Mean values and standard error (SE) were obtained from at least 3 replicates for genotypes. A *P-valu*e of < 0.05 was considered to be statistically significant. A two-way ANOVA was performed to detect cultivar, treatment, and interaction effects, a *P-value* lower than 0.05 was considered statistically significant. Screenings among accessions and treatments were displayed using principal component analysis (PCA) with R 3.3.2 Statistics software ('FactoMineR' package). Pearson correlation between analyzed parameters were also performed for 3 contrasting groups (salt-resistant, medium, salt-sensitive) using the 'corrplot' package in R 3.3.2 Statistics software.

RESULTS

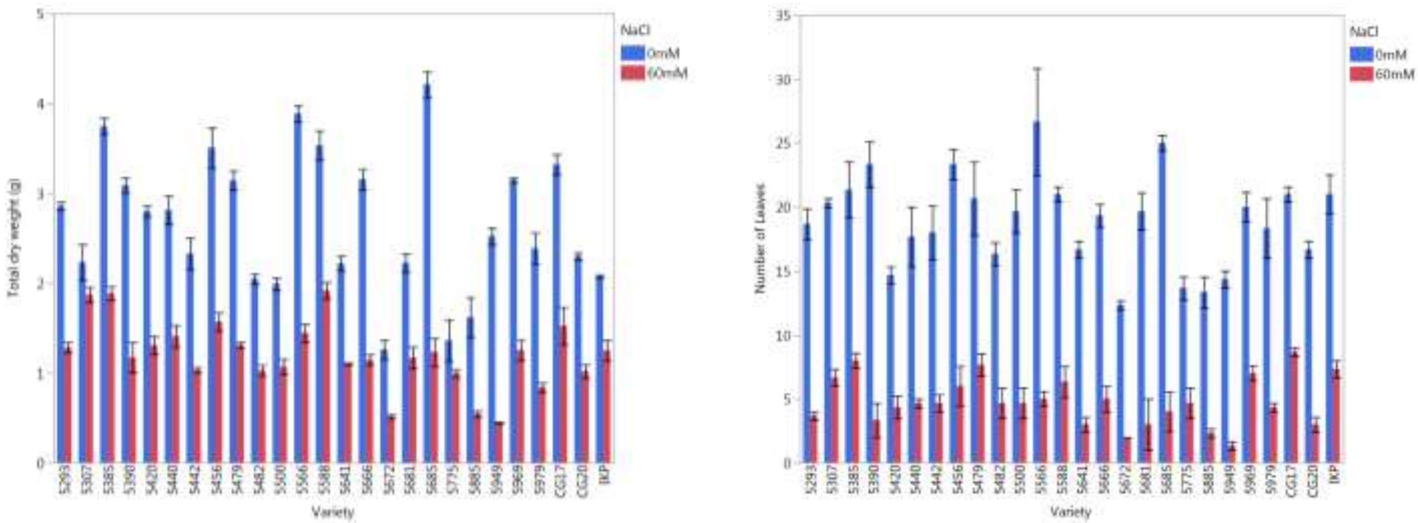
In the absence of salt, TOG5685 had the highest shoot and total biomass (expressed as dry weight) and difference was significant when compared with IKP (Figure 1A). In the presence of 60 mM NaCl, TOG5307, TOG5385 and TOG5588 exhibited the highest total biomass while TOG5885, TOG5949 and TOG5672 presented the lowest values. The mean sensitivity index was estimated for roots, shoots and whole plants (Table 1). Mean sensitivity remained low for TOG5307 and TOG5775, suggesting that these accessions displayed a similar level of tolerance comparatively to IKP. In contrast, SI values were especially high for TOG5949 and TOG5685. The mean leaf water content was similar in all genotypes under control conditions with a mean value of 83.7% in shoots and 89.4% in roots. Although the mean shoot WC decreased in response to salinity (78.4%), no significant difference was recorded among the considered accessions (detailed data not shown). The number of leaves was reduced in response to 60 mM NaCl and was the highest in CG17 and the lowest in TOG5949 and TOG5672 (Figure 1B).

Stomatal conductance in numerous varieties of *O. glaberrima* cultivated under control conditions was clearly higher than in IKP (Figure 2A). Salinity decreased stomatal conductance except in one single variety of *O. glaberrima* (TOG5979) where stomatal conductance remained unaffected by NaCl. In the absence of salt, instantaneous transpiration (*E;* Figure 2B) was higher in TOG5775 and TOG5500 than in other genotypes. Salinity reduced *E* values which however remained higher in TOG5420, TOG5775, TOG5307 and TOG5588 than in other genotypes.

Net photosynthesis (*A*; Figure 2C) slightly varied among genotypes under control conditions. From a relative point of view, differences among accessions appeared higher in NaCl-treated plants than in control conditions: while *A* values recorded in TOG5307 remained low affected by NaCl, salinity almost completely inhibited photosynthesis in TG5949 and strongly decreased it in CG20 and TOG5390. In the absence of salt, *C*i values were higher in numerous *O. glaberrima* varieties than in IKP (detailed data not shown). Salinity only had a limited impact on *C*i values, the highest concentration being recorded for TOG5442, TOG5482, TOG5775 and TOG 5979.

The root osmotic potential (Figure 3A) was statistically similar in all accessions in the absence of salt, but salinity decreased root *Ψ*s, mainly in TOG5775, TOG5969, CG17, TOG5979, TOG5456, TOG5672, and TOG5500. In the presence of NaCl, these accessions displayed significant lower root *Ψ*s values than IKP. An important decrease in the shoot water potential was also observed (Figure 3B), with recorded values being minimal for TOG5456, TOG5500 and GC17.

Numerous accessions of *O. glaberrima* accumulated more Na^+ in roots and shoots than IKP (Figures 3C and 3D). Some of them, such as TOG5307 presented high concentration in the roots but was able to restrict Na^+ accumulation in the shoot, at least to some extent. In



A B

Figure 1. Total dry weight (A) and mean number of leaves (B) in 25 accessions of *Oryza glaberrima* and one moderately salt-tolerant cultivar of *Oryza sativa* (IKP). Seedlings were exposed for 2 weeks to 0 (control) or 60 mM NaCl (stress) in hydroponic culture under controlled environmental conditions. Each value is the mean of 3 replicates and vertical bars are standard errors.

contrast, TOG5681 exhibited high Na^+ concentration in the roots and in the shoots, suggesting that both Na^+ absorption and translocation were not efficiently regulated in this accession. Salt stress reduced the K^+ concentrations in all plant organs (Figures 3C and 3D). The mean root K^+ concentration was especially low for TOG5390, TOG5420, TOG5949, CG20 and TOG5385 in plants exposed to NaCl (detailed data not shown). For the main morphological parameter and net photosynthesis, the mean tolerance index was estimated to accumulate Na^+ (Table 2). The TI_{Na} values were globally higher for roots (root DW and root length) and varied depending on the cultivar. However, for almost all considered parameters the TI_{Na} value was higher for IKP than for *O. glaberrima,* whatever the accession. Some accessions of *O. glaberrima*, however presented high TI_{Na} values for some parameter, as it was the case for TO5307 (shoot DW, root DW and net photosynthesis), TOG 5566 (net photosynthesis) and TOG5775 (shoot and root DW).

The shoot MDA content was similar in all accessions for control plants (Figure 4A) but salt stress obviously increased MDA in all tested accessions, indicating the occurrence of a secondary oxidative stress. However, MDA remained low in TOG5440 and high in TOG5672. Proline (Figure 4B) also accumulated in shoots as a result of salt exposure. While IKP, TOG5666 and TOG5420 exhibited the highest concentration of proline, TOG5307, TOG5385 and TOG5479 presented the lowest concentration in salt-treated shoots.

A first principal component analysis (PCA) was performed in order to reveal the global impact of NaCl on the whole tested material in relation to the set of analyzed parameters, (except proline and MDA since data were not available for 3 accessions). PCA revealed that 77.49% of variance was explained by the principal component 1 (Dim 1) and the principal component 2 (Dim 2) (Figure 5). Dim 1 alone displayed 68.65% of variance. Parameters that have the highest value factor coordinate for the Dim 1, with the highest variable contribution, based on correlations, were, at left, toxic ion (Na^+) and sub-stomatal cavity CO_2 concentration (*C*i). At right, they were potassium content, stomatal conductance (g_s), water content, instantaneous transpiration (*E*), net photosynthesis (*A*), height of plant, number of leaves, number of tillers, plant dry weight, root length, root dry weight and shoot dry weight.

The second plot showed the classification of seedlings in response to salt treatment in multivariate space of the first PCA (Figure 5B). Dim 1 displayed a clear opposition between the two groups: at the left, the salt-stressed seedlings and the controls seedlings at right. Salt-stressed seedlings showed positive correlation along the left side of Dim 1 which is linked to toxic ion (Na^+) and sub-stomatal cavity CO_2 concentration (*C*i). So the left side Dim 1 revealed the seedlings that were severely affected by salt stress.

In order to discriminate salt-tolerant and salt-sensitive accessions, a second PCA on salt-stressed seedlings was performed. This PCA showed that 42.02% of variance was explained by the principal component 1 (Dim 1) and the principal component 2 (Dim 2) (Figure 6). Parameters that have the highest value factor coordinate for the Dim 1, with the highest variable contribution, based on correlations, were K content, water content, instantaneous transpiration (*E*), net photosynthesis (*A*),

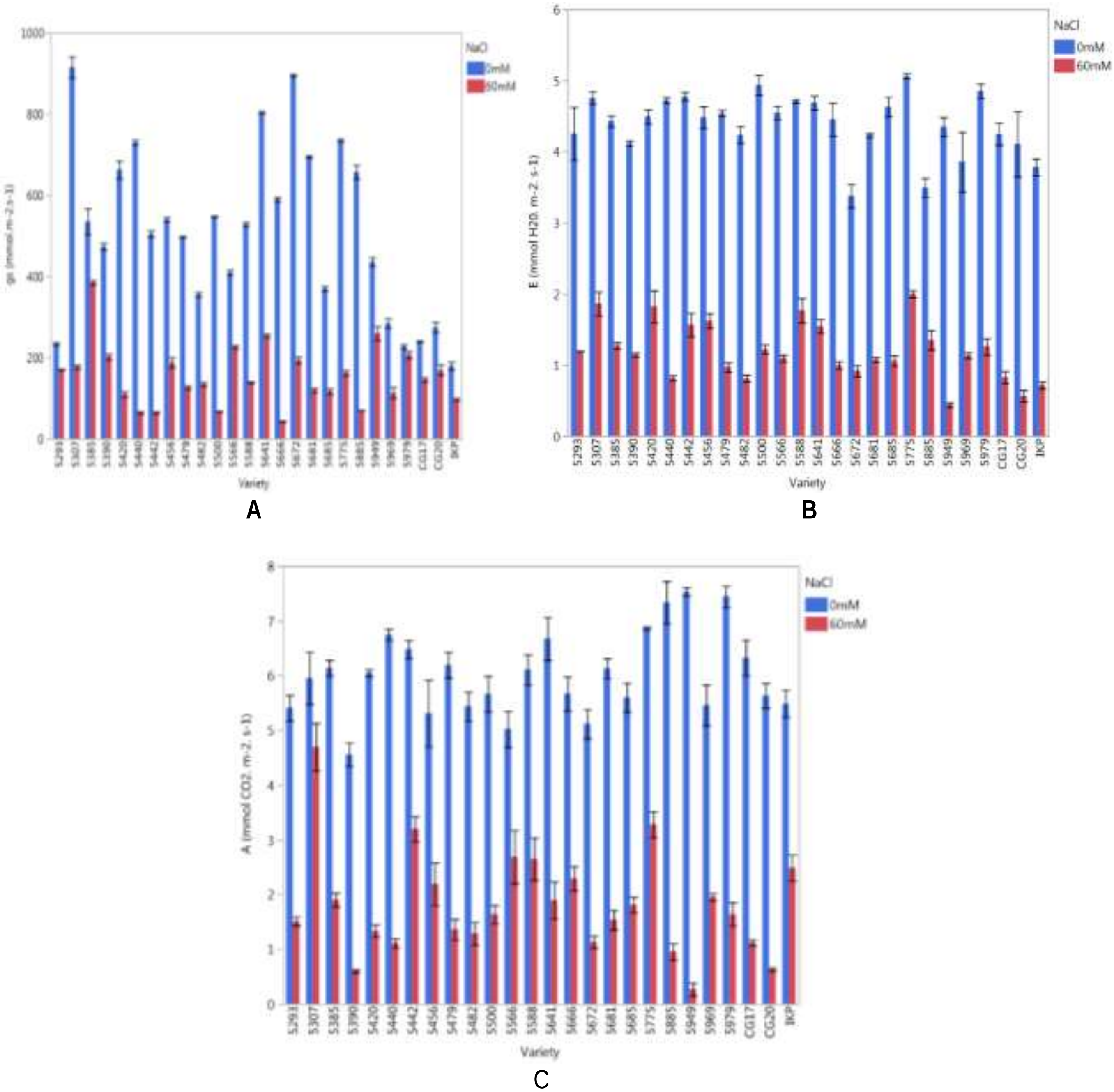


Figure 2. Stomatal conductance (A), instantaneous transpiration (B) and net photosynthesis (C) in 25 accessions of *Oryza glaberrima* and one moderately salt-tolerant cultivar of *Oryza sativa* (IKP). Seedlings were exposed for 2 weeks to 0 (control) or 60 mM NaCl (stress) in hydroponic culture under controlled environmental conditions. Each value is the mean of 3 replicates and vertical bars are standard errors.

height of plant, number of leaves, number of tillers, plant dry weight, root dry weight and shoot dry weight. The Dim 2 had high positive loading for root sodium concentration, root K concentration, instantaneous transpiration, net photosynthesis, height of plant, water content and high negative loading for plant dry weight, root dry weight, shoot dry weight, stomatal conductance (g_s), root length and number of leaves (Figure 6A). Figure 6B shows the position of all tested accessions under salt stress in the multivariate space of the Figure 6A. Dim 1 highlighted on the opposition among 3 groups species under salt stress which could be related to salt-tolerant, salt-sensitive and "medium".

Under salt stress the salt-tolerant lines showed a strong

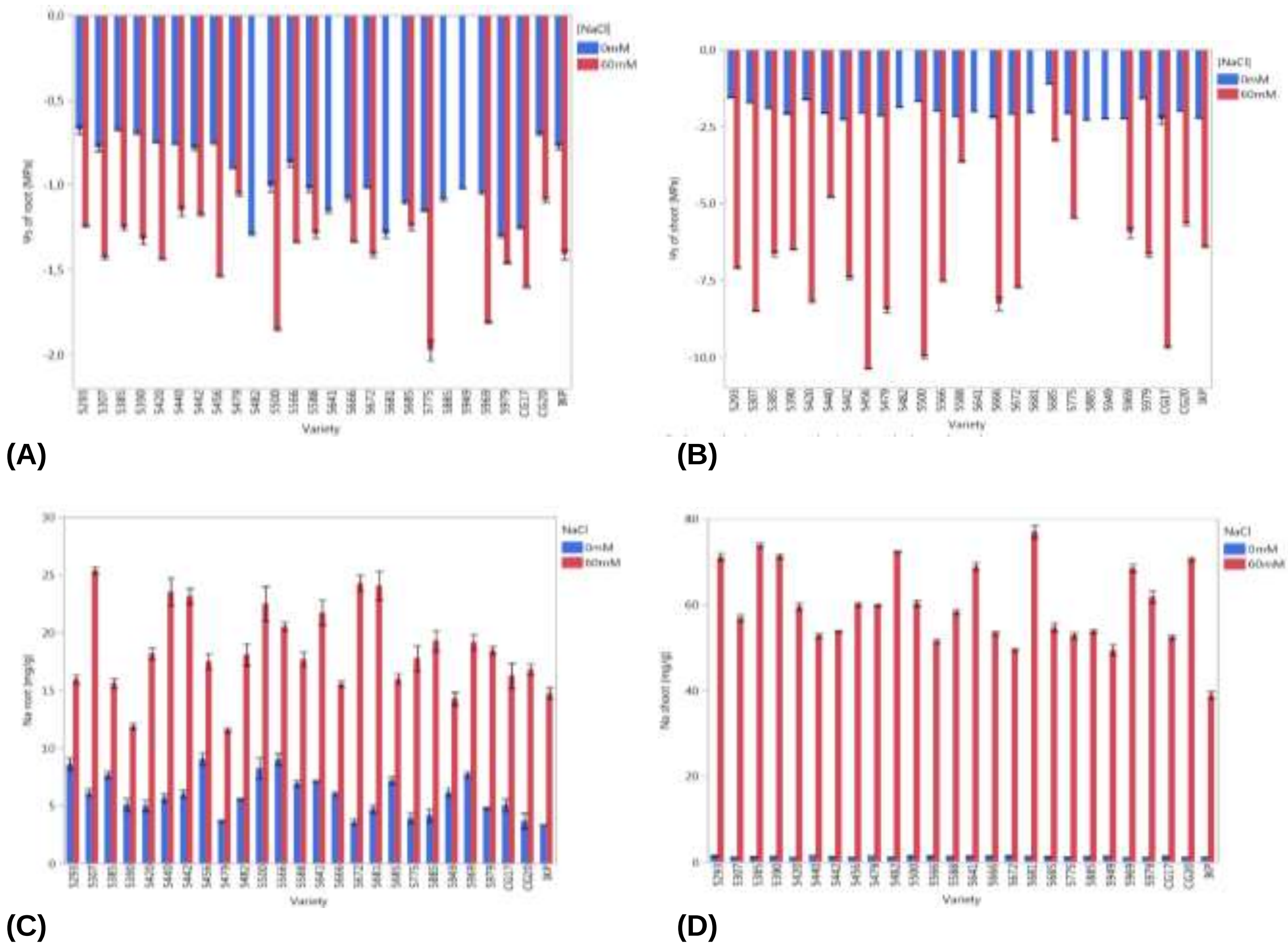


Figure 3. Root osmotic potential (A), shoot osmotic potential (B), root Na^+ concentration (C) and shoot Na^+ concentration (D) in 25 accessions of *Oryza glaberrima* and one moderately salt-tolerant cultivar of *Oryza sativa* (IKP). Seedlings were exposed for 2 weeks to 0 (control) or 60 mM NaCl (stress) in hydroponic culture under controlled environmental conditions. Each value is the mean of 3 replicates and vertical bars are standard errors. Pay attention that no values are available for shoot Ψs in the case of salt stressed plants of TOG5482, TOG5885 and TOG5949 as a consequence of a lack of available material.

positive correlation along the Dim 1 and this part of the plot was characterized by K content, stomatal conductance (g_s), water content, instantaneous transpiration (*E*), net photosynthesis (*A*), height of plant, number of leaves, number of tillers, plant dry weight, root dry weight and shoot dry weight. Lines TOG5307, TOG5456, TOG5588, TOG5385 and CG17 belong to the salt-tolerant group. In contrast, the salt-sensitive species displayed a strong negative correlation along the Dim 1. Species TOG5885, TOG5672, TOG5949, TOG5390 and CG20 belong to salt-sensitive group. The “center-reaction” group contains the other lines which have a weak correlation with analyzed parameters by PCA.

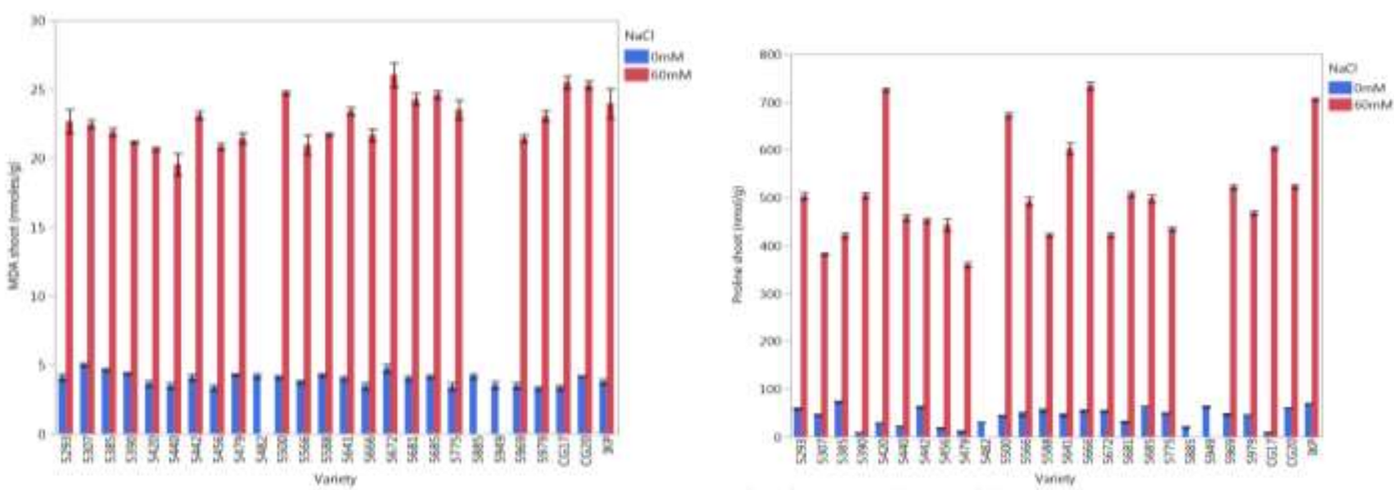
DISCUSSION

The present work confirms that *O. glaberrima* displays high variability in terms of salinity resistance at the seedling stage. Most accessions of *O. glaberrima* appear more salt sensitive than the moderately-resistant cv. I Kong Pao from *O. sativa*. In the absence of salt, numerous accessions of *O. glaberrima* displayed a high vegetative growth leading to a high total plant biomass. Such a property might be, at least partly, related to a high net photosynthesis (Figure 2). Since the mean *C*i value was usually high in *O. glaberrima*, it could be postulated that such a high photosynthesis may be linked to a high level of gas exchange which is confirmed by the high values recorded for stomatal conductance (Figure 2).

Indeed a positive correlation between *A* and g_s values under control conditions was found. The fast vegetative growth of *O. glaberrima* at the seedling stage is frequently considered as an advantage in terms of weed competition (Sarla and Mallikarjuna Swamy, 2005; Nayar, 2010).

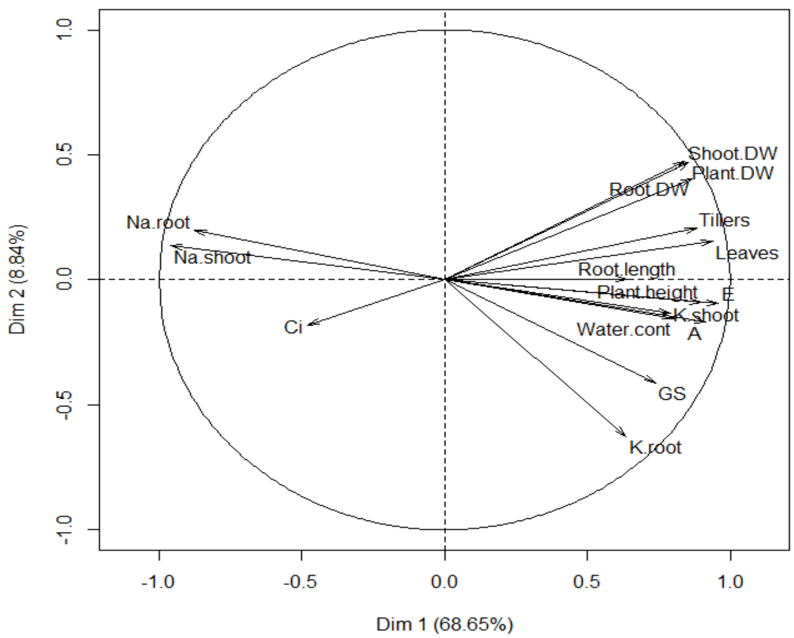
Table 2. Tolerance index (TI) of accessions from *Oryza glaberrima* estimated for shoot dry weight (TI_Shoot DW), roots dry weight (TI_Root DW), plant height (TI_plant height), number of tillers (TI_Tillers), number of leaves (TI_Leaves), net photosynthesis (TI_Net.photo) and root length (TI_Root.length). I Kong Pao is a moderately salt-resistant variety from *Oryza sativa*.

Variety	TI_Shoot DW	TI_Root DW	TI_Plant height	TI_Tillers	TI_Leaves	TI_Net.photo	TI_Root.length
IKP (I KONG PAO)	**1.68**	**2.23**	**1.91**	**1.49**	**0.90**	**1.17**	**4.96**
CG17	0.95	1.66	1.15	1.00	0.79	0.34	4.81
CG20	0.71	1.33	0.54	0.35	0.26	0.16	4.85
TOG5293	0.73	0.94	0.83	0.50	0.28	0.39	5.16
TOG5307	**1.59**	2.09	1.30	0.78	0.58	**1.39**	3.19
TOG5385	0.76	1.63	0.78	0.85	0.51	0.42	4.03
TOG5390	0.62	1.20	0.65	0.31	0.20	0.19	6.76
TOG5420	0.86	1.34	1.10	0.84	0.50	0.37	4.11
TOG5440	1.10	0.77	1.03	1.00	0.50	0.31	2.24
TOG5442	0.89	1.19	1.02	0.87	0.48	0.92	2.80
TOG5456	0.83	1.21	1.19	0.67	0.43	0.69	4.65
TOG5479	0.80	1.20	1.27	0.98	0.62	0.37	5.86
TOG5482	0.66	1.69	1.01	0.58	0.40	0.33	4.81
TOG5500	0.94	1.23	0.84	0.52	0.39	0.48	3.57
TOG5566	0.80	1.16	1.21	0.51	0.36	**1.04**	4.23
TOG5588	1.05	1.29	0.98	0.82	0.52	0.75	3.77
TOG5641	0.64	1.15	0.97	0.58	0.26	0.41	3.22
TOG5666	0.82	0.74	1.11	0.69	0.49	0.76	4.33
TOG5672	0.86	1.20	1.16	0.78	0.33	0.45	2.87
TOG5681	0.73	1.35	0.86	0.56	0.20	0.33	3.26
TOG5685	0.58	1.11	0.87	0.58	0.29	0.59	4.55
TOG5775	**1.41**	**3.62**	1.03	0.86	0.65	0.90	5.11
TOG5885	0.60	1.19	1.01	0.40	0.33	0.24	4.39
TOG5949	0.41	0.61	1.09	0.47	0.19	0.07	5.85
TOG5969	0.67	0.90	0.88	0.78	0.51	0.52	3.88
TOG5979	0.60	1.33	0.91	0.61	0.38	0.36	4.43
Mean	**0.86**	**1.36**	**1.03**	**0.71**	**0.44**	**0.54**	**4.30**

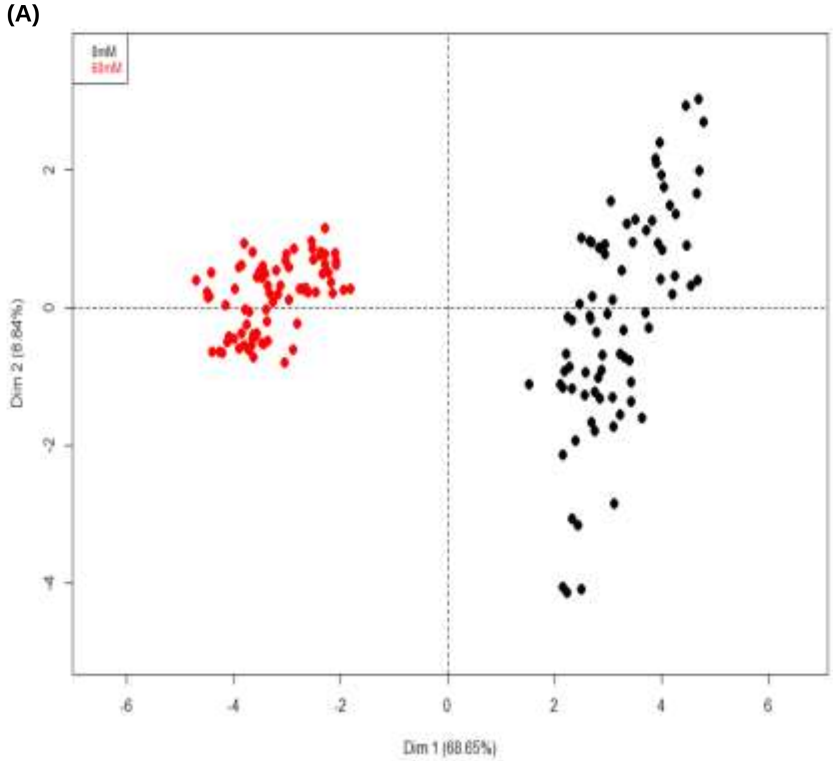


(A) (B)

Figure 4. Shoot malondialdehyde (A) and shoot proline concentration (B) in 25 accessions of *Oryza glaberrima* and one moderately salt-tolerant cultivar of *Oryza sativa* (IKP). Seedlings were exposed for 2 weeks to 0 (control) or 60 mM NaCl (stress) in hydroponic culture under controlled environmental conditions. Each value is the mean of 3 replicates and vertical bars are standard errors. Pay attention that no values are available for salt stressed plants of TOG5482, TOG5885 and TOG5949 as a consequence of a lack of available material.

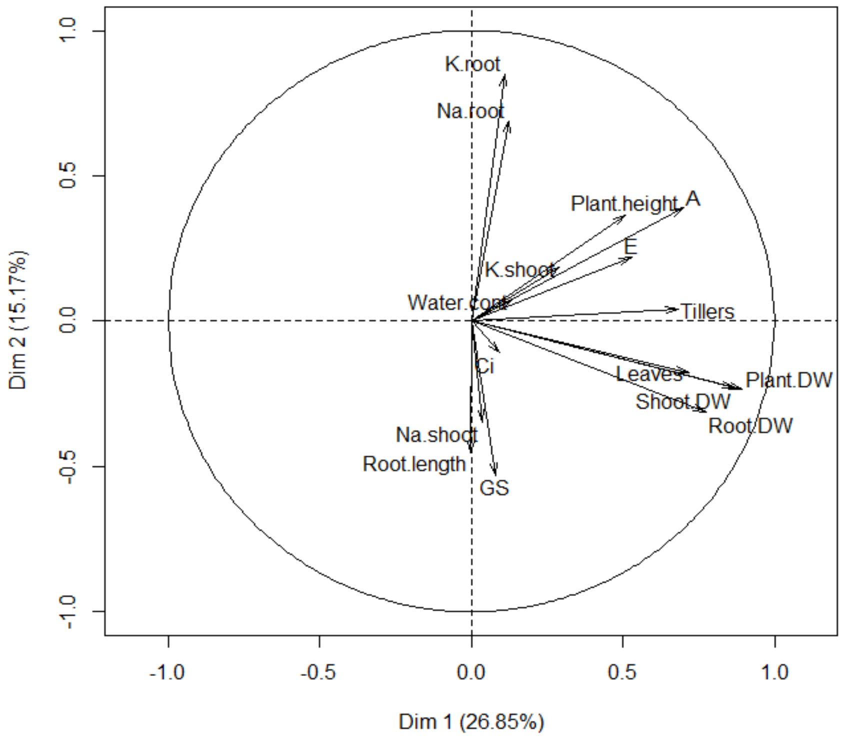


(A)

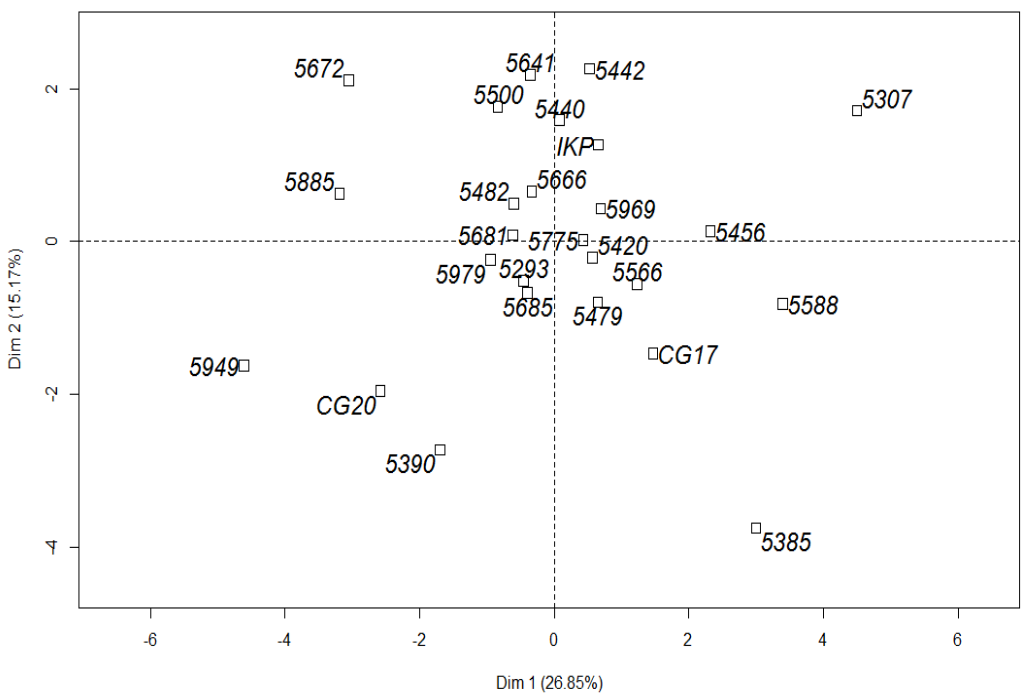


(B)

Figure 5. Principal Component Analysis (A and B) of growth and physiological parameters in the seedlings rice (25 accessions of *O. glaberrima* and one moderately salt-resistant cv of *O. sativa*) cultivated for 2 weeks in the presence of 0 (control) or 60 mM NaCl (stress). (A) Variable graph and (B) individual graph of PCA showing the control and salt-stressed seedlings groups. Only significant parameters were shown ($P < 0.05$) in (A). Plant.DW, plant dry weight; Shoot.DW, shoot dry weight; Root.DW, root dry weight; Water.cont, total water content; GS, stomatal conductance; K.shoot, shoot potassium concentration; K.root, root potassium concentration; Na.shoot, shoot Na concentration; Na.root, root Na concentration; *C*i, sub-stomatal cavity CO_2 concentration; *E*, instantaneous transpiration; A, net photosynthesis; Plant.height, height of plant; Leaves, number of leaves; Tillers, number of tillers; Root.length, root length.



(A)



(B)

Figure 6. Principal Component Analysis (A and B) of growth and physiological parameters in salt-stressed seedlings of rice (25 accessions of *O. glaberrima* and one moderately salt-resistant cv of *O. sativa* (IKP)) cultivated for 2 weeks in 60 mM NaCl. (A) Variable graph and (B) individual graph of PCA showing the impact of salt stress in seedlings. Only significant parameters were shown ($P < 0.05$) in (A). Plant.DW, plant dry weight; Shoot.DW, shoot dry weight; Root.DW, root dry weight; Water.cont, total water content; GS, stomatal conductance; K.shoot, shoot K concentration; K.root, root K concentration; Na.shoot, shoot Na concentration; Na.root, root Na concentration; Ci, sub-stomatal cavity CO_2 concentration; E, instantaneous transpiration; A, net photosynthesis; Plant.height, height of plant; Leaves, number of leaves; Tillers, number of tillers; Root.length, root length.

Salt stress induces both an osmotic and an ionic constraint in stressed plants (Acosta-Motos et al., 2017; Munns, 2005). Salinity resistance is considered to rely on avoidance mechanisms, allowing the plant to limit Na and Cl absorption and accumulation, and tolerance mechanisms allowing the plant to maintain efficient metabolism despite toxic ion accumulation. Under current experimental conditions, the tested materials appeared to be able to efficiently manage with physiological drought since no obvious decrease was recorded for the leaf water content. In contrast, salt-treated plants accumulated high Na concentration, suggesting that the ionic constraint is the major problem for *O. glaberrima*. Although the osmotic component is frequently considered as the first component acting on salt-treated plants (Munns, 2005), it has been previously demonstrated that Na^+ may reach high toxic concentration in a short term basis in rice and could be toxic even before modification of the plant water status (Lefèvre et al., 2001). The high transpiration rate recorded in some accessions of *O. glaberrima* (Figure 2) should probably contribute to increase Na^+ concentration on a short term basis. Total Na^+ concentration was indeed higher in the shoots than in the roots: although roots are commonly acting as a barrier sequestering toxic ions and avoiding their accumulation in photosynthetic tissues, the obtained results suggest that this accumulation was not efficient in *O. glaberrima* which could be related to the fact that at the young seedling stage, endoderm is not completely differentiated in the young seedling rice plant (Yeo and Flowers, 1986; Zhu et al., 2001). Despite the lower accumulation of Na^+ in the root system, it is noteworthy that under experimental conditions, the mean sensitivity index was higher for root than for shoots (Table 1), suggesting that root metabolism could be highly sensitive to salinity in *O. glaberrima*.

Beside restriction of Na^+ absorption and translocation, tolerance of photosynthetic tissues to the accumulated toxic ions is an important component of salinity resistance in plants (Roshandel and Flowers, 2009). It implies that biochemical protecting compounds have to be synthesized and/or that compartmentation processes leading to Na^+ accumulation in apoplasm or vacuoles must be operating to limit the deleterious impact of toxic ion on cytoplasm where the major steps of cell metabolism occur. In the current study, a highly significant negative correlation was found between mean TI_{Na} and the overall plant sensitivity index ($r = -0.88$; $P < 0.01$). This observation confirms that in *O. glaberrima*, tolerance mechanisms to accumulated ions are of paramount importance for the overall plant performance.

Because salinity resistance is a highly complex property, it poses serious challenge to plant breeders (Flowers and Flowers, 2005). The ability of *O. glaberrima* to display tolerance mechanisms may be a promising aspect for further breeding schemes which confirms the putative interest of the African rice for crop improvement after inter-specific crosses with *O. sativa* (Adedze et al., 2016). Proline has often been regarded as an osmo-protecting compound positively involved in salinity resistance. Proline is thought to be involved in osmotic adjustment but it may also directly act to protect cellular structures and enzymes or scavenge reactive oxygen species (Mansour and Ali, 2017). It is noteworthy, however, that in *O. glaberrima*, the most salt-resistant accessions such as TOG5307, TOG5588 and TOG5456 accumulated lower proline concentrations than salt-sensitive one. This suggests that proline does not assume key functions in salinity resistance in this species or that the signaling pathway leading to proline over-synthesis is still not triggered in these salt-resistant accessions. A similar situation was reported in *O. sativa* where salt-resistant cultivars accumulated lower proline concentrations than salt-sensitive ones (Lutts et al., 1996). According to Lutts et al. (1999), proline accumulation in this species might be due to over-accumulation of putatively toxic ammonium which induces over-synthesis of glutamine through activation of the GS/GOGAT cycle. Independently of proline synthesis, some accessions of *O. glaberrima* exhibited a fascinating ability to perform osmotic adjustment at the shoot level (Figure 3) and the identification of compounds involved in this process could be extremely useful for further improvement of salinity resistance in rice.

Principal component analysis discriminate 3 groups among the tested accessions: i) a salt-resistant group which comprises TOG5307, TOG5456, TOG5588, TOG5385 and CG17; ii) a salt sensitive group which includes TOG5949, TOG5390, CG20, TOG5885 and TOG5672 and; iii) all other accessions were classified as « medium range » for salinity resistance. A correlative analysis was performed among tested parameters in salt-stressed material within each group. Proline and MDA, however, were not included since data are not available for some accessions. Figure 7 demonstrate that the correlation profile is clearly different in each group for stressed plants. While A was negatively correlated with gs and Ci in the salt-sensitive group, this was not anymore the case in the salt-resistant one. Similarly, in the salt-sensitive group, the shoot DW was positively correlated with the root DW but this correlation disappeared in the salt-resistant accession, suggesting that root and shoot behavior were not so directly linked in this material. This hypothesis is supported by the fact that under experimental conditions, salt-sensitivity index was frequently higher for roots than for shoots (Table 1). These observations, however, are based on biomass production but maintenance of metabolic processes in stressed conditions is not always devoted to growing processes. Root metabolism may be involved in root-to-shoot signaling, mainly in relation to hormonal translocation and play a key role in salinity resistance (Ghanem et al., 2011). While the salt-resistant and the salt-sensitive group differed for correlation profile (Figure

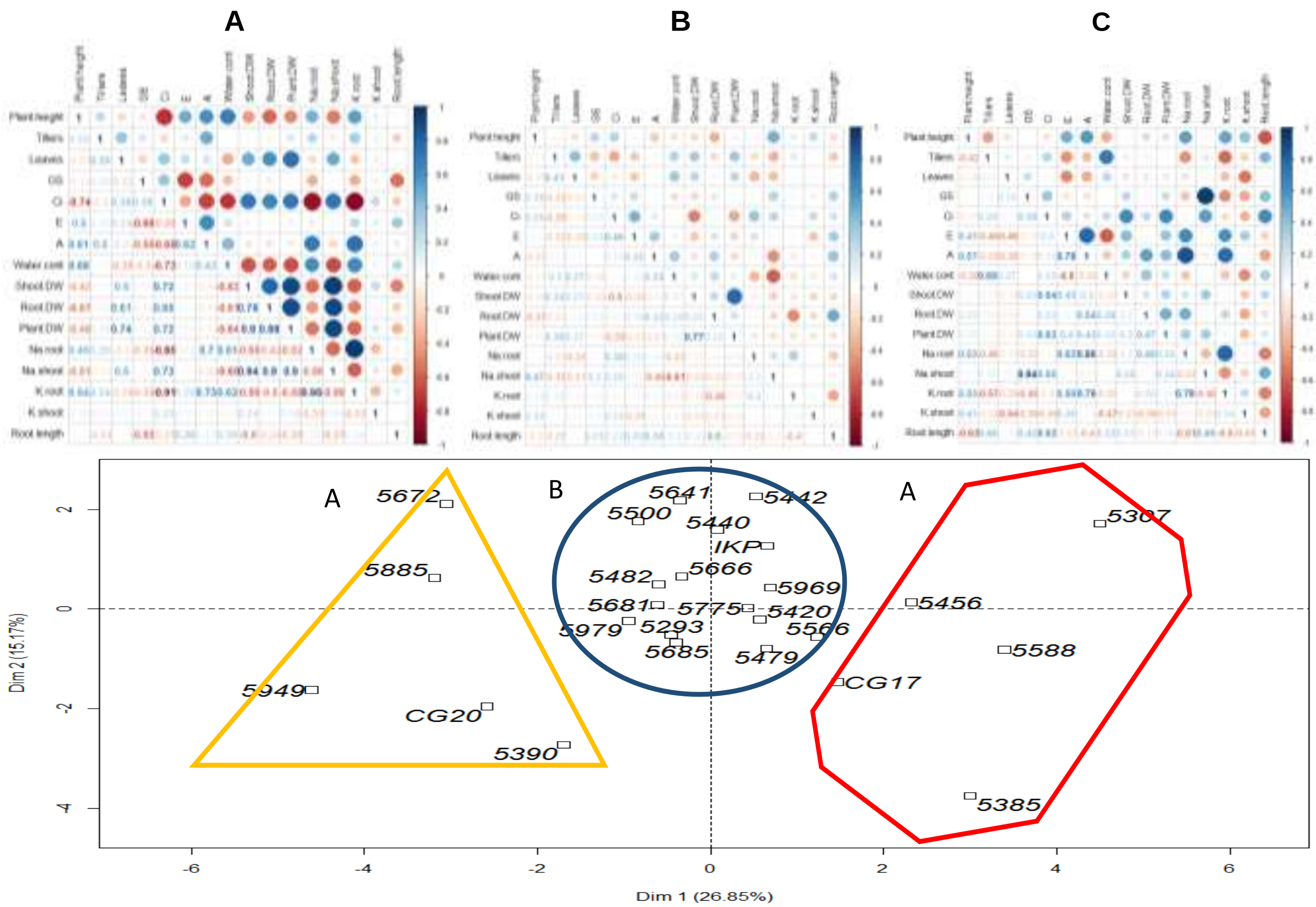


Figure 7. Correlative analysis performed separately for three distinct groups of accessions exhibiting a salt-sensitive type (yellow triangle), medium-range reaction (blue circle) and resistant type (red hexagone). For each group, correlations among morpho-physiological parameters were estimated for stressed plants, a blue circle indicating a positive correlation and a brown circle indicating a negative one. The diameter of the circle and the intensity of the colors are directly relevant of the importance and the nature of correlation.

7), the « medium-range » cultivars exhibited an intermediate behavior characterized by a rather poor level of correlations among recorded parameters.

It is concluded from the present study that *O. glaberrima* exhibit some variability for salinity resistance and that some accessions, such as TOG5307, exhibits interesting properties such as a high capacity of osmotic adjustment, maintenance of photosynthesis and high level of tolerance to accumulated Na^+ ions.

CONFLICT OF INTERESTS

There are no conflicts of interest between the authors.

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Full Length Research Paper

The effects of intercropping and plant densities on growth and yield of maize (*Zea mays* L.) and soybean (*Glycine max*) in the humid forest zone of Mount Cameroon

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A field experiment was conducted to evaluate the effects of intercropping and planting densities on the growth and yield of maize (*Zea mays*) and soybeans (*Glycine max*). A 1 ha plot located at the Institute of Agricultural Research for Development (IRAD), Ekona, South West Region of Cameroon was used. There were two blocks: block 1 which was fertilized with 60 kg/ha NPK (20:10:10) and top dressed with urea at 50 kg N and block 2 which was unfertilized. The experimental design was a randomized complete block design with three replications and a total of 15 treatments. Treatments were intercropped combinations of maize (53,320, 40,000 and 26,666 plants/ha) and soybeans (200,000, 160,000 and 100,000 plants/ha) and six sole-cropped treatments. Intercropping affected grain yields for both soybeans and maize; however, the effect on maize was not significant (P ≥ 0.05). Maize at 53,320 plants/ha intercropped with soybeans at 200,000 plants/ha produced the maximum mean number of pods (34.67), pod weight (13.09 g), number of grains (69.6) and grain weight (8.66 g) per pod. The productivity of the intercropping system indicated yield advantage of 25 to 80% in the unfertilized block and 33 to 96% in the fertilized block as depicted by the land equivalent ratio of 1.25 to 1.8 and 1.33 to 1.96, respectively. All the intercropped combinations had relative value total above unity (1.32 and 1.29) in both unfertilized and fertilized blocks, respectively, meaning a high profitability of this system as compared to monocropping. Maize at a population density of 53,320 plants/ha intercropped with soybean at a plant density of 200,000 plants/ha showed the highest profitability and overall, was the best intercropping combination in this study.

Key words: Intercropping, soybean, maize performance, yield.

INTRODUCTION

Food scarcity and security is one of the most important problems confronting the world today. On one hand, there is a growing demand for food quantity and quality; on the other hand, there are constraints on environmental protection issues and income certitudes for farmers within a global market. The challenge of agricultural research is to provide sustainable solutions to agricultural constraints to food production. As a result, farmers practice different cropping systems to increase productivity and sustainability in Africa. Intercropping, which is one of these systems is the growth of two or more crop species simultaneously in the same field during a growing season

(Carruthers et al., 2000; Onuh et al., 2011). It is also seen as a method of sustainable agriculture, where two or more crops are grown simultaneously during the same season, on the same area and are believed to utilize common limiting resources better than the species grown separately (Ghosh et al., 2006). It is a cropping system that has long been used in tropical areas because of its established advantages which include greater yield stability (Jensen, 1996), greater land-use efficiency (Zhang and Li, 2003), increased competitive ability towards weeds (Hauggaard-Nielsen et al., 2001), improvement of soil fertility (Shen and Chu, 2004; Dahmardeh et al., 2010), increase crop yield and quality (Dahmardeh et al., 2010), provision of security of returns and higher profitability due to higher combined returns per unit area of land (Javanmard et al., 2009). In the study off Javanmard et al. (2009), the dry matter yield for maize in intercrop with legumes ranged from 1044 to 1514 g/m^2, which were higher than 1002 g/m^2 obtained for maize as a sole crop.

Cereal-legume intercropping plays an important role in subsistence food production in both developed and developing countries, especially in situations of limited water resources and low fertility conditions, as it helps to maintain and improve soil fertility. The legumes fix atmospheric nitrogen, which may be utilized by the host plant or may be excreted from the nodules into the soil and used by other plants growing nearby. They can also transfer fixed N to intercropped cereals during their joint growing period and this N is an important resource for the cereals (Chen et al., 2010).

Important factors affecting competition between the intercrop components for water, sunlight, space and nutrients and hence input use efficiency, are crop density, relative proportion of component crops, spatial arrangement (Baumann et al., 2001) and time of intercropping. Plant density is an important crop management practice and is accorded a high priority (Sangoi et al., 2002). This was demonstrated in the study by Abuzar et al. (2011). They grew maize at six different plant population densities of 40,000, 60,000, 80,000, 100,000, 120,000 and 140,000 plants/ha. They observed a maximum number of grains per row (32.33) and grains per ear (4473) with the plant population of 40,000 plants/ha.

The maximum number of ears per plant (1.33), grain rows per ear (15.44), biomass yield (16890 kg/ha) and grain yield (2604 kg/ha) was observed with the plant population of 60,000 plants/ha. From this and other similar findings, it is evident that plant population density affects maize yield by influencing yield components such as number of ears per plant, number of kernels per ear and kernel mass.

Intercropping legumes with non-legume in Cameroon can be a principal means of intensifying crop production both spatially and temporally to improve crop yields for smallholder farmers. In the South West Region of Cameroon, growing soybean and maize by peasant farmers for home consumption and the market is common but documented information on the optimum plant population density of the recommended soybean and maize varieties is very scanty. Data on the profitability of soybean/maize intercropping systems in this region is lacking.

The objective of the present study was to determine the effect of intercropping and planting densities on the growth and yield of maize and soybean in the humid forest zone of Mount Cameroon area.

MATERIALS AND METHODS

Experimental site

The 1 ha plot was located at the Regional Research Center, IRAD, Ekona. Ekona Mbenge is situated in Fako division, in the South West Region of Cameroon. Its geographical coordinates are 4° 14′ 0″ North, 9° 20′ 4″ East. It has a humid tropical climate characterized by high temperatures and rainfall, with average annual rainfall of 2284 mm Hg (Etchu et al., 2012). This area has an altitude of about 400 m, a rich volcanic soil and a mean temperature of 24.4°C in the dry season while in the rainy season, it is 23.7°C. The rainy season runs from March to October and the dry season from November to March. The major activity in this region is agriculture which includes plants (major cash crops produced- coffee, cocoa and oil palm; major food crops- cocoyam, yam and plantains) and animal (poultry, small ruminants, non-conventional livestock such as grass cutter, quails and snails) (Etchu et al., 2012). This field experiment was carried out in 2016 cropping season.

Land preparation and experimental field layout

The vegetation was cleared with a cutlass, and the land was ploughed with a hoe and divided into 2 blocks separated by a 2 m path. Each block was further divided into 3 plots and each plot sub divided into 15 subplots. This gave a total of 45 subplots per block. The plots were separated from each other by a 1.5 m path and the subplots were separated by a 1 m path. Each block was 100 m x 23 m, each plot was 32 m x 23 m and each subplot was 6 m x 7 m. The experimental plots were laid out in a randomized complete block design (RCBD) with fifteen treatments and three replicates for each treatment (Figure 1). The detailed planting densities for the crops are shown in Table 1.

Soil analysis

Soil samples were collected prior to planting from different parts

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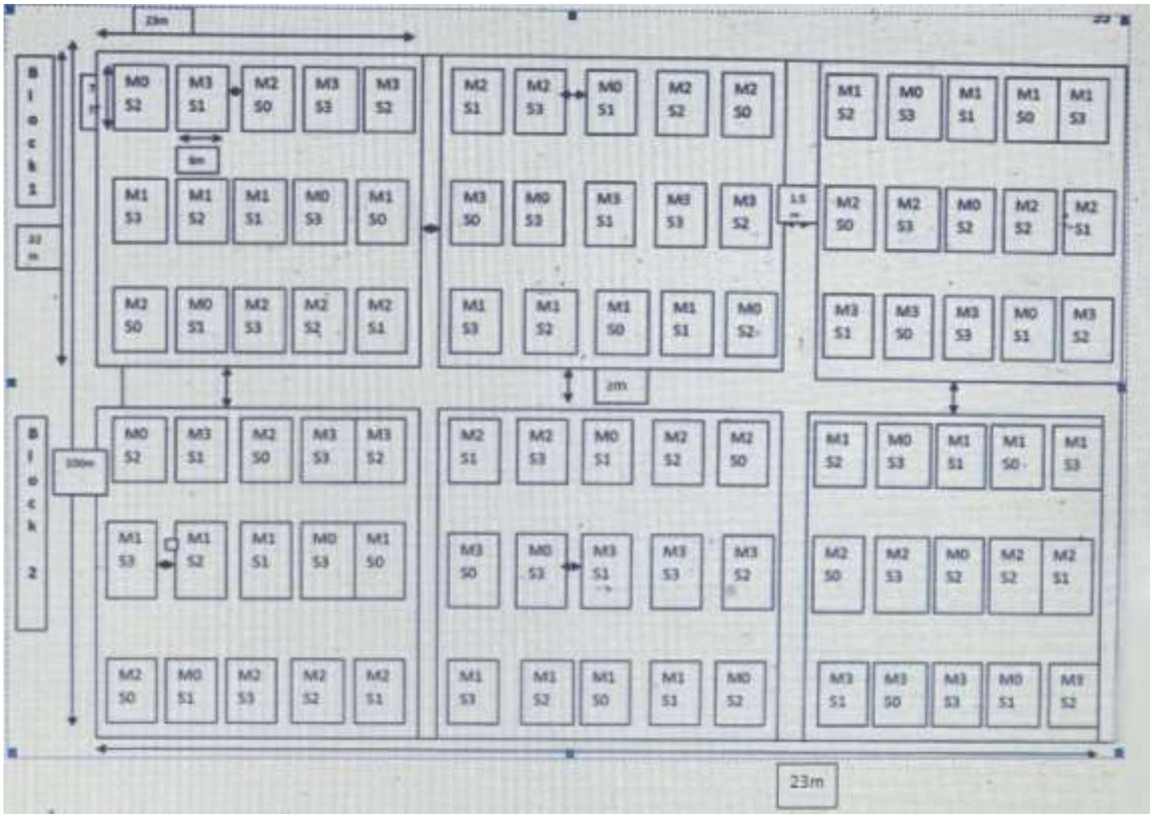

Figure 1. Experimental field layout.

Table 1. Planting densities for maize and soybeans.

Treatment no.	Plant Combinations (plants/ha)		Abbreviation
	Maize	Soybeans	
1	53,320	0	M1S0
2	53,320	200,000	M1S1
3	53,320	160,000	M1S2
4	53,320	100,000	M1S3
5	40,000	0	M2S0
6	40,000	200,000	M2S1
7	40,000	160,000	M2S2
8	40,000	100,000	M2S3
9	26,666	0	M3S0
10	26,666	200,000	M3S1
11	26,666	160,000	M3S2
12	26,666	100,000	M3S3
13	0	200,000	M0S1
14	0	160,000	M0S2
15	0	100,000	M0S3

from each of the replicated experimental plots. Samples were taken from 0 to 10, 10 to 20 and 20 to 30 cm depth using a soil auger. These soil samples were mixed for each of the replicated plots with uniformed soil layer. Chemical analysis was done in the Soil Laboratory, IRAD, Ekona. Organic C was determined by chromic acid digestion and spectrophotometric analysis (Heanes 1984). Total N was determined from wet acid digestion (Buondonno et al., 1995) by colorimetric analysis (Anderson and Graham, 1993).

Exchangeable Ca, Mg, K and Na were extracted using ammonium acetate at pH 7 (Chapman, 1965) and determined by atomic absorption spectrophotometry. Phosphorus was extracted by the Bray-1 procedure and analyzed using the molybdenum blue procedure (Murphy and Riley, 1965).

Plant varieties and densities

Plant varieties

The maize (CMS 8704 variety) obtained from IRAD, Ekona, which is yellow in colour, with a maturity period of (80-120 days) was used because of its high yield, adaptability to different climatic zones and its resistance to diseases. The soybean used was 'TGX 1448-2E' variety with medium maturity (90-120 days) which had been recommended for cultivation in the Rain forest Agro-ecology due to its high yield (Muoneke et al., 2007). The maize was sown at spacing of 75 x 25 cm, 50 x 50 cm and 75 x 50 cm and intercropped with the soybean simultaneously at 50 x 10 cm, 25 x 25 cm and 50 x 20 cm.

Planting densities

Three plant densities were used in this experiment. For maize, the low plant density contained 26,666 plants/ha, average plant density had 40,000 plants/ha, while optimum plant density consisted of 53,320 plants/ha. For soybean, low plant density was 100,000 plants/ha, average plant density was 160,000 plants/ha while optimum plant density was 200,000 plants/ha.

Weed control

Weed control was done manually. Two weeding were done at 3rd and 7th weeks after planting (WAP). A broad spectrum insecticide (Cypertex 10EC) was sprayed at 500 ml per 400 L of water per hectare using an 18 L knapsack sprayer. This was to control leaf hoppers and grasshoppers, which are the devastating leaf eating insects in soybean and maize.

Fertilizer application

Block 1 was fertilized while block 2 was not fertilized. NPK (20-10-10) was uniformly applied by side placement to both maize and soybean in block 1 (fertilized block), 4 weeks after planting at 60 kg N ha^{-1}, 60 kg P ha^{-1} and 60 kg K ha^{-1} and top-dressed with urea at 50 kg N ha^{-1}.

Harvesting

Maize and soybean were harvested at physiological maturity; brown leaf stage in soybean (Salado et al., 1993; Li et al., 2003) and black layer formation in maize (Jagtap and Abamu, 2003; Earl and Davis, 2003) 120 days after sowing. Proper sampling procedures were employed at the time of harvesting by picking the five tagged plant samples from the inner rows and thereby ensuring that no particular treatment was consistently favored or handicapped (Undie et al., 2012).

Growth determination

Data collected for maize included plant height (cm), stem diameter (cm), leaf area (m^2), cob length (cm), cob diameter (cm), hundred seed weight per cob (g), number of grains per cob, cob yield (g) and grain yield (g). Data collected for soybeans included number of pods per plant, percentage sterile pods per plant, 100-grain weight, pod yield (g), seed yield (g), plant height (cm), leaf area (cm^2) and stem diameter (cm).

From the data, land equivalent ratio (LER) and relative value total (RVT) of yield of the maize and soybean were calculated. LER was taken as an accurate assessment of biological efficiency of competition under intercropping situation (Subbian et al., 2006). This is given as:

$$LER = Yab/Yaa + Yba / Ybb \quad (1)$$

Where, Yaa = yield of maize in monoculture; Ybb = yield of soybean in monoculture; Yab = yield of maize in intercrop with soybean; Yba = yield of soybean in intercrop with maize.
Relative value total (RVT) was estimated by the following equation (Vandermeer, 1992):

$$RVT = \frac{ap_1 + bp_2}{am_i} \quad (2)$$

Where, a is the price of the main crop, b is the price of the secondary crop, p_1 is the yield of main crop of intercropping, p_2 is the yield of the secondary crop of intercropping and m_i the yield of the pure cropping of the main species.

Data analysis

Data were analyzed using the SPSS statistical package version 21 at the 5% probability level. Prior to analysis, data were subjected to variance homogeneity tests and variables with significant variations ($P < 0.05$) were log10 transformed. Data expressed as percentage were added 0.5 and square-root transformed. Analysis of variance was used to determine if significant differences existed between treatment means (blocks and intercropping densities). Where significant, means were separated using least significant deference (LSD) and Duncan's new multiple range test (DMRT) (for treatment means greater than 5). Finally, the relationships existing between variables were determined through a Pearson correlation analysis.

RESULTS

Chemical analysis of soil sample

The pH of the soil was acidic, percentage organic carbon ranged from 3.04 to 3.67 and a C/N ratio from 3 to 33 (Table 2). The highest values for most parameters were observed at 10 to 20 cm soil depth (Table 2). However, the 0 to 10 cm depth had highest values for nitrogen and potassium.

Effect of intercropping and plant densities on maize growth and yield

Overall, intercropping and planting densities had effects on maize growth and yield in both the fertilized and unfertilized plots, but the effects were not significant ($P \geq 0.05$).

Table 2. Chemical properties of soil from the experimental site.

Chemical properties	Soil depth		
	0 - 10 cm	10 - 20 cm	20 - 30 cm
pH (H_2O)	5.39	5.17	5.47
Organic carbon (%)	3.04	3.67	3.33
Nitrogen (g/kg)	1.02	0.11	1.34
Phosphorus (mg/kg)	15	16	12
Potassium (cmol/kg)	1.09	0.86	0.69
Calcium (cmol/kg)	4.02	4.30	3.10
Magnesium (cmol/kg)	1.94	2.48	1.61
C/N	3	33	3
CEC (cmol/kg)	7.84	10.50	7.35

Table 3. Effect of intercropping and plant densities on maize growth parameters.

Treatment	Stem diameter (cm)		Plant height (cm)		Leaf area (cm^2)	
	Fertilized block	Unfertilized block	Fertilized block	Unfertilized block	Fertilized block	Unfertilized block
M1S0	4.65[a]	4.50[a]	284.80[a]	300.47[a]	935.66[a]	766.76[a]
M1S1	4.80[a]	4.77[a]	288.53[a]	288.73[a]	737.42[a]	790.82[a]
M1S2	5.15[a]	4.84[a]	292.67[a]	291.33[a]	758.31[a]	757.94[a]
M1S3	4.97[a]	4.57[a]	285.20[a]	287.27[a]	800.38[a]	758.36[a]
M2S0	4.71[a]	4.47[a]	277.47[a]	289.07[a]	747.36[a]	721.11[a]
M2S1	4.71[a]	4.64[a]	287.33[a]	271.67[a]	764.17[a]	759.62[a]
M2S2	4.86[a]	4.80[a]	279.53[a]	282.73[a]	1013.23[a]	807.99[a]
M2S3	5.17[a]	4.44[a]	291.73[a]	292.73[a]	779.78[a]	699.48[a]
M3S0	4.98[a]	4.78[a]	286.87[a]	303.60[a]	753.42[a]	833.95[a]
M3S1	5.20[a]	4.60[a]	292.60[a]	283.00[a]	775.16[a]	776.21[a]
M3S2	4.82[a]	4.47[a]	288.67[a]	286.93[a]	718.84[a]	730.94[a]
M3S3	5.02[a]	4.50[a]	285.07[a]	277.80[a]	740.99[a]	704.12[a]
±S.E.	0.07	0.06	3.17	3.04	0.08	0.08
Sig	0.8	0.93	1	0.79	0.48	0.19

Maize plant height

At the end of the experimental period in the unfertilized block, the best plant height (303.6 cm) was recorded when maize was cultivated solely at the low population density of 26,666 plants/ha (Table 3). However, intercropping maize at a density of 40,000 plants/ha with soybeans at a density of 160,000 plants/ha resulted in a plant height of 292.73 cm which was not significantly different ($P \geq 0.05$) from the best height recorded. The least plant height was observed when maize at a population density of 40,000 plants/ha was intercropped with soybeans at a plant density of 200,000 plants/ha (Table 3).

In the fertilized plot, the plants were slightly shorter as compared to the observations in the unfertilized plots. Intercropping maize at population density of 53,320 plants/ha with soybeans at plant density of 160,000 plants/ha produced the best plant height of 292.67 cm, while the least plant height (277.47 cm) was observed when maize was planted solely at a population density of 40,000 plants/ha (Table 3).

Maize stem diameter

In the unfertilized block, best stem diameter (4.84 cm) was observed when maize at a population density of 53,320 plants/ha was intercropped with soybeans at a population density of 160,000 plants/ha. Reducing maize population density to 40,000 plants/ha and soybeans density to 100,000 plants/ha produced thinner plants with least diameter of 4.44 cm (Table 3).

In the fertilized plots, plants were sturdier as compared to those in the unfertilized plots. The highest stem diameter of 5.20 cm was obtained when maize at a population of 26,666 plants/ha was intercropped with soybean at a population of 160,000 plants/ha. The least stem diameter of 4.65 cm resulted when maize was grown solely at a population density of 53,320 plants/ha (Table 3).

Maize leaf area

In the unfertilized plot, maize planted solely at a population of 26,666 plants/ha produced the largest leaves, with diameter of 833.95 cm^2. Intercropping maize at a population of 40,000 plants/ha with soybeans at a population of 160,000 plants/ha led to the production of plants with slightly smaller leaves (807.99 cm^2). Growing maize at plant population of 26,666 plants/ha and soybeans at a population density of 100,000 plants/ha led to plants with the least leaf area of 704.12 cm^2 (Table 3).

In the fertilized plots, intercropping maize at a population density of 40,000 plants/ha with soybeans at a population of 160,000 plants/ha led to the production of plants with a maximum leaf area of 1013.23 cm^2. The minimum leaf area of 718.84 cm^2 was observed when maize was grown at a population density of 26,666 plants/ha intercropped with soybeans at a density of 160,000 plants/ha (Table 3).

Maize cob dry weight

In the unfertilized plots, the highest cob dry weight of 163.08 g was obtained when maize at a population density of 40,000 plants/ha was intercropped with soybeans at a population of 200,000 plants/ha. The least cob dry weight of 145.73 g was observed in maize planted solely at a population density of 40,000 plants/ha (Table 4).

Fertilization led to the production of heavier cobs. The highest cob dry weight of 180.53 g was obtained when maize at a population of 26,666 plants/ha was intercropped with soybean at a population of 200,000 plants/ha. The least cob dry weight (149.29 g) was observed when maize at a population of 40,000 plants/ha was intercropped with soybeans at a population of 100,000 plants/ha (Table 4).

Maize number of grains per cob

In the unfertilized plots, maize at a density of 40,000 plants/ha with soybeans at a density of 200,000 plants/ha produced the highest number of grains per cob (448.87), while the least number of grains per cob (382.60) was observed when maize was planted solely at a population density of 40,000 plants/ha (Table 4).

In the fertilized plots, the numbers of grains were slightly higher as compared to the observations in the unfertilized plots. Intercropping maize at a density of 26,666 plants/ha with soybeans at a density of 160,000 plants/ha produced the best number of grains per cob (454.23). The least number of grains (383.51) was observed when maize was planted solely at a population density of 40,000 plants/ha (Table 4).

Maize grain weight

In the unfertilized plots, the best grain weights (119.40 g) was observed when maize at a population density of 40,000 plants/ha was intercropped with soybeans at a population density of 200,000 plants/ha. The least grain weight resulted from maize planted solely at a population of 40,000 plants/ha (Table 4).

In the fertilized plots, plants produced slightly higher grain weight as compared to the results from the unfertilized plots. The best grain weight (127.13 g) was recorded when maize was cultivated at a population density of 26,666 plants/ha with soybeans at a density of 200,000 plants/ha, while the least grain weight (112.73 g) was observed when maize at a population of 40,000 plants/ha was intercropped with soybeans at a population of 100,000 plants/ha (Table 4).

Effect of intercropping and plant densities on soybean growth and yield parameters

Generally, cropping density had significant (P = 0.01) effects on some growth and yield parameters at harvest time in both fertilized and unfertilized blocks. It was generally noticed that the crops performed better as monocrops when compared with all the other intercropping treatments and for all parameters measured, except for plant height (Figures 2 to 6).

Soybeans plant height

At the end of the experimental period, in the unfertilized plots, the best plant height (73.13 cm) was recorded when soybeans at a population of 200,000 plants/ha was intercropped with maize at a population density of 26,666 plants/ha. The least plant height (41.47 cm) was recorded when soybeans was cultivated solely at a population of 200,000 plants/ha (Figure 2).

In the fertilized plots, the plants were slightly shorter as compared to the observations in the unfertilized plots. The best plant height (68.23 cm) was observed when soybeans at a population density of 160,000 plants/ha was intercropped with maize at a population of 40,000 plants/ha. The least (49.79 cm) was recorded when soybeans was cultivated solely at a population of 160,000 plants/ha (Figure 2).

Table 4. Effect of intercropping and plant densities on maize yield parameters.

Treatment	Unfertilized block			Fertilized block		
	Cob dry weight (g)	Number of grains per cob	Cob grain weight (g)	Cob dry weight (g)	Number of grains per cob	Cob grain weight (g)
M1S0	158.87[a]	438.60[a]	117.29[a]	159.93[a]	413.09[a]	116.65[a]
M1S1	150.31[a]	402.93[a]	110.37[a]	157.20[a]	400.58[a]	116.70[a]
M1S2	162.65[a]	422.67[a]	115.75[a]	160.07[a]	425.78[a]	124.12[a]
M1S3	154.25[a]	396.20[a]	111.87[a]	154.79[a]	395.90[a]	117.83[a]
M2S0	145.73[a]	382.60[a]	105.09[a]	154.53[a]	383.51[a]	114.11[a]
M2S1	163.08[a]	448.87[a]	119.40[a]	149.29[a]	431.02[a]	121.36[a]
M2S2	150.24[a]	401.00[a]	108.54[a]	152.21[a]	398.50[a]	113.95[a]
M2S3	159.37[a]	446.60[a]	115.85[a]	150.87[a]	394.31[a]	112.73[a]
M3S0	160.65[a]	398.67[a]	119.27[a]	154.00[a]	438.23[a]	116.14[a]
M3S1	161.97[a]	444.07[a]	117.01[a]	180.53[a]	407.11[a]	127.13[a]
M3S2	147.44[a]	394.33[a]	108.63[a]	153.57[a]	454.23[a]	120.17[a]
M3S3	149.95[a]	397.20[a]	107.01[a]	158.13[a]	397.83[a]	113.03[a]
S.E.	2.6	7.12	1.93	2.65	6.59	1.45
Sig	0.94	0.53	0.91	0.72	0.63	0.67

Soybeans number of pods per plant

In the unfertilized plots, the highest number of pods (49.87) was observed when soybeans were planted solely at a population of 200,000 plants/ha. However, intercropping maize at a population of 53,320 plants/ha with soybeans at a population of 200,000 plants/ha resulted in 34.67 number of pods, which was significantly (P = 0.01) different from the highest number of pods recorded. The least number of pods (11.33) was observed when maize at a population density of 40,000 plants/ha was intercropped with soybeans at a density of 100,000 plants/ha (Figure 3).

In the fertilized plots, the number of pods was higher as compared to the observations in the unfertilized plots. Planting soybeans solely at a population of 100,000 plants/ha produced the highest number of pods (56.4). However, intercropping maize at a population of 53,320 plants/ha with soybeans at a population of 200,000 plants/ha resulted in a significant (P = 0.01) decrease in number of pods (42.93). The least number of pods (17.73) was observed when soybeans at a population of 160,000 plants/ha was intercropped with maize at a population density of 53,320 plants/ha (Figure 3).

Soybeans pod weight

In the unfertilized plots, soybeans planted solely at a population of 200,000 plants/ha produced the heaviest (20.93 g) pods. Intercropping soybeans at a population of 200,000 plants/ha with maize at a population of 53,320 plants/ha led to the production of plants with lighter pods (13.09 g). Growing soybeans at 100,000 plants/ha intercropped with maize at a population of 40,000 plants/ha produced plants with the least pod weight of 3.84 g (Figure 4).

In the fertilized plots, pods were heavier as compared to those in the unfertilized plots. The heaviest pods (22.94 g) were produced when soybeans were planted solely at a population of 100,000 plants/ha, while the least pod weight (6.29 g) was recorded when soybeans at a population density of 160,000 plants/ha was intercropped with maize at a population density of 53,320 plants/ha (Figure 4).

Soybean number of grains

In the unfertilized plots, the best and highest number of grains (97.27) was observed when soybeans were planted solely at a population density of 200,000 plants/ha. However, intercropping soybeans at a population of 200,000 plants/ha with maize at a population of 53,320

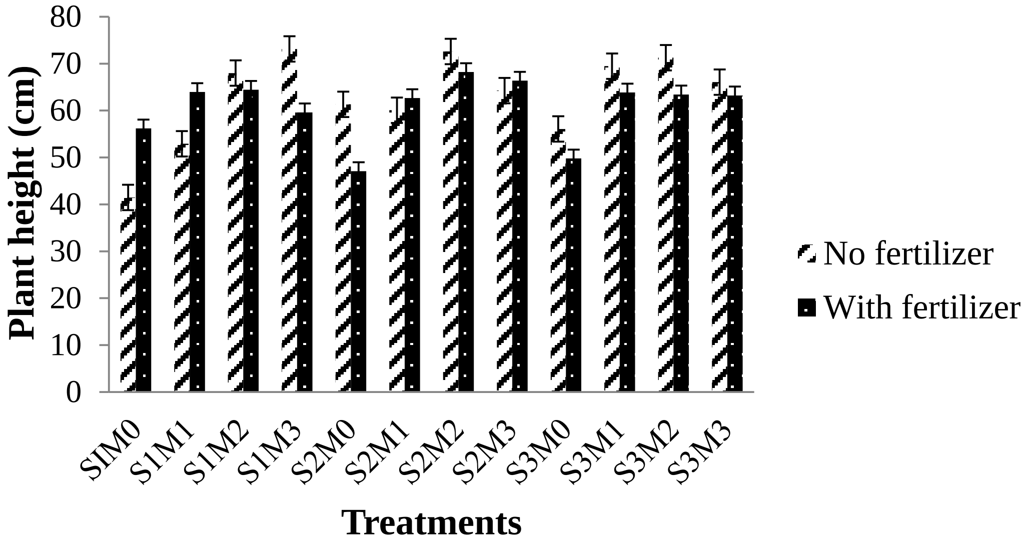

Figure 2. Effects of intercropping and plant densities on soybean plant height at harvest. Vertical bars represent standard error of mean.

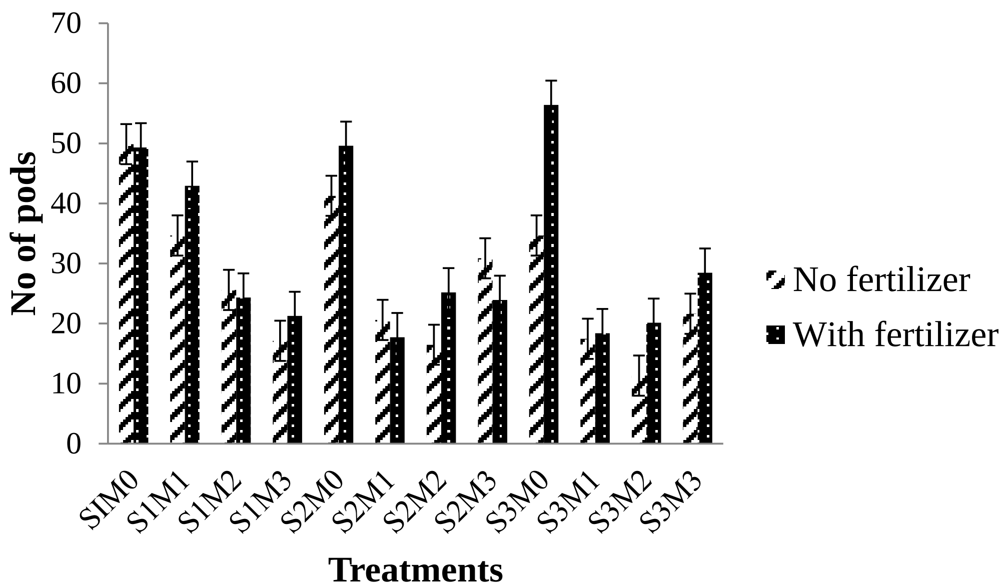

Figure 3. Effect of intercropping and plant densities on soybeans number of pods at harvest. Vertical bars represent standard error of mean.

plants/ha caused a significant decrease in grain number to 69.6. The least (23.6) was recorded in maize at a population of 40,000 plants/ha intercropped with soybeans at a population of 100,000 plants/ha (Figure 5).

In the fertilized plots, plants produced higher number of grains as compared to the unfertilized plots. The highest number of grains (109.93) was obtained when soybeans was cultivated solely at a population density of 100,000 plants/ha. Intercropping maize at a population of 53,320 plants/ha with soybeans at a population of 200,000 plants/ha produced a grain number of 97.2. The least grain number (35.47) was recorded when maize at a population of 53,320 plants/ha was intercropped with soybeans at a population of 160,000 plants/ha (Figure 5).

Soybean grain weight

In the unfertilized plots, soybeans planted solely at a plant density of 200,000 plants/ha produced the heaviest

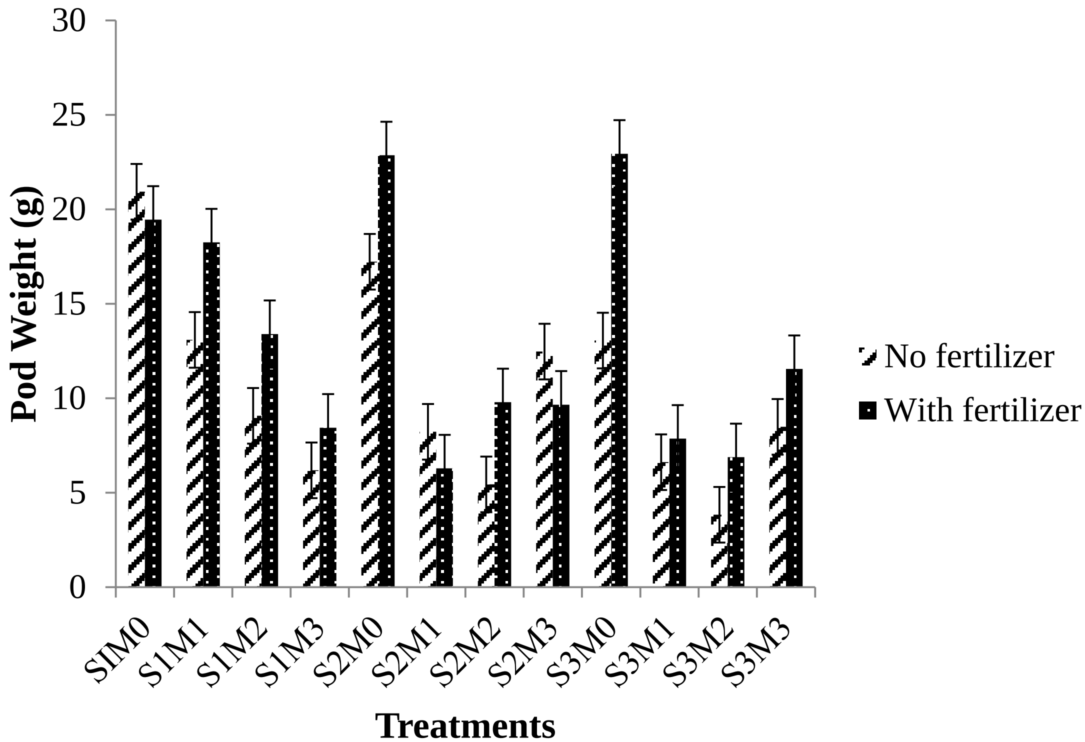

Figure 4. Effect of intercropping and plant densities on soybean pod weight at harvest. Vertical bars represent standard error of mean.

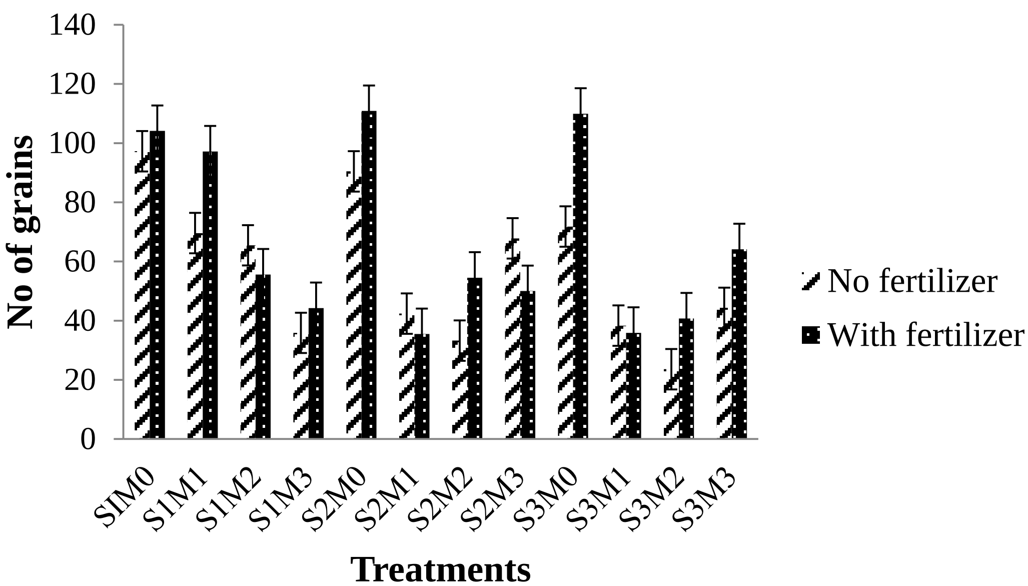

Figure 5. Effect of intercropping and plant densities on soybeans grain number at harvest. Vertical bars represent standard error of mean.

(13.69 g) grains. Intercropping maize at a population of 53,320 plants/ha with soybeans at a density of 200,000 plants/ha led to the production of plants with slightly lighter (8.66 g) grains. Growing maize at a population of 53,320 plants/ha and soybeans at a density of 160,000 plants/ha led to plants with the least (3.87 g) grain weight

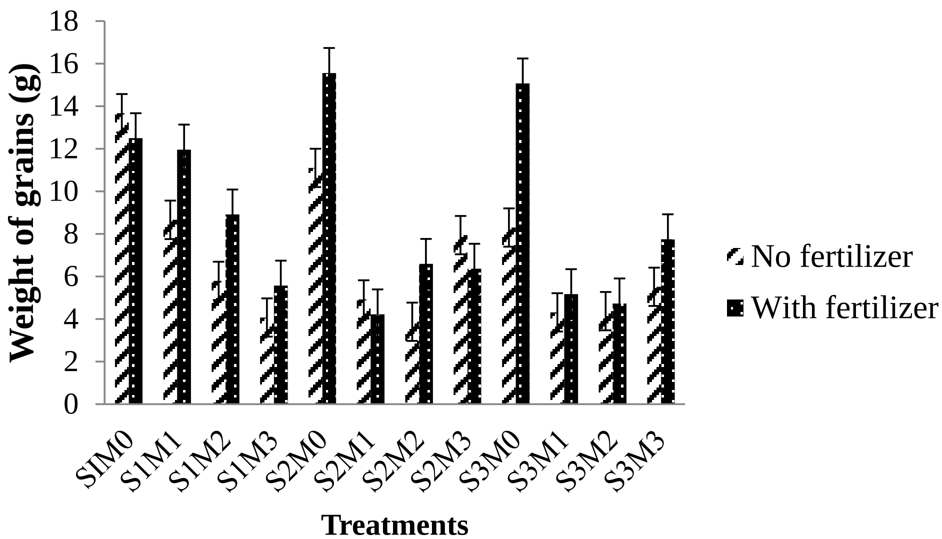

Figure 6. Effect of intercropping and plant densities on soybean grain weights at harvest. Vertical bars represent standard error of mean.

Table 5. Land equivalent ratio and relative value total of the intercropped treatments.

Treatment	RYM_{NF}	RYM_F	RYS_{NF}	RYS_F	LER_{NF}	LER_F	RVT_{NF}	RVT_F
M1S1	0.94	1.00	0.63	0.95	1.57	1.96	1.15	1.29
M1S2	0.99	1.06	0.42	0.66	1.41	1.72	1.13	1.26
M1S3	0.95	1.01	0.29	0.45	1.25	1.46	1.05	1.15
M2S1	1.14	1.06	0.44	0.27	1.57	1.33	1.27	1.17
M2S2	1.03	0.99	0.35	0.42	1.38	1.41	1.14	1.16
M2S3	1.10	0.99	0.72	0.41	1.8	1.39	1.32	1.12
M3S1	0.98	1.09	0.52	0.34	1.49	1.43	1.08	1.22
M3S2	0.91	1.03	0.53	0.31	1.44	1.34	1.02	1.15
M3S3	0.89	0.97	0.66	0.51	1.55	1.48	1.03	1.16

M1, M2 and M3: 53320, 40000, and 26666 maize plants per hectare; S1, S2 and S3: 200000, 160000, and 100000 soybean plants per hectare, respectively. Relative yields for maize non-fertilized (RYM_{NF}) and fertilized (RYM_F), Relative yields for soybean non-fertilized (RYS_{NF}), and fertilized (RYS_F), Land equivalent ratio for non-fertilized (LER_{NF}) and fertilized (LER_F), and Relative value total, non-fertilized (RVT_{NF}) and fertilized (RVT_F) for grain yields of maize and soybean at different cropping densities.

(Figure 6).

In the fertilized plots, the grains were heavier as compared to the observations in the unfertilized plots. The best grain weight (15.56 g) was recorded when soybean was planted solely at a density of 160,000 plants/ha, while the least (4.22 g) was observed when maize at a density of 53,320 plants/ha was intercropped with soybeans at 160,000 plants/ha (Figure 6).

Assessment of mixed cropping

Land equivalent ratio (LER)

Results showed that LER values were greater than 1 in all the intercropping combinations of maize and soybean, signifying yield advantage and greater crop complementarities in this intercropping system (Table 5).

In the unfertilized block, intercropping maize at a population of 40,000 plants/ha with soybeans at a population of 100,000 plants/ha recorded the highest LER value of 1.8, thus indicating the combination with the best yield advantage. The least LER value of 1.25 was obtained when maize at a population of 53,320 plants/ha was intercropped with soybeans at a plant density of 100,000 plants/ha.

In the fertilized block, intercropping maize at a population density of 53,320 plants/ha with soybeans at a density of 200,000 plants/ha recorded the highest LER value of 1.96. This was the planting density with the best yield advantage. The least LER value of 1.33 was seen when maize at a population of 40,000 plants/ha was intercropped with soybeans at a population of 200,000 plants/ha.

Relative value total (RVT)

The RVT of all treatments were greater than one (RVT>1) (Table 5). The RVT ranged from 1.02 to about 1.32 in both blocks indicating economic advantage in this cropping system. In the unfertilized block, the highest RVT of 1.32 was obtained when maize at 40,000 plants/ha was intercropped with soybeans at 100,000 plants/ha, while the least (1.02) was recorded when maize at 26,666 plants/ha was intercropped with soybeans at 160,000 plants/ha.

In the fertilized block, the highest RVT of 1.29 was obtained when maize at 53,320 plants/ha was intercropped with soybeans at 200,000 plants/ha, whilst the least (1.12) was observed when maize at 40,000 plants/ha was intercropped with soybeans at 100,000 plants/ha.

It is worth noting here that the same plant density combinations (maize at 40,000 plants/ha intercropped with soybeans at 100.000 plants/ha) that produced the highest RVT in the unfertilized block is the same one that produced the least RVT in the fertilized block.

Correlation between growth and yield parameters

Maize

Correlation results showed some significant (P = 0.01) differences in the relationship between the growth and yield parameters. In the unfertilized block, it was noticed that stem diameter was strongly and positively correlated (R = 0.05) to the yield components. Plants with larger stem diameter produced heavier cobs (fresh and dry weight). Plants with longer cob lengths had more grains and a resultant higher grain weight. Plant height also correlated positively (R = 0.01) with the yield components in that, taller plants produced heavier cob weights (fresh and dry), longer cob length, more grains and higher grain weight. There was a correlation in leaf area whereby the longer the leaf area, the heavier the cob weight (fresh and dry), the longer the cob length and the more the cob grains, irrespective of the treatments.

In the fertilized block, stem diameter was seen to be positively correlated (R = 0.05) with yield components in that, the higher the stem diameter, the heavier the cob weight (fresh and dry), the longer the cob length, the more the grain number and the higher the grain weight. Plant height also correlated positively (R = 0.01) with the yield components in that taller plants produced heavier cob weights (fresh and dry), longer cob lengths, more grains and higher grain weights. A significantly (P = 0.01) negative correlation was seen in leaf area where by the shorter the leaf area, the heavier the cob weights (fresh and dry), the longer the cob lengths and the more the cob grains, irrespective of the treatments. Generally, stem diameter and plant height were the two growth parameters that correlated (R = 0.05) most with the yield components in both blocks.

Soybeans

Results generally showed highly significant correlations (R = 0.05) between growth parameters (number of leaves, plant height, length and width of leaves) and yield parameters (% sterile pods, number of pods, weight of pods, number of grains and weight of grains) irrespective of treatments.

In the unfertilized block, the number of leaves showed highly significant and strong positive correlations (R = 0.05) with yield parameters in that, the higher the number of leaves, the more the number of pods, the higher the pod weights, the more the grain number and the higher the grain weights. Correlation between plant height and these parameters were generally weak and negative in that, the higher the plant height, the lower the number of pods, weight of pods, number of grains and grain weights. Leaf lengths showed significant (P = 0.01) and strong positive correlations (R = 0.05) in that, the longer the length of the leaf, the higher the number of pods, weight of pods, number of grains and weight of grains.

In the fertilized block, the number of leaves showed significant (P = 0.01) and strong positive correlations (R = 0.05) with reproductive parameters in that, the higher the number of leaves, the more the number of pods, the higher the pod weights, the more the grain number and the higher the grain weights. Correlation between plant height and these parameters were highly significantly (P = 0.01) negative in that, the higher the plant height, the lower the number of pods, weight of pods, number of grains and grain weights. Leaf lengths recorded no significant (P = 0.05) correlation with weight of pods and weight of grains but negative correlation in the case of number of pods and number of grains.

DISCUSSION

This study has shown that yield and yield components of the intercropped components varied significantly with planting density of the maize - legume component. The performance of the associated legume appeared to have been affected by the growth of maize and its associated micro-climatic changes. This is reflected in the significant differences among treatments in terms of grain yield.

From the results, the yields of maize in the sole crops were similar (difference were not significant ($P \geq 0.05$)) to those in the intercrops. There were neither yield gains nor yield decline. The results of this study agreed with the findings of other researchers (Undie et al., 2012; Muoneke et al., 2007; Mudita et al., 2008), which showed that maize grain yield was not significantly affected by intercropping and planting densities. It had been demonstrated in another study (Mutungamiri et al., 2001) that intercropping had no negative impact if maize population is not reduced below 37000 plants/ha. In intercrops usually, the cereal has a competitive advantage since they are taller and therefore benefits from maximum PAR reaching the foliage, hence they may not experience yield declines (Muoneke et al., 2007). Other researchers reported that the grain yield of maize in maize/soybeans mixture was reduced as compared to its sole crop yields (Ennin et al., 2002; Silwana and Lucas, 2002; Mashingaidze, 2004).

The fact that there was no yield increase in maize as a result of intercropping with soybeans indicated that it was unlikely that soybean can provide a nitrogen advantage to associated crops within an intercropping system in the same season. There is little evidence on direct transfer of significant amounts of nitrogen between roots of legumes and cereals in mixture (Geiler, 2001). The nitrogen advantage would benefit the proceeding crop after harvesting the legume (Mpepereki and Geiler, 1998). There was no reduction in maize yield due to intercropping which is probably because of lack of competition between the maize and soybean. The crops extracted nutrients from different zones in the soil profile since they had different rooting depths, so competition for nutrients could have been minimal or non-existent. The plant densities were not high enough to result in competition between the maize and soybean (Mutungamiri et al., 2001). The main effect of maize planting density showed that maize grain yield per unit area increased as maize planting density increased (53,330 plants/ha), probably due to more maize cobs, as maize plant population increased. A similar study (Olufajo, 1992) had shown that in maize/soybean intercrops, increasing maize plant density increased maize yield significantly.

Grain yield components were relatively higher for soybeans in the monocrops as compared to the intercrops probably due to a higher degree of interspecific competition and depressive effect of maize, a C_4 species on soybeans, a C_3 crop. Crops with C_4 photosynthetic pathways such as maize have been known to be dominant when intercropped with C_3 crops like soybeans (Hiebsch et al., 1995). The higher seed yield of sole over intercropped soybeans had been reported by other workers (Olufajo, 1992; Muneer et al., 2004). Also, reduction in the intercropped soybean could be as a result of the shading effect imposed by the taller maize plants. It had been reported that shading by the taller plants in mixture could reduce the photosynthetic rate of the lower growing plants and thereby reduce their yields (Olufajo, 1992; O'Callaghan et al., 1994). The intensity and quality of solar radiation intercepted by the canopy are important determinants of yield components, hence yield of soybean (Jomol et al., 2002). From the results of this study, it was observed that plant in the intercropped treatments were taller than those in the monocropped treatments. Soybean plants were taller with the lowest maize density (26,666 plants/ha) than other planting densities, probably because of their struggle for light. This result is contrary to others, where soybean was reported to be taller with the highest maize density (53,330 plants/ha) (Muoneke et al., 2007) and plant height in intercropped treatments were adversely affected due to competition with main crop for light and plant height was recorded as maximum in soybean planted alone rather than in mixture (Muneer et al., 2004).

Yield advantage

Land equivalent ratio

Previous studies have shown that, the non-legume crop is considered a suppressing crop in legume/non-legume associations like sorghum/pigeon pea (Tobita et al., 1994), groundnut/cereal fodders (Ghosh, 2004) and berseem (*Trifolium alexandrinum* L.)/barley (Ross et al., 2005). This was shown to be true in soybean/maize intercropping in the present study as indicated by the yield and yield components.

The LER gives an accurate assessment of the biological efficiency of the intercropping situation. The trade-off between increasing the yield of suppressing species and decreasing that of the suppressed species has three possible outcomes for intercropping systems, that is, yield advantage (LER > 1), yield disadvantage (LER < 1) and the intermediate result (LER = 1) (Vandermeer, 1992). The results of the present experiment showed mean LER values of above one in all the different combinations. The values above unity in most systems indicated complementarity in resource utilization by the component crops (Muoneke et al., 2007). LER greater than one had been attributed primarily to the increase in nitrogen absorption (Ghanbari, 2000).

The total land equivalent ratio was between 1.25 and 1.8 for the unfertilized block and 1.33 and 1.96 for the fertilized block. The yield advantages due to intercropping when compared with sole cropping of both maize and soybean were 25 to 80 and 33 to 96% in the unfertilized and fertilized blocks, respectively. This implies that 25 to 80 and 33 to 96% more land should be used in sole cropping in order to obtain the same yield of intercropping. It is therefore an indication of the superiority of the intercrops over pure stands in terms of the use of environmental resources during plant growth and development (Dhima et al., 2006). This also agreed with work which reported that sorghum-soybean intercropping system gave higher yield (38 to 124%) than other cropping systems (Sharma et al., 1994).

The total LER of the mixtures were contributed more by the maize component as depicted by the higher partial LER of maize in all the intercropping systems, probably because maize being a C4 crop suppressed the soybean crop. The mean LER values increased with an increased in maize planting density of 53,330 plants/ha. This is in agreement with reports in which LER increased at closer spacing (higher plant population), provided that the pure and intercropped plots were given the same level of management (Muoneke et al., 2007).

Relative value total (RVT)

The relative value total (RVT) of 32 and 29% shows that intercropping of maize and soybean can increase net income (NI) by 32 and 29%. This confirms that this type of cropping system has the advantage of generating more benefits. Therefore, intercropping of maize and soybean with high production stability can considerably increase economical revenues and the profitability of the farmlands. Higher monetary return had been reported for intercropping maize-soybean than the sole crops (Muoneke et al., 2007). Intercropping of maize-groundnut produced higher LER and monetary advantage (>1) than sole crops (Ghosh, 2004). The implication of this is that farmers in the study area would earn higher income growing maize/soybean than cropping them separately.

Conclusions

Finally, it can be concluded that intercropping and plant densities have an effect on the growth and yield of maize and soybean in the humid forest zone of Mt Cameroon area. The effect was not significant for maize. Overall, the yield components for soybeans decreased with a decrease in plant densities. The yield components for soybean grown as an intercrop with maize were significantly lower than those obtained when soybean was grown as a sole crop. Nonetheless, the combination of 53,320 plants/ha of maize and 200,000 plants/ha of soybeans showed the highest profitability and land use efficiency and could be introduced as best intercropping system.

The trading perspectives of the yields observed with intercropping could be improved if different tilling and cultivation methods are evaluated, the appropriate ones are identified and suitable genotypes of the intercrops are used. An intensification of training in agricultural techniques in secondary and vocational education as well as for the small holder farmers would also be of help. The implementation of government policies and regulations meant to control agricultural production and to secure farmers income will go a long way to improve crop production in intercropping. This is because increase in production will permit the farmers to supply local and international markets, thus increasing their income.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Addressing soil organic carbon issues in smallholders' farms in Ethiopia: Impact of local land management practices

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Soil organic carbon plays a key role in plant biomass production. On smallholder farms, crop and livestock are traditionally integrated and support each other. However, due to changes in socio-economic factors, this relationship is lost as resources are mismanaged. The present study was conducted in the Central Ethiopian highlands that represent about 90% of the country's smallholder farmers. The objective of this study was to quantify soil organic carbon in different agricultural management systems and to document the contribution of livestock to carbon storage. The study included a socio-economic survey and soil laboratory analysis. Results showed that different land uses and conservation measures had various impacts on soil carbon addition and depletion. The comparison between different land uses showed that the highest soil organic carbon was found in grazing land (27%), followed by fenced-off land (2.59%) at 0 to 15 cm soil depth. It also showed that animal waste and farmyard manure added to soil had the highest amount of organic carbon (3.90 and 1.85%, respectively) at 0-15 cm soil depth. It was concluded that livestock waste, farmyard manure, and crop residues improved soil fertility and soil organic carbon in the top soil indicating that livestock and by-products made a significant contribution to carbon storage.

Key words: Farmyard manure, land uses, organic carbon inputs, socio-economic survey, soil management practices.

INTRODUCTION

Soil carbon storage is defined as the transfer of carbon dioxide (CO_2) from the atmosphere into the soil through crop residues and other organic solids in a form that is not immediately reemitted (FAO, 2004; Lal, 2004). The transfer or "storage" of carbon helps to offset emissions from fossil fuel combustion and other carbon-emitting activities while enhancing soil quality and long-term agronomic productivity (Sundermeier et al., 2005; Barreto

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et al., 2009). It was observed that the depletion of soil carbon is increased by soil degradation and exacerbated by inappropriate land uses and soil mismanagement (Lal, 2004). Thus, the adoption of restorative land management practices can reduce the rate of enrichment of atmospheric CO_2 while having a positive impact on food security, agro-industries, water quality, and the environment. There is a clear correlation between soil organic carbon in the topsoil and crop yield (FAO, 2001; Lal, 2006).

Under smallholder crop and livestock production systems in Ethiopia, crop production is the major cash income earner (IPMS, 2004) while livestock production plays an important role as a source of draught power and organic fertilizer for crop production, and it is a living bank, which provides household income and food (Hadera, 2001). However, although livestock production is associated with environmental degradation (FAO, 2000) and wholesale devastation of rangelands and irreversible desertification (Pearson et al., 2005), there is ample evidence to show that livestock production contributes positively to carbon balance in the soil (de Han et al., 1998). The addition of animal manure and livestock waste to the soil is an alternative management option to ensure carbon input for soil carbon storage (FAO, 2001; Lal, 2002).

However, due to socio-economic factors, traditional land management practices, for instance leaving crop residues in the field after harvest have declined (Lal, 2004). Instead, crop residues are used for animal feed, house construction, firewood or sold as a source of income (FAO, 2001). Crop residues are cut close to ground level, leaving nothing to return back to the soil (Kahsay, 2004), and whatever stubble is left on the ground is extensively grazed and trampled, so that only bare soil remains, which exposes it to wind and water erosion. This type of crop residue management has thus contributed to the low levels of soil organic carbon and soil quality.

Traditionally, animal manure is among the recyclable resources that can be used to increase soil organic carbon. However, due to lack of firewood in the highlands to meet household fuel demand, farmers are using animal manure for fuel needs such as cooking and heating as well as a source of income (Tesfaye et al., 2004). It has also been estimated that the sale of animal manure in the highlands contributes about 25% of the total income from livestock production (Tesfaye et al., 2004). Under the current manure management systems in smallholder mixed agriculture, no animal waste is returned to the soil except urine. This has serious repercussions for soil carbon storage.

In general, permanent removal of crop residues and the use of animal manure for household fuel lower soil organic carbon (FAO, 2001). Nevertheless, long-term trials have shown that carbon losses due to human interventions can be reversed through improved land management practices which enhance carbon storage in the soil (Rosenberg et al., 1999). It is thus important to study the impact of different land management practices under mixed crop-livestock production systems on carbon storage as well as the contribution of livestock production to carbon storage.

Previous studies on carbon storage in Ethiopia examined natural resource management from forestry and soil perspectives (Bojo and Cassells, 1995), whereas in the current study, carbon storage was examined with regard to different land uses including livestock production. Thus, in the current study, the extent to which different local land management systems and organic addition increased soil carbon in mixed crop-livestock production systems was investigated in the central Ethiopian highlands. The research also explored the contribution of livestock to carbon storage and environmental quality.

MATERIALS AND METHODS

Study area

The study was conducted in central Ethiopian highlands that represent 90% of Ethiopian farm lands. In the highlands, the main agricultural activity is smallholder mixed farming dominated by crop production (Constable, 1984). The Ethiopian highlands, based on development potential and resource base, are further subdivided into three zones (Amare, 1980): high potential cereal/livestock (HP/CL), low potential cereal/livestock (LP/CL), and high potential perennial crop/livestock (HP/PL). Ecologically, the study area falls under the high potential livestock/crop zone (IPMS, 2004), which is located southeast of Addis Ababa at latitude 8°46’ 16.20’’ to 8°59’ 16.38’’ N, and longitude 38°51’ 43.63’’ to 39°04’ 58.59’’ E, on the western margin of the Great East African Rift Valley. The altitude of the area ranges from 1500 to 2000 m above sea level. Two major agro-climatic zones were identified in the area (IPMS, 2004): the mountain zone > 2000 m above sea level, which covers 150 km^2 or 9% of the area, and the highland zone at 1500 to 2000 m above sea level, which covers over 1600 km^2 or 91% of the area. The agro-ecology of the area is best suited for diverse agricultural production systems. It is known for its excellent quality Teff grain, which is an important staple food grain in Ethiopia that is used for making bread (Enjera). Wheat is the second most abundant crop, and pulses, especially chickpeas, which grow in the bottomlands and flood basins. Most farmers grow chickpeas in rotation with cereals. Livestock production forms an integral part of the agricultural production system. Livestock provide inputs for crop production such as draft power, transport services and manure for fertilizer and fuel for cooking (Hadera, 2001). Furthermore, livestock is central to nutrient cycling and important for the efficiency, stability and sustainability of farming systems in Ethiopian highlands.

Methodology

The study was designed to quantify soil organic carbon in different land management systems and to compare the effect of adding carbon from different organic sources in to soils. The study combined socio-economic surveys with laboratory analyses. The laboratory data were complemented by land use histories and the current crop and soil management systems. Sample sites represented 12 alternative land uses and soil management practices including fertilization practices. One site was designated as a reference point to represent an area free from human interference for over 30 years. Sample sites were described according to World Overview of Conservation Approaches and Technology (WOCAT, n.d.), classification for conservation and land use management (Appendix 1).

The 12 sites were further reclassified into land use practices and organic matter sources in order to categorize and organize them in broader land use systems and organic matter sources. Means and standard deviations were calculated for these categories. Land use categories were based on World Overview of Conservation Approaches and Technology (WOCAT, n.d) and were classified into the subclasses of crop land (sites 2, 3, 4, 5, 6, 7 and 8), grazing and pasture land (site 9), swamp land (site 12), and fenced land (sites 10 and 11). Organic matter sources were also grouped based on the same system. The carbon yield was calculated based on Adam's (1973) equation for bulk density as follows:

BD= [100\(%OM\0.224)+(100-%OM\MBD)]

where BD = bulk density, OM = organic matter, and MBD = mineral bulk density. A typical value of 1.64 was used for MBD (Mann, 1986).

Soil sampling and analysis

In June 2009, soil samples were taken from the 12 sites. Before sampling, forest litter, grass and any other material on the soil surface was removed. The sites were purposely selected to describe the different land uses and conservation measures implemented such as degradation level, crop history, and level of fertilization, residues left in the field and compost or manure application. A group interview was also conducted with about ten people from the community which included elders, women, youth and extension workers in order to document land uses and conservation measures for each site. Thus, types of crops, soil and land management practices for each site were described based on detailed interviews with the community.

Soil samples were taken at 0 to 15 cm and at 15 to 30 cm soil depth with four sub-samples from each site. Thus, the four sub-samples were pooled to make one composite for each site. The four sub-samples were taken within a radius of 30 to 50 m from each other. The composite samples were stored in plastic bags and transported to the Debrezeit Research Centre Soil Laboratory within 2 h of collection. Twelve (12) composite soil samples with four sub-samples each were used for analyses.

Soil samples were air dried and ground with a mortar and pestle and sieved through a 2-mm sieve, from which soil organic carbon content was determined by using the procedure described by Walkely and Black (1934). Soil moisture analysis was done by oven drying for 24 h at 105°C. Soil bulk density was also estimated by using the Adams equation described earlier (Adams, 1973). A typical value of 1.64 was used for mineral bulk density (Mann, 1986). Carbon per unit area was calculated using the formula described by Pearson et al. (2005) as:

C (t/ha) = [(soil bulk density (g/cm^3) × soil depth (cm) × % C)] × 100.

The carbon content was expressed as a decimal fraction, that is, 2.2% C was expressed as 0.022.

Statistical analysis

Composite topsoil samples from 0 to 15 cm and 15 to 30 cm soil depth from all sites were taken from representative areas using an augur. The proportion of organic carbon in the sampled soils was determined using the wet oxidation method (Walkley and Black, 1934). Data were captured on MS Excel and exported to SPSS Version 17.0.1 (2008) for statistical analysis. The data were then analysed by SPSS version 17.0.1 (2008) to determine means and standard deviations of soil organic carbon.

RESULTS AND DISCUSSION

Soil organic carbon content of the study sites

According to FAO (2001), when the woody biomass on the ground increases it can act as a permanent carbon sink. Woody vegetation with deep and extensive root systems can capture nutrients that are not accessible by crops to make them available through litter fall and nitrogen fixation by leguminous trees (Lal, 2002). Therefore, site 1 was chosen as a reference point or control site for comparison with other alternative soil conservation and land use management practices that have changed over time due to human interference.

Results showed that the topsoil at 0 to 15 cm depth had higher soil organic carbon (Mean 1.543%) than the subsoil at 15 to 30 cm depth (1.151%), as shown in Table 1. This was expected as reported earlier by Post and Kwon (2000), who observed that land use and management practices determined the direction and rate of change in organic carbon content. Site 1 (the reference point) had a soil organic carbon content of 1.27% at 0 to 15 cm and 0.31% at 15 to 30 cm soil depth which were below the mean at both depths as shown in Table 1. Site 11 had the highest organic carbon content (3.90%) at 0 to 15 cm followed by site 10, 9, 3, 5, 4 and 2, which had 2.32, 2.21, 2.13, 1.85, 166 and 1.65% at the same depth, respectively. This was attributed to more carbon addition from rich sources such as animal waste (site 11), fenced off grazing land (site 10), manure and urine deposits (site 9), crop rotation of cereals and pulses (site 3), crop land on farmyard manure (site 5), conservation tillage (site 4), and commercial mixed farm on farmyard manure. Sites 12, 7 and 8 had the lowest organic carbon content (0.27 and 0.07%) at the same depth compared to the reference point. This could be due to the leaching of carbon and nitrogen from the topsoil.

At 15 to 30 cm depth different results were observed. Site 12 which had among the least proportion of organic carbon content (0.27%) at the topsoil, had the highest organic carbon content (3.23%) as shown in Table 1. This could have been due to seasonal accumulation of deposits from runoffs in the swamps. Other sites which had above average organic carbon included site 9, 5, 10, 6, 11 and 3 (2.16, 1.33, 1.23, 1.17, 1.15 and 1.02%), respectively. The sites (9, 10, 5 and 6) where manure, compost or animal waste were added or where degraded lands were conserved and used for grazing or cut and carry of forage had above average amount of organic carbon content. Table 1 shows a summary of the organic carbon contents of all sites.

Table 1. Soil organic carbon content of sample sites.

Site	Land uses and conservation measure	Soil organic carbon at 0-15 cm depth (%)	Soil organic carbon at 15-30 cm depth (%)
1	Fenced and undisturbed land	1.27	0.31
2	Commercial mixed farm on manure	1.65	0.73
3	Crop land and crop rotation	2.13	1.02
4	Crop land and conservation tillage	1.66	0.34
5	Crop land and manure	1.85	1.33
6	Crop land and compost	1.12	1.17
7	Crop land, better residue management	0.07	0.80
8	Crop land and chemical fertilization	0.07	0.25
9	Degraded land and grazing site	2.21	2.16
10	Degraded, fenced, cut and carry feeding	2.32	1.23
11	Animal waste disposal and uncultivated	3.90	1.15
12	Swampy	0.27	3.23
	Mean soil organic carbon content	1.543	1.151

Table 2. Soil organic carbon content for various land use categories at 15 and 30 cm depth (Mean ±SD).

Land use category	Soil organic carbon at 0-15 cm (%)	Soil organic carbon at 15-30 cm (%)
Crop land (n=7)	1.14 ± 0.73	0.81 ± 0.55
Grazing land (n=2)	2.27 ± 0.08	1.70 ± 0.66
Swampy (n=1)	0.27	3.23
Fenced land (n=2)	2.59 ± 1.86	0.73 ± 0.59
Total	1.40 ± 1.03	0.99 ± 0.73

The influence of different land uses on soil organic carbon content and the contribution of livestock

There are many factors and processes that determine the direction and rate of change in soil organic carbon content when different land use management practices are applied (Post and Kwon, 2000). The land uses in the study area were categorized as crop land, grazing land, swamp land and land fenced without tillage. The analysis of variance at 95% level of confidence showed that there were significant differences in carbon content for the different land uses as shown in Table 2.

Categorization of sample sites based on WOCAT categories

The mean soil organic carbon content for the land use categories were 2.6, 2.27, 1.14 and 0.27% for fenced land, grazing land, crop land and swamp land, respectively, at 0 to 15 cm depth (Table 2). The carbon content was acceptable and supported the findings of other researchers (Post and Kwon, 2000), except for the lower carbon content of swamp land. The reason for the lower carbon content in swamps at 0 to 15 cm depth was due to the leaching of carbon and nitrogen to the bottom layers (FAO, 2001). This was also supported by the evidence that higher carbon content was observed in 15 to 30 cm depth for swamp land. The carbon content in grazing land in both degraded and fenced sites came second and was attributed to the addition of dung and urine to the soil (Hoffmann and Gerling, 2001) as well as the ability of livestock to move organic material from place to place and mix it with soil particles (FAO, 2004). The other plausible reason could be that grazing land might have been damaged physically but not degraded chemically as it appeared. Crop land had the lowest organic carbon because of the tillage practices.

These results have validated the importance of livestock production in soil organic carbon storage under two different grazing sites, degraded and fenced land. However, the results of this study did not support the findings of many other reports (FAO, 2006) which showed that livestock production was responsible for both physical and chemical degradation of the soil. The current findings thus call for further investigation into the role of livestock in soil degradation as well as carbon storage in other areas.

Table 3. The carbon yield from carbon inputs at 0-15 cm soil depth.

Carbon input	Carbon at (15cm) depth (%)	Bulk density (g/cm^3	Years carbon input added	Estimated current carbon (t/ha)	Difference in carbon from base site (t/ha)	Estimated carbon (g/m^2/year)
Animal waste	3.9	0.869	50	50.84	(+)32.69	102
Crop rotation	2.13	0.924	3	29.52	(+)11.37	984
Farm manure	1.75	0.937	7	24.60	(+)6.45	351
Fenced off area	1.20	0.956	10	17.21	(-)0.94	172
Compost	1.12	0.959	4	16.80	(-)1.35	402
Minimum tillage	1.06	0.961	6	15.28	(-)2.87	254
Deep tillage	0.79	0.970	3	11.50	(-)6.65	383
Crop residue and deep tillage	0.07	0.977	3	1.03	(-)17.12	34.0
Base site	1.27	0.953	30	18.15	(0)	60.5

Organic matter input and carbon storage in the soil

According to FAO (2004), the addition of organic matter to the soil through the use of farmyard manure, green manure, legumes in rotations, vermin-compost and fallows in rotations, increase soil carbon and agricultural yields. But when inorganic fertilizers were used alone they resulted in the decline of organic carbon in soil in all systems, and when they were used with no-tillage, only minimal increase in yield was realised (FAO, 2001). No-tillage increases soil organic carbon, although the accumulation is greatest when organic matter is added to the soil (Lal, 2006). Similar scenarios have shown that carbon storage in tropical dry lands can also be achieved at the different sites (Hernanz et al., 2009).

In order to improve soil organic carbon the best land management practices have to be selected based on existing farming systems (FAO, 2002). Thus, for example, the application rate of organic matter to the soil needs to correspond with quantities that are available to local farmers. However, at the field level, important trade-offs may not occur, which prevent the adoption of the best strategies for carbon storage. Crop residues may be required for livestock feed, fuel, construction material or may be sold for cash in difficult times (Kahsay, 2004). Similarly, farmyard manure may be used for energy and cash income (Tesfaye et al., 2004). Thus, many socio-economic factors interact to determine which scenario or combination of scenarios may be implemented in each growing season (FAO, 2000).

According to some research reports, soil carbon can be restored to pre-cultivation levels, and in certain circumstances to above the original level (FAO, 2004). However, the true “indigenous soil carbon level” is often difficult to establish in systems where agricultural activities have remained the same for several centuries or even millennia (Constable, 1984), like the farming systems practiced in the Ethiopian highlands. To achieve quantities of soil carbon in excess of the “original level” implies that the agricultural system had greater productivity than the native system (FAO, 2004). The scenario that predicted the highest carbon storage rate was often associated with the introduction of trees in the system (Pearson et al., 2005). It was shown that the inputs of carbon from trees were more resistant to decomposition than those from herbaceous crops and caused marked increases in the level of soil carbon (Falloon and Smith, 2002).

In the current study, nine carbon input methods were examined and compared as shown in Table 3. The highest carbon input sources were from animal waste disposal. They represented city abattoir wastes where animal offals and other wastes were deposited on the fields. For this site the soil organic carbon content was 3.9% at the depth of 0 to 15 cm and 1.15% at the depth of 15 to 30 cm. The soil organic carbon content at the depth of 0 to 15 cm showed that there was excess nutrient deposition in the topsoil than in the subsoil. Carbon yield of animal waste at 0 to15 cm depth was the highest at 50.86 t/ha, and a carbon yield of 102 gm/cm^2/year, which indicated that there was carbon saturation after a certain level of storage (Table 3). Urban dairies and abattoirs were net importers of nutrients from rural farming systems, since excess deposition of nutrients was found in their systems (Yoseph et al., 2002). It is thus worth mentioning that an alternative mechanism has to be designed in order to balance nutrient flow from one system into another.

The second best practice which contributed to soil carbon input was crop rotation of cereals and pulses which was practised for a period of over three years. The crop rotation usually involved Teff, chickpea and wheat. Soil organic carbon for crop rotation was 2.13% at 0 to 15 cm and 1.02% at 15 to 30 cm depth. The carbon yield from crop rotation at 0 to 15 cm depth was 984 g/m^2/year (Table 3).

The third most important management practice for carbon input was the use of farmyard manure. The application of farmyard manure has long been treated as a valuable source of organic matter to enhance soil fertility (FAO, 2001). According to Kapkiyai et al. (1999), for the same carbon input, carbon storage was higher with manure application than with crop residues ploughed into the soil. The reason for this difference is that manure helps the formation and stabilization of soil macro aggregates (Whalen and Chang, 2002) and particulate organic matter (Kapkiyai et al., 1999). Manure is also more resistant to microbial decomposition than crop residues (FAO, 2001). The organic carbon content of a farmyard manure plot at 0 to 15 cm depth was 1.75% and at 15 to 30 cm it was 1.03%. The carbon yield of farmyard manure application at 0 to 15 cm depth was 351 g/m^2/year, which was one of the highest carbon content storage in a short period of time (Table 3).

The area that was fenced off from grazing had a carbon yield of 172 g/m^2/year as shown in Table 3. White et al. (1987) found a value of 21 g C $m^{-2}year^{-1}$, while Burke et al. (1995) reported an accumulation of 3.1 g C $m^{-2}year^{-1}$ in a short grass steppe on unimproved and abandoned crop fields. These results suggested that longer periods are required for more pronounced increases in total soil organic carbon under conditions of low productivity. The fenced land had a higher soil carbon level in terms of carbon yield per hectare than croplands that were subjected to different tillage types. This finding was supported by similar results reported by Franzluebbers et al. (2000) and Reeder and Schuman (2002). They found that there was an accumulation of litter in an enclosed area that was shielded from any interference in a semi-arid system. As a result the soil carbon level was higher in fenced land than in cultivated and grazed lands.

In general, the current soil carbon data were variable but slightly more beneficial and associated with the addition of different carbon inputs. A positive carbon yield value greater than base site (18.15 t/ha) indicated a response to carbon addition to the soil (Table 3). There was ample evidence on the benefits associated with using organic amendments on soils. These were based on GHG emission benefits as well as increased soil health in cases where organic amendments were frequently applied. A large number of studies have shown improvements in soil carbon concentrations when manures, composts or municipal bio-solids were applied (Albaladejo et al., 2008; Kong et al., 2005; Lal, 2007; Mann, 2008).

Mean values of carbon per hectare in Table 3 was estimated using the formula described by Pearson et al. (2005). The 9 sites were selected from the 12 sites with potential organic carbon addition and depletion, according to the recollection of the interviewees. Animal waste included bones, horns, stomach, intestinal contents and blood disposed from the slaughter houses. Minimum tillage refers to conservation tillage of ploughing only once at the depth of less than 18 cm using traditional ploughs known locally as *Maresha*. Deep tillage refers to mechanized tractor ploughing deeper that 20 cm. Crop residues from cereals were left over in the fields after grain harvest. The base or reference site was protected from human and animal interference.

Deep tillage was a carbon negative practice. Even with the addition of crop residues, deep tillage produced negative carbon storage as shown in Table 3. And in general, for all the top three carbon input practices, livestock products and by-products played a greater role in carbon storage and hence the role of livestock production in soil carbon storage is vital. At the same time, livestock played a big role in increased grain and straw yield.

Conclusions

This data were collected under uncontrolled environment where management practices were exercised by individual smallholder farmers. However, the data analysis showed a trend of carbon storage similar to those managed under controlled experimental situations. In general, the comparison among different land uses in line with their ecological history showed that grazing land had higher soil organic carbon, followed by fallow or undisturbed land. Grazing land had higher soil organic carbon because of dung and urine added into the soil and the ability of livestock to move organic material from place to place. The results of this study showed that although livestock affects the topsoil structure and vegetation they contribute much more by adding organic carbon into the soil than they are depleting. When different sources of carbon inputs were added into the soil and compared, it was found that animal waste, farmyard manure and crop rotation lead to a higher organic carbon yield in the soil. Similarly, if livestock are managed well they can play an important role in maintaining ecosystem balance.

It is important to suggest here that future research direction in carbon sequestration should be down scaled to community level resource management with emphasis on their positive and negative contribution to environmental sustainability. The research strategy should focus on experimental designs that produce empirical information for decision making on environmental protection by producers, service providers and policy makers.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Appendix 1

Sample sites used for the study

Site 1: This site was undisturbed and unploughed for over 30 years. The land was covered with grass and shrubs. It was chosen as a reference point in order to compare it with other alternative soil, crop and land management practices. According to FAO (2001), when the woody biomass increases it acts as a permanent carbon sink. Woody vegetation with deep and extensive root systems can access nutrients that are not accessible to crops to make them available to crop production through the litter, and fixing of nitrogen in leguminous plants (Lal, 2002).

Site 2: This site was a commercial farm with integrated vegetable, poultry and dairy production, where farmyard manure was used for seven years. The land was cultivated continuously without rest and farm operations were carried out with heavy duty machinery.

Site 3: This site had previous crop rotations of cereals and pulses, following a pattern of Teff-chickpeas-wheat-chickpeas for three consecutive years. Crop rotation is considered to be one of the agricultural management practices that recycle nutrients in the soil (Lal, 2001).

Site 4: The land was ploughed once and herbicides were applied during or just before seeding of cereals (Teff and wheat).

Site 5: This site was a smallholder plot closer to the homestead where backyard manure was regularly applied.

Site 6: This site was a field where compost was applied for four years. The compost was made up of household waste, ashes, leaf litter, and crop and vegetable residues.

Site 7: This site was a field where crop residues were well managed. The crop residues were left in the field and ploughed into the soil at the end of the cropping season.

Site 8: Chemical fertilizers were applied at the rate of 200 kg/ha of di-ammonium phosphate and 100 kg/ha of urea for cereals every year.

Site 9: This site was an open grazing land which was overgrazed, degraded and eroded.

Site 10: This site was previously degraded and fenced off for more than 15 years. It was adjacent to Site 9. Fencing is a well-known practice for replenishing nutrients in the soil. Fenced areas are usually hillsides that cannot be used for cultivation but are rested for certain periods of time until the vegetation is regenerated (Constable, 1984). Later on beneficiaries are allowed to utilize the vegetation on a cut-and-carry basis only.

Site 11: This site was used as an animal waste disposal pilot for over 40 years without any cultivation. The site had a gentle slope and the soil was highly eroded. Animal waste such as bones, blood and offals were deposited on this site in pits which were already full.

Site 12: This site was a swampy area where run-off from mountains leached away nutrients from the farms and deposited them in the swamp. Run-off from urban areas also accumulated there during the rainy season. When the swamp dried up during the dry season (March to June) the site was used for grazing.