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Full Length Research Paper

Determinants of livelihood diversification strategies: The case of smallholder rural farm households in Debre Elias Woreda, East Gojjam Zone, Ethiopia

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Smallholder rural farm households face an increasing need of looking for alternative income sources to supplement their small scale agricultural activities. However, livelihood diversification is determined by complex and yet empirically untested factors in Debre Elias Woreda. Thus, the aim of this study is to assess the determinants of livelihood diversification strategies in the study area. The data were collected through both primary and secondary data collection methods. The data were obtained from 160 sample household heads that were selected through a combination of two-stage, purposive and simple random sampling techniques. The descriptive statistics were used to identify the livelihood strategies and the livelihood assets. The finding of the survey result indicates that much of the rural households (61%) in the study area practice diversified livelihood strategies that combined on-farm activities with non/off-farm activities. Multinomial logit model applied to investigate the determinant factors influencing the households' choice of livelihood strategies. In this regard, the econometric analysis demonstrated that out of the total sixteen variables included in the model only seven variables including land size, livestock holding size, sex of household head, mass media, market distance, total annual household income, and urban linkage are found to be the significant determinants up to 10% probability levels. The results of this study suggest that both agricultural intensification and non/off-farm diversification should be strengthened to attain smallholder households' livelihood security.

Key words: Livelihood, off-farm, non-farm, diversification and smallholder.

INTRODUCTION

Agriculture is an important sector for majority of the rural populations' livelihood in developing countries. It has been the predominant activity for most rural households in Sub-Saharan Africa (SSA) which offers a strong option for spurring growth, overcoming poverty, and enhancing food security (World Bank,

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2008). In Ethiopia agriculture serves as the primary means of rural households' livelihood, which Contributes 45% GDP, more than 80% of employment opportunities and over 90% of the foreign exchange earnings of the country (MoA, 2010).

However, farming as a primary source of income has become failed to guarantee sufficient livelihood for most farming households in sub-Sahara African countries (Babatunde, 2013). This is because the agricultural sector in the sub-Saharan African countries is highly characterized by decreasing farm sizes, low levels of output per farm, and a high degree of subsistence farming (Jirstrom et al., 2011). The agricultural activities in rural Ethiopia is also dominated by smallholders, the majority cultivating less than 0.5 ha and producing mostly basic staples for the subsistence of their households. Furthermore, their agricultural activities are characterized by backward production technologies, small fragmented land size, irregular rainfalls, increasing soil erosion, land degradation, aridity in some regions and pervasive tropical diseases in the others (Arega et al., 2013).

Thus, the expectation that achieving the goal of reducing poverty only through increasing agricultural productivity and redressing the issues of access to key agricultural resources without non/off-farm livelihood diversification could not be successful in the sub-Sahara African countries (Emanuel, 2011). For these reasons there is a strong consensus that any development intervention to improve the livelihood and food security situation of the rural poor need to take agriculture along with the non/off-farm livelihood diversification, without undue preference being given to farming as the unique solution to rural poverty.

Similarly, a report from World Bank (2005) indicated that in Ethiopia the poor to survive tend to diversify in the form of daily wage laborer, and to mitigate production risk of rain fed agriculture, choose low risk but low return crops which contribute to poverty trap. Furthermore, Reta and Ali (2012) indicated that in rural Ethiopia if there had not been other sources of income apart from agricultural production, the land scarcity by the farmers coupled with agricultural risks could not generate enough income to feed household members and they cannot fulfill household needs. This suggests that the necessity of non/off-farm diversification in rural Ethiopia. From the point of view of reducing poverty and food insecurity in rural Ethiopia, it is extremely important to reduce vulnerability of the poor through diversification of the sources of their livelihoods. Thus, it needs the analysis of the livelihood diversification opportunities available in rural areas, the productivity and returns offered by such activities, especially those in which the poor are engaged, and an identification of the factors that may affect the ability of the poor to raise productivity and returns in their activities (Deverux, 2000). Furthermore, it is crucial to recognize that rural people have their own strategies to secure their livelihoods which vary from household to household depending on numerous factors such as their socio-economic status, education and local knowledge, ethnicity, and stage in the household life cycle (Wagayehu, 2004).

The rural farm households in East Gojjam zone in general and in the study area (Debre Elias district) in particular are producing cereal crops which have low economic returns and are highly dependent on the rain-fed agricultural production systems. Furthermore, due to the insufficient land resource to absorb the household's full labor force and the rain fall pattern variability, the smallholder farming households in the study area are becoming unable to meet the annual family food requirements. As a result, they are obliged to engage in low return daily labor works, firewood selling, petty trading, and handy craft activities (like weaving, blacksmith, and pottery works) to supplement their fragmented land based livelihoods and to cope up with the agricultural risks.

In the study area, even though, the smallholder rural farm households are involved in diverse livelihood activities, the households access to different income sources beyond agriculture vary across the ownerships of different livelihood assets. Moreover, the participation of smallholder farming rural households into non/off-farm activities is determined by complex and yet empirically untested factors in the study area. It is thus, so important to identify the determinant factors of non/off-farm livelihood diversification strategies in the study area to improve smallholder rural farm households' livelihood diversification strategies. Therefore, the objectives of this paper are 1) to examine the existing livelihood strategies pursued by the smallholder farming rural households; and 2) to identify the determinants of livelihood diversification strategies among smallholder farmers.

METHODOLOGIES

Descriptions of the study area

The study conducted in Debre Elias district which is found in East Gojjam Zone, Amhara National Regional state of Ethiopia. The district is located around 335 km northwest from the capital city of Ethiopia Addis Ababa. The mean annual temperature of the district ranges from 18-27°C and receives mean annual rainfall of 1150 mm Hg with an altitude which ranges from 800 to 2200 m above sea level (Achenef and Admas, 2012). The red soils are the dominant soil type and it is moderately fertile. The area is moderately dense population that ranges from 100 to120 people per km^2 (Debre Elias Woreda Agriculture and Rural Development office report, 2012). Based on the 2007 national census conducted by the Central Statistical Agency of Ethiopia (CSA), Debre Elias district had a total population of 82,150, of whom 41,109 were men and 41,041 women; and 7,928 or 9.65% were urban inhabitants. The majority of the inhabitants practiced Ethiopian Orthodox *Tewahido* Christianity, with 98.94% reported that as their religion, while 1.01% of the populations were Muslim. Small scale mixed agriculture is the dominant source of livelihood to the local people. Maize, Barely, Wheat, *Teff* and Potatoes are the principal crops, and from the livestock Cattle, Sheep and Goats are the dominant animals (Figure 1).

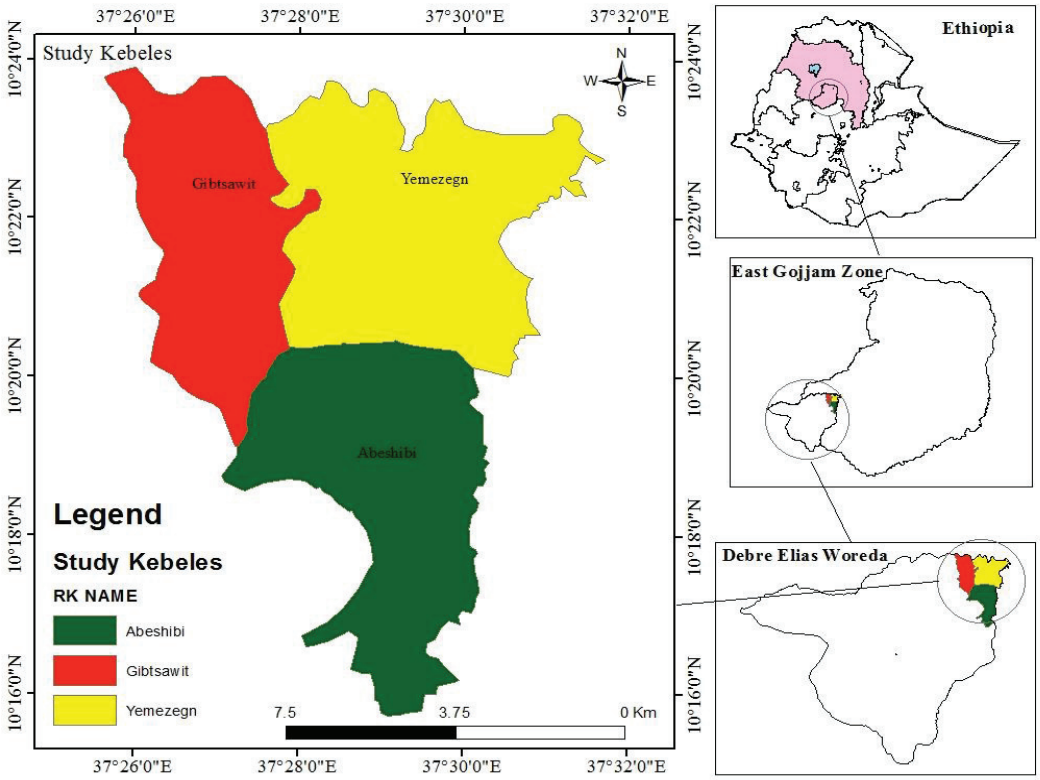

Figure 1. Location of the study area.

Data types and methods of data collection

The dataset for this study obtained from both primary and secondary data sources which are qualitative and quantitative in their nature. The primary data were collected from structured sample household head interviews. Structured sample household head interviews employed to generate household level data on the household assets, households' livelihood activities, strategies, and the determinants of livelihood diversification strategies. Key Informant Interviews (KIls), Focus Group Discussions (FGDs), and Observations were also employed to triangulate and support the primary data which obtained from the sample household head interviews. Secondary methods of data collection were reviewing published and unpublished research journals, books and theses; and assessing different records and reports of agriculture and rural development office on input and output prices, and crop and animal diseases.

Sample size and sampling techniques

The two stage sampling design was used to select the sample households. In the first stage, three *kebeles* (namely yemezegn, gibtsawit and abeshebi), where the large number of landless and smallholder farm households are prevalent, were purposively selected by the help of Debre Elias Woreda land use and administration office employees. In the second stage, according to the number of total households in each *kebele*, proportionate to size technique was applied to determine sample households size from each *kebele*. Ultimately, a total of 160 sample household heads were selected by using systematic simple random sampling technique (Table 1).

Methods of data analysis

To analyze the data, both descriptive and inferential statistics were used. The types and levels of assets a household own, types of shocks households faced, and constraints of livelihood diversification strategy choice were analyzed through descriptive statistics like maximum, minimum, mean, percentage, and standard deviations. Inferential statistics like Chi-square test and F-tests were used. Chi-square test was used to see whether there are significant differences among the different livelihood diversification strategies in relation to dummy/categorical variables. On the other hand, one way analysis of variance was used to see whether there are significant differences among the livelihood diversification strategies in relation to continuous variables. To analyze the determinants of livelihood diversification multinomial logit model was used. The descriptive and inferential data analyses were conducted using Statistical Package for Social Sciences (SPSS) version 20. The qualitative data obtained from focus group discussions and key informant interviews are stated in narrative form.

Econometric model specifications

In this study four mutually exclusive livelihood diversification strategies were identified. These include on-farm only, on-farm plus non-farm, on-farm plus off-farm, and on-farm plus off-farm plus non-farm. According to many literatures multinomial logit model is a widely used technique in applications that analyze polytomous response categories in different areas of economic and social studies. Wassie et al. (2008) stated that multinomial logit model is an important model to examine the determinants of household

Table 1. The distribution of total and sample households in the sample *kebeles*.

Kebeles	Total number of smallholder households	Total number of sample households
Yemezegn	920	62
Abeshebi	880	60
Gibtsawit	552	38
Total	2352	160

Source: Debre Elias Woreda land use and administration office, 2012.

livelihood strategy choices among the alternative livelihood strategies. Thus, to identify the determinants of smallholder farming rural households' decision to choose which livelihood diversification strategy should follow, multinomial logit model was used. The assumption is that in a given period at the disposal of its asset endowment, a rational household head choose among the four mutually exclusive livelihood strategies that could offer the maximum utility. Following Greene (2003), suppose for the i^{th} respondent faced with j choices, the utility choice j can be specified as:

$$U_{ij} = Z_{ij}\, \beta + \varepsilon_{ij} \qquad (1)$$

If the respondent makes choice j in particular, then U_{ij} is the maximum among the j utilities. So the statistical model is derived by the probability that choice j is made, which is:

$$\text{Prob}\ (U_{ij} > U_{ik}) \text{ for all others } K \neq j \qquad (2)$$

Where; U_{ij} is the utility to the i^{th} respondent from livelihood strategy j; and U_{ik} is the utility to the i^{th} respondent from livelihood strategy k. Thus, the i^{th} household's decision can be modeled as maximizing the expected utility by choosing the j^{th} livelihood strategy among J discrete livelihood strategies, that is:

$$\text{Max}_j = E\,(U_{ij}) = f_j\,(x_i) + \mathcal{E}_{ij}, \quad j=0,\ldots\ldots\ldots.J \qquad (3)$$

In general, for an outcome variable with J categories, let the j^{th} livelihood strategy that the i^{th} household chooses to maximize its utility could take the value 1 if the i^{th} household choose j^{th} livelihood strategy and 0 otherwise. The probability that a household with characteristics x chooses livelihood strategy j, P_{ij} is modeled as:

$$P_{ij} = \frac{exp\ (X'i\beta j)}{\sum_{j=0}^{J} exp\ (X'i\beta j)}\ ,\ J=0 \qquad (4)$$

With the requirement that $\sum_{j=0}^{J} Pij$ = 1 for any i

Where; P_{ij} = probability representing the i^{th} respondent's chance of falling into category j; X_i = Predictors of response probabilities; and β_j = Covariate effects specific to j^{th} response category with the first category as the reference. A convenient normalization that removes indeterminacy in the model is to assume that $\beta_1 = 0$ (Greene, 2003). So that $exp(X_i\beta_j) = 1$, implying that the generalized Equation (4) is equivalent to:

$$Pr\ (y_i = j/Xi) = \quad P_{ij} = \frac{exp\ (Xi\beta j)}{1+\sum_{j=1}^{J} exp\ (X'i\beta j)}\ , \quad \text{for } j = 0, 1\ldots J \quad \text{and}$$

$$Pr\ (y_i = 1/Xi) = P_{i1} = \frac{1}{1+\sum_{j=1}^{J} exp\ (X'i\beta j)} = \qquad (5)$$

Where; y = A polytomous outcome variable with categories coded from 0……. J.

Note: The probability of P_{i1} is derived from the constraint that the J probabilities sum to 1. That is, $P_{ij} = 1 - \sum Pij$. So similar to binary logit model it implies that we can compute J log-odds ratios which are specified as:

$$\ln\left[\frac{Pij}{PiJ}\right] = x'\,(\beta_j - \beta_J) = x'\,\beta_j,\ if\ J=0 \qquad (6)$$

The independent variables that expected to affect diversification of livelihood strategies of rural households in the study area are age of the household head, sex of the household head, dependency ratio, education level of the household head, land size of the household, livestock holding size of the household, market distance of the household, road distance of the household, access to irrigation, credit use, membership to cooperatives, extension contact, urban linkage, access to mass medias, total income and the amount of saving (Table 2).

RESULTS AND DISCUSSION

The findings of this research are organized based on the three major emergent themes, namely: types of livelihood strategies, livelihood assets, and the determinants of the choices of livelihood diversification strategies. It also presents and discusses the descriptive statistics, inferential statistics and econometric model results under each theme.

Household livelihood strategies

Livelihood strategies are the combination of activities that people choose to undertake in order to achieve their livelihood goals (Ellis and Allison, 2004). Livelihood activities are actions taken by the household to obtain household income. There are different methods of identifying livelihood strategies; but most commonly, economists group households' livelihood strategies by shares of income earned from different sectors of the rural economy (Brown et al., 2006). The approach adopted here is a simple one, but it effectively delineates households into different categories. To determine these strategies, it has been done by categorizing households who have followed similar strategies among the choices of farm, off-farm and non-farm activities. Therefore, here,

Table 2. The relationships between independent variables and dependent variables.

Variables	Nature	Value	Expected sign
Age of the hhs	Continuous	Actual age in years	+ve/-ve
Sex of the hhs	Dummy	1 if male and 0 if female	+ if male
Education level	Dummy	1 if literate and 0 if illiterate	+if literate
Dependency ratio	Continuous	The ratio of dependents to independents	+ve/-ve
Land holding	Continuous	The total land size in hectare(2012/13)	+if /-ve
Road distance	Continuous	Distance to nearest road in km	-ve if large dist
Market distance	Continuous	Distance to nearest market in km	-ve if large dist
Livestock holding	Continuous	Livestock holding size in TLU	+ve if large size
Extension contact	Continuous	Total no of contacts in a year(2012/13)	+ve if large
Access to irrigation	Dummy	1 if yes 0 if no	+ve if yes
Access to mass media	dummy	1 if yes 0 if no	+ve if yes
Access to credit	Dummy	1 if having urban friend/relatives 0 if no	+ve if yes
Crop risk	Dummy	1 if there was crop prdn risk and 0 if no	+ve if yes
Urban linkage	Dummy	1 if yes and 0 if no	+ve if yes
Cooperative member	Dummy	1 if yes 0 if no	+ve if yes
Total income	Continuous	The total income of a household(birr)	+ve if large

livelihood strategies grouped based on clustering the sources of income that were identified in the study area. In the study area, smallholder farm households obtained their household income from three major categories of livelihood activities which include on-farm, non-farm, and off-farm activities.

On-farm activities are focused on both crop production and animal husbandry activities. Different crops are grown in the study *kebeles*. Some of the major crops grown in the study area include *Teff*, Maize, Wheat, *Nouge*, Bean and Barely. Cattle, sheep and goats, donkey, horse, and poultry are reared for both income and consumption purpose. Livestock by-products which are valuable in the study areas are skimmed milk, butter, yoghurt, whey, and cheese. Key informants stated that livestock serve as a draught power, transportation service, and provides meat, milk, yoghurt, and cheese. Based on the survey result, the majority (92.25%) of the households were engaged in rearing at least one of the livestock types. In contrast to this, 6.75% do not participated in any one of the livestock rearing activities

Off-farm activities here refer to agricultural activities which take place outside the person's own farm. The activities include local daily wage labour at village level or the neighbouring areas in return for cash payment or the agricultural work at another person's farm in return for part of the harvest in kind. Natural resource based activities like firewood and charcoal selling are the other source of off-farm income for some households in the study sites. From the total sample households, only 36.5% of the households participated in off-farm activities while 63.1% households did not participated in any one of the off-farm activities. Again from the total off-farm participants' majority (55.9%) of the households engaged in agricultural wage labor activities.

Non-farm activities in this study refer to activities takes place outside the agricultural sector. It includes handicraft activities (weaving, spinning, carpentry, house mudding, poet making, remittance etc), petty trade (grain trade, fruits and vegetables trade), selling of local drinks, trading of small ruminants and cattle, and remittance transfers within and across nations. From the total sample households 46.3% of the households are engaged in non-farm activities while 53.7% of the households are not engaged in any one of non-farm activities.

Rural farm households in the study area have followed one, two or a combination of these livelihood activities to pursue their livelihood strategies. Accordingly, four livelihood strategies were identified which include the on-farm only strategy, on-farm plus non-farm, on-farm plus off-farm and a combination of on-farm off-farm and off-farm activities.

As shown in the pie chart (Figure 2), 39% of the households entirely depend on the on-farm only livelihood strategy, 17% households depends on on-farm plus off-farm, 21% of the respondents depends on on-farm plus non-farm, and the rest 23% of sample respondents depend on on-farm plus off-farm plus non-farm livelihood diversification strategy (Figure 2).

As shown in Table 3, the household survey witnessed that almost all average net annual income (88.9%) of the households were obtained from agricultural crop production and animal husbandry sources; and only 11.1% of the household's average net annual income are obtained from a combination of non/off farm activities. This is in consistent with national estimate of the country,

where more than 80% of the rural peoples' livelihood income gained from agriculture activities (CSA, 2010).

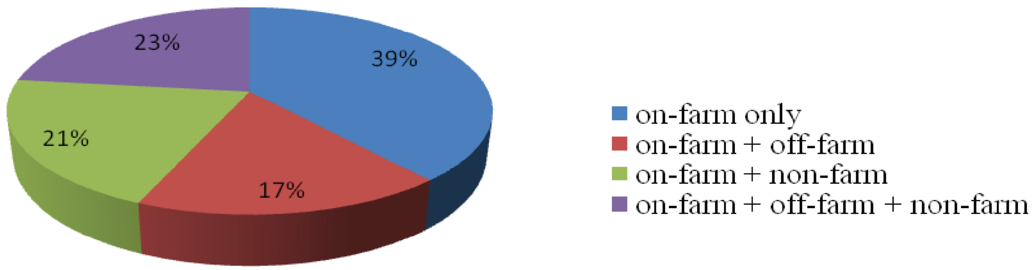

Figure 2. Livelihood diversification strategies the contribution of livelihood activities to the household income. Source: Own survey result, 2013.

Table 3. The contribution of each income sources to the total household net annual income.

Income sources	Sum	Mean	Percentage
Agricultural income	1,826,622.82	11,416.39	88.9
Off-farm income	58,915.5	368.2	2.9
Non-farm income	169,525	1,059.53	8.2
Total income	2,055,063.32	12,844.12	100

Source: own survey data in 2013.

According to the survey result the contribution of non/off-farm activities to the total household income was very low. In line with small percentage contribution of non/off-farm activities, key informants stated that non/off-farm activities in the study area are low paying and non ruminative activities. Moreover, they stated that rural farm households in the study area are engaged in non/off farm activities as part time activities.

Livelihood capitals/assets

Different researchers agreed that mainly there are five types of livelihood assets namely human, economic, social, natural, and physical capitals. Therefore, this study intended to assess the five types of capitals.

Natural capitals

In the agrarian economy, land is the basic livelihood asset for all farm activities and it is important for both crop and livestock production (Siraji, 2007). In the study area almost all household's livelihood income depends on agricultural production, so land is the main factor of production that can determine the livelihood of rural farm households. The overall average private land size of the sample respondents in the study *kebeles* is 1.4 ha.

The one way analysis of variance result has shown that there is a significant mean land size differences among the different livelihood strategies at less than 1% level of significance. The farm households who have large mean land size are depends on agricultural activities alone whereas farm households with smaller mean land size are engaged in non-farm and off-farm livelihood diversification strategies (Table 4). This is clearly indicates that the smallholder rural farm households are engaged into non/off-farm livelihood diversification strategies for push reasons. The smaller amount of land size could not support household food and other financial requirements and hence forces them to look for other alternative sources of income. Therefore, the above result suggests that improving the participation of smallholder farm households into profitable non/off-farm activities other than their farming activities is an effective way to reduce financial problems of smallholder farmers.

The key informants stated that the main means of accessing lands in the study area are acquisition from government land distribution, family gift, inheritance, land renting, crop land sharing and a combination of these.

Land renting and crop land sharing are the main means of accessing land for smallholder and landless households. The key informants stated that landless and smallholder households shared in land from farmers who have lands but no traction power, capital and labor to cultivate the lands. The share cropping agreements are held between the negotiating parties and local mediators depending on the crop type to be grown and land suitability for crops. In the study sites there is a locally accepted standard to rent in and out the land. The key informants reported that the current mean contract price of 1 *timmad* (one-fourth a hectare of land) of land for one year varies between 500-100 birr depending upon fertility and suitability to a particular crop types. In the study

Table 4. Summary statistics of the continuous variables by the choice of livelihood strategies.

Independent variables	Y=0	Y=1	Y=2	Y=3	Total	F-value
	Mean(SD)	Mean(SD)	Mean(SD)	Mean(SD)	Mean(SD)	
Extension contact	15(15.7)	15.5(16.7)	17.5(18.9)	10.2(11.6)	14.4(15.7)	1.343
Dependency ratio	0.99(0.82)	0.77(0.58)	0.78(0.89)	0.94(0.83)	0.90(0.79)	0.806
Road distance	2.85(1.76)	3.87(2.35)	3.38(1.71)	3.51(2.10)	3.31(1.99)	2.155*
Market distance	3.90(1.73)	4.91(2.06)	5.00(1.60)	4.93(2.04)	4.54(1.91)	4.001***
Land size	1.70(0.84)	1.30(0.96)	1.21(0.60)	1.05(0.51)	1.38(0.81)	6.477***
Age	36.85(10.4)	36.55(8.1)	37.96(9.09)	36.35(10.7)	36.87(9.74)	0.162
Livestock size	6.59(3.48)	4.73(3.85)	4.72(3.04)	3.42(2.47)	5.15(3.48)	7.740***
Amount of saving	665.9(1,933)	641.3(1,799)	797.1(2,488)	416.8(1,240)	626.2(1,871)	0.239***

Source: own survey, 2013. *, **, and *** indicates significant at 10, 5, and 1% probability level respectively. Y=0, Y=1, Y=2, and Y=3 represents on-farm only, on-farm plus non-farm, on-farm plus off-farm, and on-farm plus off-farm plus non-farm respectively.

kebeles the landless male focus group discussion participants stated the following regarding to access to land.

"We were born in this kebele. But, the government did not yet distribute the land to us to cultivate and as a result, we are not legally certified land owners. Thus, the only option available for us to access the land is inherit a piece of land from our family, crop land sharing and land renting. By taking this chance we would like to thank the local mediators who mediated the land owners and us (landless) in crop sharing arrangement and land renting. But now it has becomes difficult to live through crop sharing and land renting because the costs of land renting and agricultural crop production raw materials are escalating from time to time. Therefore, the concerned bodies should give us an immediate response."

Human capitals

The main indicators of human capital in this study are sex, age, extension contact, education level, and dependency ratio of the household heads. Regarding education level of the household head, the more educated household heads are engaged in non-farm and off-farm diversification strategies and chi-square test indicates that there is a significant association between education level of the household head and livelihood diversification strategies at less than 5% probability level (Table 5). This is because the better educated households are capable of calculating the costs and benefits of income generating activities and hence, enable them to engage in non/off-farm activities. Sex of the household head is also significant across livelihood diversification strategies at less than 5% probability level. As shown in Table 5, from the total 8.1% female headed households' majority (6.9%) of them are engaged in non/off-farm activities other than farming activities. This is attributed that females have easy access to participate into non/off-farm activities in the study area. According to informants view this is because the dominant non-farm and off-farm activities in the study area are female roles which includes preparing and selling local drinks (*Tella* and *Areka*), petty trading (like grain trading, orange and lemon trading by basket), and fire wood selling.

Social capitals

Membership to *Iddir,* religious meetings, self-help groups (like *Debo* and *Wonfel*), and cooperatives are found to be the most important social assets in the study area. According to the key informants' interview membership to *Iddir* enables the members to help each other, solve internal conflicts, and thus, reducing powerlessness. However, the survey result indicates that membership to *Iddir* found to be statistically insignificant variable (Table 5).

The informal social ties like friendships, relationships and neighborhood activities (like coffee ceremony) are found as the other social capitals in the study area. Key informants stated that livestock shares, crop land sharing, credit services and other benefits are shared based on social ties, friendship, relatives and membership to local institutions. The landless and smallholder farmers who need additional unit of land for crop production makes agreement with those households who have land but lack inputs, traction power and labor are mediated through local institutions and local elders.

With regard to urban linkage, the respondents were enquired as to whether they have friends and relatives in the town, majority (52.5%) of the respondents confirmed that they have friends and/or relatives in the town and the rest 47.5% of the respondents have no relatives neither friends' in the town. Chi-square test result shows that urban linkage is significantly different among livelihood diversification strategies at 5% probability level. This is because friends and/or relatives in the urban area offered information on the non/off-farm employment opportunities

Table 5. Summary of statistics for the categorical variables by choice of livelihood strategies.

Variables	households Response	Y=0	Y=1	Y=2	Y=3	Total	χ^2 value
Sex of hhs	Female	1.2	3.8	1.2	1.9	8.1	6.501**
	Male	37.5	16.9	16.2	21.2	91.9	
Education level	Illiterate	15.0	5.6	6.9	8.8	36.2	21.983**
	Basic education	16.9	8.8	8.1	7.5	41.2	
	1st cycle primary school	3.8	3.8	1.2	2.5	11.2	
	2nd cycle primary school	1.2	0.0	0.6	4.4	6.2	
	Secondary school and above	1.9	2.5	0.6	0.0	5.0	
Land tenure	Secured	32.5	17.5	11.2	16.9	78.1	5.783
	Not secured	6.2	3.1	6.2	6.2	21.9	
Member to Iddir	Yes	38.8	20	17.5	22.5	98.5	0.454
	No	0	0.6	0	0.6	1.5	
Mass medias	Yes	16.2	13.2	6.2	13.2	48.8	6.933***
	No	22.5	7.5	11.2	10.0	51.2	
Irrigation	Yes	6.9	5	2.5	3.8	18.1	1.207
	No	31.9	15.6	15	19.4	81.9	
Cooperatives	Yes	35.6	18.8	15.6	20.0	90.0	0.812
	No	3.1	1.9	1.9	3.1	10.0	
Saving account	Yes	12.5	8.1	7.5	8.8	36.9	1.103
	No	26.2	12.5	10.0	14.4	63.1	
Credit access	Yes	21.9	15.0	11.9	15.6	64.4	3.014
	No	16.9	5.6	5.6	7.5	35.6	
Urban linkage	Yes	18.8	13.8	8.8	11.2	52.5	3.367**
	No	20.0	6.9	8.8	11.9	47.5	

Source: Own survey, 2013. *, ** and *** indicates significant at 10, 5 and 1% probability level respectively. Y=0, Y=1, Y=2, and Y=3 represents on-farm only, on-farm plus non-farm, on-farm plus off-farm, and on-farm plus off-farm plus non-farm respectively.

to the rural peoples.

Financial capitals

In the study area the main indicators of financial capital are crop production income, livestock rearing income, off /non-farm income, credit, and saving. The average annual agricultural income, off farm income, and non-farm income of a household were 14,887.84, 368.22 and 1,064.84 birr ETB respectively.

Livestock holding in the study area is an important source of financial income. Key informants stated that a large number of livestock holding is the indicator of wealth and prestige in the study area. The mean livestock holding are significantly different across different livelihood diversification strategies at less than 1% probability level (Table 4). This is because a small number of livestock holding do not enable them to generate enough income to support family needs which cause them to participate in non/off-farm activities other than farm activities.

The other source of financial income is saving. As shown in Table 4, the amount of saving is significantly different across livelihood diversification strategies at 1% level of significance. This is because a large amount of saving enables the farm households to invest in non-farm activities. The key informants explained that in the study area, *Ekub* is the main scheme that rural households used to accumulate or save money by rotation/turn. This is essential to start petty trading or investing in new non-farm activities. In this regard one key informant participant claimed the following idea.

"I was the member of Ekub institution with 13 other members and we saved 50 birr weekly. After I accumulated three thousand ETB in my turn I started trading in small ruminants at the occasions of religious holidays and in the annual festivals. My wife also was engaged in local beverages (like Tella and katikala) preparation and trading. By now we are able to support our family annual incomes through the participation of the non-farm activities other than our agricultural production."

Physical capitals

In this particular study physical capital includes access to mass media, road distance, market distance, and access to irrigation. The survey result shows that 48.8% households have had access to at least one of the mass medias like listening to radio and watching television. From the total households who have access to mass media a considerable percent of households (32.6%) are participants of non/off-farm livelihood diversification (Table 5). Furthermore, the chi-square test result shows that access to mass media is significantly different among livelihood diversification strategies at 1% level of significance. This reflects that access to mass media enhances rural farm households' information on non/off-farm diversification opportunities.

The mean road and market distance for only on-farm livelihood strategy participants are lower than the mean market and road distance for non/off-farm livelihood diversification participants (Table 4). This indicates that households who are residing nearer to road and market center are depending only on agriculture rather than non/off-farm livelihood diversification. On the other hand those households who reside far from the market center are involved more on off-farm diversification. According to key informants this is because an easy access to roads and market facilitates movement of farm inputs and outputs in a cost effective way which makes households profitable from the agricultural production in turn it attract farm households to depend only on agriculture. They also informed that those households who reside far from market center may engaged low paying off-farm activities to solve the liquidity problems. This result is contradicted with Gebrehiwot and Fekadu (2012) result which shows that easy access to market and roads reduces transaction costs, and enhance non-farm employments.

Vulnerability contexts in the study area

Vulnerability refers to both exposures to unfavorable developments like rainfall failure, or livestock loss that would cause considerable harm to livelihood; as well as the lack of means to cope with the loss without losing the household's livelihood base (Chambers, 2006). This definition was directly applied to this study.

Trends

The high dependency of people on natural resources for subsistence needs coupled with high rates of deforestation for commercial interests renders most of the forest communities' people vulnerable to natural and financial shocks (FAO, 2005). According to the key informants discussion in the study area also due to the non-availability of other alternatives all of the farm households use forests and woods for cooking and heating, for the construction of new houses and/or to repair the existing ones, and for charcoal production purpose. Therefore, the declining trend of forest in the study area is one cause of vulnerability.

Natural resource degradation is another type of vulnerability. Almost all of key informants agreed that soil fertility is becoming reduced. The cost of agricultural inputs is increasing from time to time. Informants stated that around 8 or 9 years ago the cost of 50 kg DAP was only 70 birr but now it has scored up to 700 birr per 50 kg DAP.

Shocks

The results of this study shows that crop pests and diseases like stock borer, smut, warms, locust, lack of grazing land, and livestock disease coupled with less veterinary service coverage are the most common problems raised by the participants. As shown in Appendix Table 5, 74.1% respondents reported that crop pests and diseases are the major challenges of crop production. Key informant participants also strongly complained that crop pests and disease, locust, earth warm, stock borer, and smut are the most common problems.

According to the survey result, 23.2% of the respondents reported that lack of grazing lands, animal diseases, lack of drinking water for animals, and lack of veterinary medicine are the commonest problems in the study area (Appendix Table 6). Key informants discussion ensured that Trypanosomosis, Anthrax (*kureba*), Bloating (*wajima*), Brucellosis (abortion), Mastites, Ticks (*mezhiger*), and animal foot and mouth disease are the highly prevalent livestock rearing challenges (Appendix Tables 3 and 4).

Seasonal ties

The spatial-temporal distributions of elements of climate determine cropping pattern, cropping calendar and type of livestock to be raised (Degefa, 2005). The high dependency of rural people on rain fed agriculture and limited irrigation practices worsen the vulnerability of the people to climate change (Dula, 2007). According to the woreda agriculture and rural development office report (2012) from the total 39,100 ha rain fed and irrigated land only 2,696 ha (6.7%) of the total lands were irrigated in the 2012/2013 production year. This indicates that almost all people were depending on rain fed agriculture with minimal irrigation.

Key informants and group discussants have shown that engagements in non/off farm activities are mostly seasonal and done on a part-time basis. The main cropping season is the summer (May to December) season which largely dominated by agricultural activities on own farm especially in times of good rains. Similarly, Haggablade et al. (2007) found that in most developing countries off-farm activities were highly seasonal, and fluctuates with availability of agricultural raw materials.

Econometric model results on the determinants of livelihood diversification

Before running the multinomial regression logit model it is necessary to conduct a multicollinearity test. Thus, variance inflation factor was used to test the multicollinearity problem among continuous variables and contingency coefficient was computed to see the degree of association among dummy/categorical variables. The larger value of Variance Inflation Factor (VIF), usually values exceeds 10 indicates a serious multicollinearity problem. The value of contingency coefficient ranges between 0 and 1. A value close to 0 indicates weak association and a value close to 1 indicates presence of strong association. Therefore, contingency coefficient value of 0.75 or above indicates a stronger relationship between explanatory variables and shows presence of multicollinearity (Gujjirati, 2003). The multicolticollinearty test results have shown no serious problems among the continuous and categorical independent variables (Appendix Tables 1 and 2).

Discussions of the econometric model results

Here, the researcher tries to estimate and present findings on the factors that determine choices of different livelihood strategies. Multinomial logit model regression shows the determinant variables for each category versus the base category. Accordingly, the base category is the household who choose on-farm only as a livelihood strategy. This strategy is used as a reference category. The STATA version 11 was used to generate the parameter estimates. The parameter estimates of the multinomial logit model give only the direction of the effect of explanatory variables on the dependent variable, but the estimates neither stand for the actual size of change nor the probabilities (Chilot, 2007). However, the marginal effect measures the expected change in the probability of a given choice that has been made in relation to the unit change in the explanatory variable. Thus, the predicted probabilities are better interpreted using the marginal effects of the multinomial model (Greene, 2003).

The multinomial logit model analysis shows that out of the total sixteen explanatory variables entered into the model seven variables including sex of the household head, land holding size (ha), market distance (km), livestock holding size (TLU), access to mass media, total household income, and urban linkage were the significant determinants of livelihood diversification strategies up to 10% level of significance (Table 6).

Land size of the household

As hypothesized, land size is significantly and negatively related to on-farm plus non-farm, on-farm plus off-farm, and on-farm plus non-farm plus off-farm livelihood diversification strategies equally at less than 1% level of significance with respect to on-farm only as a reference category. The negative coefficients indicated that the households with large land size are participated less in non/off-farm livelihood diversification strategies and participated more on on-farm only livelihood strategy. Keeping the other factors remain constant, the probability of smallholder farm households livelihood diversification into non-farm, off-farm, and combined off-farm and non-farm activities other than agriculture decrease by 21.9, 15.3 and 19% respectively as the land size increases by one hectare. The possible reason can be a smaller amount of cultivated land is not enough to the households to make a sufficient living from farm production alone, causing them to look for supplementary non/off-farm income generating activities. Similarly, Adugna (2008) and Fikru (2008) stated that farmers with smaller land size are involved in off-farm diversification activities because of shortage of land to support their livelihood. On the contrary to this result, Kebede et al. (2014) found that the total cultivated land size has positive and significant influence on off-farm participation perhaps households with better holding opted for additional income in casual laborer works to smoothen their farm operations.

Sex of the household head

This variable opposed the pre-assumed expectations, sex has a negative and significant relationship to on-farm plus non-farm livelihood diversification strategy choice at 5% level of significance. The negative coefficient

Table 6. Multinomial logit model estimates of households' choice of livelihood diversification strategies.

Variables	Households livelihood diversification strategies					
	On-farm + non-farm		On-farm + off-farm		On-farm + off-farm + non-farm	
	Coef (SE.)	Marg.effct	Coef (SE.)	Marg.effct	Coef (SE.)	Marg.effct
SEX	-2.610** (1.309)	-0.547	-0.276 (1.348)	0.111	0.291(1.265)	0.184
AGHHS	0.053 (0.036)	0.004	0.048 (0.032)	0.003	0.053 (0.032)	0.005
EDCTION	-0.057(0.690)	-0.001	-0.139 (0.602)	-0.018	-0.060 (0.591)	-0.001
IRRIGAT	0.506 (0.727)	0.070	-0.239 (0.790)	-0.070	0.320 (0.739)	0.048
DPNRT	-0.156 (0.384)	-0.026	-0.117 (0.379)	-0.025	0.211 (0.337)	0.050
LAND	-2.779*** (0.724)	-0.219	-2.194*** (0.719)	-0.153	-2.259***(0.701)	-0.190
ROAD	0.255 (0.233)	0.040	-0.140 (0.220)	-0.033	0.019 (0.216)	0.001
MARKET	0.280(0.252)	-0.001	0.591** (0.235)	0.064	0.480** (0.236)	0.046
MASMEDIA	1.194*(0.667)	0.112	0.026 (0.610)	-0.099	1.261**(0.595)	0.177
CREDIT	0.938 (0.767)	0.093	0 .513 (0.633)	0.036	0.354 (0.630)	0.005
URBLNK	1.523** (0 .659)	0.139	0.729 (0.620)	0.013	1.098*(0.597)	0.100
TOTINCOM	0.0002*** (0.001)	0.001	0.001**(0.001)	0.699	0.001* (0.001)	0.311
LIVESTOCK	-0.408*** (0.142)	-0.033	-0.233*(0.125)	-0.005	-0.385*** (0.127)	-0.042
EXTENSION	0.015(0.020)	0.001	0.027(0.018)	0.004	-0.002 (0.020)	-0.002
COOPER	-0.166(1.174)	0.009	-0.317(1.083)	-0.022	-0.447(1.004)	-0.061
CRPRSK	0.614(1.020)	0.102	-0.779 (0.876)	-0.150	-0.319 (0.894)	-0.026
Const	-2.930(1.918)		-2.001(1.791)		-2.421(1.717)	

Number of obs.=160, LR chi2(48)=108.19, Prob > chi2= 0.000***, Log likelihood= -159.758, Pseudo R2= 0.253. Source: Own survey, 2013. ***, **, * indicates significant at 1, 5 and 10% probability levels respectively.

indicates that male headed households are more probably engaged in on-farm only livelihood strategy and less probably engaged in non-farm livelihood diversification strategy. If the other factors remain constant, the likelihood of adopting the on-farm plus non-farm strategy in favor of male households' decreases by 54.7% and the opposite is true for female headed households with reference to the on-farm only strategy. The possible reason could be in the study area due to the gender division of labor male headed households are mostly depends on on-farm activities than female headed households. According to key informants, in the study area farming activities like plough are male roles and thus male headed households are usually involved in farming only. On the other hand, female headed households do not plough their land by themselves unless they hired male labor. Thus, they arranged their land for sharecropping and involved in non-farm activities other than their sharecropping income. Moreover, the common non-farm activities like preparing and selling local drinks, spinning and poetry work, petty trading like grain and fruits trading, and selling firewood are women roles and thereby, women engaged in these activities. On the contrary to this result, according to Amare and Belaineh (2013) sex of a household head found to have a significant and positive relation with non/off-farm wage, self and mixed self-wage employment activities participation at 1, 5 and 1% levels of significance, respectively revealing that the male headed households were able to participate in all non/off-farm employment activities compared to female headed households because women are busy by domestic activities.

Mass media

As hypothesized, mass media is positively and significantly related to on-farm plus non-farm and a combination of on-farm, non-farm, and off-farm livelihood diversification strategies at 10 and 5% level of significance respectively. The positive coefficient indicates non/off-farm livelihood diversification is high in favor of the rural households having access to media. On the other hand, households having access to mass media are less likely to participate in on-farm only livelihood strategy. Holding the other factors constant, in favor of the respondents who listen to the radio and watching the television once in a week increases the probability of smallholder farming rural households' participation into on-farm plus non-farm, and a combination of three (on-farm, off-farm and non-farm) livelihood diversification strategies by 11.2 and 17.7% respectively. The possible reason could be that the access to mass media may improve rural households' information on non-farm opportunities. Similarly, Emanuel (2011) found that households who listen to a radio and watching TV at least once in a week were found to have a greater likelihood to be engaged in non-farm work. Because access to TV and radio enhances non-farm activities information which enable the rural farm households to participate in non-farm livelihood diversification strategy.

Urban linkage

As hypothesized having liaison/connection with the urban area peoples (urban linkage) has a positive and significant influence on on-farm plus non-farm, and a combination of the three (on-farm plus non-farm plus off farm) livelihood diversification strategies at less than 5 and 10% level of significance in the reference to on-farm only strategy. The positive coefficient indicates that if the other factors are remain constant, the probability of the households who have connection with urban dwellers probability of livelihood diversification into on-farm plus non-farm, and a combination of the three (on-farm plus non-farm plus off-farm) activities the marginal effects increased by 13.9 and 10% respectively. This could be that having friends/relatives in the urban area improves the farm households' information on non/off-farm livelihood diversification opportunities. This suggests that improving rural-urban linkages could facilitate non/off-farm livelihood diversification.

Livestock holding

Livestock holding in TLU is negatively and significantly related to on-farm plus off-farm plus non-farm livelihood diversification strategy at 1% level of significance. Moreover, as the livestock numbers in TLU increases by one unit, the likelihood of smallholder rural farm households' choice of combining on-farm, off-farm, and non-farm livelihood diversification strategies decreases by 4.2%, provided that the other factors remain constant. On the other side, a unit TLU increase in livestock increases the rural farm households adoption of on-farm only livelihood strategy. When the livestock size increase by one TLU the probability of households' choice of on-farm plus non-farm, and on-farm plus off-farm livelihood strategies decrease by 3.3 and 0.5% respectively, provided that the other factors remain constant. In the study area, livestock are the source of cash income. Thus, the large livestock holding creates better opportunity to earn more income from livestock production. Therefore, households who obtained the required amount of cash from livestock may not need to involve in non/off-farm activities for additional income whereas farmers with lower livestock holding may be obliged to diversify livelihoods into off-farm and non-farm activities to fulfill household needs. Similarly, Adugna (2008) and Yisehak et al. (2014) found livestock holding has negative and significant relation with non/off-farm livelihood diversification strategies. On the contrary to this result, Amare and Belaineh (2012) found that livestock holding significantly and positively influence participation in wage activities at 5% level of significance. Households with more livestock holding do have the capacity to participate in lucrative non/off-farm employment activities than those households with no or small size livestock holding.

Market distance

On the contrary to the hypothesis, market distance is positively and significantly related to on-farm plus off-farm, and a combination of on-farm, non-farm and off-farm livelihood diversification strategies equally at 5% probability level. As the market distance increases by 1 km, the likelihood of the farm households participation into on-farm plus off-farm, and a combination of on-farm, non-farm, and off-farm livelihood diversification strategies increase with 6.4 and 4.6% respectively, and decrease for on-farm only strategy provided that the other factor remains constant. The possible reason could be that the closer to the market center reduce the transaction costs of acquiring agricultural inputs and profitably selling outputs and hence, good profits may attract them to depend on agriculture only. The other reason could be as the farm households located far from the market center the probability of farm households' engagement into agricultural daily wage activities are higher to resolve liquidity problems. Furthermore, the closer to the market center may expose rural non-farm participants to high competition from factory-made substitutes sold in rural market centers which may lessen rural households' non/off-farm livelihood diversifications. On the contrary to this result, Amare and Belayneh (2012) stated that market distance and non/off-farm diversification had positive and significant relationship because residing nearer to the market enables farm households to engage in non-farm activities (like petty trading and shop keeping).

Total annual household income

As expected, this variable found to have positive and significant influence on households choice of on-farm plus non-farm, on-farm plus off-farm, and combination of on-farm, non-farm and off-farm livelihood diversification strategies at less than 1, 5 and 10% probability level respectively. The positive coefficient implies that households with large total household income are more likely to diversify the livelihood strategies into non-farm and/or off-farm activities. The possible reason can be farm households with large total income can invest in alternative livelihood strategies, especially in non-farm activities. From the model result, other things being constant, the marginal effect reveals that the probability of a household diversifying into non-farm, off-farm, and combined non-farm and off-farm activities increased by 0.1, 69.9 and 31.1%, respectively, for those farm households with more level of income. Similarly, Yisehak et al. (2014) found that the total annual cash income have positive and significant relationship with on-farm plus non-farm; and a combination of on-farm off-farm and non-farm activities equally at less than 5% probability level. According to their justification the adequate income sources can overcome financial constraints to engage in alternative non/off-farm activities.

CONCLUSIONS AND RECOMMENDATIONS

Agriculture is found to be the dominant economic activity and contributes 89.9% of the smallholder farm households' total annual household income in the study area. Thus, to improve the smallholder farm households income due attention should be given to agricultural intensification and commercialization of agricultural crops.

Different crop pests and diseases as well as animal diseases are highly existent in the study area. Therefore, to improve agricultural productivity the concerned bodies should design crop and animal disease controlling mechanisms. The survey result shows that despite the high level of smallholder rural farming households' participation in non/off-farm activities, the contribution of non/off-farm income to total household income is small compared to farm income. This reflects that the smallholder rural farming households in the study area are engaged in low profitable, low return and non rewarding non/off-farm activities. Therefore, the smallholder farm households' participation in lucrative non-farm activities needs to be addressed.

Women dominate many of the non-farm activities in the study sites such as household-based food processing, local drink sales, local crafts (pottery and sewing) and petty trading. Therefore, giving financial and vocational assistance to women by the governmental and non-governmental agencies could accelerate rural livelihood transformation from mere agricultural production to livelihood diversification into non/off farm activities.

In the study area majority (61%) of the sample households are participated in non/off-farm livelihood diversification strategies to pursue their livelihood income. This indicates that in the study area, the agricultural crop production and livestock rearing alone without non/off-farm livelihood diversification is not enough to provide smallholder households income. The econometric analysis demonstrated that the smallholder farming households in the study area are likely to have a diversified livelihood when they have access to mass media, creating relationship with urban peoples, more expansion and recognition of female non-farm roles. Thus, the concerned bodies should give due attention to the significant variables. Thus, it is recommended that the concerned bodies should encourage rural-urban linkages and address the outreach of listening to radio through the expansion of electricity facilities and road networks in the study area.

Conflict of Interest

The authors have not declared any conflict of interest.

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Appendix Table 1. Contingency coefficients for categorical independent variables.

Variables	SEX	EDCTN	IRRIG	MASMID	CREDIT	URBLNK	COOP	CRPRSK
SEX	1							
EDCTIN	-0.034	1						
IRRIGAT	0.081	0.152	1					
MASMID	0.061	0.267**	0.158*	1				
CREDIT	0.352**	-0.045	0.079	0.177*	1			
URBLNK	0.129	0.194*	0.090	0.202*	0.129	1		
COOPR	0.358**	-0.078	0.049	0.158*	0.274**	0.100	1	
CRPRSK	0.194*	-0.049	-0.154	0.012	0.125	-0.084	0.088	1

Source: Own survey result, 2013.

Appendix Table 2. The variance inflation factors of continuous independent variables.

Continuous variables	Collinearity statistics	
	Tolerance	VIF
AGE	0.830	1.205
DEPNTR	0.914	1.094
LAND	0.384	2.606
ROAD	0.421	2.375
MARKET	0.400	2.498
TOTINCOM	0.350	2.857
LIVESTOCK	0.489	2.043
EXTENSION	0.878	1.139

Source: own survey, 2013.

Appendix Table 3. Conversion factors used to estimate tropical livestock unit.

Type of livestock	TLU	Type of livestock	TLU
Cow and ox	1	Calf	0.4
Heifers	0.75	Sheep/goats	0.1
Bull	1	Chicken	0.013
Horse/mule	0.8	Donkey	0.5

Source Storck et al. (1996) cited in Adugna (2008).

Appendix Table 4. Conversion factors used to estimate adult equivalent (AE).

Age categories	Male	Female
<10	0.6	0.6
10-14	0.9	0.75
15-50	1	0.8
>50	1	0.8

Source: Storck et al. (1991) cited in Siraji (2007).

Appendix Table 5. The challenges of crop production.

Challenges	Frequency	Percent	Valid percent
No challenges reported	16	10	10.1
Crop pests and disease	117	73.1	74.1
Lack of rain fall	4	2.5	2.5
Crop disease and lack of rain fall	3	1.9	1.9
Crop disease, ice and frosts	5	3.1	3.2
Crop disease, ice, frosts, and lack of rainfall	3	1.9	1.9
Shortage of capital, labor and land	10	6.3	6.3
Sub Total	158	98.8	100.0
Not grown crops	2	1.2	
Total	160	100	

Source: Own survey, 2013.

Appendix Table 6. Problems for livestock rearing.

Problems	Frequency	Percent	Valid percent
No problem reported	2	1.3	1.3
Lack of grazing land only	36	22.5	23.2
Lack of veterinary medicine only	3	1.9	1.9
Presence of animal diseases only	8	5.0	5.2
Lack of grazing land plus drinking water	10	6.3	6.5
Lack of grazing land plus veterinary medicine	16	10.0	10.3
Lack of grazing land plus animal disease	15	9.4	9.7
Lack of grazing land and drinking water plus lack of veterinary medicine plus different animal diseases	36	22.5	23.2
Lack of grazing land plus drinking water plus veterinary medicine	12	7.5	7.7
Lack of grazing land plus lack of veterinary medicine and water	12	7.5	7.7
Absence of improved varieties plus presence of animal diseases	2	1.3	1.3
Lack of grazing land plus lack of improved varieties	2	1.3	1.3
Others(like lack of labor and skill to manage)	1	0.6	0.6
Total	155	96.9	100.0
Not reared livestock	5	3.1	
Total	160	100	

Source: own survey, 2013.

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Full Length Research Paper

Effect of salinity on seed germination of *Abelmoschus esculentus*

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Salinity is one of the most common abiotic factors in the world and which strongly limits crop yields. Germination under salt stress could be a quick test to look for salt-tolerant plants. Our study was carried out on the seeds of okra (*Abelmoschus esculentus* L.), a mallow native to East Africa, known for its fruit used as a vegetable, rich in vitamin C and calcium. The objective of this experiment is to study the effect of salt stress on germination using NaCl at different concentrations. The seeds are germinated at a temperature of 25°C. The results obtained show that the first sprouts appear from the second day after planting seeds for the controls as for stressed seeds salinity; changing germination accelerates with decreasing salt concentration. By cons, salinity does not affect the final rate of germination but rather influences the duration of the germination by lengthening when the medium of the salt concentration increases.

Key words: *Abelmoschus esculentus* L., tolerance, germination, salt stress, glycophytes.

INTRODUCTION

Climate changes made since ten years are constraints to the growth and development of plants in all regions of the world in general (Higazy et al., 1995) and especially the Mediterranean countries where drought has long been observed, has clearly led to soil salinization process (Gaucher and Burdin, 1974), consequently the first stage of the life of plants namely seed germination conditions its future.

Indeed germination becomes a determining factor for the success of plant growth in saline environments (Khane and Rizvi, 1994). Being a very complex biological phenomenon, germination requires a good understanding of the factors of precocious germination of the seeds that would classify genotypes (Obendorf and Wettanfer, 1984) The duration of germination which is also often cited as a criterion possible effect and the gap between the first and last germinated seeds that affects the success of the plant (Ungar and Badger, 1989).

In order to enhance agricultural production *Abelmoschus esculentus* L. in Mediterranean regions, it is necessary to better understand the species. Originally from Africa, (Macleod and Ames, 1990), okra is a Mallow, known since the year 1216 B.C. for its fruit used as a vegetable (MACLEOD and AMES, 1990) and all its organs which are of great interests (Grieve, 1984).

To evaluate the response of seeds of this glycophyte, action salinity, we propose initially to study how early germination, then a seed germination kinetics, germination

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rate and finally the final rate seed germination.

MATERIALS AND METHODS

Plant material

The seeds used in germination tests were collected during the month of July 2010 in the region of Nechmaya east of Algeria. Once harvested, the seeds are carefully dusted off and stored in the dark at 5°C for dormancy. After 6 months, the seeds are ready for manipulation. The seeds are disinfected with sodium hypochlorite 1% by soaking them for 3 minutes, then rinsed with distilled water several times to remove traces of chlorine. The seeds used for the germination tests are divided into lots of 10 seeds placed in sterile petri dishes of 10 cm diameter filled with two layers of filter paper.

The Petri dishes are placed in an oven with a thermostat ensuring adequate thermal stability (± 1°C). In each, Petri dishes are paid 7 ml distilled water to control seeds and the same volume of saline for other seeds. Was used three treatments NaCl: to 50 meq.l^{-1} (2.72 g.l^{-1}), 100 meq.l^{-1} (5.45 g.l^{-1}) and 200 meq.l^{-1} (10.9 g.l^{-1}).

In this study, the authors considered that a seed germinated when the radicle had pierced the shell and became visible to the naked eye as defined Come (1970). During the observations, the authors have taken care to imbibe the culture medium, basting as needed. The atmosphere of the oven is kept moist by placing in the bottom of it full of water tray.

At the onset of the tip of the radicle through casings, we proceeded steadily counting sprouts. When the germination rate stabilizes, we completed our observations.

Early germination

In general, each species has a specific germination early to his nature, because even placed in the same experimental conditions the early emergence of the radicle through the membrane will not take place simultaneously in all the seeds (Renard and Quillec, 1975).

This is determined when we see the first sprouts. In this case, early germination is expressed by the rate of the first sprouts corresponding to the time interval between the planting of seeds and raw seeds germinated (Belkhodja, 1996).

Estimated germination

Based on the total number of seeds used (Nt), we calculate the percentage of germinating seeds (Ni) according to the relation: Tg = 100 × Ni / Nt (Tg: germination rate).

Germination time

When the seeds placed in the optimum conditions do not germinate immediately after sowing, are said to represent a germination period (Come, 1970). And germination time is the time (in days) between the first time sprouts and end of germination.

Germination rate

It characterizes the variation in time of the germination rate at the onset of the first peak of the radicle of a seed to the stability of the germination. The authors used the formula of Kotowski (1926) to calculate the coefficient of velocity (Cv) and germination average time (Tm):

Cv = (N1 + N2 + N3 + ... + Nn / N1T1 N2T2 + + + ... N3T3. NnTn +) x 100
N1T1 Tm = + + N2T2 N3T3 + ... + NnTn / N1 + N2 + N3 + ... + Nn

N1: Number of seeds germinated at time T1; N2: Number of seeds germinated at time T2; N3: Number of seeds germinated at time T3 and Nn: Number of germinated seeds at time Tn.

Germination daily rate

The daily germination rate is calculated based on the number of newly germinated seeds at each observation.

Final germination

This rate is obtained by adding the daily rates of sprouts from the beginning to the end of germination.

Statistical treatment

For the control group and for each of the treatment applied concentrations were taken five repetitions, and obtained experimental data were statistically analyzed by Student's test at the 5% significance level (Snedecor and Cochran, 1984).

RESULTS

Early germination

Seed germination decreases as the salinity increases in concentration (Figure 1). Indeed, the earliest seeds for sprouting are those soaked in distilled water because the highest rates are achieved (90%) from the 2nd day after sowing.

When the NaCl solution is applied to 50 meq.l^{-1}, the response of the first start their seeds with a germination rate of 80% during the same time. When the concentration of saline twice, the response of seeds is always manifested from the 2nd day but with more reduced rate of 64% for the treatment at 100 meq.l^{-1} and 6% for the treatment 200 meq.l^{-1} NaCl.

Germination rate

The highest velocity factor is that of control seeds (32.94%). For saline treatments 50 meq.1^{-1} and 100 meq.l^{-1} Cv does not very much, but as soon as the double salt concentration, Cv drops to 24.74% (Figure 2).

In terms of the average germination time (Tm), it does not vary much between the different treatments is for control seeds (3.03 days) or treated with 50meq.l^{-1} (3.07 days) and 100 meq.l^{-1} NaCl (3.17 days) where it does not exceed three days.When the medium is 200meq.l^{-1} NaCl; the mean time to germination increases to 4.04 days.

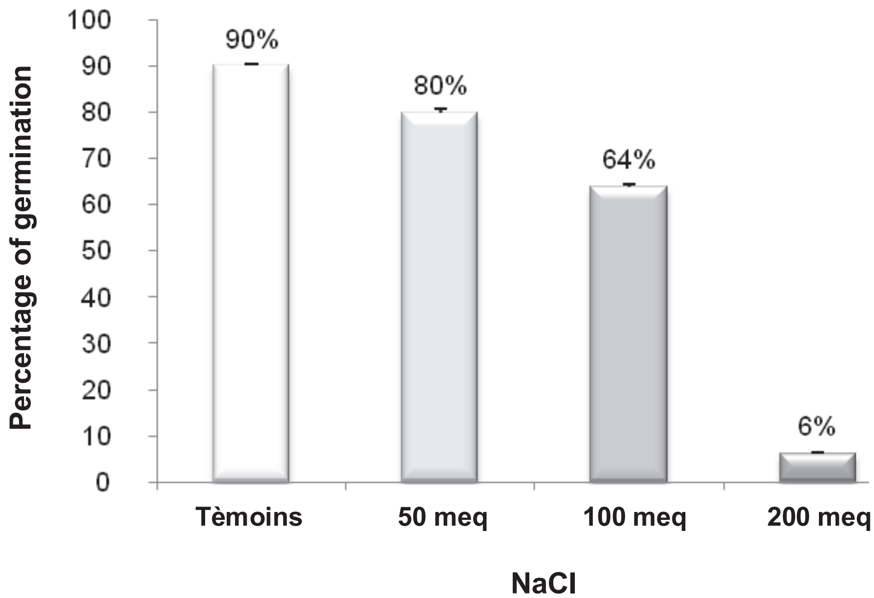

Figure 1. Early germination of *Abelmoschus esculentus* L. under different concentrations of NaCl.

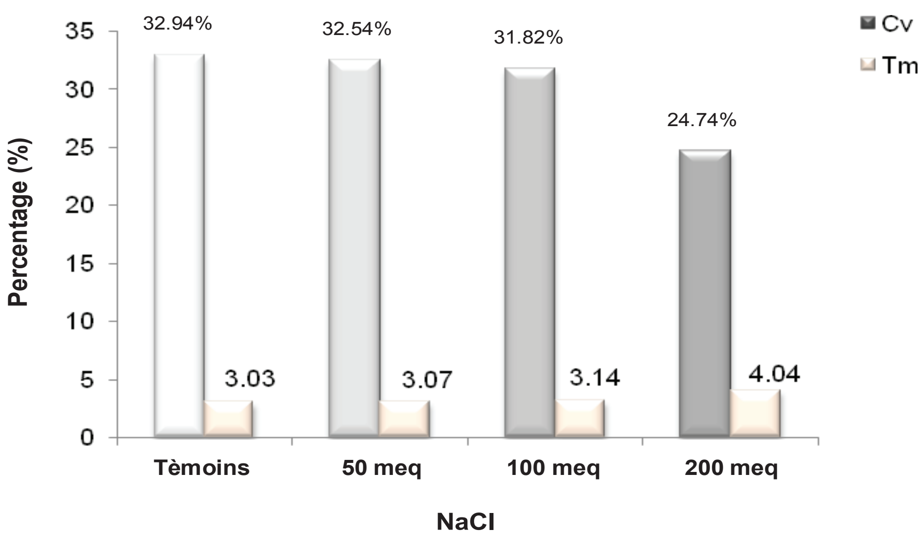

Figure 2. Coefficient of velocity (CV) and mean time to germination (Tm) of *Abelmoschus esculentus* L. seeds treated with NaCl.

Final rate of germination

The final rate of germination is 100% for control seeds watered with distilled water and sheaths treated with saline 50 and 100 meq.l^{-1} NaCl (Figure 3). According to the Student test, unlike the germination rate is not significant compared to the control for the seeds watered with saline NaCl 50 and 100 meq.l^{-1} (100%). However, this difference was highly significant in stressed seeds NaCl 200 meq.l^{-1} (86% ± 0.6).

Kinetic of germination

For the control seeds and seeds watered NaCl 50 meq.l^{-1}, the germination starts the second day after sowing, with respective rates of 90% and 80 to 96% for both batches after the 3rd day shown in Figure 4. For the seeds watered 100 meq.l^{-1} NaCl, germination also starts the second day after seeding, but with a rate of 64% of sprouts Changes in cumulative rates of sprouts three batches overlap and germination rate stabilizes in the

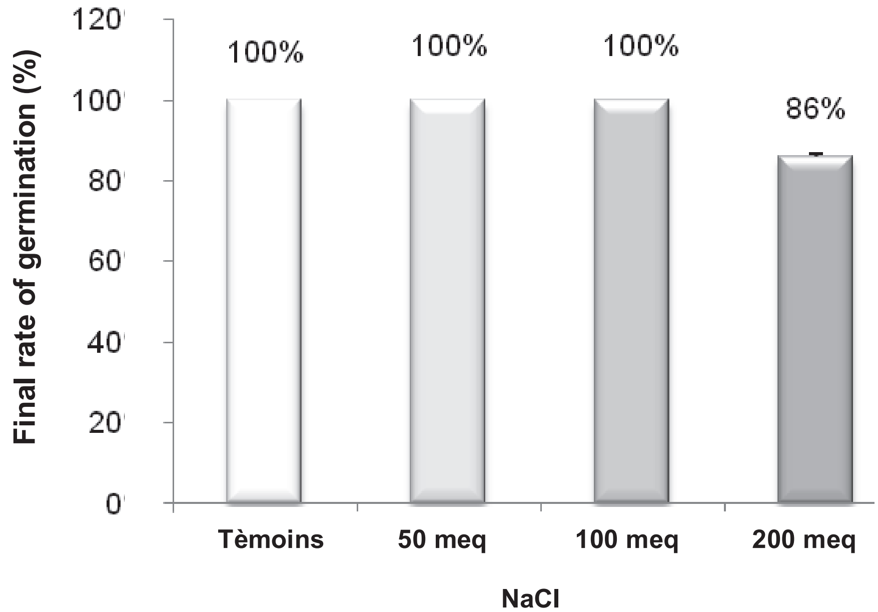

Figure 3. Final rate *Abelmoschus esculentus* L. seeds germination treated with NaCl.

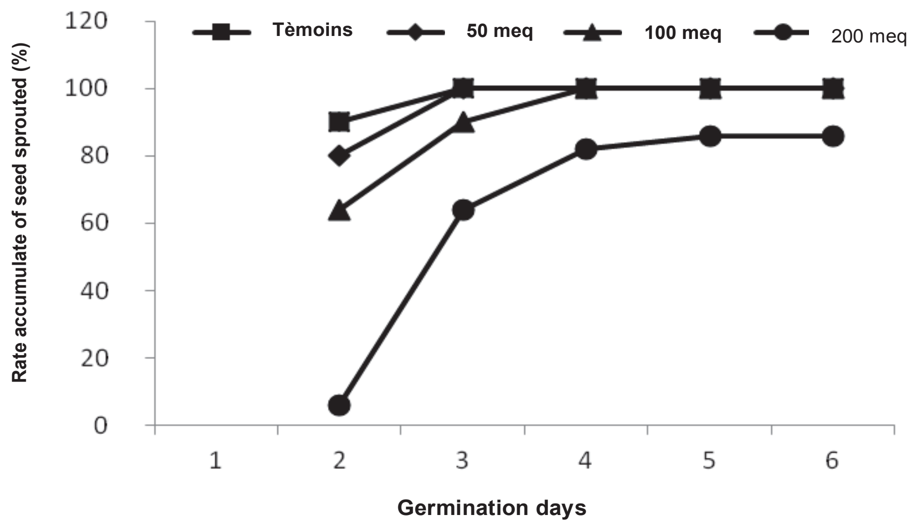

Figure 4. Kinetics of germination of *Abelmoschus esculentus* L. seeds treated with NaCl.

4th with 100% sprouts.

For the saline treatment at 200 meq.l^{-1} the cumulative rate of germination is progressing very slowly compared to the control batch and that receiving 50 and 100 meq.l^{-1} NaCl. Germination was completed after 5 days after sowing with a rate of 86% of all the tested seeds.

DISCUSSION

Changes in the germination of seeds *A . esculentus* L. recorded in the experimental conditions as described above involve a number of reflection. The final rate of seed germination under different salt treatments did not change much but the speed and germination time varies depending on the treatment applied. Indeed similar results have been observed in many plant species (Demir et al., 2003; Khajeh-Hosseini et al., 2003; Okcu et al., 2005; Kayam et al., 2006). These authors have demonstrated that osmotic potential due to NaCl affects the absorption of water and the mean time to germination but not the final germination. On the other hand, according Askri et al. (2007), the delay caused by the salt is not binding for the final crop yield, agronomic point of view, but rather the germination capacity which is the more decisive. In fact, the germination is not regulated by genotypic characteristics but also by the environmental conditions and in particular, the availability of water in the soil and the presence of salt (Gutterman, 1993).

In halophytes as in glycophytes, salinity reduced germination capacity and delays the initiation process for germination (Bayuelo-Jiménez et al., 2002). However, responses are variable and specific for each species (Ungar, 1991) indeed glycophytes species where most species of agronomic interest its rows has diminished growth in the presence of excessive salinity in the soil generally above 100 $meq.l^{-1}$ NaCl (Marouf and Reynaud, 2007).

High concentrations of salts, particularly sodium chloride (NaCl), can inhibit the germination of seeds due to osmotic and toxic effects (Perez and Tambelini, 1995). The low external potential can inhibit the enzymatic activity of seeds and delay the release and development of the radicle (Perez and Tambelini, 1995). The Na^+ absorption has toxic effects on seed germination, primarily by the disruption of the movement of Ca^{+2} Na^+ In the cell wall which could disrupt its synthesis and, therefore, prevent the growth of rootlets (Zidane et al., 991; Xue et al., 2004; Martinez- Ballesta et al., 2004).

NaCl also affects the permeability of the plasma membrane by increasing the influx of external ions and efflux solutions cytosol (Allen et al., 1995). Furthermore, it increases the rigidity parietal (Nabil and Coudret, 1995) and decreases the fluid conductance of the plasma membrane (Cramer, 1993).

During germination of most seeds, reserves are degraded by amylases, phosphorylases and glucosidase (Bewley and Black, 1994) and much of the hydrolysis products are transported to the embryo for growth (Sun and Henson, 1991).

The slowdown in the mobilization of reserves is due either to delay the activation or synthesis hydrolases or to transfer inhibition hydrolysis products of the endosperm to the embryo. This slowdown in the mobilization of reserves is mainly due to the salinity effect (De-Oliveira et al., 1998).

Conclusion

The results on the influence of salinity on seed germination of *A. esculentus* L. shows that if the seeds germinate better in the absence of salt (100%) with an average time most current (3.07 days), seeds germinate even at a concentration equal to or less than 100 $meq.l^{-1}$ NaCl. At high NaCl concentrations to 200 $meq.l^{-1}$ is slightly inhibited germination (86%) with an average longest time (4.04 days). The average time of germination decreases with the decrease of the NaCl concentration against the germination speed, expressed as velocity coefficient (Cv) decreases with increasing salt concentration. These results suggest that during the seed germination, the species *A. esculentus* L. behaves as salt tolerant glycophytes.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Rainwater harvesting potential for crop production in the Bugesera district of Rwanda

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The objective of this study was to test the utility of a spatial explicit water balance technique in assessing the rainwater harvesting potential for crop production to design food security strategies in the Bugesera District. The district was delineated into 19 catchments through the hydroprocessing algorithm in ILWIS using the SRTM 90 m DEM, and runoff, a proxy of the potential rainwater harvest, was computed using the Natural Resources Conservation Service Curve Number method. Results from the analyses indicate that based on the average antecedent moisture condition, the average daily runoff that can be collected out of Bugesera district is approximately 1,320 x 10^6 m^3/day. Allowing a third of this runoff for environmental requirements and evaporation losses, the amount of rainwater that could be used for crop production has been estimated to be 880 x 10^6 m^3 per day. By using the CSIRO's precision weighing systems to measure water use by various crops and yield from the crops, the amount of harvested rainwater has the potential of producing between 398 x 10^3 to 531 x 10^3 tones of paddy rice and 1,390 x 10^3 to 1,620 x 10^3 tones of maize. This potential crop yield can significantly improve food security in the Bugesera district. It was therefore concluded that rainwater harvesting for crop production is a viable option in Bugesera district and further implantation modalities should be explored.

Key words: Rainwater harvesting, natural resources conservation service (NRCS) curve number, crop production, digital elevation model (DEM), catchment delineation, Bugesera District.

INTRODUCTION

Many parts of Africa rely on rain-fed agriculture, often subjecting these areas to frequent food insecurity. Rain-fed agriculture is practiced on approximately 95% of sub-Saharan Africa's agricultural land (Ching et al., 2011; Rockström et al., 2002). Agriculture accounts for 35% of the continent's Gros Domestic Product (GDP), 40% of its export, 70% of its employment, and more than 70% of the population depend for their livelihoods on agriculture and agri-business (Ngigi, 2003; Kijne, 2000). Unfortunately there has been a marked increase in rainfall variability as well as decrease in rainfall (mean annual rainfall) that makes rain-fed agriculture risky (Barron and Stacey, 2008). This has resulted in low yields being

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obtained from rain-fed agriculture in sub-Saharan Africa ranging around 1 t/ha of grain crops such as maize and rice (Rockström, 2001; Senay and Verdin, 2004). According to the World Food Programme (WFP) (2006), recent assessments suggest that the low productivity in rainfed agricultural land is more due to poor water management than to low physical potential. Rwanda is a Sub-Saharan African country which there is no exception to the problem of water management in the region. However, the consequences are more severe in drier parts of the country. Bugesera District, in the Eastern Province of Rwanda, is among the regions that receive little amounts of rainfall; an average of 400 to 600 mm/annum and rarely exceeds a maximum of 800 mm/annum. This District has been facing prolonged periods of drought since year 1998 which resulted in food insecurity and massive population migration to other regions of the country (ICT-Environment Linkage, 2007). Agriculture is the backbone of the economy of the District of Bugesera with more than 90% of the population engaged in agricultural activities, of which 97 % is rain-fed (WFP, 2006).

More irrigation projects are required to raise agricultural production in the Bugesera district. Studies in similar arid and semi-arid regions have shown that 1 to 3 applications of supplementary irrigation at critical stages of crop growth could make a difference between 1 ton/ha (rain-fed) and 4 tons/ha (with supplementary irrigation) for a wheat crop in North Africa and West Asia (Oweis and Hachum, 2006; Senay and Verdin, 2004). As rainfall in the Bugesera District is principally lost through runoff, infiltration and evaporation, there is an urgent need to profitably utilize that portion of rainfall that is lost in the catchments for agricultural purposes; a process known as rainwater harvesting (RWH). This is a method of collecting surface runoff from a catchment area and storing it in surface reservoirs, or in the root zone of a defined area (Tripathi et al., 2005; Munyao, 2010). It can be a source of water for a variety of purposes in arid and semi arid regions when common sources such as streams, springs, or wells fail (Fraiser, 1980). Tripathi et al. (2005) noted that the first step in developing and implementing water resource management through rainwater harvesting is the evaluation of the region's rainwater harvesting potential.

It is useful to make use of rainwater harvesting techniques through models that incorporates different hydrological components such as interception, infiltration and evaporation as these influence soil moisture content and runoff generation (both process and volume) in an area (ICRAF, 2005; Mwenge et al., 2008). Such methods require several inputs such as rainfall, landcover, soils and topographic derivatives and have been found to meet the water requirements of transplanted crops such as rice (Srivastava et al., 2004). The Natural Resources Conservation Service Curve Number (NRCS CN) method is one of the rainfall runoff models that have been widely adopted for rainwater harvesting assessment (Senay and Verdin, 2004; de Winnaar et al., 2007). This method integrates the various remote sensing (RS) quantification methods with the spatial data handling capabilities of Geographic Information Systems (GIS) to simulate runoff for rainwater harvesting (Senay and Verdin, 2004). Remote sensing is very useful in that it allows for the spatial and temporal quantification of major environmental variables such as topography (Lane et al., 2004), landcover and landuse (Chrysoulakis et al., 2004) that are key inputs into the NRCS CN model. This also could further help to meet the challenges of managing water-related problems, food insecurity and sustainable development of the Bugesera District.

The curve number method was developed by the United States Department of Agriculture (USDA) NRCS from an empirical analysis of runoff from small catchments and hillslope plots monitored by the USDA (USDA-NRCS, 1972). It is widely used and is an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area (Rao et al., 1996; Sharma et al., 2001; Senay and Verdin, 2004; USDA, 2004). It estimates excess precipitation as a function of cumulative precipitation, soil cover, land use, and antecedent moisture levels. The hydroprocessing algorithm in the Integrated Land and Water Information Systems (ILWIS) Open Software (Version 3.6) allows for the delineation of sub-catchments. Runoff representing the amount of rainwater that could be harvested can be easily computed from daily rainfall records using the NRCS curve number method with soil groups and land use/cover as input layers into this model. This method is based on repeated measurements of the water available for runoff after different rainfall intensities on different land cover/landuses. In summary the method is an integration of the interception, evaporation and storage of precipitation on surfaces with specific land cover/use and soil characteristics.

By determining the water available for runoff and its flow through the Bugesera watersheds, the main objective of this study was to assess the rainwater harvesting potential in the district for improving agricultural production. The effectiveness of integrating RS and GIS (data preparation and model parameterization) with hydrological modelling (NRCS curve number) to identify potential rainwater harvesting sites (rainwater catchments) in the district was explored.

STUDY AREA

This study was conducted in the Bugesera district which is located in the Eastern Province, southeast of Kigali, the capital city of Rwanda. The population of the district was about 300,000 people and its surface area is 1,334 km^2. Figure 1 shows the location of Bugesera district in Rwanda and its constituent sectors. The relief of the

Figure 1. Map of Bugesera district showing its location in Rwanda and the sectors that form the district.

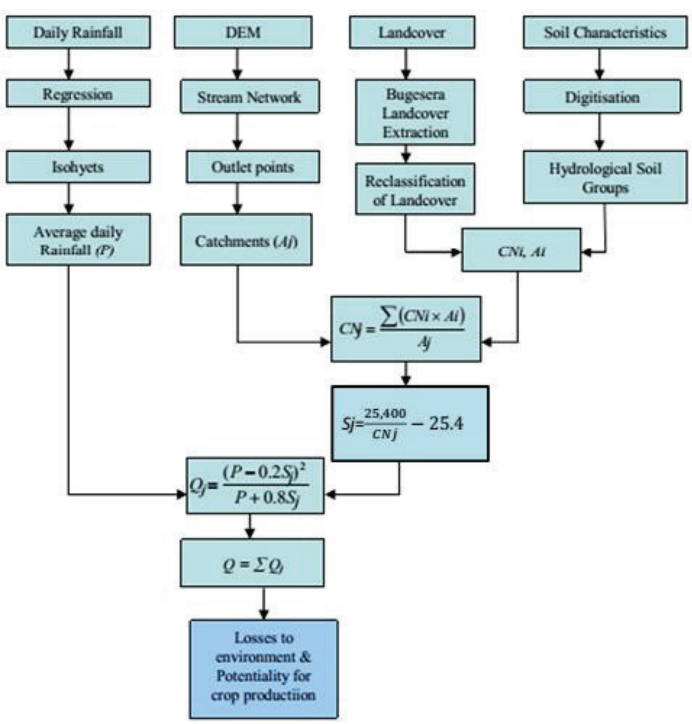


Figure 2. A framework for estimation of potential runoff and the potential amounts for crop production.

district is a succession of trays in the heights subsided and whose altitude varies between 1300 and 1667 m (Figure 1).

In comparison to other regions of Rwanda, the Bugesera district is regarded as one of the drought-prone regions, experiencing frequent rainfall deficit and a significant number of dry spells (MINITERE/CERECE, 2003). The maximum temperatures range between 26 and 29°C, and minimum temperatures range between 13 and 15°C (ICT-Environment Linkage, 2007). The area is recognized as the hottest and driest in the country.

Agriculture is the backbone of the economy of the Bugesera district with more than 90% of the population engaged in agricultural activities, of which 97% is rain-fed (WFP, 2006). Crop production in Bugesera is negatively affected by climatic risks, in particular the dryness on the hills and the floods in marshes. Moisture tolerant crops such as sorghum, cassava and sweet potatoes are generally cultivated on the hillsides, while crops sensitive to moisture stress such as banana and vegetables are grown on hill bottoms where soil moisture is higher compared to the hillsides (Tabor, 1995). In 2006, an estimated 53,000 people out of about 297,000 in the district were severely food insecure and required urgent humanitarian assistance (WFP, 2006). This was exacerbated by high population densities, and poor soil fertility. Rainwater harvesting could increase water availability for all Bugesera district sectors. Such an initiative would also encourage farmers to invest in the land for improved productivity.

MATERIALS AND METHODS

Figure 2 summarizes the major steps followed in the estimation of potential runoff and the probable irrigable area for crop production. These steps are described in detail in the next paragraphs. The field study and data collection was conducted from July 2007 to January 2008.

Primary datasets

Readily available land cover data for the study area from the FAO Africa Cover website (http://www.africover.org) was used (FAO, 2003). This land cover map was derived from visual interpretation of digitally enhanced LANDSAT TM images of 2004. The pedological map of Rwanda (Carte pédologique du Rwanda) made under the supervision of the University of Gand (Belgium), Department of Geology and Pedology from 1981 to 2000 was also used. It classifies the soil texture of the country based on the United States Department of Agriculture (USDA) triangle of soil textures. The meteorological data include rainfall time series from 1975 to 2005 from 6 stations in and around Bugesera District as provided by the Rwandan Meteorological Services. These stations are Karama, Nyamata and Ruhuha inside the District and Masaka, Butamwa and the Kigali International Airport Station in the north of Bugesera. The country's 90 m Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) used for catchment delineation was obtained from the Centre for Geographic Information System at the National University of Rwanda.

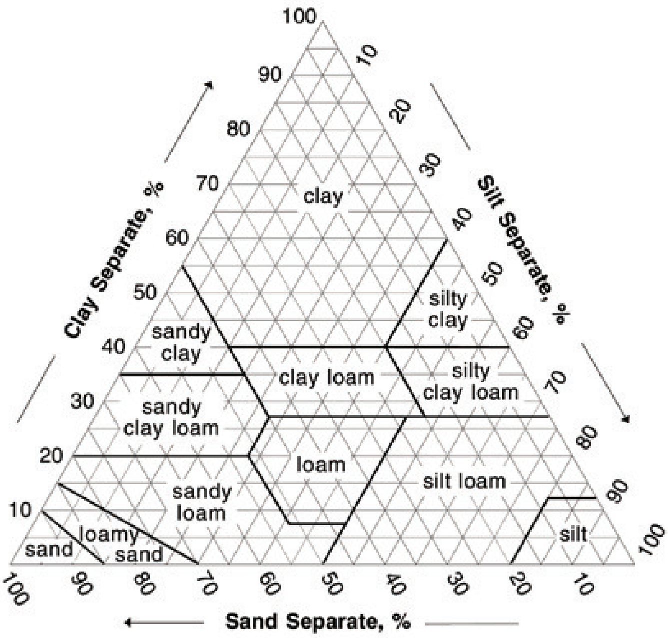


Figure 3. Soil texture triangle (Pedosphere.com, 2002).

Table 1. Daily average rainfall for the Bugesera stations based on data from 1975 to 2005.

Station	Daily average rainfall (mm)
Kigali International Airport	2.77
Butamwa station	2.99
Masaka station	2.79
Nyamata	3.45
Ruhuha	2.80

Evaluation of the rainfall distribution using GIS

The average daily rainfall at each station was obtained and GIS was used to map the spatial locations of these stations. The average daily rainfall for the whole district was computed using isohyets generated from GIS interpolation techniques.

Landcover analyses

The Medium Resolution Imaging Spectroradiometer (MERIS) derived landcover (Bontemps et al., 2011) was reclassified to conform to the NRCS TR-55 tables runoff Curve Number values (USDA-NRCS, 1964, 1972). All cropped lands were classified as agricultural land, forest plantations were classified as forest land, natural lakes as water bodies, and permanently flooded land and post flooding croplands were classified as wetland. Open shrubs and sparse trees were classified as rangeland, while urban land was retained as urban to yield six classes. An assumption is that impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition was made (USDA-NRCS, 1964). The landcover map was then overlayed with the boundary of Bugesera district.

Soil classification

To classify the different soil types into hydrologic soil groups, the pedological map of Rwanda [Carte pédologique du Rwanda] was digitised and visually interpreted. The soil texture of the country was classified into four main classes based on the USDA triangle of soils textures (Figure 3). The soil types in Bugesera District were classified into the Hydrologic Soil Groups (Group A-D) of the NRCS CN method (Perdue Research Foundation, 2004) using Table 1 as the look up reference table. The soil groups are as follows:

Group A: sand, loamy sand and sandy loam types of soils.
Group B: silt, silt loam and loam soils.
Group C: sandy clay loam soils.
Group D: clay loam, silty clay loam, sandy clay, silty clay and clay soils.

DEM hydroprocessing for catchment delineation

The delineation of catchments in Bugesera District was done using an automated approach in Integrated Land and Water Information System (ILWIS) (Maathuis et al., 2006). Using this algorithm, pre-processing of the DEM was performed to fill sinks for removal of local depressions, determination of flow direction and flow accumulation and to derive the stream network (Garbrecht and Martz.,1997). Catchment extraction was based on the derived drainage network and the flow direction map and a minimum drainage length of 2,000 m. A total of 19 outlet points were defined and the same number of catchments (19) were delineated and extracted.

Derivation of CN map and runoff simulation

The NRCS method computes direct runoff in a catchment through an empirical equation that requires the rainfall and a catchment coefficient as inputs. The catchment coefficient, curve number (CN) represents the runoff potential of the land cover-soil complex (Equation 1).

$$Q = \frac{(P - \lambda S)^2}{P + (1 - \lambda)S} \tag{1}$$

Where: Q = Direct runoff depth, in mm; P = Average daily precipitation, in mm; S = Potential maximum soil water retention, in mm, and λ = the initial abstraction ratio, dimensionless.
The initial abstraction ratio consists mainly of interception, infiltration and surface storage, all of which occur before runoff begins. The standard CN method assigns a value of 0.2 to the initial abstraction ratio (λ = 0.2). This reduces Equation (1) to:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad \text{for P > 0.2S} \tag{2}$$

The value of S is defined as:

$$S = \frac{25{,}400}{CN} - 254 \tag{3}$$

The CN is mainly a function of soil type and land cover. As different soil types and land covers were found in the same catchment, a

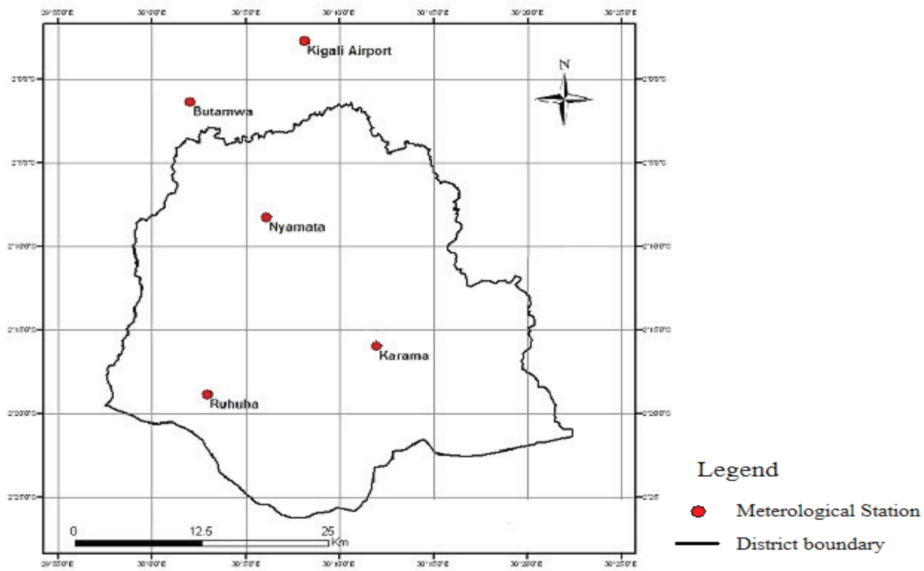


Figure 4. Distribution of meteorological stations in and around the Bugesera District.

weighted CN for each catchment was computed using the formula:

$$CN = \frac{\sum (CNi \times Ai)}{A} \tag{4}$$

Where CN = weighted curve number; CN_i = curve number for landcover type; A_i = area with curve number CN_i and A = the total area of the catchment.

Using the NRCS TR-55 look up tables (USDA-NRCS, 1964, 1972), curve numbers were selected by picking the Hydrologic Soil Group (HSG), antecedent Moisture Condition (AMC) and landcover within the Bugesera. The curve numbers were also linked to the District's antecedent moisture conditions (dry, average and wet) which is an index of basin wetness (Silveira et al., 2000). The AMC I, AMC II and AMC III represent respectively conditions of the soil in the District. From the weighted Curve Number, the potential maximum soil water retention (S) and the average daily precipitation (P), the runoff is estimated for each sub-catchment in the study area by using Equation (1). Daily total runoff for the whole district was obtained by simple summation of the daily totals from each sub-catchment.

Harvesting water for agricultural purposes

Not all runoff can or should be harvested for agricultural uses; about a third of it is generally required to sustain the environment (UNEP, 2006). It was therefore allowed a third of this runoff for environmental and evaporation requirements in order to compute the amount of rainwater that could be used for crop and the equivalent in tonnes of paddy rice production. Commonwealth Scientific and Industrial Research Organisation's (CSIRO) precision weighing systems were used to measure water use by various crops, and yield from the crops (http://rivermurray.com/html/about_the_murray/water_use.html). The CSIRO studies used precision weighing systems to measure water use by various crops, and yield from the crops as follows:

(i) To produce 1 kg of maize, it takes 540 to 630 L of water

(ii) For 1 kg of paddy rice, 1,650 to 2,200 L of water

RESULTS AND DISCUSSION

Rainfall interpolation

Table 1 shows the daily average rainfall for the 5 stations in and around Bugesera District. Figure 4 shows the spatial distribution of meteorological stations in and around Bugesera District. Only Kigali station had adequate records and therefore was used to generate daily rainfall for the other stations using linear regression of monthly total rainfall. The coefficient of correlation (R^2) obtained while generating missing data varied from 0.81 to 0.89, indicating an acceptable level of correlation. Daily rainfall records for 30 years (1975 to 2005) for each station were obtained for use in the NRCS CN method. Butamwa station had the highest average daily rainfall of 2.99 mm and Kigali International Airport had 2.77 mm. Figure 5 shows the isohyets map interpolated from the average daily rainfall at each station. The 6 classes in the generated isohyets map range from a minimum of 2.3 mm to a maximum of 3.5 mm. The average daily rainfall for the Bugesera District computed from the isohyets was found to be 2.87 mm.

Landcover analyses and soil classification

Figure 6a shows the extracted 2009 Globcover map of the Bugesera District and Figure 6b shows the reclassified landcover map to conform to the NRCS Curve Number values (USDA-NRCS, 1964). The dominant landcover was found to be agricultural land

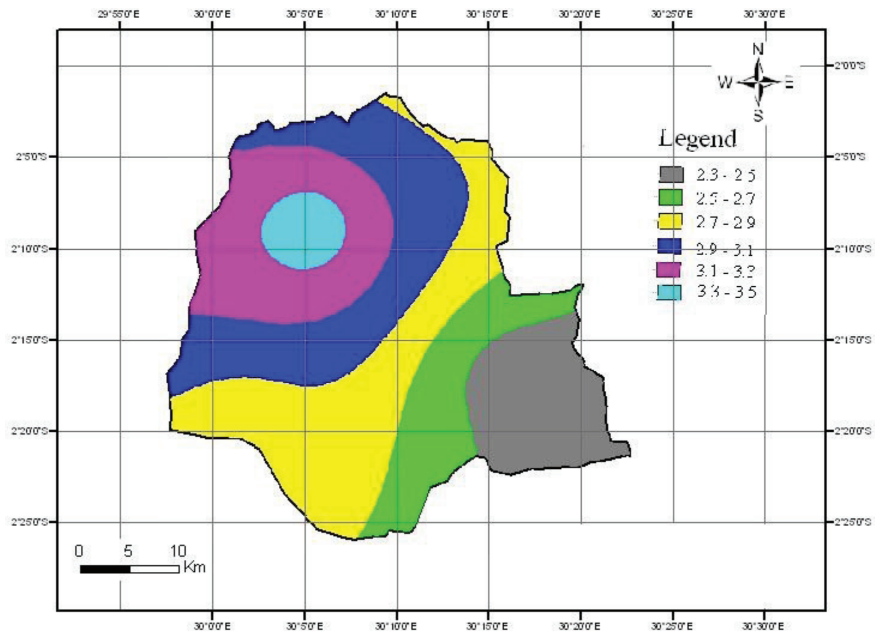
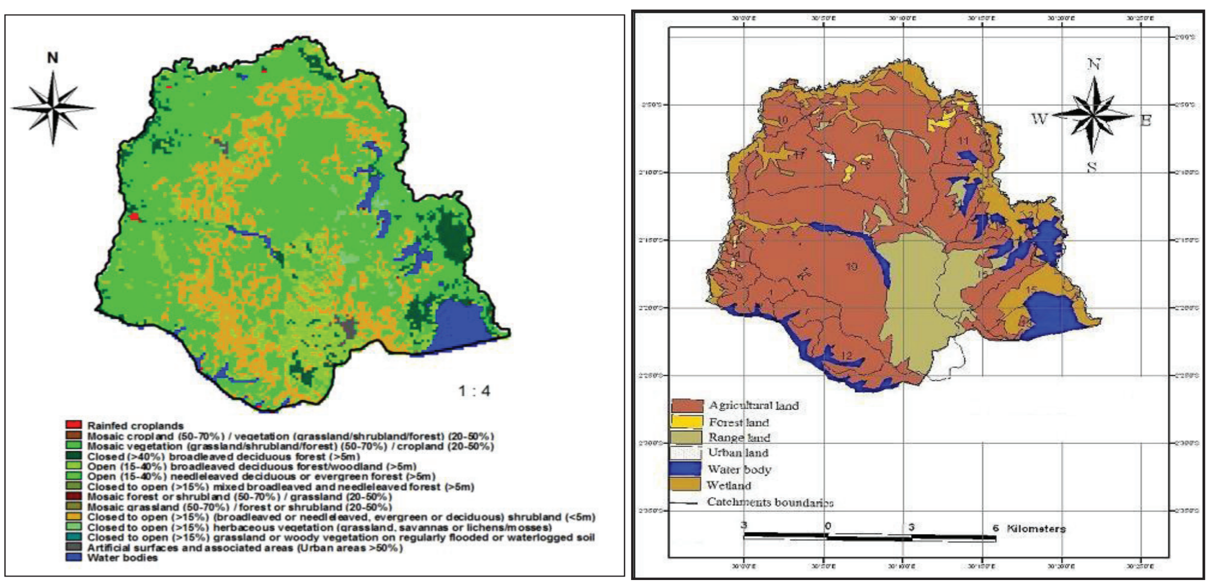


Figure 5. Bugesera District Isohyets map, based on data from 1975-2005.



(a) (b)

Figure 6. (a) Extracted 2009 Globcover map, (b) Reclassified landcover of the Bugesera District.

followed by rangeland. The forests are concentrated to the northern and eastern part of the District whilst the water bodies are concentrated in patches in southern and eastern part of the District.

Figure 7 shows the 3 soil groups plus lake area that resulted in the selection of curve numbers (CN) based on the USDA triangle of soils textures. A greater percentage of the district is covered by Soil Group B. Group C is only in the Northerly strip while Group D consists of east and west strips.

DEM hydroprocessing results

The delineation of catchments resulted in the filled DEM, flow direction and flow accumulation maps as shown in

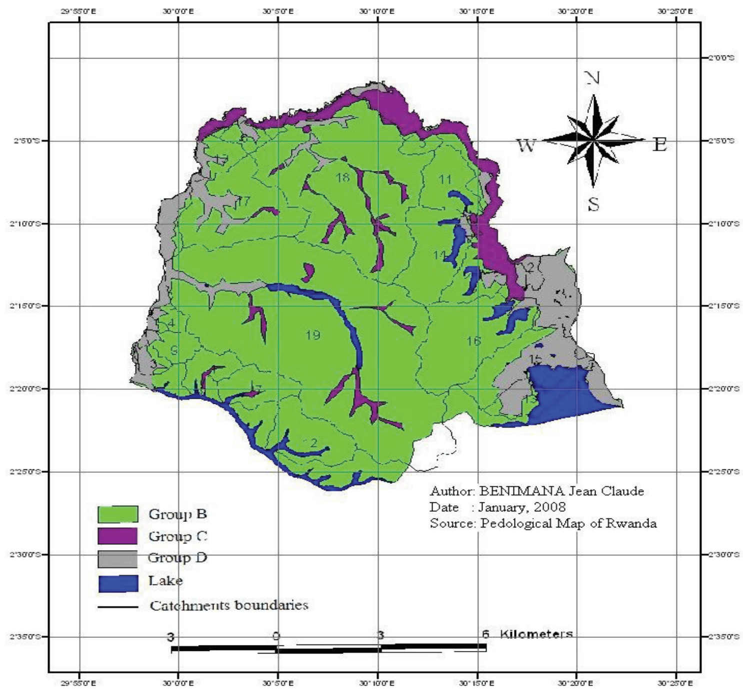


Figure 7. Hydrologic Soil Group of different soils in the District.

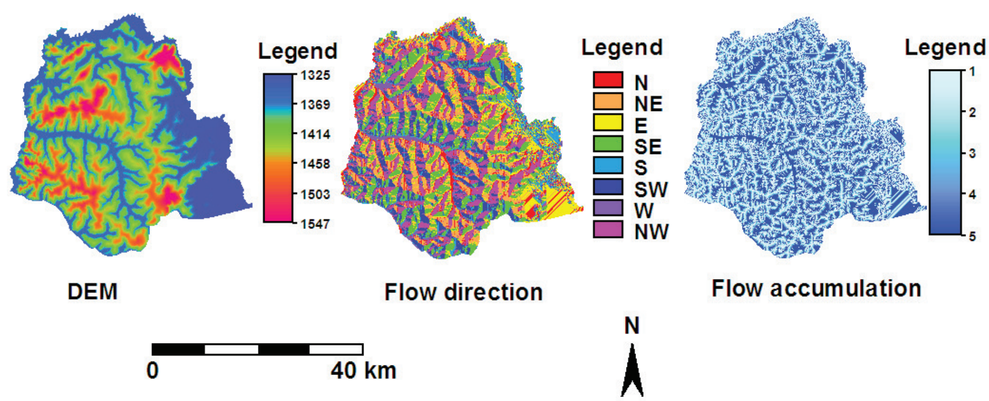


Figure 8. The DEM of Bugesera District, flow direction and flow accumulation map.

Figure 8. The elevation ranges from a minimum of 1,300 m on the eastern side of the district to a maximum of 1,500 m above mean sea level. Most streams flow in the SE and NW direction in the Bugesera District.

The polygons in Figure 9 present the extracted catchments within the boundary of the Bugesera District. All the catchments were found to be located within the boundary of the Bugesera District except the catchment C19 which extends some part beyond the District's boundary.

The occupied surface areas and the longest flow path length within each catchment are presented in Table 2. The catchment with the largest catchment surface area is C19 (392 km^2) and with the smallest surface catchment area is C4 (6 km^2). Catchment C19 has the longest flow path length (43 km) and C6 the shortest flow path (5 km). This already has an implication on the potential amount of runoff generated by each subcatchment. Runoff generation is also a function of catchment area.

Runoff estimation through the NRCS curve number method

Table 3 shows the soil cover complex, occupied surfaces area (A_i), corresponding curve number (CN_i), direct runoff

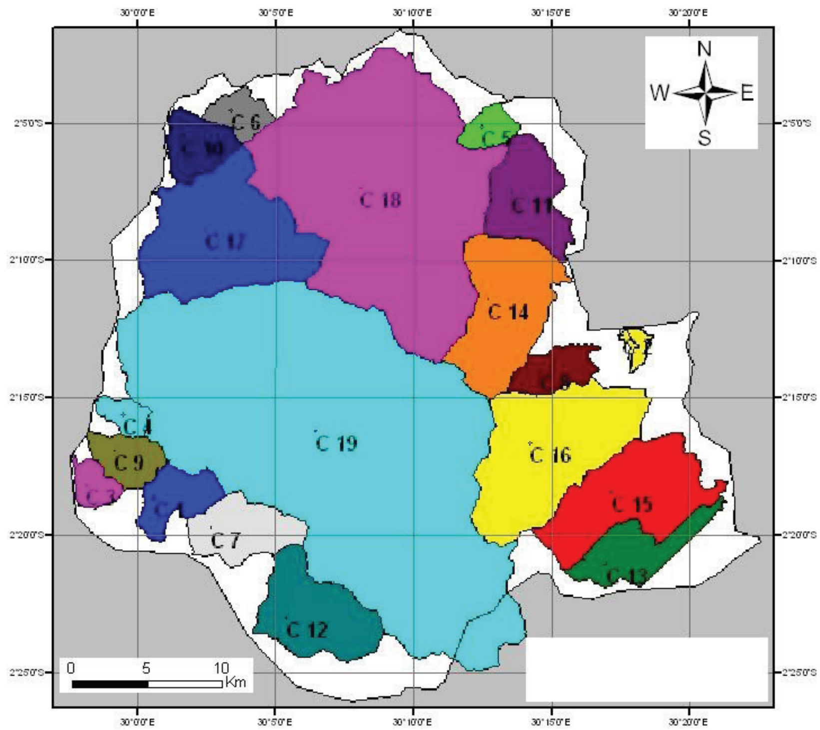


Figure 9. Delineated catchments within the boundary of Bugesera District.

Table 2. Characteristics of delineated catchments.

Catchment	Catchment area (km^2)	Longest flow path length (km)
C 1	16.59	7.86
C 2	8.84	7.37
C 3	7.53	5.03
C 4	6.37	4.83
C 5	7.81	4.85
C 6	9.67	4.78
C 7	24.41	8.32
C 8	13.37	7.98
C 9	13.39	6.54
C 10	16.00	6.27
C 11	31.05	10.56
C 12	38.60	10.17
C 13	23.34	14.52
C 14	52.60	12.58
C 15	54.33	16.57
C 16	76.65	19.69
C 17	76.58	15.85
C 18	207.13	28.81
C 19	392.12	42.62
Total	1,076.37	

(Q, mm) and the computed runoff volume (Q, $*10^6$ m^3) for each subcatchment. Assuming average antecedent moisture condition AMC II (Artan et al., 2001), the average daily rainfall that flows out of Bugesera District

Table 3. Soil cover complex, occupied surfaces area (Ai) and corresponding Curve Number (CNi).

Catchment	Soil cover complex	Surface area (Ai) in km^2	AMCII curve Number (CNi)	Weighted curve number (CNj)	Direct runoff Q (mm)	Runoff Volume Q (x10^6 m^3)
C 1	B, agricultural	15	81	82.15	1.29	21.35
	C, agricultural	1	88			
	Water	1	100			
C 2	C, wetland	8	100	100.00	2.87	25.37
	D, wetland	1	100			
C 3	B, agricultural	3	81	92.54	2.09	15.72
	D, wetland	5	100			
C 4	B, agricultural	5	81	84.53	1.45	9.22
	D, wetland	1	100			
C 5	B, agricultural	7	81	84.09	1.42	11.06
	C, wetland	1	100			
C 6	B, agricultural	7	81	84.30	1.43	13.83
	C, wetland	0	100			
	D, agricultural	2	91			
C 7	B, agricultural	23	81	81.94	1.27	31.09
	C, agricultural	1	88			
	Water	1	100			
C 8	B, agricultural	11	81	84.42	1.44	19.24
	Water	2	100			
C 9	B, agricultural	12	81	83.12	1.35	18.08
	D, wetland	1	100			
C 10	B, agricultural	11	81	86.50	1.59	25.42
	C, agricultural	1	88			
	D, wetland	4	100			
C 11	B, agricultural	29	81	82.44	1.31	40.54
	Water	2	100			
C 12	B, agricultural	34	81	83.31	1.36	52.62
	Water	5	100			
C 13	B, agricultural	8	81	93.86	2.21	51.62
	D, wetland	9	100			
	Water	7	100			
C 14	B, agricultural	40	81	81.41	1.24	65.23
	B, rangeland	4	56			
	B, forest	1	60			
	D, wetland	2	100			
	Water	6	100			

Table 3. Contd.

C 15	B, agricultural	17	81	94.22	2.25	122.02
	D, wetland	25	100			
	Water	13	100			
C 16	B, agricultural	60	81	79.74	1.14	87.20
	B, rangeland	9	56			
	C, wetland	0	100			
	D, wetland	2	100			
	Water	5	100			
C 17	B, agricultural	63	81	84.12	1.42	108.62
	C, agricultural	1	88			
	D, wetland	12	100			
C 18	B, agricultural	173	81	80.18	1.16	241.18
	B, forest	4	60			
	C, forest land	3	73			
	C, rangeland	20	70			
	D, wetland	8	100			
C 19	B, agricultural	260	81	75.65	0.91	356.98
	B, rangeland	98	56			
	C, agricultural	14	88			
	C, rangeland	4	70			
	D, wetland	11	100			
	Water	5	100			
TOTAL						**1,316.39**

was equal to 1.320 x 10^9 m^3. The CN value generated using the curve number for landcover type; A_i-area with curve number CN_i and A: the total area of the catchment in the Bugesera District gives an impression of the area that can generate more runoff in the study area. High CN values indicate areas that have the lowest infiltration and more runoff is expected from these areas since the initial abstraction and storage area would be minimal.

This study analyzed how the catchments of rainwater are distributed in the District and how much water could be collected from each catchment and from the district as a whole using the NRCS Curve Number method. The major outlet points of surface runoff from the District are identified and the catchments draining water to those points, delineated. By assessing how much water is possible to collect in the District through rainwater harvesting, it can be observed that sub catchment C19 by virtue of its drainage pattern and its large surface area would generate 357 x 10^6 m^3/day followed by C18 that would also generate 240 x 10^6 m^3/day per day. The subcatchment that would generate the least amount of runoff would be C4 with 9 x 10^6 m^3/day. Thus from a general point of view, subcatchments C19 and C18 act as best potential rainwater harvesting sites and subcatchment C4 would be least suitable as a water harvesting site. The extracted catchments derived through the DEM hydroprocessing are rainwater harvesting potential areas and they give a clear indication of the spatial extents and this existing potential can be a starting point for creating awareness among stakeholder at the local and national scale. Because of lack of routing of runoff from individual pixels and connecting channels to the watershed outlet as highlighted by the work of Senay and Verdin (2004), it is unclear how the large size of the modelling unit would affect the runoff estimation in the District.

Crop production potential

Not all the runoff can or should be harvested for agricultural uses; about a third of it is needed to sustain the environment (UNEP, 2006; Gupta et al., 1997). Considering that a third is allocated for environmental purposes, the remaining runoff that could be collected in Bugesera District from the average daily rainfall of 1,320 x 10^9 m^3, is equal to 877 x 10^6 m^3 per day. Using the CSIRO figures, the amount of runoff that may be collected in Bugesera District, 877 x 10^6 m^3/day, have the capacity to induce harvest of between 398 x 10^3 and 531 x 10^3 tones of paddy rice annually. When used for the production of maize, between 1,390 x 10^3 tonnes and 1,620 x 10^3 tones may be harvested. The same estimations may be obtained for other crops. This highlights the huge potential that rainwater harvesting has in the production of crops. The main agricultural areas in the Bugesera District fall within the range of 360 and 450 mm of annual runoff (MINITERE/CERECE, 2003). These are areas that require supplementary irrigation to mitigate inter-seasonal crop failures and increase the crop yields.

Improved certainties in assessing the potential in the production of crops, would require social considerations of population density and also the required watershed size needed to fill a small storage reservoir that can be used for alleviating water stress during a crop growing season. Thus for effective implementation of potential rainwater harvesting in any area, the number of potential ponds per family emanating from physical watershed and social considerations would go a long way in boosting crop production Sub-Saharan Africa (Senay and Verdin, 2004).

Conclusions

Integrating RS and GIS (data preparation and model parameterization) with hydrological modelling to identify the potential for rainwater harvesting in the Bugesera District is an effective strategy. The strength of this integration technique in this work lies on the use and application of spatially distributed soils, landcover, topographic data sets and rainfall interpolated in a GIS from meteorological stations. Therefore accuracy of these interpolation methods and DEM Hydroprocessing algorithms for catchment delineation needs to be ensured to avoid uncertainties that can compromise the final assessment for rainwater harvesting.

The amount of rainfall runoff that can be safely harvested from the Bugesera District has been estimated to be 877 x 10^6 m^3/day. If used for the production of rice, between 400 x 10^3 and 530 x 10^3 tones of paddy rice could be obtained annually, while if used for maize production, between 1390 x 10^3 tones and 1620 x 10^3 tones may be harvested. As the potential of rainwater harvesting in Bugesera District is high, this might require water storage and other detention facilities such as ponds, which cannot be provided by the farmers in the district. It is therefore recommended that the Government, through the District Agricultural Units help in providing these facilities. This would contribute immensely in improving agricultural productivity of the land and provide food security and livelihood for the population in the District and Rwanda.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Insecticidal activities and chemical composition of the essential oil from *Tarchonanthus camphoratus* (L.), leaves against *Sitophilus zeamais* Motschulsky, and *Sitophilus oryzae* (L.)

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The essential oil of *Tarchonanthus camphoratus* dry leaves growing in Kwa-Zulu Natal, South Africa was obtained by hydrodistillation and evaluated for its repellent effect, contact and fumigation toxicity against both *Sitophilus zeamais* and *Sarocladium oryzae.* Chemical composition of the essential oil was analysed by gas chromatography mass spectrometry (GC/MS). The study revealed that the essential oil of *T. camphoratus* had no contact and fumigation toxicity against stored insect pests, *S. zeamais* and *S. oryzae*. The oil, however, showed good repellent activity of over 50% after 24 h for all the concentrations used on both *S. zeamais* and *S. oryzae*. A total of 27 compounds accounting for 73% of the total oil composition were identified of which sesquiterpene hydrocarbons, (59.18%), were the most dominant. These results suggest that the essential oil of *T. camphoratus* could be considered a potential control agent of stored grain pests as a repellent.

Key words: Essential oil, chemical composition, *Tarchonanthus camphoratus, Sitophilus zeamais, Sitophilus oryzae,* fumigation, repellency, toxicity.

INTRODUCTION

Sitophilus zeamais Motschulsky and *Sitophilus oryzae* (L.) are pests of stored grains capable of surviving in extreme cold and hot temperatures and hence found all over the world (Walgenbach and Burkholder, 1986). Although they are primarily associated with maize and rice, *S. zeamais* and *S. oryzae* are capable of

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developing on all cereal grains and cereal products (Walgenbach and Burkholder, 1986). They are internal feeders that not only cause damage to the grains but also promote secondary insect pest and fungal infestations that further affect the quality and quantity of grains (Gupta et al., 1999). Currently, the control of stored product insects relies heavily on the use of non-natural insecticides and fumigants, which has led to problems such as environmental pollution, pest resurgence, resistance to pesticides and lethal effects on non-target organisms in addition to direct toxicity to the users (Zettler and Arthur, 2000). Plant derived natural products are considered a potential alternative to these toxic and environmentally unsustainable compounds. Because they represent a rich source of bioactive chemicals it was hypothesized that plants native to South Africa could provide alternatives to currently used insect control agents. More than 2,000 plant species have been found to possess insecticidal activity with the most well known botanical pesticides being pyrethrum, neem, rotenone, nicotine and plant essential oils (Philogene et al., 2005; Isman, 2006). Essential oils have been shown to control stored product pests by fumigant activity, contact insecticides and as repellents. Additionally, these bioactive plant secondary metabolites do affect insect growth rate and oviposition (Denloye et al., 2011; Chen et al., 2011; Stefanazzi et al., 2011).

The camphor bush, *Tarchonanathus campharatus* (L.), (family Asteraceae) is a shrub of reaching six meters in height and occurs in a wide range of habitats (van Wyk et al., 1997). The strongly scented tree of *T. campharatus* has many medicinal applications in traditional healing in South Africa, such as smoking the leaves or drinking infusions or decoctions. The infusions and tinctures of the leaves are used for abdominal pain, headache, toothache, asthma, bronchitis and inflammation and smoke from the fresh or dried plant is inhaled for rheumatism (Hutchings and Van Staden, 1994). In East Africa, the dry leaf infusion is drunk for tapeworm, the leaves are put underarm as perfume and to prevent tiredness and they are used for the control of bedbugs (Anonymous, 2005). The plant shows powerful insect repellent action (Omolo et al., 2004) and wild animals living in the areas where *T. camphoratus* grows, particularly Cape buffaloes and black rhinoceri, rub themselves against the leaves to deter mosquitoes and flies. The plant also seems to drive away tse-tse fly, a pathogenic agent of trypanosomiasis (Anonymous, 2005).

The purpose of this study was to determine the insecticidal activities of the essential oil of the dry leaves of *T. camphoratus* under laboratory conditions against *S. zeamais* and *S. oryzae*. *T. camphoratus* was selected as a model for this study based on its broad spectrum use in traditional medicine and preliminary reports of its insecticidal activity (Omolo et al., 2004; Anonymous, 2005).

MATERIALS AND METHODS

Plant material

Fresh materials of *T. camphoratus* were collected from Sangoyana in the northern part of Kwa-Zulu Natal province, South Africa in March, 2010. The plant was identified by the local people during the time of collection and further identified by Mrs N.R Ntuli in the Department of Botany, University of Zululand. A voucher specimen, (NSKN 1), was deposited at the University of Zululand herbarium.

Extraction of the essential oil

Air-dried leaves were subjected to hydro-distillation using a Clevenger-type apparatus (British Pharmacopia, 1980). The essential oil was collected 4 h after boiling, weighed and kept at 4°C in sealed glass vials before analysis and bioassay.

Determination of the insecticidal activity

Rearing of test insects

Adults of *S. zeamais* and *S. oryzae* were obtained from a colony maintained by the Plant Protection Research Institute, Pretoria. South Africa. These were mass reared on whole maize grains in 5 L glass jars in a controlled chamber, at 28 ± 20°C and 56 to 65% Relative humidity in the Department of Agriculture, University of Zululand. Newly emerged, one week old insects were used in the bioassay (Odeyemi et al., 2008).

Fumigant toxicity of the essential oil

The fumigation chambers consisted of 500 ml glass jars with screw-on lids. For the bioassay, solutions of 0, 5, 10, 20, 30 and 40µl of the oil were each diluted with 1ml hexane to correspond to concentrations of 0, 10, 20, 40, 60 and 80 µl/L air. One ml of each concentration was then separately applied to 7 mm discs of WhatmanNo.1 filter paper, air-dried for 10 min and placed at the bottom of the jars. Twenty, one-week old, adult insects were placed on muslin cloths (21 x 29 mm) each with 40 g whole maize grains. The cloths were tied closed with rubber bands and hung at the centre of the jars, which were then sealed with air-tight lids. There were four replicates for each concentration. Fumigation was carried out for 24 h after which the insects were transferred from the fumigation chambers onto clean maize, and mortality was checked daily for 28 days (Tapondjou et al., 2005).

Contact toxicity of the essential oil

The contact effect of the essential oil of *T. camphoratus* on the adults of *S. zeamais* and *S. oryzae* was investigated (Tapondjou et al., 2005). Maize grains were treated with concentrations of 0, 25, 50, 100, 200 and 300 µl of essential oil in 1 ml hexane. The different concentrations of the oil were mixed with 40 g of maize in 500 ml glass jars, corresponding to concentrations of 0, 0.625, 1.25, 2.5, 5.0 and 7.5 µl/g of maize grain respectively. These were thoroughly stirred to allow for homogeneity of the oil on the treated grains. Treated samples were air dried for an hour in order to get rid of the solvent. The grains were then infested with twenty, one-week old, *S. zeamais* or *S. oryzae* adults per jar and each jar was covered with a cotton mesh held in place by cover rims. There were four replicates per treatment. Insect mortality was checked daily for 28 days.

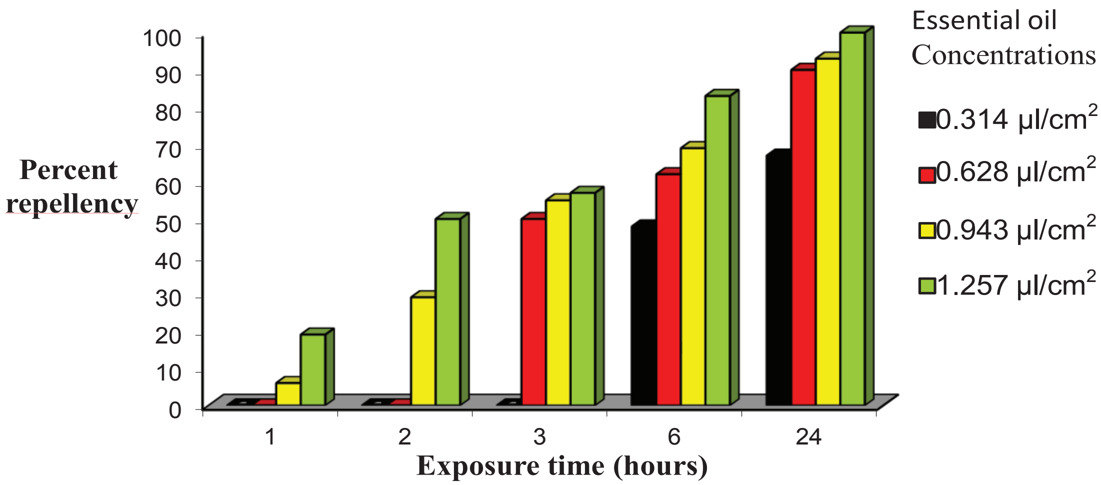

Figure 1. Plot of percent repellency against time of exposure, *S. zeamais*.

Repellency tests

The repellent effect of *T. camphoratus* essential oil against *S. zeamais* and *S. oryzae* was studied using a modified area preference method (Tapondjou et al., 2005). The test area consisted of a 9 cm Whatman No.1 filter paper cut into two halves. Different oil concentrations were prepared by diluting 10, 20, 30 and 40 µl of the oil in 1ml hexane and these corresponded to concentrations of 0.314, 0.628, 0.943 and 1.257 µl of oil/cm^2 of the filter paper respectively. The other half was treated with 0.5 ml hexane alone and this served as a control. Both essential oil treated and hexane treated filter paper halves were air-dried under a fan to evaporate the solvent completely. With the aid of a clear adhesive tape, both halves were later joined together into full discs and placed in 9 cm glass Petri dishes. Twenty one-week old, unsexed adult insects were released at the centre of the rejoined filter paper disc and the Petri dish was covered. Each treatment was replicated four times for each *S. zeamais* and *S. oryzae*. The number of insects present on the control and on the treated areas of the filter paper was recorded after 1, 2, 6, 4 and 24 h. Percentage repellency (PR) was calculated as follows (Nerio et al., 2009):

$$PR = ((Nc - Nt)/(Nc + Nt)) \times 100$$

Nc was the number of insects on the untreated area after the exposure interval and Nt was the number of insects on the treated area after the exposure interval. The mean number of insects on the treated portion of the filter paper was compared with the number on the untreated portion. Results were presented as the mean of percentage repellency ± the standard error.

Statistical analysis

Data was analysed using the QED statistics software. Means for percentage repellency for both insects at the four concentrations at a particular time interval were compared using one way ANOVA. The median repellent dose (RD_{50}) was determined from the linear regression equation through regression analysis.

Gas chromatography-mass spectrometry analysis

The GC-MS analysis was carried out using an Agilent 6890 GC with an Agilent 5973 mass selective detector [MSD, operated in the EI mode (electron energy = 70 eV), scan range = 45-400 amu, and scan rate = 3.99 scans/s], and an Agilent ChemStation data system. The GC was equipped with a fused silica capillary HP-5 MS column of an internal diameter of 0.25 mm, film thickness 0.25 µm and a length of 30 m. The initial temperature of the column was 70°C and was heated to 240°C at a rate of 5°C/min. Helium was used as the carrier gas at a flow rate of 1 ml/min. The split ratio was 1:25. Scan time was 50 min with a scanning range of 35 to 450 amu. A 1%, w/v, solution of the sample in hexane was prepared and 1 µl was injected using a splitless injection technique.

Identification of components

The identification of the oil constituents was based on their retention indices determined by reference to a homologous series of *n*-alkanes (C_8-C_{30}), and by comparison of their mass spectral fragmentation patterns with those reported by Joulain and Koening (1998) and Adams (2007) and stored in the MS library [NIST database (G1036A, revision D.01.00)/ChemStation data system (G1701CA version C.00.01.080)]. The percentages of each component are reported as raw percentages based on the total ion current without standardization.

RESULTS

Insecticidal activities

The essential oil of *T. camphoratus* did not show fumigation and contact toxicity against both *S. zeamais* and *S. oryzae* at the concentrations used. All the *S. zeamais* and *S. oryzae* tested remained alive after the 28 days of exposure. However, the essential oil showed repellent activity against *S. zeamais* and *S. oryzae* at the concentrations used. A percent repellence (PR) value of greater than 50% from the four replicates was noted at all concentrations for both *S. zeamais* and *S. oryzae* 24 h after treatment (Figures 1 and 2). Repellent action was highly dependent upon oil concentration and exposure

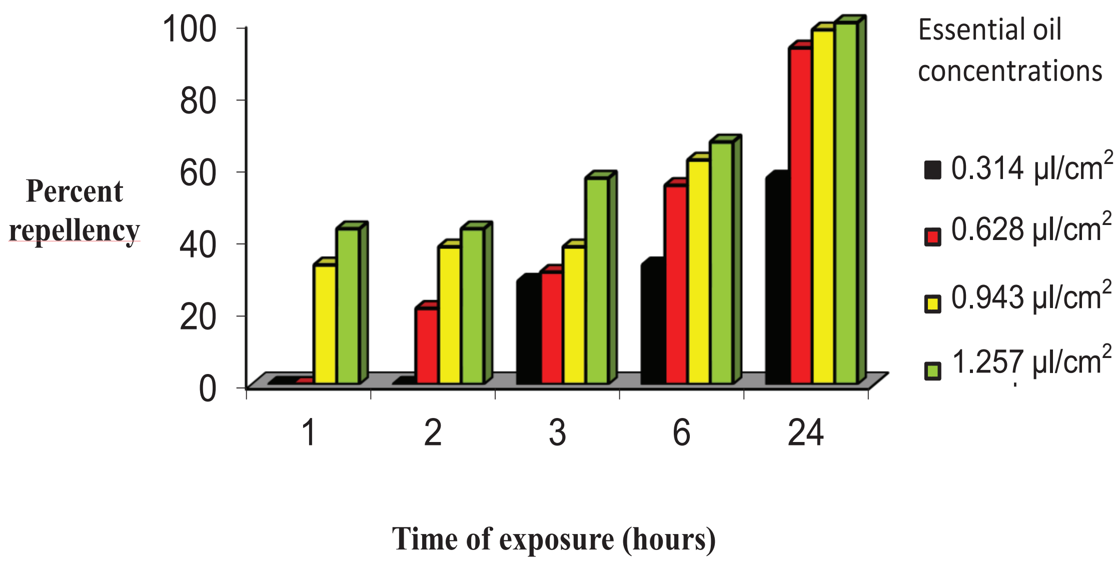

Figure 2. Plot of percent repellency against time of exposure*, S. oryzae*.

time. There were no significant differences between the means of percentage repellence for both insects at the four concentrations at a particular time interval at $p< 0.05$. The median repellent doses were 0.945 and 0.910 μl/cm^2 for *S. zeamais* and *S. oryzae* respectively. Percent repellence increased with both increasing concentration and time of exposure.

Chemical composition

The dry leaves of *T. camphoratus* yielded 0.23% (w/w) of yellowish green oil with a strong camphor aroma. Twenty seven compounds were identified in the oil accounting for 73.01% of the total oil composition. The oil was dominated by sesquiterpene hydrocarbons (59.18%) of which allo-Aaromadendrene, β-Guaiene, γ-Cadinene, δ-Cadinene, aromadendrene, Beta-caryophyllene and γ-Muurolene were the major components (Table 1). Monoterpene hydrocarbons formed 1.61% of the oil and the percentage composition of the oxygenated monoterpenes and oxygenated sesquiterpenes were 6.26 and 3.19% respectively.

DISCUSSION

The essential oil of the dry leaves of *T. camphoratus* showed no contact and fumigation toxicity on both *S. zeamais* and *S. oryzae* at the concentrations used. Previous studies have shown that the toxicity of essential oils obtained from aromatic plants against storage pests is related to the oil's main components (Lee et al., 2003). Among the essential oil components monoterpenes have drawn the greatest attention for insecticidal activity against stored product pests (Asgar, 2011). Various monoterpenes like 1,8 cineole, linalool, α-pinene, terpinen-4-ol, and α-terpinene have been reported to show contact and fumigation toxicity to stored product pests (Papachristos et al., 2004; Stamopoulos et al., 2007). These monoterpenes, although present in the essential oil under study were in trace amounts and lack of toxicity of the essential oil may be attributed to the low total concentration of monoterpenes in the oil (Table 1). However, the oil showed good repellent activity against both *S. zeamais* and *S. oryzae*. One of the major compounds in the oil, δ-cadinene, has been reported to have repellent activity against some anthropods (Yatagai et al., 2002), and may be responsible for the observed repellent activity of the oil. However, there is a possibility of synergetic action between major and minor components to effect the repellent action of the oil. Biological activity of essential oils has been reported to be affected by interactions among the structural components of the oil where even the minor compounds can have critical function due to coupled effects and additive action between the different chemical classes (Tapondjou et al., 2005).

Conclusion

The essential oil of the dry leaves of *T. camphoratus* from Kwa-Zulu Natal, South Africa is mainly dominated by sesquiterpene hydrocarbons. The oil is not toxic to *S. zeamais* and *S. oryzae* but could be considered a potential in the control of stored product pests as a repellent.

Table 1. Percent chemical composition of the essential oil of the dry leaves of *T. camphoratus* from Kwa-Zulu Natal, South Africa.

Compound	Kovat Index	Percent composition
Monoterpene hydrocarbons		**1.61**
α- Pinene	938	0.45
Camphene	952	0.33
α-Terpinene	1017	0.65
p-Cymene	1026	0.18
Sesquiterpene hydrocarbons		**59.18**
α-Copaene	1378	2.33
α-Elemene	1393	2.98
Calarene	1403	3.60
(-)-Isoledene	1419	2.72
Beta-caryophyllene	1427	**5.48**
α-Guaiene	1439	2.73
α-humulene	1461	0.97
γ-gurjunene	1472	0.43
Aromandrene	1475	**6.12**
γ-Muurolene	1480	**5.13**
Eremophilene	1486	0.10
β-Guaiene	1500	**10.70**
γ-Cadinene	1513	**9.09**
δ-Cadinene	1526	**6.80**
Oxygenated monoterpenes		**6.26**
1,8-Cineole	1033	1.94
Linalool	1098	1.77
Camphor	1145	0.62
Terpinene-4-ol	1180	0.43
(-)-α-Terpineol	1190	0.82
Carvacrol	1299	0.68
Oxygenated sesquiterpenes		**3.19**
Elemol	1549	2.76
Spathulenol	1578	0.43
Others		**2.77**
Butanal	620	2.77

Conflict of Interest

The authors have not declared any conflict of interest.

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Short Communication

Integrated management of leaf and neck blast disease of rice caused by *Pyricularia oryzae*

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An investigation was carried out at two locations during *Kharif* 2007 - 2008, to evaluate the efficacy of fungicides, bio-agent and botanicals for the management of rice blast caused by *Pyricularia oryzae* Cavara, on highly susceptible cv. Pankhali. All the spray treatments proved effective and reduce leaf and neck blast intensity and significantly increased the yield parameters. Among the treatments, tricyclazole proved significantly superior over rest of the treatments for all the attributes, viz., leaf blast, neck blast, grain, straw yield and 1000 grain wt. at both the locations and in pooled analysis. The next effective treatment was *Pseudomonas fluorescens* but it was at par with iprobenfos.

Key words: Blast, *Pyricularia oryzae* Cav, fungicides, bio-agent, botanicals.

INTRODUCTION

Blast of rice caused by *Pyricularia oryzae* Cav. (*Magnaporthe grisea* Sacc.) is one of the most destructive disease (Ou, 1985) and it accounts for 30 to 100% yield losses in all rice growing areas of the country (Padmanabhan, 1965). In South Gujarat (Ahwa-Dangs and in hilly area of Dharmpur and Vansada), it is a major disease of rice and occurs every year on high yielding improved susceptible varieties during kharif (Anonymous, 1984-2007).

The blast of rice causes huge losses of quality and quantity of harvest. The various chemicals, antagonists and botanicals were recommended in different area to control the blast. Hence, the present investigation was undertaken.

MATERIALS AND METHODS

An experiment was conducted at two locations using Randomized Block Design (RBD) with three replication in Kharif 2007 - 2008 at Krishi Vigyan Kendra, Waghai Rajendrapur and Hill Millet Research Station, Rambhas farm (Ahwa-Dangs) of Navsari Agricultural University, Waghai, on highly susceptible cv. Pankhali. It was transplanted in 2.00 x 2.25 m net plots with 20 x 15 cm spacing. The fertilizers and other recommended cultivation practices were followed to raise good crop. The fungicides *viz*., tricyclazole (Beam 75WP 1 g lit^{-1}), iprobenfos (Kitazin 48EC 1 ml lit^{-1}), mancozeb (Dithane M-45 75WP 2.5 g lit^{-1}), bio-agent *Pseudomonas fluorescens* (Sudocel 0.5WP 2 x 10^8 cfu g^{-1}) and botanicals viz., neem and tulsi leaves extracts (10%) were sprayed after appearance of disease, two spray at boot leaf stage and third at flowering stage. The incidence of leaf and neck blast were recorded

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Table 1. Integrated management of rice leaf and neck blast diseases.

S/ No.	Treatments	Leaf blast intensity (%)			Neck blast intensity (%)		
		Waghai	Rambhas	Pooled	Waghai	Rambhas	Pooled
1	Tricyclazole (Beam 75WP) 1 g l^{-1}	8.64* (16.99)**	10.49 (18.77)	9.56 (17.88)	22.96* (28.54)**	25.55 (30.28)	24.25 (29.41)
2	Iprobenfos (Kitazin 48EC) 1 ml l^{-1}	14.44 (22.30)	17.90 (24.95)	16.17 (23.62)	40.24 (39.34)	38.64 (38.40)	39.44 (38.87)
3	Mancozeb (Dithane M-45 75WP) 2.5 g l^{-1}	19.50 (26.17)	22.71 (28.42)	21.11 (27.29)	43.33 (41.14)	45.80 (42.56)	44.56 (41.85)
4	*Pseudomonas fluorescens* 2x10^8 CFU/g	13.58 (21.54)	16.66 (24.05)	15.12 (22.79)	38.51 (38.33)	36.41 (37.09)	37.46 (37.71)
5	*Azadirachta indica* (Neem leaf extract) 10%	25.67 (30.38)	28.64 (32.31)	27.16 (31.35)	45.55 (42.42)	48.76 (44.27)	47.15 (43.35)
6	*Ocimum sanctum* (Tulsi leaf extract) 10%	38.82 (38.49)	45.55 (42.43)	42.19 (40.46)	59.38 (50.41)	60.61 (51.12)	59.99 (50.76)
7	Control (No spray)	46.54 (42.99)	52.46 (46.39)	49.50 (44.69)	63.35 (52.74)	66.79 (54.80)	65.07 (53.77)
	CD *(P=0.05)*	4.28	3.93	2.49	4.82	4.79	2.98
	CV (%)	8.47	7.12	7.77	6.48	6.31	6.39

* Figures those outside are original values, ** Figures in parenthesis are angular transformed values.

from 30 hills/plot randomly selected and labelled. These labelled plants were observed for disease intensity using Standard Evaluation System for Rice, IRRI (1988) at 10 days interval till harvest. The percent disease intensity was worked out by using the formula:

$$PDI = \frac{\text{Sum of numerical ratings}}{\text{No. of hills observed x Maximum ratings (9)}} \times 100$$

The grain and straw yield/plot and 1000 grain weight were record and statistically analyzed.

RESULTS AND DISCUSSION

All the treatments had significantly reduced the percent leaf and neck blast as compared to control at both the locations (Table 1). The bio-efficacy of all the fungicides were all most same in controlling the disease at both the locations and location pooled analysis. Tricyclazole (beam) was found significantly superior than the rest of treatments and recorded minimum (9.56%) leaf blast intensity. The next effective treatment was *Pseudomonas fluorescens* (15.12%) which was statistically at par with iprobenfos (kitazin) (16.17%), followed by mancozeb (dithane M-45) (21.11%), neem leaf extract (27.16%) and tulsi leaf extract (59.99%).

The similar trend was observed in case of controlling neck blast. The tricyclazole recorded significantly lowest (24.25%) neck blast intensity than the rest of treatments. The next best treatment was *P. fluorescens* (37.46%) which was statistically at par with iprobenfos (39.44%), followed by mancozeb (44.56%), neem leaf extract (47.15%) and tulsi leaf extract (59.99%) in location pooled analysis.

The results of grain and straw yield were significant at both location and in location pool analysis (Table 2). Here also trend of yield production was similar due to different treatment was almost same. Significantly highest grain yield (3197 kg/ha) was harvested in tricyclazole which was at par with *P. fluorescens* (3044 kg/ha) and iprobenfos (2805 kg/ha). Grain yield performance of mancozeb (2580 kg/ha) and neem leaf extract (2300 kg/ha) were also superior over control treatment (1805 kg/ha). Treatment of tulsi leaf extract gave numerically higher grain yield (2014 kg/ha) as compared to untreated control but was at par with control treatment in grain yield performance.

The straw yield performance was similar to that of grain yield due to different treatments at both location and in pool analysis. The straw yield was significantly highest (5900 kg/ha) in tricyclazole which was at par with *P. fluorescens* (5583 kg/ha) and iprobenfos (5472 kg/ha). Straw yield performance of mancozeb (5300 kg/ha) and neem leaf extract (5027 kg/ha) were also superior over control treatment (4178 kg/ha). Incase of 1000 grain wt., the effect of treatment was similar to earlier parameters. The tricyclazole was found significantly superior over the rest of treatments as highest (24.52 g) 1000 grain wt. was recorded. The next best was *P. fluorescens* (22.43 g) which was at par with iprobenfos (21.70 g) and mancozeb

Table 2. Effect of fungicides, botanicals and bioagents on grain yield and 1000 grain wt. of rice.

S/No.	Treatments	Grain yield (kg/ha)			Straw yield (kg/ha)			1000-grain wt. (gm)		
		Waghai	Rambhas	Pooled	Waghai	Rambhas	Pooled	Waghai	Rambhas	Pooled
1	Tricyclazole (Beam 75WP) 1 g l^{-1}	3250	3144	3197	5944	5855	5900	24.69	24.36	24.52
2	Iprobenfos (Kitazin 48EC) 1 ml l^{-1}	2894	2717	2805	5500	5444	5472	21.97	21.42	21.70
3	Mancozeb (Dithane M-45 75WP) 2.5 g l^{-1}	2650	2511	2580	5322	5277	5300	20.60	19.76	20.18
4	*Pseudomonas fluorescens* $2x10^8$ CFU/g	3061	3028	3044	5666	5500	5583	22.63	22.24	22.43
5	*Azadirachta indica* (Neem leaf extract) 10%	2350	2250	2300	5077	4978	5027	18.62	18.47	18.55
6	*Ocimum sanctum* (Tulsi leaf extract) 10%	2028	2000	2014	4522	4289	4405	17.65	17.31	17.48
7	Control (No spray)	1855	1755	1805	4278	4078	4178	16.75	16.42	16.58
	CD *(P=0.05)*	387.20	415.36	240.47	535.24	702.58	373.17	2.24	2.15	1.31
	CV (%)	8.42	9.39	8.90	5.80	7.80	6.85	6.19	6.04	6.12

(20.60 g). Treatment of neem and tulsi leaf extract gave numerically higher 1000 grain wt. 18.55 and 17.48 g, respectively, as compared to untreated control (16.58 g) but was at par with control treatment in their performance.

In the present study, tricyclazole was found significantly superior over rest of the treatments for all the attributes viz., leaf blast, neck blast, grain yield, straw yield and 1000 grain wt. at both the location and in pooled data. This may be due to tricyclazole, a melanin biosynthesis inhibiting fungitoxicant, which provide an effective control of rice blast (*P. oryzae* Cav.) by preventing pathogen from entering through the host epidermis and also prevents melanization of appressoria and subsequent formation of infection peg apparatus. The next effective treatment was *P. fluorescens* which was at par with iprobenfos. It may be due to *P. fluorescens* suppress rice blast through salicylic acid accumulation and induction of systemic resistance. While, iprobenfos act as a chitin inhibitor in rice blast pathogen, *P. oryzae* Cav.

The results of our studies are similar to earlier of several workers. Singh and Prasad (2007) reported tricyclazole (beam) as most effective fungicide for the control of rice blast and increase the yield. Similar result was also reported by Prajapati et al. (2004). Effectiveness of iprobenfos (kitazin) in controlling rice blast and increasing grain yield has also been reported by Sharma and Kumar (1992). While, Vidhyasekaran et al. (1997) who reported that when *P. fluorescens* applied as foliar spray, it suppress rice blast in field condition.

Conflict of Interest

The authors have not declared any conflict of interest.

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Sensitivity of *Colletotrichum lindemuthianum* from green beans to fungicides and race determination of isolates from State of São Paulo, Brazil

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This study determined the physiological races of *Colletotrichum lindemuthianum* isolates, causal agent of anthracnose, collected in green bean producing regions, and assessed the *in vitro* and *in vivo* sensitivity of isolates to fungicides. Physiological races of isolates were determined by inoculation of bean differential cultivars under controlled conditions. *In vitro* sensitivity of colony growth and conidial germination were evaluated for carbendazim, chlorothalonil, copper oxide, mancozeb, pyraclostrobin, thiophanate-methyl and for the mixtures of mancozeb + copper oxychloride, metiram + pyraclostrobin and thiophanate-methyl + chlorothalonil at concentrations of 1, 10, 100 and 1000 µg/mL on PDA medium. *In vivo* sensitivity was determined in detached primary leaves of green beans previously treated with the same fungicides (commercial doses) recommended for the crop, and then inoculated with conidial suspensions of *C. lindemuthianum*. *C. lindemuthianum* isolates were identified as belonging to races 65 and 81. Treatments with pyraclostrobin and the mixture metiram + pyraclostrobin were the most effective in inhibiting the colony growth and conidial germination *in vitro*, a result also observed for the *in vivo* experiments, where these chemicals were the most effective in controlling the green bean anthracnose.

Key words: Chemical control, *Phaseolus vulgaris*, anthracnose, physiological race, snap bean.

INTRODUCTION

Anthracnose, caused by *Colletrotrichum lindemuthianum*, is one of the major diseases of green bean, occurring in almost all producing countries, including Brazil. The disease affects leaves and pods of the plants, reducing productivity and the product quality for commercialization, being the cultivation of susceptible cultivars in regions with mild temperatures and high humidity one of the main factors for this wide distribution (Dalla Pria et al., 2003).

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Use of resistant cultivars and chemical control are essential for the efficient control of anthracnose (Ghini and Kimati, 2000). The knowledge of the physiological races of *C. lindemuthianum* that occurs on green beans and the sensitivity of isolates to fungicides are fundamental for the adoption of effective control measures, whether by the use of resistant cultivars to prevalent races of the pathogen in a region or for the chemical control in susceptible cultivars with appropriate fungicides.

Early studies in Brazil about the races of *C. lindemuthianum* were made during the 60's and 70's, but due to high pathogenic variability of the pathogen and the small number of differential cultivars used, the results were not reliable, as well as the use of different systems for naming the races caused difficulties to measure the variability in the fungus pathogenicity (Paradela Filho et al., 1991; Rodriguez-Guerra et al., 2003). After the work of Pastor-Corrales (1991), using 12 differential bean cultivars to study the pathogenic variability of *C. lindemuthianum* isolates, there was the standardization and creation of a binary scale for symptoms assessment, according to anthracnose severity, which provided the description of new races and breeding of new sources of resistance. Several studies have identified the occurrence of races of *C. lindemuthianum* in different regions of Brazil (Somavilla and Prestes, 1999; Thomazella et al., 2002; Bonett et al., 2008), but without specifying the origin of the isolates according to host (common beans or green beans).

Chemical control of anthracnose with fungicides have shown satisfactory results, resulting in high grain yield in common bean (Conner et al., 2004; Garcia et al., 2007; Gillard et al., 2012). In Brazil, there are more than 100 chemicals registered for the control of anthracnose in common bean, however, for green beans, only seven fungicides, from four different active ingredients (copper oxide, mancozeb, mancozeb + copper oxycloride and thiophanate-methil) are registered for use (Agrofit, 2015). Some chemicals used to control the anthracnose of common beans cannot be used on green bean, due to problems of residues. *C. lindemuthianum* isolates from common beans have shown a variation in the sensitivity of mycelial growth for benzimidazole fungicides (benomyl, carbendazim and thiophanate-methyl) (Maringoni and Barros, 2002; Sartorato, 2007; Sartori and Maringoni, 2007), but there is no information about the sensitivity of isolates from green beans.

The knowledge of physiological races and the sensitivity of *C. lindemuthianum* isolates to fungicides are essential for the efficient management of the anthracnose of green bean. On this study, the physiological races of 12 monosporic isolates of *C. lindemuthianum* from green bean producing regions of State of São Paulo, Brazil, were identified, as well the *in vitro* and *in vivo* sensitivity of isolates to fungicides recommended for the crop were determined.

MATERIALS AND METHODS

Cultures and growth conditions

Pods of green beans naturally infected by *C. lindemuthianum* were collected from producing regions of State of São Paulo, Brazil. Small portions of conidia present in the lesions were transferred to potato dextrose agar medium (PDA) (Acumedia, Baltimore, USA), followed by incubation in the dark (25°C/10 days). Isolates 3149, 3151, 3152, 3153 and 3158 (collected in Botucatu), 3148 (Campinas), 3154 (Itatiba), 3147 (Jaú), 3150 (Morungaba), 3156 (São Manuel), 3155 (São Paulo) and 3157 (Vinhedo) were purified and monosporic cultures obtained and preserved according to Castellani's modified method (Dhingra and Sinclair, 1995). All isolates had typical cultural and morphological characteristics of *C. lindemuthianum* according to Schwartz (1991). For all experiments, inoculum was produced on PDA in the dark (25°C/10 days). For the *in vitro* sensitivity of conidial germination experiment, inoculum was produced on oatmeal agar medium (60 g oat meal, 12 g agar and 1.000 mL distilled water) at same conditions, but for 15 days.

In vitro sensitivity of *C. lindemuthianum* isolates to fungicides

Colony growth sensitivity of all isolates were assessed to commercial fungicides carbendazim, chlorothalonil, copper oxide, mancozeb, pyraclostrobin, tiophanate-methyl and to the mixtures mancozeb + copper oxychloride (57% + 43%), metiram + pyraclostrobin (92% + 8%) and chlorothalonil + thiophanate-methyl (71% + 29%) at 1, 10, 100 and 1000 µg/mL in 90 × 16 mm Petri dishes with PDA medium. PDA medium without fungicides was used as control. Mycelial discs (7 mm) were transferred to the Petri dishes with the treatments and plates were incubated in the dark (25°C/10 days). The average diameter of the colonies (mm) was assessed and the percentage of inhibition calculated based in the control treatment growth. Experimental design was completely randomized with four replications for each fungicide concentration and for each isolate. The effective dose causing 50% inhibition of mycelial growth (ED_{50}) was determined according to Sartori and Maringoni (2007), and numerical index for each range of ED_{50} were assigned: index 1 (ED_{50} < 1 µg/mL), index 2 (ED_{50} from 1 to 10 µg/mL), index 3 (ED_{50} from 10 to 100 µg/mL), index 4 (ED_{50} from 100 to 1000 µg/mL) and index 5 (ED_{50} > 1000 µg/mL).

Conidial germination sensitivity was evaluated for isolates 3147, 3150, 3155 and 3158 that showed sensitivity in the colony growth experiment to mancozeb and to the chlorothalonil + tiophanate-methyl mixture. PDA preparation, fungicides and concentrations were the same used for the assessment of colony growth sensitivity. Suspensions were standardized to 5×10^5 conidia/mL (Maringoni and Barros, 2002) and 100 µL of each suspension were distributed on the surface of the media with fungicides followed by incubation in the dark (25°C/24 h). Mycelial discs (1.5 cm) were transferred to microscope slides and stained with lactophenol cotton blue to paralyze the fungal growth. For each isolate and fungicide concentration the germination of 100 conidia were assessed per disc. Experimental design was completely randomized with four replications and each plot represented by a mycelial disc. With the results the effective dose causing 50% inhibition of conidial germination (ED_{50}) was determinated according to the numerical index previously described.

In vivo sensitivity of *C. lindemuthianum* isolates to fungicides

Green beans plants cv. Itatiba II were cultivated in 2 L pots with substrate (mixture of soil, weathered cattle manure and sand (1:1:1), plus 0.6 kg of ammonium sulfate, 17 kg of superphosphate, 0.6 kg of potassium chloride and 0.8 kg of lime for every m^3 of the

Table 1. Effective dose causing 50% inhibition of mycelial growth (ED_{50}) for *Colletotrichum lindemuthianum* isolates from green beans to fungicides.

Fungicides	Isolate											
	3147	3148	3149	3150	3151	3152	3153	3154	3155	3156	3157	3158
Carbendazim	5	5	5	5	5	5	5	5	5	4	5	5
Chlorothalonil	4	5	4	3	4	4	3	3	3	3	4	4
Chlorothalonil + thiop.-methyl	4	5	4	4	4	4	3	4	4	4	5	4
Copper oxide	5	5	5	5	5	5	5	5	5	5	5	5
Mancozeb	5	5	5	5	5	5	4	5	4	5	5	5
Mancozeb + copper oxychloride	5	5	5	5	5	5	5	5	5	5	5	5
Metiram + pyraclostrobin	3	4	4	3	4	4	4	4	4	4	4	4
Pyraclostrobin	2	2	2	2	2	2	2	2	2	2	2	2
Thiophanate-methyl	5	5	5	5	5	5	5	5	5	5	5	5

Numerical index from 1 to 5 correspond to different ranges of ED_{50}: index 1 - ED_{50} < 1 µg/mL; index 2 - ED_{50} from 1 to 10 µg/mL; index 3 - ED_{50} from 10 to 100 µg/mL; index 4 - ED_{50} from 100 to 1000 µg/mL and index 5 - ED_{50} > 1000 µg/mL.

mixture) under greenhouse conditions (20-28°C/70-90% RU) till the phenological growth stage V2. The primary leaves were collected, immersed in a solution of 10% Tween 80 (10 s), and then immersed, separately, in suspensions of commercial fungicides carbendazim (1 mL/L), chlorothalonil (1.5 g/L), copper oxide (1.72 g/L), mancozeb (3.20 g/L), mancozeb + copper oxychloride (0.88 + 0.66 g/L), metiram + pyraclostrobin (1,65 + 0.15 g/L), pyraclostrobin (0.15 mL/L), thiophanate-methyl (1.40 g/L) and chlorothalonil + thiophanate-methyl (1.75 + 0.70 g/L) for 5 s. The leaves were transferred in Petri dishes (150 × 15 mm) containing two paper filters wetted with distilled water and sprayed with conidial suspensions (10^6 conidia/mL) of each isolate, after 24 h of the fungicide treatment (Gulart, 2009). Petri dishes containing two primary leaves each were kept in the dark for 24 h and incubated in BOD (20°C/7 days) under a 12 h photoperiod (2400 Lux). Control treatment consisted of leaves immersed in water and inoculated with conidial suspensions. Absolute control consisted of leaves immersed in water without inoculation. Disease severity on leaves was determined seven days after inoculation according to the diagrammatic scale proposed by Dalla Pria et al. (2003). Experimental design was completely randomized, with three replicates for each isolate and fungicide. Data were subjected to variance analysis and means were compared by Scott-Knott's test at 5% probability.

Determination of physiological races of *C. lindemuthianum* isolates

Seedlings of bean differential cultivars AB 136, Cornell 49-242, G 2333, Kaboon, Mexico 222, Michelite, Michigan Dark Red Kidney, Perry Marrow, Pi 207262, TO, TU and Widusa were obtained under greenhouse conditions in plastic trays of 84 cells containing sterile vermiculite. The aerial part of five seedlings of each cultivar were inoculated by spraying with a suspension (10^6 conidia/mL) of each isolate, 10 days after emergence, according to Pastor-Corrales (1991) and Carbonell et al. (1999). One plant of Pérola cultivar, susceptible to most races of *C. lindemuthianum*, was used as a negative control for each differential series. Seedlings were kept in a climatic room (23°C/90% RU) under a 12 h photoperiod (2400 Lux).

The disease severity was evaluated 10 days after inoculation based on disease scale from 1 to 9, with grades from 1 to 3 representing resistant genotypes, and grades above 3, susceptible genotypes (Pastor-Corrales, 1991; Gonçalves-Vidgal et al., 2007).

RESULTS

In vitro sensitivity of *C. lindemuthianum* isolates to fungicides

Results of colony growth and conidial germination *in vitro* sensitivity of *C. lindemuthianum* isolates to fungicides are described in Tables 1 and 2, respectively. All isolates showed low sensitivity on colony growth and conidial germination (ED_{50} > 1000 µg/mL) to thiophanate-methyl. For chlorothalonil and thiophanate-methyl + chlorothalonil, 50% and 75% of isolates had ED_{50} between 100 and 1000 µg/mL for colony growth, respectively. For conidial germination, 100% of the isolates showed ED_{50} between 10 and 100 µg/mL to chlorothalonil + thiophanate-methyl, while chlorothalonil was the most effective fungicide for inhibition of conidial germination of isolates (100% of isolates with ED_{50} < 1 µg/mL). It was also observed a low sensitivity to carbendazim (ED_{50} > 1000 µg/mL) to 100% (conidial germination) and 91.7% (colony growth) of the isolates.

Regarding to mancozeb and mancozeb + copper oxychloride, 83.4% and 100% of isolates had an ED_{50} higher than 1000 µg/mL for colony growth, respectively, while 100% of the isolates showed ED_{50} between 10 and 100 µg/mL for conidial germination for these chemicals. All isolates evaluated were sensitive to pyraclostrobin and metiram + pyraclostrobin (ED_{50} from 1 to 10 µg/mL) for conidial germination. For colony growth, the sensitivity was reduced in the mixture metiram + pyraclostrobin (83.4% of isolates with ED_{50} from 100 to 1000 µg/mL) in relation to pyraclostrobin (100% of isolates with ED_{50} from 1 to 10 µg/mL). The isolates did not show sensitivity to copper oxide with an ED_{50} higher than 1000 µg/mL for colony growth and conidial germination.

Table 2. Effective dose causing 50% inhibition of conidial germination (ED_{50}) for *C. lindemuthianum* isolates from green beans to fungicides.

Fungicides	Isolate			
	3147	3150	3155	3158
Carbendazim	5	5	5	5
Chlorothalonil	1	1	1	1
Chlorothalonil + thiop.-methyl	3	3	3	3
Copper oxide	5	5	5	5
Mancozeb	3	3	3	3
Mancozeb + *copper* oxychloride	3	3	3	3
Metiram + pyraclostrobin	2	2	2	2
Pyraclostrobin	2	2	2	2
Thiophanate-methyl	5	5	5	5

Numerical index from 1 to 5 correspond to different ranges of ED_{50}: index 1 - ED_{50} < 1 µg/mL; index 2 - ED_{50} from 1 to 10 µg/mL; index 3 - ED_{50} from 10 to 100 µg/mL; index 4 - ED_{50} from 100 to 1000 µg/mL and index 5 - ED_{50} > 1000 µg/mL.

Table 3. Anthracnose severity in detached primary leaves of green bean cv. Itatiba II treated with fungicides and inoculated with *C. lindemuthianum* isolates.

Fungicide	Isolate			
	3147	3150	3155	3158
Control (water)	71.7a*	100.0a**	100.0 a	100.0a
Carbendazim	66.7a	41.7b	51.7 b	46.7c
Chlorothalonil	4.0c	1.7c	1.7 e	1.7e
Chlorothalonil + thiop.-methyl	8.7c	6.0c	9.3 d	8.0d
Copper oxide	31.7b	40.0b	35.0 c	40.0c
Mancozeb	1.7c	2.7c	1.7 e	3.0e
Mancozeb + *copper* oxychloride	4.0c	2.7c	2.0 e	5.0d
Metiram + pyraclostrobin	0f	0f	0f	0f
Pyraclostrobin	0f	0f	0f	0f
Thiophanate-methyl	41.7b	43.3b	43.3b	55.0b
V.C.%	17.6	17.0	10.7	9.6

*Data transformed in arcsen√x/100. **Means followed by same letter are not significantly different at P<0.05 probability using Scott-Knott's test.

In vivo sensitivity of *C. lindemuthianum* isolates to fungicides

Results of *in vivo* sensitivity of *C. lindemuthianum* isolates to fungicides are described in Table 3, and were very similar to those obtained from the *in vitro* experiments. Pyraclostrobin and metiram + pyraclostrobin were the most effective fungicides for the control of anthracnose on green beans leaves, independent of the *C. lindemuthianum* isolate evaluated, showing complete absence of symptoms in the inoculated leaves.

The treatments with chlorothalonil, mancozeb and the mixtures mancozeb+ copper oxychloride and chlorothalonil + thiophanate-methyl were also effective in the reduction of anthracnose severity on green beans leaves. However, the fungicides from the group of benzimidazole (carbendazim and thiophanate-methyl) and copper oxide did not controlled the disease on the leaves, similar results to those obtained from *in vitro* studies.

Determination of physiological races of *C. lindemuthianum* isolates

Isolates 3149, 3151, 3152, 3158, 3147, 3148, 3150 and 3157 of *C. lindemuthianum* were identified as race 65, while isolates 3153, 3154, 3155 and 3135 were identified as race 81 (Table 4).

DISCUSSION

The variation in colony growth sensitivity of *C. lindemuthianum* isolates from common bean to

Table 4. Reaction of bean differential cultivars inoculated with *C. lindemuthianum* isolates from green beans from various locations of São Paulo State.

Differential cultivar	Binary value	Isolate											
		3147	**3148**	**3149**	**3150**	**3151**	**3152**	**3153**	**3154**	**3155**	3156	3157	3158
Michelite	1	S	S	S	S	S	S	S	S	S	S	S	S
Michigan Dark Red Kidney	2	R	R	R	R	R	R	R	R	R	R	R	R
Perry Marrow	4	R	R	R	R	R	R	R	R	R	R	R	R
Cornell 49-242	8	R	R	R	R	R	R	R	R	R	R	R	R
Widusa	16	R	R	R	R	R	R	R	R	R	R	R	R
Kaboon	32	R	R	R	R	R	R	R	R	R	R	R	R
México 222	64	S	S	S	S	S	S	S	S	S	S	S	S
Pi 207262	128	R	R	R	R	R	R	R	R	R	R	R	R
TO	256	R	R	R	R	R	R	R	R	R	R	R	R
TU	512	R	R	R	R	R	R	R	R	R	R	R	R
AB 136	1024	R	R	R	R	R	R	R	R	R	R	R	R
G 2333	2048	R	R	R	R	R	R	R	R	R	R	R	R
Race		65	65	65	65	65	65	81	81	81	81	65	65

benzemidazole fungicides (benomyl, carbendazim and thiophanate-methyl) has been reported in several studies in Brazil with ED_{50} ranging from 1 to 1000 µg/mL (Maringoni and Barros, 2002; Sartorato, 2007; Sartori and Maringoni, 2007). On this study we detected an low sensitivity of colony growth of *C. lindemuthianum* isolates from green beans to benzimidazoles fungicides (carbendazim and thiophanate-methyl) (Table 1). The low sensitivity of conidial germination from *C. lindemuthianum* isolates evaluated on this study to carbendazim and thiophanate-methyl agrees with Maringoni and Barros (2002), where isolates from common beans were also resistant to these fungicides.

C. lindemuthianum isolates from common beans also exhibit variation in colony growth sensitivity to chlorothalonil with ED_{50} ranging from 10 to 800 µg/mL (Rava et al., 1998; Maringoni and Barros, 2002), results similar to the obtained in this study for green beans isolates. Most isolates here evaluated showed an ED_{50} from 100 to 1000 µg/mL for colony growth to chlorothalonil + thiophanate-methyl, results discrepant to those obtained by Balardin and Rodrigues (1995) and Sartori and Maringoni (2007), who reported inhibition of *C. lindemuthianum* isolates from common beans to concentrations ranging from 10 to 100 µg/mL. Regarding conidial germination, chlorothalonil was the most effective fungicide (ED_{50} < 1 µg/mL), while thiophanate-methyl did not show a satisfactory result (ED_{50} > 1000 µg/mL). These results show that the best performance of the mixture chlorothalonil + thiophanate methyl (ED_{50} from 10 to 100 µg/mL) in comparison with thiophanate-methyl alone is due to the chlorothalonil activity, showing the absence of a synergistic action between these fungicides.

C. lindemuthianum isolates evaluated in this study showed an ED_{50} for mancozeb and the mixture mancozeb + copper oxychloride higher to those described by Rava et al. (1998) for isolates from common beans, indicating a lower sensitivity of these isolates to these chemicals. No information about the sensitivity of *C. lindemuthianum* isolates to copper oxide was found, although Tsai et al. (2006) evaluated isolates of *C. gloesporioides* and *C. musae* from fruit species and found and ED_{50} ranging from 10 to 100 µg/mL for cupric fungicides, values lower to those found on this study.

ED_{50} values for the colony growth to pyraclostrobin found on this study were lower to those reported by Sartorato (2007) for *C. lindemuthianum* isolates from common beans (ED_{50} of 187.5 µg/mL) and close to the results obtained by Sartori and Maringoni (2007) to trifloxystrobin, a strobilurin from the same group of pyraclostrobin. However, colony growth sensitivity of *C. lindemuthianum* isolates from green beans was reduced for the mixture metiram + pyraclostrobin, which most of the isolates had and ED_{50} ranging from 100 to 1000 µg/mL, concentration higher than that reported by Tsai et al. (2006) for *C. gloesporioides* and *C. musae* (ED_{50} from 10 to 100 µg/mL). There is no information about conidial germination sensitivity from *C. lindemuthianum* isolates to pyraclostrobin and metiram + pyraclostrobin, however, there is information about other fungi, such as *Cylindrocladium candelabrum* on eucalyptus (Ferreira et al., 2006) and *Cercospora sojina* on soybean (Zhang et al., 2012), demonstrating the sensitivity of conidial germination of these fungi to strobilurins.

Pyraclostrobin was also the most effective fungicide for the control of anthracnose on green bean leaves, a result that agrees with Conner et al. (2004) and Gillard et al. (2012) for white and common beans, respectively. The high sensitivity of isolates here evaluated to metiram + pyraclostrobin may have occurred due probably to the sensitivity showed by them to the pyraclostrobin. There are no reports of *C. lindemuthianum* sensibility to metiram and copper oxide.

The disease severity reduction found on this study for the mixture chlorothalonil + thiophanate-methyl, compared to thiophanate-methyl alone, demonstrates the sensitivity of *C. lindemuthianum* isolates to chlorothalonil and the low sensitivity to benzimidazole fungicides, results also observed by Garcia et al. (2007) in common beans.

According to Bashir et al. (1985), benomyl and chlorothalonil were effective for the control of anthracnose on mung bean; results similar to those obtained in this study to chlorothalonil, but differed for thiophanate-methyl, fungicide with mode of action similar to benomyl. Castro et al. (1991) also reported the efficiency of chlorothalonil for the control of anthracnose in common beans.

The efficiency of mancozeb and mancozeb + copper oxychloride observed on this study in reducing the severity of anthracnose on green bean leaves also agrees with Castro et al. (1991), who reported a disease severity reduction in common beans treated with these chemicals. The authors also demonstrated the effectiveness of carbendazim in controlling the anthracnose in common beans, result not observed on this study with green bean isolates.

Studies with *C. lindemuthianum* isolates from common beans also identified the prevalence of races 65 and 81 in Brazil (Somavilla and Prestes, 1999; Carbonell et al., 1999; Thomazella et al., 2002). Until now there was no information about the races of *C. lindemuthianum* that occur on green beans demonstrating that genotypes with resistance to races 65 and 81 of *C. lindemuthianum* should be used in genetic breeding programs of green beans, aiming the incorporation of resistance genes to anthracnose in susceptible cultivars.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Combining ability of some sorghum lines for dry lands and sub-humid environments of East Africa

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Sorghum (*Sorghum bicolor* L. Moench) is a major food crop grown in dry lands and sub-humid areas of East Africa. A study was conducted between 2010 to 2012 in dry lands (Miwaleni, Kiboko) and sub-humid (Ukiriguru) environments to identify parents for hybrid production. It involved 121 lines from ICRISAT and 121 hybrids developed from 36 male sterile lines and 42 restorer lines in a line × tester crossing. Experiments were planted in an alpha lattice design with three replications. Analysis revealed significant (P < 0.05) differences between parents and between crosses for yield and yield components, indicative of potentiality for exploitation. Line IESV23010 expressed best (-6.5) general combing ability (*GCA)* for days to 50% flowering (DAF). Highest general combiner for height was -55.4 expressed in ICSR24007 and for yield was 382.8 expressed in IESV92156DL. The crosses SDSA4×ICSR43 and SDSA4×ICSR59059 exhibited high and significant specific combining ability (*SCA*) for DAF. Lines IESB2 and ICSB44 were suited to sub-humid, whereas BTX623, ICSB15 and ICSB6 to dry lands environments. Testers IESV91104DL, IESV91131DL, ICSR93034 were well suited to dry lands whereas KARI-MTAMA1 and IESV23019 to sub-humid environments. The parents identified could be used to produce hybrids and varieties for the dry lands and sub-humid environments.

Key words: Combining ability, lines, restorers, sorghum, top-cross hybrids.

INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is a major staple crop grown in water stressed areas of the tropics (Abdulai et al., 2012), because of its resiliency. Lately, sorghum has received significant attention because of its multiple uses as food, feed, and raw material in brewing and biofuel industries (Paterson, 2008). According to FAO (2010), Africa contributes over 60% to the total land area dedicated to cultivation of sorghum. A report by Tanzania's Ministry of Agriculture Food Security and Cooperatives (MAFSC, 2012) indicates that, annual demand for white sorghum in Tanzania is 3,360 metric tonnes while the supply in the country during 2011/2012 was only 1,084 metric tonnes, indicating a significant difference between demand and supply. Further, demand

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for white sorghum in East Africa has increased dramatically after the East Africa Breweries Limited company started to use it for beer production. However, according to FAO (2010), sorghum productivity in Eastern Africa has been low (<1 t ha^{-1}). Among the main causes for this low production level is the continuous use of low yielding landraces (Aruna and Audilakshmi, 2008) which could mainly be attributed to scarcity of adapted hybrids (Makanda et al., 2012). Deployment of adapted sorghum hybrids could be a practical and fast approach to boost productivity. Report by Makanda et al. (2012), Patil (2007) and Bantilan et al. (2004) indicates that sorghum hybrids can out yield non-hybrid cultivars by up to 60%. Despite all these benefits, most national sorghum breeding programs in the region have been focused on development of open pollinated varieties, with less emphasis on hybrids possibly due to lack of suitable parents for hybrid production and lack of means to buy seed every season. Sustainable sorghum hybrid program requires availability of locally adapted male sterile and restorer lines. The International Crops Research Institute for Semi Arid Tropics (ICRISAT) introduced new inbred lines from India and collections from various parts of East Africa but their combing ability has not been studied. Knowledge of general combining ability (*GCA*) and specific combing ability (*SCA*) is vital to start a hybrid program. The *GCA* assesses the average performance of an inbred line in hybrid combinations, while *SCA* identifies the crosses in which its combinations perform relatively better or worse than would be expected on the basis of *GCA* of the parents (Reddy et al., 2007). Theobjective of this study was to identify the best hybrids and their parents through estimation of *GCA* and *SCA* for yield and yield components of a comprehensive set of introduced inbred lines for sub-humid and dry low-lands of East Africa.

MATERIALS AND METHODS

Description of experimental sites

Experiments were conducted in Tanzania (Ukiriguru and Miwaleni) and Kenya (Kiboko) locations respectively. Ukiriguru is found in sub-humid climate (ILCA, 1987) and is located at 2° 43' 0" S and 33° 1' 0" E on 1198 m above sea level. Temperatures vary from 18.3 to 29.6°C and annual rainfall of about 861 mm. Soil is mainly sandy loam. Miwaleni is located at 3° 25' 30" S and 37° 26' 45" E at 720 m above sea level. The soil types are reddish brown and the area experience tropical semi-arid climate. Temperatures range between 10 to 39°C and the annual rainfall ranging from 500 to 700 mm (John, 2010). Kiboko lies between 37°45'E and 2°15'S at 960 m above sea level and experiences a semi-arid tropical climate with a bimodal rainfall pattern. The annual rainfall is 655 mm (www.kari.org). The temperature varies from 13.7 to 24.7°C. The soil type at this location is sandy clay group.

Development, selection and evaluation of hybrid sorghum

A total of 121 sorghum lines including 36 pairs of male sterile (A, B lines) and 42 restorers (R-lines) were obtained from ICRISAT-Nairobi (Appendix 1) for evaluation and generating experimental hybrids. Production of the hybrids was conducted at Kiboko in 2010. Seed for all parents was hand planted in 2-m rows. Two rows of A-lines were grown parallel to 1 row of B-lines (for maintenance of A-lines and data collection on yield) alongside a block of R-lines. Each R- line occupied a single row. All plants were bagged before flowering to avoid cross pollination. Pollen was collected in paper bags from R-lines in morning (before 11:00) and dusted on to female panicles. Each single head of A-line was pollinated by single R-line and both bagged right after pollination. A total of 353 hybrids developed but only 121 had enough seed for multi-location testing to determine combining ability. These hybrids were sown in single, 4-m rows with 60 cm between rows and 50 cm between plants. A basal fertilizer application of 20 kg ha^{-1} (N/ha), and 20 kg ha^{-1} (P/ha) was applied during sowing. Five plants from each entry were selfed with pollination bags before flowering to determine the fertility status of the hybrid. Pollination bags were removed at the soft dough stage and the seed set on bagged heads was assessed visually using a scale of 0 to 100%; where 0% represented a completely sterile head without seed set, and 100% represented a completely fertile head with complete seed set. Thinning was done two weeks after emergence to 2 plants per hill. Top-dressing with urea, at the equivalent of 45 kg ha^{-1} was done at four weeks after emergence. Other agronomic practices including weeding and disease control was practiced as per requirements. Data were recorded for days to 50% flowering (whole-plot), plant height, tillers per plant, panicle length, panicle width, panicle exsertion, grain colour and grain yield using sorghum descriptors (IPGRI, 1993) on the five plants that were randomly selected and bagged before flowering.

Statistical analysis

The *GCA* and *SCA* effects were determined using SAS General Linear Model (GLM) procedure, (SAS Institute 2008, SAS V9.2). Both *GCA* and *SCA* effects were significantly different at P<0.05 and were calculated according to Kearsey and Pooni (1996)

Where by: $GCA_f = X_f - \mu$ and $GCA_m = X_m - \mu$

Note: X_f, X_m = mean performance of female and male lines in crosses respectively; GCA_f and GCA_m= GCA for female and male parents respectively; μ = grand mean of all crosses.

$$SCA_X = X_x - E(X_x) = X_x - GCA_f + GCA_m + \mu$$

where: SCA_X = SCA effects of the two parents in the cross; X_x= observed mean value of the cross; $E(X_x)$= expected value of the cross basing on the GCA effects of the two parents; GCA_f and GCA_m= GCA for female and male parents respectively and μ = grand mean of the crosses.

RESULTS AND DISCUSSION

Data on mean monthly temperature, rainfall and relative humidity from three locations are presented in Figures 1, 2 and 3 respectively. Ukiriguru experienced high relative humidity (77 to 79%) and temperatures (18.4 to 29.3°C)

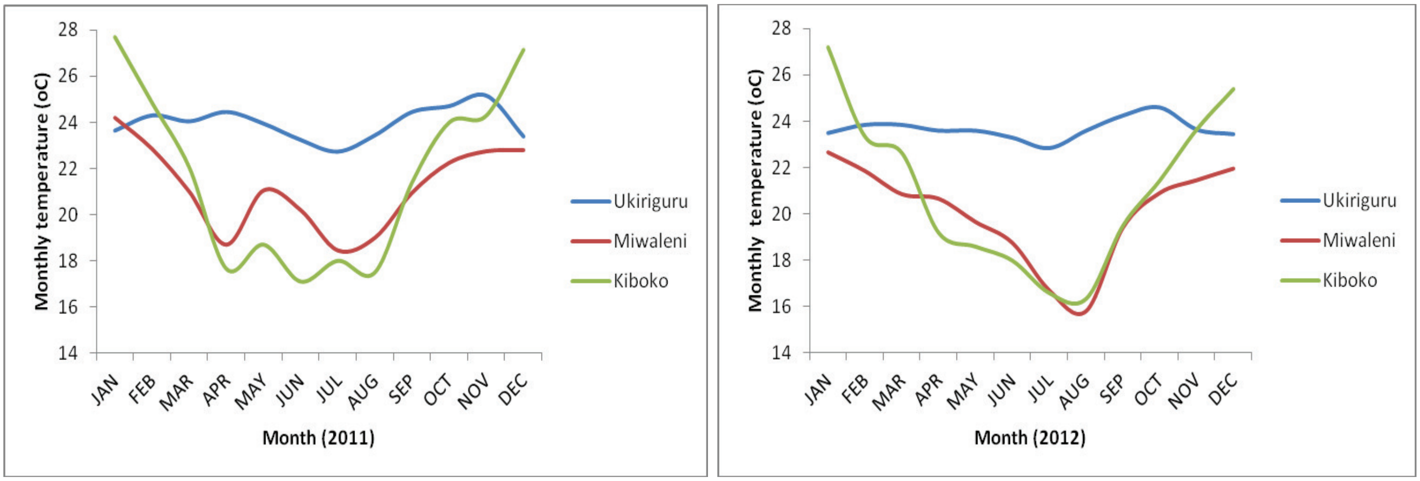

Figure 1. Monthly temperature (^oC) at Ukiriguru, Miwaleni and Kiboko during 2011 and 2012 growing seasons.

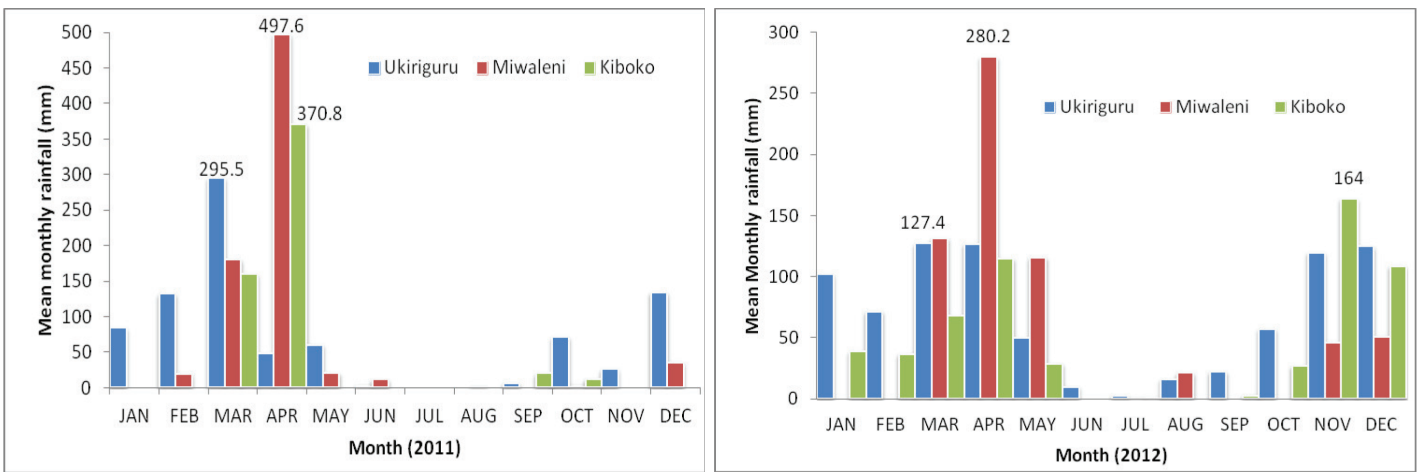

Figure 2. Monthly rainfall (mm) at Ukiriguru, Miwaleni and Kiboko during 2011 and 2012 growing seasons.

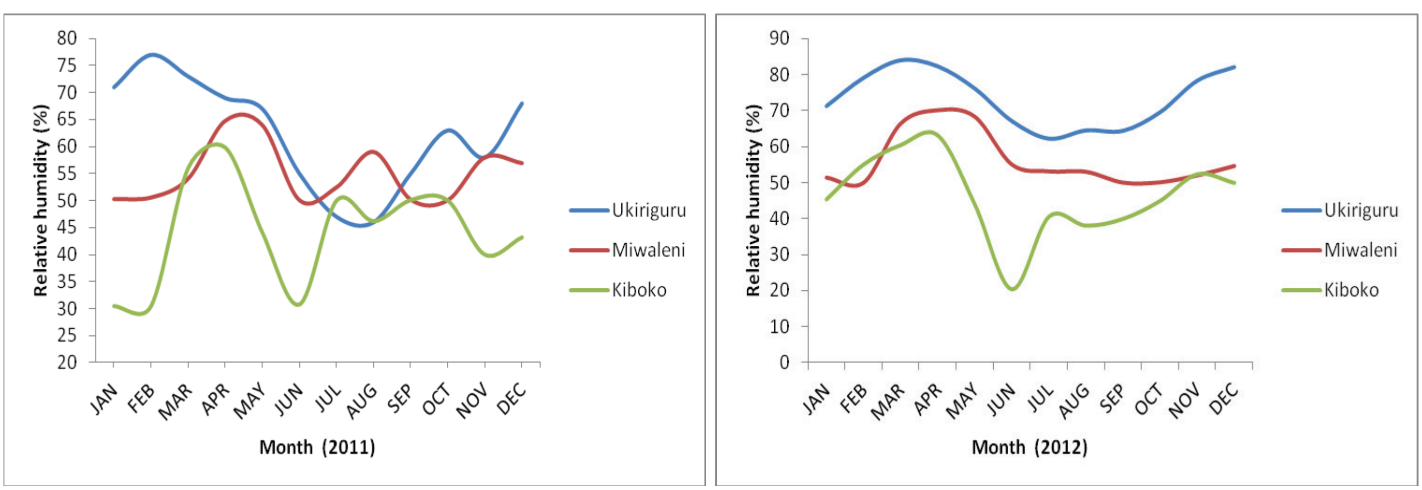

Figure 3. Monthly relative humidity (%) at Ukiriguru, Miwaleni and Kiboko during 2011 and 2012 growing seasons.

Table 1. Analysis of variance for some traits evaluated in sorghum across dry lands and sub-humid environments of Tanzania and Kenya.

Source of variation	Mean squares							
	Df	Days to 50% flowering	Productive tillers	Plant height (cm)	Panicle length (cm)	Panicle width (cm)	Grain yield /panicle (g)	Grain yield/plot (g)
Environment (Env)	2	2382.2**	468.8**	179447.7**	2839.1**	962.6**	111459.7**	89300603.4**
Crosses	91	56.5**	3.2**	5316.3**	49.5**	9.6**	1700.6**	467301.8**
Females	27	157	5.6	6714.1**	106.1**	18.4**	1933.9**	518475.6
Males	45	18.7**	2.0*	7540.4**	35.2**	6.9**	1587.2**	486877.4**
Females × Males	26	8.9	2.5**	528.6	12.4**	4.4**	1628.6**	384797.2
Env × Crosses	184	13.4**	2.9	616.1**	8.2**	3.4	785.2	454484.6**
Env × Females	54	19.1**	4.8**	720.3**	10.6**	5.3	883.4	454590.6**
Env × Males	78	11.1	1.9	550.6**	8.8**	2.9	721.6	420757.0**
Env × Females × Males	52	10.8	2.4**	606.2**	4.8	2.1	778.5	504965.9**
Error	420	5.6	0.9	221.9	4.7	1.5	580.6	187013.2

*, ** Significant at 1 and 5% level respectively

Table 2. Rating scale and summary for seed set of sorghum evaluated at Kiboko and Miwaleni in 2011 season.

Seed set (%) range	Description	Number of hybrids		Total	% Hybrids
		Kiboko	Miwaleni		
100	The whole head is filled with grain seed set.	64	46	110	32.6
80 to <100	Seed set above three quarters of head.	166	147	313	92.9
60 to <80	Above two thirds of the head showing seed set.	2	28	30	8.9
40 to <60	Half of the total head showing seed set.	12	11	23	6.8
20 to <40	About a quarter of the head showing seed set.	4	23	27	8.0
1 to <20	Less than a quarter of the head showing seed set.	17	34	51	15.1
0	Total sterility, no seed set on the head.	72	48	120	35.6

Seed set percent range adopted from sorghum descriptors (IPGRI, 1993)

especially during flowering (February). The mean monthly rainfall was lower (102 mm average) during the same period. Miwaleni location was characterised by relatively higher monthly rainfall (average of 156.2 mm), low temperatures (17.3 to 24.4°C) and low relative humidity (54 to 66.3%) during flowering (March). Kiboko experienced similar conditions to Miwaleni except that rainfall was relatively lower (114 mm) in March. Differences in grain yield and its associated traits between environments could be due to location's differences in weather during growing season and genetic potential of the specific cultivar. Significant variations in sorghum for yield and yield traits across environments have also been reported by Warkard et al. (2008). Kiboko location received relatively higher rainfall than other location resulting to overall high grain yield.

Differences among crosses and among male lines were significant (P ≤ 0.05) for days to 50% flowering, productive tillers, plant height, panicle length, panicle width and yield (Table 1) indicating broad genetic diversity of sorghum materials used in this study. There was no significant difference between female parents. This could be due to the fact that, the female lines were purposely derived for developing hybrids suitable for dry lowlands and sub humid environments hence comparatively same background. Moreover, the differences recorded for parents and crosses imply that the materials are suitable for combining ability studies. The interaction between females and males were not significantly different for days to 50% flowering, plant height and panicle exsertion. The significant differences for Female × Male interaction for the productive tillers, panicle length, panicle width, panicle shape and grain yield indicate high contribution of SCA effects to those traits and, therefore, predominance of non-additive gene action. Similar results were reported by Vinaykumar et al. (2011). This necessitated testing the parents and hybrids for GCA and SCA effects across several environments and enable identification of outstanding cultivars for general and specific adaptation.

The summary of fertility restoration for experimental hybrids tested at Kiboko and Miwaleni is presented in Table 2. There was high difference in seed setting among the hybrids (Figure 4). Most of the test hybrids, 313

Figure 4. Fertility status of some hybrids tested at Kiboko and Miwaleni (a) fully restored (b) partially restored (c) extremely low restoration on bagged panicles indicated by arrows.

(93%) exhibited ≥ 80% seed set, with Kiboko registering higher values than Miwaleni. Only 110 (32%) of the hybrids had 100% restoration; among those, 64 were at Kiboko, and 46 at Miwaleni. One hundred and twenty hybrids (35.6%) did not produce seed at all in the bagged panicles in both locations. Three female lines A2DN55, ICSA479, ICSA469, consistently produced poor hybrids in terms of seed set irrespective of male parent used. A total of 171 hybrids were within the recommended fertility restoration range, 80 to 100%, for multi-location advanced trials. Due to seed availability, only 121 hybrids were tested in three sites alongside their parental lines for yield and its components and combining ability. There were significant differences observed in fertility restoration among hybrids and could be attributed to the specific interaction between the male and female parent genotypes and the environmental influences. Relatively lower mean temperatures at Ukiriguru and Miwaleni coupled with high relative humidity could have resulted in the low seed set. Effect of temperature and relative humidity has also been reported by Leland and House (1985).

The hybrids that failed to produce seed on the bagged panicles indicates that the corresponding male parents in such hybrid were non-restorers as also reported by Singh et al. (1997), and could serve as a source of A-lines. The hybrids that expressed full seed set in some bagged panicles but not others within and across environments were an indication that the male parents for such hybrids were segregating for fertility restoration, and cannot be used as they are in a breeding program (Murty et al., 1994). The A-lines A2DN55, ICSA479 and ICSA469 produced poor hybrids in terms of seed set irrespective of male parent could be due to the environmental effects and/or the genetic background of the A-line (Sleeper and Poehlman, 2006). Purification through recurrent backcrossing is recommended for these lines before used for hybrid production. Since these male sterile lines were recently introduced into Africa from different climatic conditions, some could be poorly suited for the new agroecologies. The temperature at the three locations ranged between 18 and 29.3°C which is within the optimum range for most sorghum cultivars (Reddy et al., 2007).

Negative GCA for plant height, days to flowering and positive GCA for yield and productive tillers is desired for a good genotype. This study found no parent that exhibited high and desired GCA for all traits evaluated including yield, plant height productive tillers (Table 3). The top 3 male sterile and restorer lines for early flowering were MB6, CK60B, ICSB11, and IESV 23010DL, S35, SP74279. Early maturing sorghum hybrids and parental lines could be favourable for semi-arid areas because they can utilize the limited moisture available and hence escape terminal drought. The male-sterile lines and restorer lines for plant height that expressed high and negative *GCA* were ICSB91002, ICSB89004 and ICSB90001; and ICSR24007, ICSR89001 and ICSR38. Negative *GCA* for plant height in sorghum is preferable as it is directly related to dwarfness, hence making plants less susceptible to lodging (Singh et al., 1997) and easier to handle for harvesting. Modification of plant height could be possible using the above lines as the height in those lines was determined by a relatively large proportion of additive genes, as shown by their significant *GCA* effect. The potential general combiners for productive tillers were ICSB654, ICSB687, and ICSB479 and ICSR153, Siaya#66-2, and IESV23011DL. A total of 14 male sterile parents revealed significantly negative (undesirable) *GCA* on productive tillers per plant of which SDSB4, ICSB366 and ICSB9 expressed highly negative significant effects.

Table 3. Estimates of general combining ability (gca) for selected traits in some sorghum lines evaluated across 3 locations.

Parents	Days to 50% flowering	Tillers /plant	Height (cm)	Panicle exertion (cm)	Panicle length (cm)	Panicle width (cm)	Grain weight /panicle (g)
BTX623	-1.6**	-0.1	1.94*	-0.17	-0.39**	-0.24**	10.31**
CK 60B	-5.4**	0.6**	-15.42**	3.72**	-2.48**	-0.59**	5.01**
ICSB 11	-4.5**	0.2**	-14.72**	1.43**	-1.75**	-1.40**	0.74
ICSB 12	0.7**	0.1	11.06**	-0.21	-0.06	-0.23**	6.27**
ICSB 15	-0.1	0.1	13.98**	-0.16	1.27**	-0.34**	10.85**
ICSB 276	2.1**	0.2**	21.39**	3.93**	0.60**	1.08**	0.42
ICSB 293	1.20**	0.18**	-21.33**	6.17**	1.74**	1.40**	28.62**
ICSB 366	-2.55**	-0.65**	-4.66**	-1.64**	-2.23**	-0.32**	-3.57*
ICSB 371	-3.88**	-0.41**	-9.60**	0.3	-2.01**	-0.89**	-3.06*
ICSB 376	-2.30**	0.11	43.90**	9.62**	-1.69**	0.53**	-11.68**
ICSB 44	-0.13	-0.36**	12.07**	0.16	-3.71**	0.61**	9.93**
ICSB 479	3.87**	1.83**	-0.62	-7.08**	-8.99**	-1.22**	-17.23**
ICSB 6	0.42**	0.34**	15.54**	-0.64**	0.92**	1.04**	15.62**
ICSB 654	-2.97**	2.44**	-14.90**	3.37**	-1.64**	-1.45**	-18.26**
ICSB 687	-3.72**	1.88**	-15.81**	-2.53**	1.54**	2.58**	-3.20*
ICSB77	0.03	-0.04	-21.63**	0.92**	-0.71**	0.19**	-12.68**
ICSB 88001	-0.07	-0.09	15.19**	-2.38**	2.38**	1.60**	9.94**
ICSB 88006	2.70**	0.02	7.81**	0.68**	0.54**	-0.87**	-0.35
ICSB 89003	1.48**	-0.21**	2.81**	1.83**	1.49**	-0.03	-8.47**
ICSB 89004	3.37**	-0.49**	-42.50**	-3.17**	3.22**	1.13**	9.32**
ICSB 9	0.45**	-0.56**	-8.67**	3.16**	1.77**	-1.37**	-17.97**
ICSB 90001	3.44**	-0.25**	-29.61**	-3.70**	3.32**	1.16**	0.85
ICSB 91002	-2.13**	-0.51**	-43.25**	1.77**	-0.39**	-0.09	-6.91**
IESB 2	-0.33*	-0.16*	-22.22**	-5.18**	-2.01**	0.64**	-11.45**
MB 6	-6.08**	0.24**	24.11**	9.67**	-3.80**	-0.65**	-11.32**
SDSB 1	3.06**	-0.38**	20.86**	-0.72**	-0.26*	-1.13**	-6.28**
SDSB 4	5.26**	-0.81**	-3.88**	-2.92**	4.94**	-0.95**	-14.05**
ICSB73	-1.30**	-0.2**	2.81**	2.08**	-0.22*	0.03**	-7.21*
AIHR91075	-3.30**	-0.79**	-23.87**	4.08**	-3.53**	-1.05**	-10.44**
GADAM	-4.80**	-0.16	6.57**	-0.32	-2.49**	-0.25**	13.41**
ICSR 108	0.45*	-0.21*	-17.80**	0.78**	0.38*	0.70**	-13.89**
ICSR 153	-2.97**	2.44**	-14.90**	3.37**	-1.64**	-1.45**	-18.26**
ICSR 160	0.98**	-0.41**	-8.89**	-1.67**	2.61**	0.49**	-0.26
ICSR 162	0.58**	-0.07	17.59**	0.70*	1.22**	0.31**	2.26
ICSR 172	-0.07	-0.22**	-34.11**	-0.71*	-1.38**	-1.19**	-1.97
ICSR 196	1.37**	0.28**	-18.33**	0.45	-0.33	-0.24**	-5.38**
ICSR 23019	-0.13	-0.52**	32.27**	-0.78**	0.92**	0.43**	23.89**
ICSR 24007	-1.97**	-0.09	-55.37**	-3.35**	-3.31**	-0.54**	-27.18**
ICSR 24008	2.03**	-0.32**	-14.88**	-2.23**	2.43**	1.78**	-0.73
ICSR 24009	3.32**	-0.34**	-18.67**	-1.26**	1.90**	-0.55**	-8.45**
ICSR 24010	1.20**	-0.19*	39.65**	0.1	-2.17**	0.96**	-7.90**
ICSR 38	-2.13**	-0.51**	-43.25**	1.77**	-0.39*	-0.09	-6.91**
ICSR 43	4.70**	-0.77**	-15.54**	-1.78**	5.11**	0.18*	-7.24**
ICSR 56	0.03	-0.59**	-2.93*	5.48**	0.14	-1.49**	-16.89**
ICSR 89001	3.37**	0.01	-50.17**	-2.70**	4.19**	1.05**	18.59**
ICSR 89028	3.37**	-0.49**	-42.50**	-3.17**	3.22**	1.13**	9.32**
ICSR 89058	1.87**	-0.54**	-26.13**	-1.48**	3.94**	-0.14	-15.17**
ICSR 89059	4.53**	-0.76**	-7.90**	-4.50**	5.44**	-0.84**	-13.01**
ICSR 92003	2.78**	-0.16	-13.67**	-1.70**	2.11**	0.59**	-3.47
ICSR 93001	1.70**	-0.26**	9.05**	-0.93**	1.79**	0.05	19.87**

Table 3. Contd.

ICSR 93034	-0.38	0.68**	28.21**	-3.14**	2.17**	1.60**	16.56**
ICSV 95022	-2.13**	0.18*	-31.77**	-2.10**	2.76**	0.60**	-7.16**
IESV 23010 DL	-6.47**	-0.22**	7.88**	4.69**	-3.08**	-0.58**	-1.69
IESV 23011DL	-0.41*	1.54**	18.15**	1.71**	0.61**	1.86**	9.46**
IESV 23013 DL	-2.30**	0.11	43.90**	9.62**	-1.69**	0.53**	-11.68**
IESV 23019 DL	2.20**	0.44**	51.00**	1.78**	1.37**	0.60**	4.57*
IESV 91104 DL	1.14**	-0.02	8.11**	-1.34**	-2.66**	0.57**	20.81**
IESV 91136 DL	1.98**	-0.17*	-25.31**	0.21	-0.14	-1.80**	-11.14**
IESV91131DL	-0.80**	-0.29**	-20.83**	2.28**	1.56**	-0.82**	1.16
IESV92156	0.03	0.19*	-18.23**	-0.12	1.37**	-0.47**	-1.94
IESV92158DL	0.70**	1.18**	-21.60**	-0.80**	-0.48**	-0.84**	-7.99**
IESV92172 DL	-1.63**	-0.01	-19.50**	4.85**	1.09**	-0.99**	-2.49
KARIMTAMA 1	-0.66**	-0.1	22.55**	-1.12**	-1.43**	0.52**	19.21**
MACIA	-3.15**	0.01	-17.39**	-0.53	-0.11	-0.33**	-5.86**
MAKUENILOCAL	-4.24**	0.11	39.36**	5.02**	-1.55**	0.68**	-8.81**
S35	-6.47**	0.93**	23.97**	6.38**	-3.66**	-0.93**	6.49**
SIAYA # 66 – 2	3.87**	1.83**	-0.62	-7.08**	-8.99**	-1.22**	-17.23**
SIAYA #46-2	2.37**	-0.06	42.17**	-4.10**	-2.01**	-0.55**	-1.19
SIAYA#42	1.03**	0.31**	-17.57**	-8.27**	-4.08**	-1.17**	-14.49**
SP 74278	-4.63**	0.38**	-25.30**	9.65**	-3.09**	-1.67**	-11.19**
SP 74279	-6.13**	0.04	-37.13**	3.40**	-0.59**	-2.14**	-17.61**
TEGEMEO	-2.47**	0.41**	43.20**	2.62**	-0.73**	0.36**	22.72**
BUSIA #28-1	3.20**	-0.29**	47.53**	-4.88**	-6.04**	-0.90**	-1.59
R8602	-4.80**	0.94**	-42.07**	1.60**	-1.09**	-1.09**	-17.69**

*, ** significant at 5 and 1% level respectively.

Tillering is generally among important traits affecting accumulation of biomass and ultimately grain yield in sorghum. Hammer et al. (1996) reported significant yield advantage of high-tillering sorghum types when water was plentiful, whereas such types incurred a significant disadvantage under water-limited circumstances. Generally, tillering is undesirable in sorghum male sterile lines as this give rise to a range in seed size and maturity in the field but it is desirable in pollen parent (restorers) as this gives a longer duration of pollen shed, as stated by Singh et al. (1997).

Panicle exsertion is an important attribute for clean seed in sorghum. The expression of *GCA* effects ranged from -7.1 (ICSB479) to 9.7 (MB6). Negative *GCA* for panicle exsertion is undesired (Dogget, 1988), because the leaf sheath provides favorable conditions for fungi and insects to develop at the base of the panicle hence extend to the whole panicle. The line MB6 is therefore the best source breeding material for well exerted-panicle sorghum hybrids. Positive and significant *GCA* effect on panicle width was recorded on 11 male sterile lines and 20 restorers. The male sterile lines ICSB687, ICSB88001 and ICSB293 were the best general combiners for panicle width. Basing on the same trait for the restorers, ICSR24008, IESV23011 and ICSR93034 had positive and significant *GCA* effects. Four lines; SDSB4, ICSB90001, ICSB88001 and ICSB89004 were best general combiners for panicle length across environments. The least general combiners for panicle length were ICSB479, MB6 and ICSB44 among the female lines. The best restorers for panicle length were ICSR89059, ICSR43 and ICSR89001. Panicle characteristics including length, width and shape is positively related to the final yield in sorghum as also reported by Can et al. (1997). Long, broad and compact panicles results into higher yields compared to their counterparts.

The best general combiners for grain yield were ICSB293, ICSB6, ICSB15 and BTX623, for female lines, and ICSR23019, Tegemeo, IESV91104DL and KARI MTAMA1 for restorers. In general, the means from all locations indicate that line ICSB687 expressed significant negative (desired) GCA effects for four traits viz days to 50% flowering, mature plant height, panicle length and panicle width. This parent could be utilized as a source of breeding lines for both dry lands and sub-humid areas. The potential combination for developing hybrids from the best parents basing on the GCA effects of the parents can be easily worked out and ranked (Table 4). The rank for the combination is obtained by taking combining ability as significant positive (high), non-significant (average) and significant negative (low). For days to 50%

Table 4. Possible combinations for hybrids basing on gca effects of the best 6 parents.

Possible hybrid combination	Agronomic trait considered		
	Days to 50% flowering	**Plant height (cm)**	**Grain weight per plot (g)**
IESA2 × IESV91104DL	High × Low	High × Low	High × High
IESA2 × KARI MTAMA1	High × High	High × Low	High × High
IESA2 × IESV91131DL	High × High	High × High	High × High
IESA2 × MACIA	High × High	High × High	High × Average
ICSA15 × IESV91104DL	Average × Low	Low × Low	High × High
ICSA15 × KARI MTAMA1	Average × High	Low × Low	High × High
ICSA15 × IESV91131DL	Average × High	Low × High	High × High
ICSA15 × MACIA	Average × High	Low × High	High × Average
ATX623 × IESV91104DL	High × Low	Low × Low	High × High
ATX623 × KARI MTAMA1	High × High	Low × Low	High × High
ATX623 × IESV91131DL	High × High	Low × High	High × High
ATX623 × MACIA	High × High	Low × High	High × Average

Rank for the combination is obtained by taking gca effects as significant positive (high), non-significant (average) and significant negative (low). For days to 50% flowering and plant height, significant positive combining ability effects is taken as low, non-significant as average and significant negative as high combining ability.

flowering and plant height, significant positive combining ability effects is taken as low, non-significant as average and significant negative as high. A majority of the potential cross combinations could not possess all traits in a desired manner.

The SCA estimates for some phenotypic traits are presented in Table 5. The best specific combiner for days to flowering were SDSA4×ICSR89059 (-5.26), SDSA4×ICSR43 (-4.59), SDSA1×ICSR43 (-4.06), ICSA479×Siaya#66-2 (-3.87) and ICSA90001 ×ICSR89001 (-3.44). The negative combing ability effect is desirable as it is associated with earliness in sorghum. Similar results have been reported by Makanda et al. (2012). The best cross combinations that showed significant and positive *SCA* effects for productive tillers per plant were ATX623×*Macia*, ICSA88001×ICSR 93034 and ICSA90001×ICSR162. Productive tillers in sorghum parents are desirable as they provide pollen for longer time as compared to non-tillering ones and do add to grain yield of a particular parent as supported by Reddy et al. (2007) and Singh et al. (1997). Considering the plant height, the best crosses that expressed significant negative (desired) *SCA* effect comprised of ICSA376×IESV23O13DL (-43.90), ICSA6×ICSR93034 (-43.25), ICSA276 × IESV91104DL (-31.26), MA6×S35 (-28.35) and MA6×Makueni local (-23.73). As for the *GCA*, negative *SCA* for plant height is desired as it is directly related to shortness and less lodging in sorghum as supported by Singh et al. (1997).

Crosses ICSA479×Siaya#66-2, ICSA44×Makueni local, ICSA11×S35 and CK60A×IESV 23010 showed highly significant positive specific combination for panicle length. Furthermore, ICSA11×S35, ICSA645×ICSR153, ICSA11×SP74279 and ICSA9×ICSR56 showed highly significant positive *SCA* effect for panicle width. The significant positive panicle length and width are related to grain yield per plant in sorghum hence total yield. Furthermore, the ultimate yield in sorghum depends on grain yield per plant through various other components such as panicle characteristics (Figure 5), and thus determination of grain yield per panicle deserves attention. The results in the present study revealed the existence of considerable positive *SCA* effect for yield per panicle in five crosses which included ATX623×IESV91104DL, ICSA12×ICSR172, ICSA15×IESV91104DL, CK60A×KARI MTAMA1 and ICSA12×KARI MTAMA1. Specific combining ability for panicle exsertion varied from -9.2 (ICSA376×IESV23013) to 6.0 (SDSA1×ICSR43). Negative *SCA* for panicle exsertion is undesired (Dogget, 1988), because the leaf sheath provides favourable conditions for fungi and insects to develop at the base of the panicle and can destroy the entire panicle. Based on days to 50% flowering, plant height and grain yield, it is interesting to note that IESV91104DL produced 3 early maturing crosses including ICSA44×IESV91104DL, ICSA15×IESV91104DL and ATX623×IESV91104DL. Although IESV91104DL expressed positive but low general combining ability effect for days to flowering and plant height, the yield was significantly high across locations. The positive significant effect of the two traits has no bad implications on synchrony to flowering and pollen to recipient sterile lines because, as reported by Singh et al. (1997), female parents should be 125 to 175 cm shorter while male parents are supposed to be 175 to 250 cm taller.

Conclusion

Significant differences recorded for parents and crosses

Table 5. Specific combining ability (sca) effects of sorghum hybrid parents for various traits across dry low land and sub-humid environments.

Cross	Days to 50% flowering	Productive tillers	Height (cm)	Exertion (cm)	Panicle length (cm)	Panicle width (cm)	Weight per plot (g)
ATX623×GADAM	1.6	0.0	-1.9	0.2	0.4	0.2	104.4
ATX623×ICSR23019	1.6	0.0	-1.9	0.2	0.4	0.2	104.3
ATX623×ICSV95022	1.6	0.0	-1.9	0.2	0.4	0.2	104.3
ATX623×IESV91104DL	-0.2*	-0.2	-11.1	-0.4	0.1	-0.1	276.9**
ATX623×IESV91131DL	0.4	-0.3	-3.2	0.0	0.3	0.6	242.7
ATX623×IESV91136DL	1.6	0.0	-1.9	0.1	0.4	0.2	-104.3
ATX623×KARI-MTAMA1	0.3	-0.1	-6.2	0.1	-1.3	-0.8	-170.0
ATX623×MACIA	2.9**	1.1**	-8.0	0.8	1.7	0.3	198.6
ATX623×MAKUENI LOCAL	2.1*	0.3	-7.0	-2.5	0.7	-0.6	-173.0
CK60A×IESV23010DL	3.7**	-0.7	10.4	-6.9**	3.0**	0.4	-237.7
CK60A×KARI-MTAMA1	-1.9**	0.7	-4.3	-0.4	0.6	1.1*	332.3**
CK60A×SP74278	5.4**	-0.5	15.4*	-3.7*	2.5**	0.6	-109.6
CK60A×R8602	5.4**	-0.5	15.4*	-3.7*	2.4**	0.6	-109.6
ICSA11×ICSR172	2.9**	-0.5	13.6*	-1.9	0.4	1.0*	136.1
ICSA11×S35	5.2**	0.0	18.9**	-5.6**	3.4**	1.8**	-192.4
ICSA11×SP74279	4.5**	-0.2	14.7*	-1.4	1.7*	1.4**	-182.1
ICSA12×ICSR162	-0.7	-0.5	3.3	1.2	-0.5	-0.4	-113.8
ICSA12×ICSR172	-2.2*	-0.5	-7.8	0.7	1.4	0.4	435.2*
ICSA12×ICSR93001	-1.8	0.2	-21.2**	-0.8	0.3	0.2	-162.1
ICSA12×IESV23019DL	-0.7	0.0	-11.1	0.2	0.1	0.2	-179.4
ICSA12×IESV91104DL	0.6	0.2	-4.1	0.4	0.2	0.6	212.5
ICSA12×IESV92156	-0.7	-0.1	-11.1	0.2	0.1	0.2	-179.4
ICSA12×IESV92158DL	-0.7	-0.1	-11.1	0.2	0.1	0.2	-179.4
ICSA12×IESV92172DL	-0.7	-0.1	-11.1	0.2	0.1	0.2	-179.4
ICSA12×KARI-MTAMA1	1.3	-0.3	-1.9	-0.8	-0.7	-0.1	249.4**
ICSA12×SIAYA46-2	-0.7	-0.1	-11.1	0.2	0.1	0.2	-179.4
ICSA15×ICSR160	-0.9	0.2	-16.2*	0.9	1.7	-0.2	-130.0
ICSA15×ICSR162	0.6	-0.6	-15.5*	-2.0	1.6	0.2	-451.7*
ICSA15×ICSR172	-0.3	0.7	4.4	0.6	0.0	-0.1	-287.4
ICSA15×IESV91104DL	0.4	0.1	-14.6*	0.6	-1.1	-0.6	267.8**
ICSA15×TEGEMEO	0.1	-0.1	-13.9*	0.2	-1.3	0.3	-379.4*
ICSA276×ICSR162	-0.2	0.2	8.8	1.6	-1.8*	-0.7	293.9
ICSA276×ICSR24008	-1.8	-0.1	-18.4**	2.6	-1.4	-2.4**	187.9
ICSA276×IESV91104DL	-1.7	0.3	-31.2**	-1.3	2.3**	0.5	-559.4**
ICSA293×ICSR24009	-3.3**	0.3	18.6**	1.2	-1.9*	0.5	258.3
ICSA366×KARI-MTAMA1	1.5	0.0	-3.1	0.8	0.6	-0.5	-211.5
ICSA366×MACIA	2.2*	0.1	-2.1	0.7	0.8	0.3	-130.6
ICSA371×MACIA	3.1**	-0.1	17.3**	0.5	0.1	0.3	165.7
ICSA376×IESV23013DL	2.3*	-0.1	-43.9**	-9.6**	1.7	-0.5	170.6
ICSA44×ICSR172	1.9	0.3	-18.8**	2.8	-0.3	-1.7**	-177.4
ICSA44×IESV91104DL	-0.5	-0.2	-17.2**	-2.8	1.6	0.5	191.9
ICSA44×MAKUENI LOCAL	1.7	0.0	-7.2	-2.9*	4.2**	1.1*	-216.0
ICSA479×SIAYA66-2	-3.8**	-1.8**	0.6	4.1**	8.9**	1.2**	485.5*
ICSA6×ICSR162	-0.5	-0.8	-17.8**	-3.7*	-0.3	-0.2	-314.7
ICSA6×ICSR93034	0.9	-1.3**	-43.2**	1.5	-1.7*	-2.3**	-140.2
ICSA6×IESV23011DL	-0.3	-0.1	-2.8	2.9*	-1.8*	-1.2**	144.1
ICSA654×ICSR153	2.9**	-2.4**	14.9*	-3.3*	1.6	1.4**	187.6
ICS687×ICSR162	-2.2*	-1.4**	-15.6*	1.0	-2.2*	-1.0*	168.7
ICS687×IESV23011DL	1.9	-0.1	-20.1**	-3.4*	0.3	-1.1*	-272.1
ICSA77×ICSR108	-0.9	0.4	14.9*	-1.3	0.1	-0.5	151.6

Table 5. Contd.

ICSA77×ICSR160	-1.8	-0.1	8.4	2.6	-3.4**	-0.2	-170.2
ICSA77×ICSR196	-0.1	0.0	21.6**	-0.9	0.7	-0.2	231.2
ICSA88001×ICSR108	0.9	-0.3	-8.5	2.7	-1.7*	-1.2**	106.6
ICSA88001×ICSR160	2.7**	0.0	0.3	-1.9	-1.1	-0.9*	179.0
ICSA88001×ICSR93034	-1.3	1.1*	12.5*	1.4	-1.5	-0.3	130.4
ICSA88001×KARI-MTAMA1	0.5	-0.73	-0.9	1.6	1.2	0.6	-178.8
ICSA88001×MACIA	-0.2	-0.1	-10.1	1.7	-0.4	-1.1*	96.1
ICSA88006×ICSR162	-0.9	-0.3	1.5	1.4	-0.4	-0.1	165.4
ICSA88006×IESV91131DL	-1.5	0.2	-17.0**	0.1	-0.9	0.6	119.8
ICSA88006×KARI-MTAMA1	0.5	0.4	0.6	-1.3	1.7	0.3	-272.3
ICSA89003×ICSR89058	-1.1	0.2	0.2	-0.8	-1.6	0.1	188.6
ICSA89003×ICSR92003	-3.2**	0.8	0.8	0.5	-2.6**	-1.2**	-48.1
ICSA89003×IESV23011DL	0.1	-1.8**	20.5**	1.8	-2.3**	-1.2*	-46.5
ICSA 89004×ICSR89028	-3.3**	0.5	42.5**	3.2*	-3.2**	-1.1*	-264.2
ICSA9×ICSR56	-0.4	0.5	8.6	-3.2*	-1.7*	1.3**	152.1
ICSA9×ICSR89058	-1.4	0.5	20.4**	-0.8	-2.3**	0.2	165.8
ICSA90001×ICSR162	-1.8	0.8*	10.7	3.1*	-4.5**	-2.1**	53.0
ICSA90001×ICSR172	-1.6	0.1	15.7*	0.2	-0.6	0.5	187.2
ICSA90001×ICSR24008	-0.7	0.4	26.1**	2.7	-1.4	0.0	-77.3
ICSA90001×ICSR43	-3.1**	0.5	13.9*	-1.6	-2.8**	0.2	340.2
ICSA90001×ICSR89001	-3.4**	0.2	29.6**	3.7*	-3.3**	-1.1*	129.3
ICSA90001×ICSR89058	-2.7**	0.3	14.8*	0.4	-2.6**	-0.1	-99.1
ICSA90001×ICSR92003	-1.7	-0.3	25.9**	1.3	-2.2*	0.1	241.3
ICSA91002×ICSR38	2.1*	0.5	43.2**	-1.7	0.4	0.1	121.7
IESA2×ICSR24007	0.3	0.2	22.2**	5.2**	2.0*	-0.6	136.1
IESA2×ICSR24008	-2.6*	-0.1	22.8**	-0.3	0.9	-0.4	392.2*
IESA2×ICSR24009	-2.4*	0.1	-5.2	-0.8	-0.3	0.2	229.9
IESA2×ICSR24010	-1.2	0.3	4.8	5.8**	0.6	1.0*	218.3
MA6×MAKUENI LOCAL	4.0**	-0.1	-23.7**	-4.2**	2.9**	-0.2	-173.3
MA6×S35	5.4**	-0.4	-28.3**	-5.4**	2.1*	0.2	-272.8
SDSA1×ICSR24009	-0.6	0.4	-14.5*	0.6	1.3	-0.2	94.6
SDSA1×ICSR24010	-1.5	0.2	-3.5	0.0	1.6	-0.5	-159.0
SDSA1×ICSR43	-4.0**	0.2	-11.9	6.0*	-1.0	0.0	172.6
SDSA1×ICSR93001	-1.8	0.2	-10.6	1.7	-0.1	1.1*	85.9
SDSA1×IESV91104DL	-3.0**	0.2	-3	0.7	-0.5	-0.8	-332.3
SDSA1×IESV91131DL	-3.0**	0.4	-10.3	0.0	0.6	0.8	173.0
SDSA1×BUSIA28-1	-3.1**	0.3	-20.8**	0.7	0.3	1.1*	123.2
SDSA4×ICSR24009	-2.7**	0.3	27.6**	1.6	-3.4**	-0.4	154.4
SDSA4×ICSR43	-4.6**	0.7	10.6	2.9*	-4.1**	0.7	-149.0
SDSA4×ICSR89059	-5.2**	0.8	3.8	2.9*	-4.9**	0.9*	211.3

*, ** significant at 5 and 1% level respectively.

for yield and yield components suggest presence of promising combining ability character for exploitation. Majority of sorghum expressed desirable >90% restoration capacity. Only A2DN55, ICSA479 and ICSA469 produced poor hybrids in terms of seed set irrespective of male parent used probably due to environmental effects and/or the genetic background of the lines. These lines should be avoided in breeding programs as they require purification through recurrent backcrossing which is time and resource consuming. The best general combiner for days to flowering was IESV23010 whereas best specific combiners for the same trait were SDSA4×ICSR43 and SDSA4×ICSR59059. The best general combiner for yield and height were IESV92156DL and ICSR24007 respectively. Basing on overall performance, lines IESB2 and ICSB44 were well suited to sub-humid, whereas BTX623, ICSB15 and ICSB6 were more appropriate to

(i) Makueni local (ii) IESV 95046 (iii) ICSV 189 (iv) Siaya # 46-1

Figure 5. Panicle shapes and exsertion of sorghum evaluated: (i) semi loose drooping primary branches (ii) semi compact elliptic- (iii) compact oval (iv) compact elliptic.

dry lands environments. Restorer lines IESV91104DL, IESV91131DL, ICSR93034 were well suited to dry lands while KARI-MTAMA1 and IESV23019 were better adapted to sub-humid environments. These materials could be employed in hybrid program to produce high yielding, short and early maturing hybrids in East Africa and regions with similar condition. The information gathered is essential in selecting parental lines for producing suitable hybrid for particular agro-ecological zones of East Africa.

Conflict of Interest

The authors have not declared any conflict of interest.

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Appendix 1. List of sorghum lines used in this study

S/no	A-lines	Origin	Status	S/no	A-lines	Origin	Status	S/no	R-lines	Origin	Status
1	A_2 DN_{55}	ICRISAT-India	Inbred line	28	ICSA 89003	ICRISAT-India	Inbred line	17	ICSR 108	ICRISAT -India	Inbred line
2	ATX 623	ICRISAT-India	Inbred line	29	ICSA 9	ICRISAT-India	Inbred line	18	ICSR 153	ICRISAT -India	Inbred line
3	CK 60A	ICRISAT-India	Inbred line	30	ICSA 90001	ICRISAT-India	Inbred line	19	ICSR 160	ICRISAT -India	Inbred line
4	ICSA 11	ICRISAT-India	Inbred line	31	ICSA 91002	ICRISAT-India	Inbred line	20	ICSR 162	ICRISAT -India	Inbred line
5	ICSA 12	ICRISAT-India	Inbred line	32	IESA 2	ICRISAT-India	Inbred line	21	ICSR 172	ICRISAT -India	Inbred line
6	ICSA 15	ICRISAT-India	Inbred line	33	MA 6	ICRISAT-India	Inbred line	22	ICSR 24007	ICRISAT -India	Inbred line
7	ICSA 276	ICRISAT-India	Inbred line	34	SDSA 1	ICRISAT-India	Inbred line	23	ICSR 24008	ICRISAT -India	Inbred line
8	ICSA 293	ICRISAT-India	Inbred line	35	SDSA 29	ICRISAT-India	Inbred line	24	ICSR 24009	ICRISAT -India	Inbred line
9	ICSA 324	ICRISAT-India	Inbred line	36	SDSA 4	ICRISAT-India	Inbred line	25	ICSR 24010	ICRISAT -India	Inbred line
10	ICSA 366	ICRISAT-India	Inbred line		**R-lines**	**Origin**	**Status**	26	ICSR 38	ICRISAT -India	Inbred line
11	ICSA 371	ICRISAT-India	Inbred line	1	Busia #28-1	ICRISAT-Nairobi	Landrace	27	ICSR 43	ICRISAT -India	Inbred line
12	ICSA 376	ICRISAT-India	Inbred line	2	SIAYA # 42	ICRISAT-Nairobi	Landrace	28	ICSR 56	ICRISAT -India	Inbred line
13	ICSA 44	ICRISAT-India	Inbred line	3	AIHR 91075	ICRISAT-Nairobi	Landrace	29	ICSR 89001	ICRISAT -India	Inbred line
14	ICSA 452	ICRISAT-India	Inbred line	4	GADAM	ICRISAT-Nairobi	Variety	30	ICSR 89028	ICRISAT -India	Inbred line
15	ICSA 469	ICRISAT-India	Inbred line	5	IESV 23011 DL	ICRISAT -India	Inbred line	31	ICSR 89058	ICRISAT -India	Inbred line
16	ICSA 479	ICRISAT-India	Inbred line	6	IESV23010DL	ICRISAT-India	Inbred line	32	R 8602	ICRISAT -India	Inbred line
17	ICSA 592	ICRISAT-India	Inbred line	7	TEGEMEO	ICRISAT-Nairobi	Variety	33	ICSR 92003	ICRISAT -India	Inbred line
18	ICSA 6	ICRISAT-India	Inbred line	8	SIAYA # 66-1	ICRISAT-Nairobi	Landrace	34	ICSR 93001	ICRISAT -India	Inbred line
19	ICSA 654	ICRISAT-India	Inbred line	9	SP 74278	ICRISAT-Nairobi	Landrace	35	ICSR 93034	ICRISAT -India	Inbred line
20	ICSA 43	ICRISAT-India	Inbred line	10	SP 74279	ICRISAT-Nairobi	Landrace	36	ICSV 95022	ICRISAT -India	Inbred line
21	ICSA 683	ICRISAT-India	Inbred line	11	MACIA	ICRISAT -India	Variety	37	MAKUENI LOCAL	ICRISAT-Nairobi	Landrace
22	ICSA 686	ICRISAT-India	Inbred line	12	IESV23019DL	ICRISAT -India	Inbred line	38	S 35	ICRISAT-Nairobi	Landrace
23	ICSA 687	ICRISAT-India	Inbred line	13	IESV 91136 DL	ICRISAT -India	Inbred line	39	SIAYA # 46-2	ICRISAT-Nairobi	Landrace
24	ICSA 73	ICRISAT-India	Inbred line	14	IESV 23019 DL	ICRISAT -India	Inbred line	40	IESV 92156	ICRISAT -India	Inbred line
25	ICSA 77	ICRISAT-India	Inbred line	15	IESV 91104 DL	ICRISAT -India	Inbred line	41	KARI MTAMA 1	ICRISAT -India	Inbred line
26	ICSA 88001	ICRISAT-India	Inbred line	16	IESV 91131 DL	ICRISAT -India	Inbred line	42	AIHR 91075	ICRISAT -India	Inbred line
27	ICSA 88006	ICRISAT-India	Inbred line								

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Sustainable timber utilization and management in Ebonyi State, Nigeria

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This study was carried out to ascertain the perception of the people on sustainable timber utilization and management in Ebonyi State, Nigeria. Three Local Government Areas (LGAs) were purposively selected from the timber producing areas of the state, and multi stage random sampling technique was employed to select a total of 150 respondents. Primary data were used for the study. Structured questionnaire was used to collect information from the respondents. Statistical and econometric tools used for analysis included mean, percentages, frequencies and exploratory factor analysis. Major causes of timber exploitation and illegal logging observed from the study were: poverty and hunger; high cost of timber products; expanding agriculture; expanding population; rapid urbanization and high cost of alterative wood products. Results of multiple regression showed that the socio-economics characteristics that influenced timber exploitation were: gender, occupation, education all significant at 5% and marital status with significance level of 1%. The perception of farmers as regards strategies that could be adopted for sustainable utilization and management of timber were: use of forest-regulators in the control of timber exploitation; creating awareness on the need for environmental protection and sustainability; emphasis on agroforestry, aforestation and reforestation programme; arresting of defaulters and subsequent charging of fines; support of research on alternative source of energy. The identified constraints to effective timber management were: lack of public awareness of timber resource management; population pressure; lack of fund to tackle the problem of unsustainable use of timber; poverty and institutional problem; limited manpower to enforce environmental laws and regulation and poor value system and moral ethics. The study recommended that the law enforcement approach should be complemented with incentive based development of alternative income earning opportunities for local people involved in illegal timber harvesting.

Key words: Sustainable, timber, utilization, exploitation, management, Nigeria.

INTRODUCTION

According to Meyer and Turner (2009), societies have profoundly altered their environments in the pursuit of wealth and power; and have been punished by environmental catastrophes (natural and man-induced). Today, world forest area has been reduced by some 20% and a large area of land converted from

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its original vegetation cover to cropping. Moreover, Putz (2011) maintained that the major causes of lumbering are increasing demand for housing and infrastructural facilities, timber export, poor agricultural practices, cutting of fuel wood for urban areas, head loading (cutting of fuel wood for sale), forest fires, logging, and overharvesting. One difficult task faced by both developed and developing countries is how to guarantee sustainable utilization of natural resources especially timber at the lowest possible environmental cost, while still ensuring both economic and social development (Klawitter, 2004). For instance, the impacts and scars from almost 130 years of logging and destruction of the Amazon forest in Brazil and Fraser Island respectively are still very evident; although, the controversy is no longer current.

Already, in parts of Latin America, Asia, Middle East, and Africa, shortage of timber resources is becoming a source of political unrest and international tension. The recent destruction of much of Africa’s forest zone was more severe than if an invading army had pursued a scotched-earth policy. Yet most of the affected governments still spend far more to protect their people from invading armies than from invading desert (Babagana et al., 2012). Also, by the words of Lanky (2012), many governments have cut back efforts to protect the environment and to bring ecological considerations into development planning. Timber exploitation has caused a substantial reduction of the average size of the trees which occur and lessened the grandeur of forests. The greatest aesthetic impact in a forest is the appreciation of trees of great stature and age; but apparently, most of these have now been removed and people travel great distances just to observe the few remaining and to hold them in awe (Cronin and Amit, 2009). The traditional mode of natural resource consumptions and development as well as the current inefficient exploitation are severely threatening long term utilization of timber. The rate at which forests are destroyed in the name of furniture-making, pulp and paper production and a provision of domestic energy is alarming. Whilst countries around the world promote economic growth, at the same time, most of them have committed themselves to reduce environmental impacts and to reverse global environmental deterioration (Millenium Ecosystem Assessment (MEA), 2003).

Generally speaking, in the face of conflicting economic and environmental goals, it is often hard to reconcile new developments with environmental protection and nature conservation (Barbier, 2005). The increased demand for timber resources and the technology adopted by man for their extraction and exploitation has caused severe degradation of forest resources (Jimoh, 2001). The rate of timber destruction has accelerated significantly since the turn of the century. The loss of timber resources beyond sustainable limit is purely a serious issue in Nigeria, thus requesting for a holistic approach that dwells on building strong institutions. In essence, effective means for controlling logging do not exist in most localities in Nigeria of which Ebonyi State is a typical case study. Laws and regulations that permit government to exercise such control, when existent, often cannot be enforced because of strong public resentment and resistance. This conflict is not within the scope of science and technology; instead, it is a question of attitudes and values heavily embodied in “frontier mentality” and “corporate greed” by free riders, with its resultant negative externalities on the natural environment (Conservation International Biodiversity (CIB), 2009).

Today, forest related policy and decision making processes relating to logging at national and international levels are not clearly defined, because they demand a holistic and scientific approach to management without the ability to provide the supporting tools for the achievement of the desired objectives (Adger et al., 1995). Due to that, the existing scientific support for the decisions taken at international and national levels is merely a hypothesis and still to be tested. In closer terms, one finds that while problems and issues are well recognized, and there is some increase in community concern over sustainable use of timber in many localities around the country, in most cases, unfortunately, there is no perceived need to address the problems involved and no sense of urgency to find and implement solutions. It is against this backdrop that the study sought to ascertain sustainable timber utilization and management in Ebonyi state. Specifically, the study: (i) identified the major causes of timber exploitation and illegal logging; (ii) examined the effects of socio-economic characteristics of the respondents on timber exploitation (iii) assessed the perception of the local people as regards systematic management and improved utilization of timber and (iv) identified the major constraints to effective timber management.

MATERIALS AND METHODS

Study area

The study was carried out in Ebonyi State, Nigeria. The state lies approximately within longitudes 7° 30' and 8° 30' East of the Greenwich Meridian and latitudes 5° 40' and 6° 45' North of the Equator. It is bounded in the North by Benue State to the West by Enugu State, to the East by Cross River State and to the South by Abia State. Ebonyi State has a total of 13 Local Government Areas (LGAs) (Ebonyi State Government, 2009). By the 2006 population census, the population of Ebonyi State was put at 2.1 million (NPC, 2006). It has a total land area of about 5,935 km^2. The State is blessed with enormous mineral resources: salt lakes at Uburu, Okposi and Oshiri; Zinc and Lead deposits at Enyigba as well as Kaolin and Limestone at Ishiagu, Afikpo and Nkalagu (EB-SEEDS, 2004). Agriculture is a major industry in Ebonyi State. An estimated 85% of the population earns their living from one form of agriculture or another. Major food crops grown in large quantities include rice, yam, cassava, maize, cocoyam, cowpea and groundnut. Cash crops such as oil palm, cashew, cocoa, rubber, etc are vigorously cultivated.

At present, the State has eleven (11) officially gazzetted forest reserves and many sacred grooves which protect the rich biodiversity of the State. The Akanto game reserve (with an area of about 450 ha) is a protected area where endemic wildlife species are conserved. The Ministry of Agriculture has planted over 6000; 5000 and 8,000 seedlings of teak (*Tectonia grandii*) at Effium, Ovuum and Ozziza Reserves respectively; and has embarked on the forest reserve study of Federal Government of Nigeria aimed at the development of a forestry management plan (EB-MANR, 2011).

Sampling procedure

The sampling techniques adopted and utilized for selecting the respondents for the study were the multi-stage sampling technique. Out of the thirteen Local Government Areas (LGAs) in the state, three LGAs were purposively selected from the areas where forest reserve exists. Then, random sampling procedure was used to select five Communities from each LGA making a total of 15 communities for the study. From each sampled community, 10 households were randomly selected to give a sum of 150 respondents.

Data collection and analysis

Data for the study were collected from primary source only. This was done using a set of structured and pre-tested questionnaire. In order to realize the specific objectives of the study, relevant analytical tools were employed. Descriptive statistics such as frequency, mean and percentage were used to realize objectives (i) and (iii). Objective (ii) was achieved using multiple regression model. The principal component factor analysis model was used to realize objective (iv).

Model specification

Multiple regression model

This was employed to analyze the effects of the socioeconomic characteristics of the farmers on timber exploitation. The dependent variable here was number of timber exploited, while the socio economic attributes of the farmers will be the independent variables.

The explicit form of the model becomes:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + B_6X_6 + B_7X_7 + \ldots + B_nX_n + e$$

Where
Y = Timber exploitation (measured in logs)
Bo = Intercept
$B_1 - B_n$ = Coefficients of independent variable.
e = Stochastic disturbance/error term.

The hypothesized socioeconomic characteristics of timber exploiters include:

X_1 = Gender (Male = 1, Female = 2)
X_2 = Age (in Years)
X_3 = Level of Education (years spent in school)
X_4 = Marital Status (married =1, Not married = 2)
X_5 = Household size (in number)
X_6 = Occupation (farming =1, others =2)
X_7 = Farm size (in hectares)
X_8 = Farming Experience (years)
X_9 = Farmers' co-operative society Participation (Member =1, Non-member =2).

Likert Scale rating technique

A four point Likert-type rating scale was used for determining the perception of the local people as regards systematic management and improvement of forest areas to ensure sustainability of timber species in the area while the scaling was regarded as; Strongly Agree (SA), Agree (A), Disagree (D), Strongly Disagree (SD) or other similar ratings with corresponding values of 4, 3, 2 and 1 respectively.

The mean score of respondents based on a 4-point rating scale was computed as;

$$\frac{4+3+2+1}{4} = \frac{10}{4} = 2.50 \text{ (cut off point).}$$

Using the interval scale of 0.05, the upper cut-off point was 2.50 + 0.05 = 2.55 while the lower limit cut-off was 2.50 – 0.05 = 2.45. Based on this, any item mean score below 2.45 was taken as Strongly Disagree or Disagree as the case may be, while those items with mean values between 2.45 and 2.55 were considered as Agree or Strongly Agree as the case may be.

$$Item\ mean\ score = \frac{\sum rating\ score\ X\ no\ of\ respondents\ for\ the\ score}{Total\ number\ of\ repondents}$$

Factor analysis model

Principal component factor analysis model was used in achieving objective (iv). It was stated as follows:

$$Y_1 = a_{11}\, x_1 + a_{12}\, X_2 + \ldots\ldots\ldots + a_{1n}\, X_n$$

$$Y_2 = a_{21}\, x1 + a_{12}\, x_2 + \ldots\ldots\ldots\ldots + a_{2n}\, x_n$$

$$Ym = ani\ X + a_{n2}X_2 + \ldots\ldots\ldots\ldots + a_{mn}\, X_n$$

Where:
Y_1, Y_2..........Y_m = Observed variables or constraints to effective management and sustainability of timber resource in the study area.
A_{11} – am_n = factor loading or correlation coefficients.
x_1, x_2........x_n = Unobserved underlying factors constraining the local people in the study area, from adopting measures in halting uncontrolled logging of timber.

RESULTS AND DISCUSSION

Causes of timber exploitation in the study area

Perception of respondents on the causes of timber exploitation

The summary of the perception of the respondents on the causes of timber exploitation was presented in Table 1.

From the result, 94 out of the 150 respondents admitted that poverty and hunger among the rural dwellers was is a very serious cause of timber exploitation. With respect to absence of forest regulations, 83 respondents perceived that it as a fairly serious cause of timber exploitation; whereas about 47 of the respondent saw it as not serious. Only very few respondents saw it as a very serious cause of timber

Table 1. Respondents' perception of causes of timber exploitation.

S/N	Causes	Responses		Frequency		Total	Item mean score	R
		Very serious VS	Serious (S)	Fairly serious (FS)	Not serious (NS)			
1	Poverty and hunger	94	38	18	0	150	3.51	VS
2	Absence of forest regulation	6	14	83	47	150	1.88	FS
3	High cost of timber products	90	43	16	1	150	3.48	VS
4	High cost of alterative wood products	13	87	14	36	150	2.60	S
5	Expanding agriculture	75	60	15	0	150	3.40	VS
6	Inadequacy of farmland	0	109	30	11	150	2.65	S
7	Illiteracy	4	84	50	12	150	2.53	S
8	Corruption	70	70	7	3	150	3.38	S
9	Expanding population	59	43	27	21	150	2.93	VS
10	Rapid urbanization	93	17	30	10	150	3.23	VS
11	Deforestation of primary forests	59	82	8	1	150	3.33	S
12	Lack of trained officials	3	12	51	84	150	1.58	NS
13	Public resentment	0	2	20	128	150	1.34	NS
14	Unstable government policies	5	0	22	123	150	1.24	NS

Source: Field Survey (2014).

exploitation. Majority (90 and 75) of the respondents agreed that high cost of timber products and expanding agriculture respectively had been very serious factors that spawned timber exploitation in the study area over the years.

Again, high cost of alternative wood products and lack of adequate education in the timber producing areas were viewed to be serious causes of uncontrolled harvesting of timber as agreed by 87 and 84 out of the 150 respondents respectively. Corruption was one of the driving forces of logging since 70 respondents agreed that it was either very serious or just a serious cause of illegal logging.

This is comparable with the findings of Global Witness (1995), using Cambodia as a case study, where it was asserted that "the role of the government in the allocation of forest to private logging companies has been rather worse in abating illegal logging. It was very corrupt and in one particular year, a minimum of US$ 187 million of timber was smuggled out of the country and only US$ 12 million made it into the exchequer." As many as 82 respondents agreed that it was a serious cause of illegal timber exploitation.

Lack of trained officials, public resentment, and unstable government policies recorded 84, 138 and 123 respectively who agreed that they are not serious causes of timber exploitation. In addition, 51, 20 and 27 admitted that lack of trained officials, public resentment (rebellion) and unstable government policies respectively were fairly serious causes of illegal logging of wood products in the study area. Lastly, expanding population and rapid urbanization were viewed by many 59 and 93 as very serious causes of timber exploitation.

Assessment of the effects of socio–economic characteristics of rural households on timber exploitation

A multiple regression model was used to assess the effects of socio-economic characteristics of the rural households on timber exploitation in Ebonyi State. The independent variables were Gender of Household Head (X_1), Age (X_2), level of education (X_3), marital status (X_4), family size (X_5), occupation (X_6), farm size (X_7), farming experience (X_8), co-operative membership (X_9). The result is presented in Table 2.

Gender distribution (X_1) and occupation (X_6) were found to be positive and significant at 5% level of probability. This indicates that the two variables were important determinants of timber exploitation in the study area. In other words, the males in the study area were much more involved in timber exploitation than their female counterparts. Majority of the household heads (males) only perceive it as a trade or means of complementing their source of livelihood. This is similar to the findings of Asner et al. (2003) who opined that in the midst of ever-diminishing stands of tree, the men are always at the forefront of logging large rounds of wood with no effort to replace them. Also, farmers whose major occupation was farming only were much more dependent on the forest and its products played major roles in harvesting these products even in off season.

Also, level of education (X_3) was statistically significant at 5% level of probability with a negative sign. This agrees with a priori expectation. The implication is that in most cases, level of education has negative correlation with timber exploitation. Education trains the mind and

Table 2. Socio-economic characteristics of the farmers that affected timber exploitation.

Variable	Variable name	Regression coefficient	Standard error	t-value
Y	Timber exploitation			
b_o	Constant	4.182	1.259	3.321*
X_1	Gender	0.004	0.120	0.037**
X_2	Age	0.223	0.127	1.762
X_3	Level of education	-0.051	0.040	-1.277**
X_4	Marital status	0.082	0.131	0.623*
X_5	Family size	0.170	0.112	1.513
X_6	Occupation	0.062	0.064	0.970**
X_7	Farm size	0.239	0.120	1.99
X_8	Farming experience	0.081	0.119	0.681
X_9	Co-operative members	-0.020	0.026	-0.790***

***, ** and * signify 10, 5 and 1% levels of significance respectively. R^2 = 0.879 = 87.8%; Adjusted R^2 = 0.889 = 88.9%; F – ratio = 1.620; Durbin Watson Constant (DW) = 1.281; Standard Error of Estimates (SEE) = 2.42821. Source: Field Survey (2014).

character of individuals. Farmers with lower levels of education may be harsher on natural resources, for they may have less knowledge of the environmental or socio-economic implications of illegal logging. The more enlightened farmers are the more they are apt to change and adopt innovations. Timber dealers with higher level of education have been observed to adopt the conventional harvesting (CH) approach which is more sustainable than selective harvesting (SH). Conventional harvesting uses improved technology that gives room for forest regrowth after they have been evenly harvested.

Marital status (X_4) was significant at 1% level of probability, married people have greater need for resources for family upkeep and may have greater tendency to over exploit timber. Also, co-operative membership (X_9) had a negative sign but significant at probability level of 10%. This agrees with a priori expectation. In other words, there exist a negative correlation between cooperative participation and illegal timber exploitation. Studies have found that farmers who belong to one co-operative society or the other have greater potentials of receiving novel ideals on managing natural resources from change agents as opposed to farmers who are non-members. Moreover, farmers who belong to co-operative societies easily obtain agro-related information that enhance their level of awareness of efficient farm management system that will reduce to the barest minimum, any eminent losses that are associated with environmental degradation through forest destruction.

On the other hand farm size (X_7) and farming experience (X_8) all had positive signs but not significant. Here, a priori expectations were equally met. What this means is that the size of farm and the experience derived by the farmer over time were not significant determinants of timber exploitation though they also exert some effect on timber exploitation in the study area.

Age (X_2) and family size (X_5) were also not statistically significant, though with positive signs. Reasons may be that the age and family size of the respondents though not significant were important variables in influencing the level of timber exploitation.

Perception of the respondents on systematic management and improved utilization of timber

The perception of the respondents as regards systematic management and improved utilization of timber was explored and the results presented in Table 3.

Use of forest-regulators in the control of timber exploitation (3.40) and creating awareness on the need for environmental protection and sustainability (3.40) ranked first (Table 3) on respondents' perception on systematic management and improved utilization of timber. Emphasis on agroforestry, aforestation and reforestation programme (3.11) followed suit. Arresting of defaulters and subsequent charging of fines to (2.63) and support of research on alternative source of energy followed in that order. These are perhaps the relevant measures that would be adopted to encourage more meaningful sustainable forest management.

Adoption of improved technology in wood harvesting (1.60) scored below the acceptance point of 2.5 and was therefore regarded as not important.

Constraints to effective management of timber resources

From the outcome of the exploratory factor analysis conducted, the following variables were found to constrain sustainable timber management in Ebonyi State, Nigeria (Table 4). The factors were: lack of public awareness of timber resource management, poverty and institutional factors, poor legal framework, absence of

Table 3. Respondents' perception on systematic management and improved utilization of timber.

S/N	Item	VI	I	FI	NI	Total score	Remarks
i	Adoption of improved technology in harvesting of timber	0.94	0.37	0.42	0	1.60	5th
ii	Use of forest regulators/guards in the control of timber exploitation	2.2	0.8	0.4	0	3.40	1st
iii	Arresting of defaulters and susbsequent charging of fines	1.70	0.84	0.47	0.2	2.63	3rd
iv	Creating awareness on the need for environmental protection/sustainability	2.40	0.9	0.1	0	3.40	1st
v	Emphasis on agroforestry, afforestation and reforestation programme.	2.88	0.320	0.1	0	3.11	2nd
vi	Support of research on alternative source of energy	0.7	0.75	0.86	0.14	2.45	4th

VI = Very important; I = Important; F = Fairly important; NI= Not important. Source: Field Survey (2014).

Table 4. Varimax distribution of respondents' constraints to effective timber management in the strong area.

S/N	Constraint Variables	Socio-economic factor	Economic/Managerial factor	Cultural factor	Communality
V_o1	Lack of Public awareness of timber resource management	0.6926	- 0.168	- 0.178	0.540
V_o2	Poverty and institutional factor	0.002	0.458	- 0.098	0.219
V_o3	Poor legal framework	- 0.105	0.049	- 0.213	0.059
V_o4	Absence of alternative source of energy	- 0.048	- 0.049	0.015	0.005
V_o5	Population pressure	0.400	0.053	0.088	0.251
V_o6	Lack of forest governance	- 0.043	0.028	0.159	0.028
V_o7	Limitation of manpower to enforce environmental laws and regulation	0.172	0.946	0.086	0.932
V_o8	Lack of fund to tackle the problems of unsustainable use of timber	0.711	0.190	0.035	0.543
V_o9	Financial and social pressure	0.261	0.178	- 0.096	0.109
V_o10	Poor value system and moral ethics	0.270	- 0.417	0.899	1.055
	Eigenvalue	1.33	1.38	0.95	3.741

Source: Field Survey (2014).

alternative source of energy for heating, population pressure, weak forest sector governance, limitation of manpower to enforce environmental laws and regulations, financial and social pressure, poor value system and moral ethics.

The decision rule for the result of the Principal Component Factor Analysis (PCFA) in Table 4 is 0.3 This is to say that any factor loading of a variable less than 0.3 is ignored and cannot be considered as a relevant factor that has constrained the sustainable utilization and management of timber products in the study area; whereas those that loaded high (from 0.3 and above) were chosen as relevant factors that have significantly constrained the management of forest resources (timber) in Ebonyi State.

Meanwhile, these constraint variables have been generally grouped into three component factors as; socio-economic factor, managerial factor and cultural factor. Variables that loaded high under socio-economic factors were: lack of public awareness of timber resource management (0.629); population pressure (0.400) and lack of fund to tackle the problem of unsustainable use of timber (0.711). Variables that loaded high under managerial/economic factors were: poverty and institutional problem (0.458) and limitation of manpower to enforce environmental laws and regulation (0.946). Poor value system and moral ethics (0.899) was the only factor that loaded high under cultural factor. From the foregoing, one can deduce that among the factors that loaded high, limitation of manpower to enforce environmental laws and regulation (0.946) appeared to be the most significant variables that strongly constrained relevant efforts to ensure sustainable exploitation of timber in the study area.

CONCLUSION AND RECOMMENDATIONS

From the study the following conclusions were drawn:

i) Use of forest-regulators; creation of awareness on the need for environmental protection and sustainability; emphasis on agroforestry, aforestation and reforestation programme; arresting of defaulters and subsequent charging of fines; support of research on alternative source of energy are strategies that could be adopted for sustainable timber utilization and management.
ii) Constraints to effective timber management were: lack

of public awareness of timber resource management; population pressure; lack of fund to tackle the problem of unsustainable use of timber; poverty and institutional problem; limitation of manpower to enforce environmental laws and regulation and poor value system and moral ethics.

The study therefore recommended that the relevant stakeholders like the Ministry of Agriculture should adequately sensitize the public on long term implication of illegal logging. Also, the strict law enforcement approach should be complemented with a soft law enforcement approach that provides incentives for developing alternative income earning opportunities for local people involved in illegal timber harvesting. Moreover, government and concerned stakeholders should be aware that efficient management is assured if people who are directly dependent on forest resource are involved in the management. The combination of a participatory approach and effective management allows for transparency and accountability in implementing governance rules and regulations.

Conflict of Interest

The authors have not declared any conflict of interests.

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Diagrammatic scale for blister spot in leaves of coffee tree

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Blister Spot is a disease transmitted through seeds. This characteristic of the disease reveals the studies of severity can offer more replies than the studies of incidence. Due to the inexistence of standardized for visual quantification of the Blister Spot's severity, the aim of this work was to build up and validate a diagrammatic scale for evaluating the severity of Blister Spot in coffee tree. Leaves in the field were collected with different intensities of symptoms disease, and electronically determined the real severity. Based on the frequency distribution of the severity values, and according to the law of visual stimulus of Weber-Fechner, the maximum and minimum limits, and the intermediate levels of the scale were defined. The validation was realized by eight evaluators that estimated the severity in 50 leaves with different intensities of symptoms. An evaluation without the aid of the diagrammatic scale was realized, and two others with its use, having intervals of seven days. The accuracy, precision, repeatability and reproducibility of the estimate were evaluated. The developed scale shows seven 0 (0%), 1 (0.1-3%), 2 (3.1-6%), 3 (6.1-12%), 4 (12.1-25%) and5 (≥25.1%). Using the scale proposed, the evaluators presented better levels of accurancy, precision, reproducibility and repeatability in the estimate, once compared to the evaluators who did not use the diagrammatic scale. The diagrammatic scale was adjusted to aid in the visual estimate of the severity of the Blister Spot in coffee leaves

Key words: *Coffea arabica*, *Colletotrichum gloeosporioides,* pathometry.

INTRODUCTION

The Blister Spot is a disease of the coffee tree, whose causal agent found in Brazil, is the fungus *Colletotrichum gloeosporioides* PENZ. (Miranda, 2003). Its symptoms are light green spots with less brightness in relation to asymptomatic areas, having oily looking, ranging from 2 to 10 mm diameter. With the progress of the disease, the spots show the necrotic, which can coalesce and result in necrosis of bigger areas and leaves fall. Besides these symptoms, the pathogenic can be associated with the mummifications and fruits' abscision and the wilt and dry of the branch (Pozza et al., 2010). The season of higher intensity of these symptoms is between October and February, period of higher rainfall index (Ferreira et al., 2009a).

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To quantify the intensity of the symptoms described, aiming to select resistant cultivars, evaluate the efficiency of fungicides, study epidemiology and the management of disease, the researchers have used different methods. Studying the resistance of coffee *Colletotrichum* spp., Ferreira et al. (2005) evaluated the incidence of infected fruits, instead of measuring the severity of the disease. In another work, Ferreira et al. (2009a) have already used the counting number of injury in the leaves in order to evaluate the progress of the disease in different treatments with fungicides, although this methodology is laborious and a little precise to measure the severity of the disease. Moreover, in many cases, two smaller injuries can occupy a smaller area of the leaf when comparing to a large one, generating errors (Madden et al., 2007). In another attempt, instead of measuring the severity of the disease, Ferreira et al. (2009b) evaluated the incidence of Blister Spot to estimate its progress in the field, although this variable, depending on the aims of the work, can not provide the necessary precision and accurancy to represent the extension of the injured foliar area (Campbell and Madden, 1990). The way to estimate the severity of the disease in a more accurate way, precise and fast, is through the use of diagrammatic scales (Nutter Jr et al., 2006). Some diagrammatic scales have been developed to assess disease in coffee (Belan et al., 2014; Capucho et al., 2011; Custódio et al., 2011; Salgado et al., 2009).

To elaborate the diagrammatic scales, important aspects should be considered, such as checking out if the upper limit of the scale corresponds to the maximum real of disease observed, determine if the real intensity of disease and its representation in the scale are precise and if the subdivisions of the scale follow through on the law of Weber-Fechner. According to this law, the human visual acuity is proportional to the logarithm of the stimulus intensity (Horsfall and Barratt, 1945). Furthermore, in order to verify the quality of the estimate obtained from the diagrammatic scale, the levels of accuracy, precision and reproducibility have to be validated (Campbell and Madden, 1990, Nutter Jr et al., 1993; Nutter Jr and Schultz, 1995).

Likewise, the objective of this work was to develop and validate a diagrammatic scale to evaluate Blister Spot's severity in coffee tree.

MATERIALS AND METHODS

In order to develop the diagrammatic scale, 120 coffee leaves with different severity levels of the disease were collected. These leaves were from coffee trees naturally infected by *C. gloeosporioides*, in farming of different cultivars. To onfirm the causal agent of the disease, the isolation in malt extraction MEA at 2% was realized, and the identity was verified through morphology analysis in optical microscope. The injured leaves were scanned in multifunctional printer. Having the help of software Assess® (American Phytopathological Society, St. Paul, MN, USA), the real severity of the disease was determined (percentage of injured foliar area).

Pale green spots were considered foliar injury, as well as necrotic scores inside these spots.

Considering the minimum and maximum levels of severity observed, the frequency distribution of data, in other words, how many leaves per interval of percentage of injured foliar area, to determine the most frequent intervals of the injures. Based on the law of visual acuity of Weber-Fechner (Horsfall and Barratt, 1945; Nutter Jr and Schultz, 1995), and in the intervals of class with higher frequency (Belan et al., 2014), the diagrammatic scale was developed. After establishing the intervals of severity to be represented, and considering the way and the distribution of the injuries, real images of leaves with injuries of Blister Spot were used to develop a scale.

In the validation test of the diagrammatic scale, 50 images of coffee leaves with symptoms of the disease, representing all the levels of the scale were used. These images were randomly inserted in individual slides for visualizing in Microsoft® PowerPoint® 2010, and presented to eight evaluators without experience in quantification of plant diseases, in three evaluations, with interval of seven days.

In the first evaluation, the evaluators scored the leaves presented without any help of the scale. After seven days, the same evaluators realized the second one, using the diagrammatic scale for the first time. To evaluate the repeatability of the estimates with the diagrammatic scale, seven days after the first evaluation, a new sequence of the same leaves was organized, and a second visual estimate with the aid of the scales was realized by the same evaluators.

The accuracy and precision of each evaluator were determined through the simple linear regression with real severity as independent variable and the estimate severity as dependent variable.

The accuracy of the estimate for each evaluator and the group f evaluators was determined by test t applied to the intercept of the linear regression (β_0), in order to verify Ho hypothesis: $\beta_0 = 0$, and to the angular coefficient of a line (β_1), to test Ho hypothesis: $\beta_1 = 1$, at level 5% of probability (p=0.05). Values of intercepts significantly different from 0 (zero) indicate overestimation (>0) or underestimation (<0) of the real severity at low levels of intensity of the disease, while values of angular coefficient of a line, which divert significantly from 1 (one) indicate systematic superestimation (>1) or underestimation (<1) of the real severity in all the intensities of the disease (Nutter Jr and Schultz, 1995).

The precision of the estimation was determined by coefficient of regression determination (R^2), variance of absolute errors (estimate severity minus real severity, and repeatability of the estimate, determined by regression analysis of the second evaluation in relation to the first one of the same sample unit, that is, the same set of leaves presented randomly (Nutter Jr et al., 1993).

The reproducibility of the estimate was evaluated by analyzing R^2 values obtained from linear regressions between the estimated severity of the same sample unit by different evaluators in pairs (Campbell and Madden, 1990; Nutter Jr and Schultz, 1995).

The data were tabulated using the software Microsoft® Excel® 2010, and the statistical analyses realized in the program SAS® v 9.3.

RESULTS

The severity of the 120 leaves wih Blister Spot, obtained electronically, showed minimum and maximum values of 0.98 and 46.9%, respectively. The frequency distribution of the severity had 93.3% of the leaves analyzed with injured foliar area in lower intervals of 24% (Table 1).

Based on frequency distribution, and the fact that the higher frequency is located in intervals lower than 24% of the disease's severity, the scale was developed with a

Table 1. Frequency distribution, at unit intervals, of the severity values (%) for Blister Spot in coffee tree.

Interval (severity %)	Frequency	Percentage	Cumulative frequency	Cumulative percentage (%)
0-1	9	7.5	9	7.5
1-2	3	2.49	12	9.99
2-3	2	1.66	14	11.65
3-4	6	4.98	20	16.63
4-5	7	5.81	27	22.44
5-6	2	1.66	29	24.1
6-7	7	5.81	36	29.91
7-8	5	4.15	41	34.06
8-9	3	2.49	44	36.55
9-10	7	5.81	51	42.36
10-11	4	3.32	55	45.68
11-12	5	4.15	60	49.83
12-13	4	3.32	64	53.15
13-14	8	6.64	72	59.79
14-15	4	3.32	76	63.11
15-16	11	9.13	87	72.24
16-17	6	4.98	93	77.22
17-18	0	0	93	77.22
18-19	4	3.32	97	80.54
19-20	4	3.32	101	83.86
20-21	4	3.32	105	87.18
21-22	2	1.66	107	88.84
22-23	4	3.32	111	92.53
23-24	1	0.83	112	93.36
>24	8	6.64	120	100

bigger number of classes below this value, considering the following scores of percentage intervals; Score 0 – 0%, 1 – 3%, 2 – 3 to 6%, 3 – 6 to 12%, 4 – 12 to 24%, and 5 - 24 to 50 % of severity (Figure 1), following through on “Weber-Fechner” law. The lower and upper limit of the disease’s severity represented in the scale were 0 (zero) and 46.9%, respectively. Images of leaves with value of severity higher than 46.9% were not added to the diagrammatic scale due to the fact of not being found leaves with severity over this value.

Evaluation with the scale provided a higher precision and accuracy in relation to the evaluation without using the scale (Table 2). All the evaluators superestimated the severity of the diasease when it was not being used. Among the evaluators, at least one of the hypotheses $\beta_0 = 0$ e $\beta_1 = 1$, of the linear regression between real and estimated severity, was rejected, while for the evaluators A and E the two hypotheses were rejected (Table 2), indicating superestimation of the disease’s severity.

Through the use of the diagrammatic scale, the evaluators were more accurate to evaluate the disease’s severity. In the first evaluation using the scale, 62% of the evaluators showed intercept and angular coefficient of a line of linear regression equal to 0 (zero) and 1 (one), respectively. However, in the second one, no evaluator had angular coefficient different from 0 and 1 (Table 2).

All the evaluators presented low precision without using the scale. Nevertheless, using it, both in the first and in the second evaluation, there was a significant increase in R^2 values, obtaining then higher precision (Table 2).

There was reduction in the absolute errors when the scale was used, occurring lesser extent of the values (Figure 2). In fact, the minimum and maximum values observed for the residues of all evaluators without using the scale were, respectively, -36.09 and 93.98, while using the scale, the average between the two evaluations, had the interval reduced -39.76 and 23.85.

The values of the absolute errors were also reduced with the use of the scale. In the evaluation without the scale, 52% of the residues were out of the interval between -10 and +10. Between the two evaluations, using the scale, the average of 98% of the absolute errors were into this interval, that is, there was reduction of the errors.

The evaluators showed a good repeatability at the the estimate of severity for Blister Spot in coffee leaves with the use of the scale proposed. The increase in the precision was confirmed by the repeatability of the estimate. The average of variation in the first evaluation explained in comparation with the second one was of

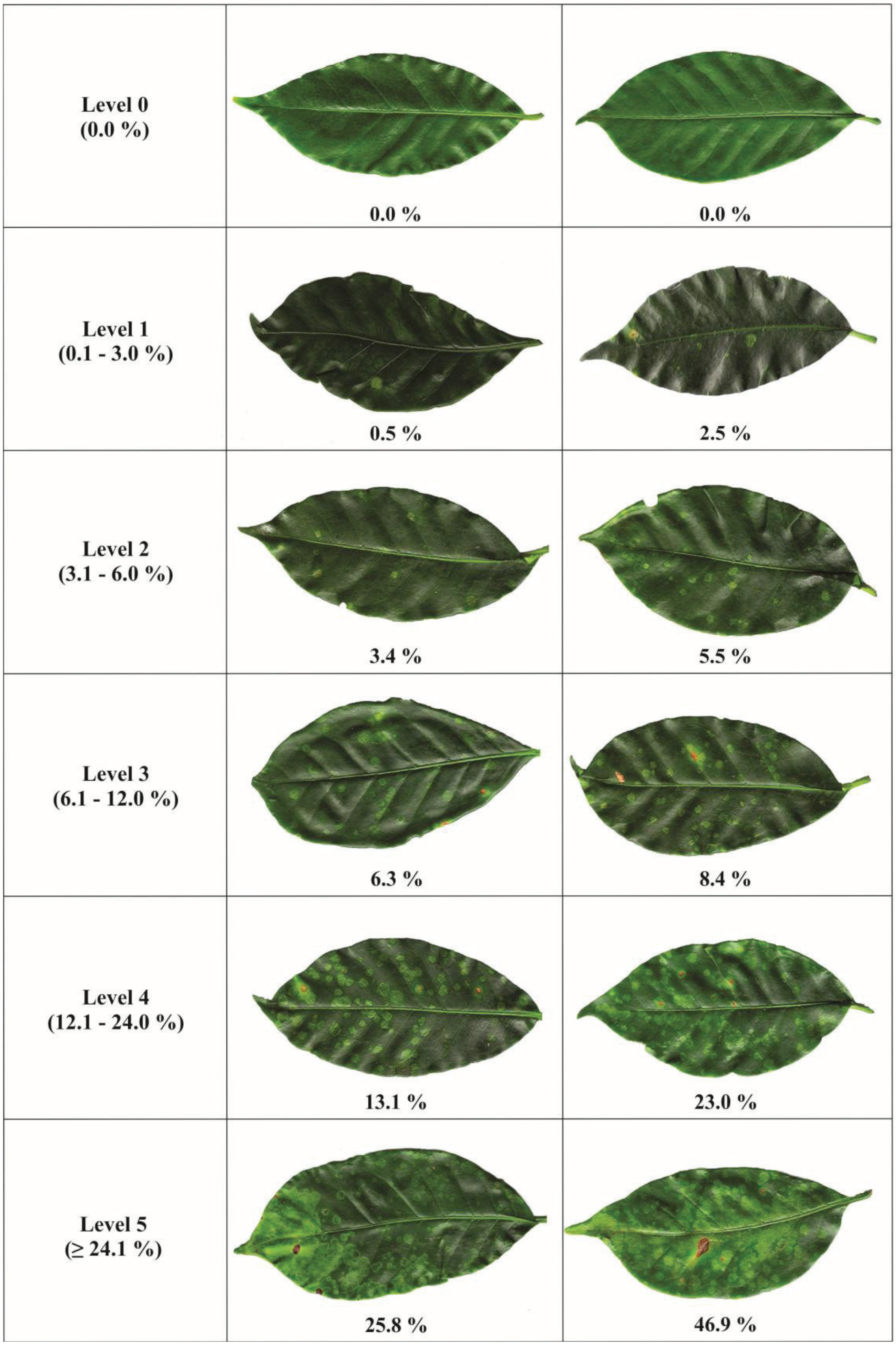

Figure 1. Diagrammatic scale to evaluate the severity for Blister Spot (*Colletotrichum gloeosporioides* PENZ) in coffee leaves (*Coffea arabica* L.). Numbers represent the percentage of foliar area affected by the disease.

Table 2. Intercept (β_0), angular coefficient of a line (β_1) and coefficient of determination (R^2) of equations for linear regression relating visual estimations of severity for Blister Spot in coffee leaves, realized by evaluators with and without the aid of the diagrammatic scale, for real severity determined electronically.

Evaluators	Without scale			First evaluation with scale			Second evaluation with scale		
	β_0	β_1	R^2**	β_0	β_1	R^2**	β_0	β_1	R^2**
A	5.59*	1.57*	0.74	1.92^{ns}	0.79^{ns}	0.79	1.01^{ns}	0.94^{ns}	0.88
B	6.96^{ns}	2.57*	0.64	2.1^{ns}	0.88^{ns}	0.73	1.44^{ns}	0.97^{ns}	0.76
C	8.17*	0.43^{ns}	0.25	0.76^{ns}	0.97^{ns}	0.79	0.3^{ns}	1.02^{ns}	0.85
D	0.72^{ns}	1.73*	0.66	0.3^{ns}	1.08^{ns}	0.86	0.14^{ns}	1.06^{ns}	0.86
E	7.99*	1.56*	0.62	0.84^{ns}	0.98^{ns}	0.82	0.35^{ns}	1^{ns}	0.83
F	1.84^{ns}	1.56*	0.69	0.1^{ns}	0.98^{ns}	0.80	0.4^{ns}	0.99^{ns}	0.83
G	26.13*	0.08^{ns}	0.00	0.35^{ns}	1.03^{ns}	0.83	0.21^{ns}	1.02^{ns}	0.84
H	36.83*	0^{ns}	0.00	0.34^{ns}	1^{ns}	0.81	0.11^{ns}	1.02^{ns}	0.83

* and ns represent situations the null hypothesis (β_0 = 0 ou β_1 = 1) was, respectively rejected and not, by test t (P= 0.05); ** represents significant situations with probability of 5% for test t (P <0.05).

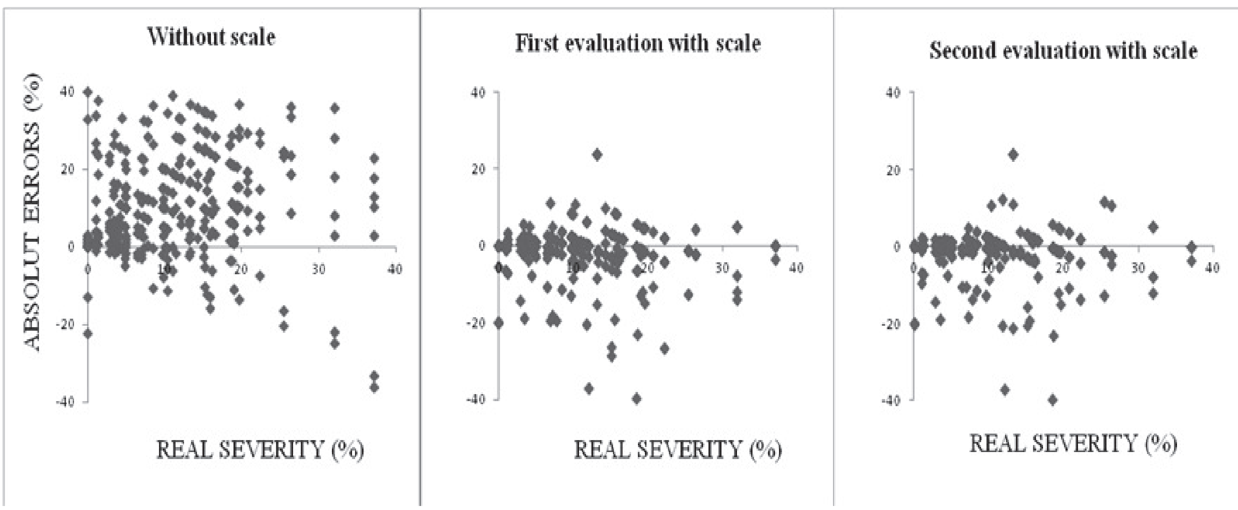

Figure 2. Distribution of residues (estimate severity – real severity) of the estimations of Blister Spot in coffee leaves estimate without and with the aid of the diagrammatic scale in two evaluations.

91%, and the value of the angular coefficient of a line was significantly similar, showing precision of the estimate in 100% of the evaluators (Table 3).

The scale showed high reproducibility. Without its usage, the value of R² of the regressions between the pair of evaluators varied from 0 to 0.76, with the average of 0.31 (Table 4). Using the diagrammatic scale, R² values varied from 0.79 to 0.94% and 0.82 to 0.98% in the first and second evaluations, respectively, being ≥0.75 in 87% of the evaluators' combinations.

DISCUSSION

The diagrammatic scale proposed in this article like others, were constructed defining the intervals according to the law of "Weber-Fechner" (Custódio et al., 2011; Salgado et al., 2009), however, without following the same intervals of severity proposed by Horsfall and Barratt (1945) due to the disease's peculiarity. Among these characteristics, the maximum severity found in the field and the frequency intervals of higher concentration for the severity of the disease must be observed. (Belan et al., 2014; Capucho et al., 2011). Thus, the scale developed was divided into the intervals in logarithm scale in order to reduce the erros in the estimate of the disease.

Images of leaves with severity value higher than 46.9% were not included in the diagrammatic scale because leaves with higher value of intensity than this one were not found. To develop diagrammatic scales for brown wye spot (Custódio et al., 2011) and bacterial bight in

Table 3. Intercept (β_0), angular coefficient of a line (β_1) and coefficient of determination (R^2) of equations for linear regression related with the second to the first estimate of severity for Blister Spot in coffee leaves, realized by the same evaluator with the diagrammatic scale.

Evaluators	Coefficients		
	β0	β1	R^2**
A	2.25^{ns}	0.85^{ns}	0.67
B	0.21^{ns}	1.01^{ns}	0.88
C	0.37^{ns}	0.98^{ns}	0.92
D	-0.26^{ns}	0.96^{ns}	0.97
E	-0.17^{ns}	0.99^{ns}	0.96
F	0.70^{ns}	0.99^{ns}	0.96
G	-0.01^{ns}	0.98^{ns}	0.98
H	0.04^{ns}	0.99^{ns}	0.97

* and ns represent situations the null hypothesis (β_0 = 0 ou β_1 = 1) was, respectively, rejected and not by test t (P= 0.05); ** represents significant situations with probabilities of 5% for test t (P <0.05).

Table 4. Coefficient of determination (R^2) of equations of linear regression related to visual estimate of Blister Spot's severity in coffee leaves between evaluators in pairs without the aid of the diagrammatic scale in the first and second evaluations.

Without scale							
Evaluators	**B**	**C**	**D**	**E**	**F**	**G**	**H**
A	0.76	0.31	0.73	0.74	0.73	0.01	0.02
B		0.28	0.67	0.55	0.61	0.00	0.00
C			0.21	0.18	0.35	0.12	0.02
D				0.56	0.72	0.01	0.04
E					0.54	0.00	0.01
F						0.00	0.00
G							0.61

1° Evaluation with scale							
Evaluators	**B**	**C**	**D**	**E**	**F**	**G**	**H**
A	0.76	0.84	0.77	0.81	0.76	0.79	0.82
B		0.83	0.8	0.85	0.84	0.86	0.79
C			0.91	0.91	0.89	0.9	0.88
D				0.91	0.9	0.91	0.91
E					0.94	0.94	0.89
F						0.91	0.93
G							0.92

2° Evaluation with scale							
Evaluation	**B**	**C**	**D**	**E**	**F**	**G**	**H**
A	0.78	0.85	0.85	0.82	0.83	0.84	0.84
B		0.82	0.85	0.85	0.85	0.83	0.82
C			0.98	0.95	0.94	0.95	0.93
D				0.95	0.94	0.95	0.94
E					0.97	0.95	0.93
F						0.96	0.95
G							0.94

coffee leaves (Belan et al., 2014), the authors also used the upper limits of the scales next to the maximum limit found in the fields, 49.0 and 45.1% respectively.

The diagrammatic scales have the function of helping in the determination of the leaf injured area, approximating the evaluation from the real. In general, the diagrammatic scales that have already been built up provide more precision and accuracy in relation to the evaluations without its use (Capucho et al., 2011; Salgado et al., 2009). Without using the scale, the evaluators tended to overestimate the disease (Belan et al., 2014, Custódio et al., 2011) and in relation to the hypotheses $\beta_0 = 0$ e $\beta_1 = 1$, were less accepted when scales in the evaluation of the disease severity were not used (Andrade et al., 2005).

According to Amorim (1995), the evaluator's visual ability in the quantification of the disease is connected with factors, such as training, experience and individual perception, resulting in different answers to different visual stimulus. According to Vale et al. (2004), realizing several evalutions, the accurate evaluators follow standards of minimum deviation between the estimated value and the real severity.

In the evaluation with the scale, 98% of the deviation ranges were between -10 and +10, being these acceptable according to criteria adopted by training programs in the quantification of diseases, such as Disease Pro (Nutter Jr and Worawitlikit, 1989). However, the presence of some level of absolute error in the measurements using the diagrammatic scale in order to quantify the severity of the disease can be compensated if the evaluators keep the level of error realizing the other evaluations (Micheref et al., 2006).

The repeatability refers to the evaluator's capacity, using the scale, for repeating the estimate in the same sample (Vale et al., 2004). The diagrammatic scale for the Blister's Spot of the coffee tree permitted to repeat the measurement of the disease in the first one in relation to the second evaluation, using the scale, similar to what was observed in the diagrammatic scale proposed by Belan et al. (2014) and Custódio et al. (2011).

Using the diagrammatic scale, R^2 values for evaluators' combinations in the first and second evaluations were higher than 0.75 in 87% of the combinations, showing a good reproducibility. Similar results were obtained in validations of diagrammatic scales in other pathosystems (Gomes et al., 2004; Martins et al., 2004).

Conclusion

It was possible to build up diagrammatic scale for evaluating Blister's Spot severity in coffee leaves. The diagrammatic scale was developed to aid and quantify Blister's Spot severity in coffee leaves, providing better levels of accuracy, precision and reproducibility of the evaluations in relation to evaluations of its use.

Conflict of Interest

The authors have not declared any conflict of interest.

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Sources and rates of nitrogen fertilizer used in Mombasa guineagrass in the Brazilian Cerrado region

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Brazilian Cerrado is constituted largely by extensive grazing. In this region, livestock production indices are low, because the producers do not perform a soil amendment. The aim of this work was to study a pasture with high production potential using sources and rates of nitrogen (N). Nitrogen sources used were: Ammonium nitrate, ammonium sulfate, ammonium sulphonitrate, sulfammo and urea applied on the basis of 100 kg ha^{-1} per harvest, and N rates (0, 50, 100, 150 and 200 kg ha^{-1} per harvest), using urea as source, in five harvests. The forage used was [*Panicum maximum* (syn. *Megathirsus panicum*) cv. Mombaça], and were evaluated: Dry matter yield (DMY), crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF). Dry matter yield increased on the second harvest, as a function of N rates. Acid detergent fiber and NDF concentrations there were no significant to the sources, and no adjustment with increasing of N rates. Crude protein content showed no adjustment for the N rates, as well as the N sources were not significant. Because the N performance, we recommend the urea, as this is more affordable and the application of 50 kg ha^{-1} of N for the maintenance of the Mombasa guineagrass.

Key words: Acid detergent fiber, crude protein, dry matter yield, neutral detergent fiber, *Panicum maximum*.

INTRODUCTION

Brazil is a leading meat producer worldwide because, in addition to its favorable climate, it has an abundance of land and vegetation. However, the Brazilian cattle industry faces seasonal fodder production and nutritional pasture deficiencies, the basis of its production system (Figueiredo et al., 2007). In general, there is excess production during the rainy season and shortage in the dry season. There are many grass species used for pasture in Brazil and due to its high DMY potential and good animal feed quality *Panicum maximum* is one of the most widely used for cattle (Corrêa and Santos, 2003).

Proper soil fertility management and understanding the nutritional requirements of this grass are extremely important for pasture management, which is reflected by higher food yield and availability for animals. The use of fertilizers can significantly increase forage production, providing greater capacity and thus resulting in higher milk and meat production per unit of area used (Pereira

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et al., 2011; Iwamoto et al., 2015). Additionally, it can also provide other supplementary effects that increase the efficiency of the system as a whole, such as the production of silage or hay to be used during the dry season (Cecato et al., 2001).

It is known that of all mineral nutrients, N is quantitatively the most important for plant growth. It is also a major nutrient to intensify grass yield, since it is an essential constituent of proteins and directly interferes in the photosynthesis process by its participation in the chlorophyll molecule (Moreira et al., 2005; Costa et al., 2008; Oliveira et al., 2010). In most studies, N has provided immediate and visible increase in forage production, this is because the amount of N available from the soil, from organic matter, does not seem to be enough to adequately provide or meet the needs of forage plants (Batista et al., 2014; Dupas et al., 2010; Hancock et al., 2011; Silva et al., 2011, 2013). Therefore, studies on the behavior of N in the soil-plant system are very important, especially if conducted under different pasture management conditions and at different times of the year, thereby reducing losses and increasing the efficiency of using N fertilizers for forage.

The most used source of N is still urea, by having more N per kilogram of product, however, is that the source can more easily be lost volatilization of ammonia ($N\text{-}NH_3$). To minimize these losses, the urea can be coated with polymers, have the urease inhibitor or nitrification inhibitor, thus slowing the release of $N\text{-}NH_3$. In addition there are other urea nitrogen sources such as ammonium nitrate has the form of 50% of $N\text{-}NH_4^+$ and 50% of $N\text{-}NO_3^-$ and incorrect operation can result in leaching of $N\text{-}NO_3^-$; ammonium sulfate contains N and sulfur (S) and has acidifying effect to the soil; the ammonium sulphonitrate contain N and S has the nitrification inhibitor for minimize the leaching losses of $N\text{-}NO_3^-$ (Cantarella, 2007).

Silveira et al. (2015) working with N rates (0, 60 and 120 kg ha^{-1} per year) and N sources (ammonium nitrate, ammonium sulfate, urea, urea treated with Agrotain, urea with urease inhibitor and ammonium sulphonitrate) for *Paspalum notatum* for three years, observed that the DMY increased linearly with rates of N and to the sources of N, occurred only difference for the second year of studies when used ammonium nitrate, reducing DMY compared with the other sources. Bennett et al. (2008) working with sources of N (ammonium sulfonitrate, ammonium sulfate and urea) and N rates (0, 50, 100, 150, 200 kg ha^{-1} by harvesting) for Marandu palisadegrass (*Brachiaria brizantha* cv. Marandu), observed that the sources of N did not affect DMY, only with the increase of N rates was increased DMY.

Therefore, this work studies the sources of N (ammonium sulphonitrate with nitrification inhibitor (Entec), sulfammo, ammonium nitrate, ammonium sulfate and urea), as well as N rates using urea as source, in the forage species [*P. maximum* (syn. *Megathirsus panicum*) cv. Mombaça], grown in the lower latitude Cerrado regions.

MATERIALS AND METHODS

The experiment was conducted at the School Farm, Research and Extension at the "Júlio de Mesquita Filho" University - Campus of Ilha Solteira - São Paulo State (20° 21' S and 51° 22' W), at an altitude of 326 m in an area previously occupied by *P. maximum*. Soil of the area was classified as Dark Red Alfisol (EMBRAPA, 2013), of sandy texture. The climate is characterized as humid subtropical climate (rainy in Summer and dry in Winter), according to the Köppen classification (Köppen and Geiger, 1928) and total rainfall, average and minimum temperature, average global radiation and average net radiation for 5 harvests shown in the Figure 1.

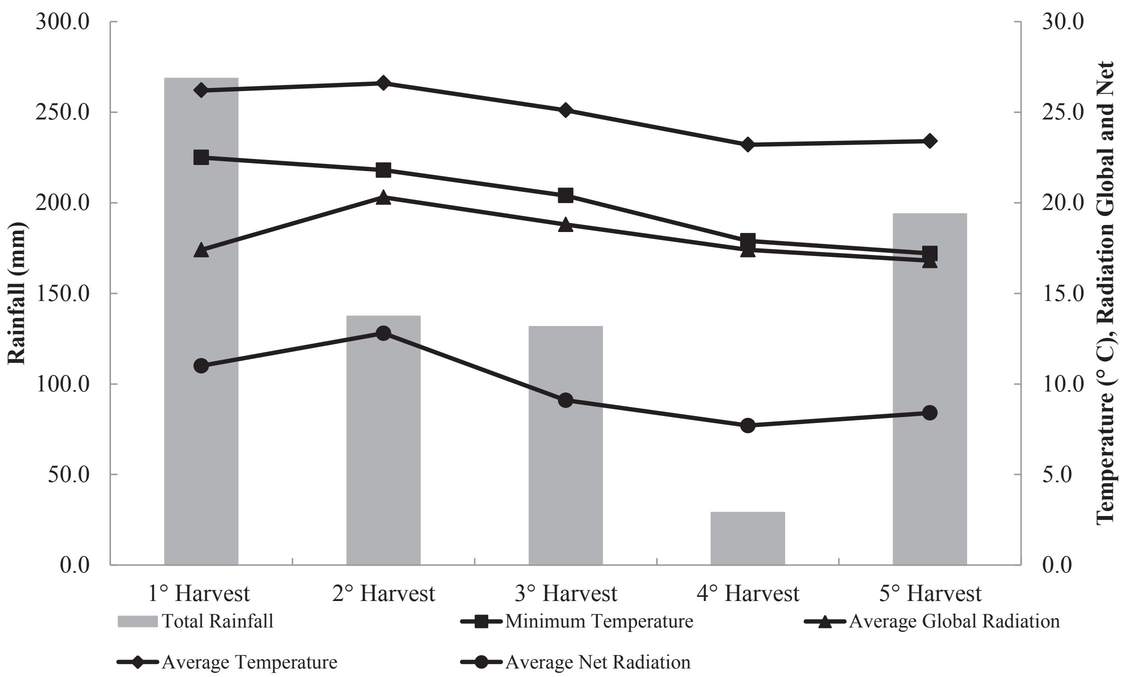
The soil chemical characteristics were determined according to Raij et al. (2001), before the experiment presented the following results: Phosphorus (P) resin = 13 mg dm^{-3}, pH determined in $CaCl_2$ (0.01 mol L^{-1}) = 5.2, potassium (K), calcium (Ca), magnesium (Mg), hydrogen + aluminum (H+Al) and exchange cation (EC) = 2.2, 35.0, 7.0, 16.0 and 60.2 $mmol_c\ dm^{-3}$, respectively.

The area was prepared with one plowing and two harrowings and the Mombasa guineagrass was sown by direct seeding in January 2006. For the grass, the soil fertility was corrected by applying 20 kg ha^{-1} of N (urea - 45% of N). As for the P and K these were based on theoretical rates to achieve values of 30 mg dm^{-3} of P and K at 5% of the EC according to Werner et al. (1997), using simple superphosphate (SS - 18% of P_2O_5) and potassium chloride (KCl - 60% of K_2O) as sources.

The experimental design was randomized blocks with four replications, with five N sources: Urea (45% of N), as it is the most widely used N fertilizer and with possible loss of $N\text{-}NH_3$ by volatilization; ammonium sulphonitrate (26% of N and 13% of S), with nitrification inhibitor (Entec®); ammonium nitrate (32% of N) as the sole source of N; ammonium sulphate (18% of N and 22% of S) to verify the combined effect of N and S, since Entec and Sulfammo have S in their constitution; and Sulfammo (26% of N and 11% of S), with urea coated with seaweed waste, for the gradual release of N. Urea was used in five rates of N (0, 50, 100, 150 and 200 kg ha^{-1} per harvest), to verify the efficiency of the other N fertilizers, which were tested in a single rate to provide 100 kg ha^{-1} of N, per harvest, for each source. Each plot had an area of 6.0 m^2 (3 × 2 m), with 1 m spacing between them.

The harvests were made from February 19, 2010 until October 22, 2010, with fertilizing performed at every three harvests, supplying 40 kg ha^{-1} of K in every area. These harvests were performed manually at 30 cm (Carnevalli et al., 2006) above the ground in random locations within each plot, delimiting the area of 0.5 m^2 (metal quadrate of 1.0 × 0.5 m) for cutting and at time intervals according to pasture growth. The harvested forage was packed in paper bags and then dried in a forced air circulation oven, at a temperature of around 65°C, for 72 h. Next, the samples were weighed to quantify the DMY that was produced in the representative area and then grounded in a Wiley type mill equipped with a 1 mm sieve. The remaining grass portions were cut with a mechanical shredder and removed from the plots. After each forage harvest, the reaped material was removed from the area and the N rates applied to the grass in each plot, according to the treatment.

Dry matter yield of the Mombasa guineagrass was calculated based on the amount of green mass (kg m^{-2}), percentage of original dry mass and harvested area. Neutral detergent fiber, ADF and CP concentrations were also determined, using the methodology described by Silva and Queiroz (2002). For the determination of total nitrogen (TN) digestion was the sulfuric acid and the analytical



1st harvest - February 15th 2010; 2nd harvest - March 16th 2010; 3rd harvest - April 21th 2010; 4th harvest - May 20th 20 and the 5th harvest - October 22th 2010.

Figure 1. Total rainfall, average and minimum temperature, average global radiation and average net radiation for the 5 harvests of Mombasa guineagrass. Data were collected from the metereological station located in the School Farm, Research and Extension at the "Júlio de Mesquita Filho" University - Campus of Ilha Solteira, São Paulo State, 2010.

method was the micro-Kjeldahl. Crude protein concentration was calculated by multiplying the concentration of TN by 6.25.

All data underwent analysis of variance (F test), using the Tukey's test for the N sources to compare the means, and performing regression analysis for the N rates were applied through the statistical application Sisvar (Ferreira, 2011).

RESULTS AND DISCUSSION

Dry matter yield was not affected (*p<0.05*) by N rates in all harvests, except for the second harvest, where there was linear increase with N rates, it can be seen that the fertilization with 200 kg ha^{-1} of N resulted in an average yield of 44%, higher than the control (Table 1). Other studies showed that N fertilization significantly increases DMY in forage (Primavesi et al., 2006; Benett et al., 2008; Dupas et al., 2010; Batista et al., 2014). This shows that the soil where the experiment was conducted still had N reserve to nourish the plants to the productivity level achieved. Nevertheless, it is emphasized that compared to control (without N application) of this forage in the average of the five cuts, there were increases of 21.45 and 27.21%, respectively, for the rates of 50 and 100 kg ha^{-1} of N in the form of urea.

On the other hand, the dry matter biomass produced was satisfactory to ensure the stability of grass and animal production, since these values are higher than the 1600 kg ha^{-1} rate, which is proposed by Mott (1984) to ensure satisfactory forage intake.

As for the different sources (Table 1), no significant difference was found in any of the Mombasa guineagrass harvests for DMY. The same was observed by Silveira et at. (2015), who used the sources: ammonium nitrate, ammonium sulphate, urea, urea treated with Agrotain, Super U and ammonium sulphate nitrate and 3 N rates (0, 60 or 120 kg ha^{-1} per year) applied to Tanzania guineagrass (*P. maximum* cv. Tanzania), where there were no significant differences in the DMY. In contrast, Costa et al. (2010), working with Marandu palisadegrass and applying two N sources (ammonium sulfate and urea), observed that ammonium sulfate resulted in greater DMY than urea, in all rates and years evaluated. Crude protein concentrations increased with increase in N rates in all harvests, which were adjusted to linear regression, except in the first one (Table 1).

These results are consistent with those obtained by Dupas et al .,(2010) (using marandu palisadegrass), Barros et al. (2002) (using Tanzania guineagrass), Silveira et al. (2015) (using *Paspalum notatum*) and Freitas et al. (2007) (using *P. maximum*), who found linear increase in CP concentration due to the increase in N rates.The different N sources did not affect the CP concentration (*p<0.05*). These results disagree from those found by Benett et al. (2008), who working with

Table 1. Means, coefficients of variation (C.V.), Tukey's test and regression equations relating to the dry matter yield (DMY) and crude protein (CP) of Mombasa guineagrass in five harvests.

N rates ($kg\ ha^{-1}$)	1st harvest 02/19/2010	2nd harvest 03/16/2010	3rd harvest 04/21/2010	4th harvest 05/20/2010	5th harvest 10/22/2010
			DMY ($kg\ ha^{-1}$)		
0	3250	709 (1)	1575	1622	1662
50	3675	1129	1950	1961	2128
100	3800	1237	2025	2243	2340
150	3825	1164	2000	1936	2447
200	3900	1253	1925	1907	1938
C.V. (%)	14.68	19.27	15.44	17.04	27.10
N Sources (100 $kg\ ha^{-1}$ of N)					
Ammonium sulphonitrate	2800[a]	980[a]	2225[a]	1856[a]	2494[a]
Ammonium nitrate	3125[a]	1111[a]	2100[a]	1932[a]	2128[a]
Ammonium sulfate	2675[a]	1137[a]	2050[a]	2013[a]	2644[a]
Sulfammo	4125[a]	1355[a]	1700[a]	1902[a]	2639[a]
Urea	3800[a]	1237[a]	2025[a]	2243[a]	2340[a]
L.S.D. (5%)	1332	622	507	854	694
C.V. (%)	21.46	28.45	13.38	22.86	15.10
($kg\ ha^{-1}$)			**CP (gkg^{-1} DM)**		
0	64.7	110.9(2)	114.4(3)	130.4(4)	83.2(5)
50	73.2	129.1	127.5	142.2	92.8
100	66.6	151.9	128.8	150.9	96.9
150	75.9	149.4	147.2	163.6	100.5
200	88.2	147.2	140.7	164.1	113.3
C.V. (%)	15.29	9.17	7.89	6.24	8.84
N Sources (100 $kg\ ha^{-1}$ of N)					
Ammonium sulphonitrate	77.8[a]	152.9[a]	95.7[a]	176.8[a]	103.7[a]
Ammonium nitrate	76.3[a]	138.8[a]	145.1[a]	161.9[a]	115.1[a]
Ammonium nitrate	76.6[a]	147.2[a]	164.1[a]	172.6[a]	115.1[a]
Sulfammo	72.8[a]	132.5[a]	141.6[a]	169.6[a]	98.9[a]
Urea	66.6[a]	151.9[a]	128.8[a]	150.9[a]	96.9[a]
L.S.D (5%)	3.85	4.22	14.81	4.10	4.10
C.V. (%)	11.40	6.63	24.50	5.55	8.62

(1) DMY = 874.30 + 2.24 N (R^2= 0.63); (2) CP = 118.00 + 0.20 N (R^2 = 0.78); (3) CP = 119.00 + 0.14 N (R^2 = 0.72); (4) CP = 134.00 + 0.18 N (R^2 = 0.92); (5) CP = 84.00 + 0.14 N (R^2 = 0.92). Means followed by equal letters in the column do not differ among themselves by Tukey's test at 5% level of probability.

Marandu palisadegrass and using urea, ammonium sulphonitrate and ammonium sulfate as N sources, reported that the use of ammonium sulphonitrate provided higher CP concentrations, differing only with urea, in the first harvest. While in the second harvest, the N sources did not differ. As for the third harvest, ammonium sulfate had the lowest CP concentration, statistically differing from the ammonium sulphonitrate and urea sources.

Crude protein concentration of plants is associated with the soil N availability. However, N fertilization had no significant effect (p>0.05), probably due to the dilution effect caused by this system's material accumulation. According to Soest (1994), CP forage contents less than 70 g kg^{-1} of DM cause digestion reduction, due to inadequate N levels for the microorganisms in the rumen, reducing their population and, consequently, reducing digestibility and dry matter intake. Thus, higher concentrations of CP are needed to meet the animal protein requirements. In this work, it was observed that CP concentrations of Mombasa guineagrass, when fertilized, showed optimal concentrations, reaching

Table 2. Means, coefficients of variation (C.V.), Tukey's test and regression equations relating to the neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentration in Mombasa guineagrass in five harvests.

N Rates (kg ha^{-1})	1st harvest 02/19/2010	2nd harvest 03/16/2010	3rd harvest 04/21/2010	4th harvest 05/20/2010	5th harvest 10/22/2010
			NDF (g kg^{-1} DM)		
0	697.3	645.0	685.2	584.3	635.6
50	701.0	565.4	691.1	592.4	641.8
100	689.9	675.6	664.4	594.2	654.5
150	711.3	669.4	669.3	596.6	645.9
200	728.9	654.1	680.5	599.7	638.8
C.V. (%)	3.97	11.00	2.90	1.96	2.33
N sources (100 kg ha^{-1} of N)					
Ammonium sulphonitrate	631.8^a	662.8^a	670.4^a	611.5^a	654.5^a
Ammonium nitrate	728.3^a	643.4^a	697.0^a	601.8^a	624.6^a
Ammonium sulfate	722.9^a	672.4^a	688.5^a	587.9^a	661.9^a
Sulfammo	711.8^a	665.9^a	666.1^a	590.9^a	663.1^a
Urea	689.9^a	675.6^a	664.4^a	594.2^a	654.5^a
L.S.D. (5%)	24.45	5.26	5.88	8.20	8.43
C.V. (%)	7.88	1.78	1.95	3.10	2.91
(kg ha^{-1})			**ADF (gkg^{-1} DM)**		
0	358.6	311.6	335.7	273.0	334.2
50	355.2	240.1	346.3	276.6	336.3
100	348.4	305.4	327.9	283.4	333.4
150	364.7	299.9	324.3	263.4	321.0
200	353.7	300.5	324.8	274.4	320.8
C.V. (%)	4.59	15.17	3.49	2.82	4.02
N sources (100 kg ha^{-1} of N)					
Ammonium Aulphonitrate	318.1^a	301.4^a	327.4^a	278.6^a	329.6^a
Ammonium Nitrate	362.9^a	292.9^a	333.1^a	291.2^a	309.9^a
Ammonium Nitrate	358.9^a	301.6^a	330.0^a	266.0^a	329.0^a
Sulfammo	357.2^a	309.2^a	321.1^a	275.6^a	336.8^a
Urea	348.4^a	305.4^a	327.9^a	283.4^a	333.4^a
L.S.D. (5%)	14.33	2.81	5.26	8.01	4.10
C.V. (%)	9.29	2.09	3.61	6.46	2.81

Means followed by equal letters in the column do not differ by Tukey's test at 5% level of probability.

values of 164.1 g kg^{-1} of DM, when fertilized with 200 kg ha^{-1} N. These higher concentrations of CP due to N fertilization indicate that it cans result in increased support capacity and animal live weight gain (Dias et al., 1998).

Neutral detergent fiber concentration negatively correlated with the animals voluntary intake and with forage quality, showed no significant differences for the different N sources and N rates (Table 2). These results corroborates with Quadros and Rodrigues (2006), who worked with N rates of 101.5, 145, 188.5 and 232 kg ha^{-1} applied to Tanzania guineagrass and Mombasa guineagrass, verifying that the NDF concentration of leaves and stems did not undergo a well defined affect in terms of N fertilization. Vitor et al . (2009) also obtained no significant response for the NDF, with regards to increasing N rates applied to Elephant grass (*Pennisetum purpurem*) during the rainy season, attributing it to the accelerated plant maturity, when in favorable weather conditions associated to N application, thereby limiting their beneficial effect on the NDF concentration.

Costa et al. (2011) found negative linear effects of N rates on NDF of Xaraés grass (*Brachiaria brizantha* cv. Xaraés*)* Castagnara et al. (2011) working with three tropical forage grasses (Mombasa, Tanzania guineagrass and *Brachiaria* sp. cv. Mulato) and four N rates (0, 40, 80 and 160 kg ha^{-1}), observed that the NDF concentration were affected significantly by N rates, fitting a quadratic equation. The differences in the various experiments are due to soil and climate conditions, management of the species used and the productivity achieved.

According to Soest (1994), NDF concentration is the most limiting factor to forage intake, with levels of cell wall constituents over 55 to 60%, in dry weight, negatively correlated with forage intake. Thus, in general, it is observed that for animal intake the Mombasa guineagrass is less attractive forage.

Neutral detergent fiber concentration, the concentrations of ADF in Mombasa guineagrass and which are negatively correlated with digestibility, also was not affected by N rates (Table 2). The same was found by Vitor et al. (2008) working with Brachiaria grass with N rates (0, 50, 100 and 150 kg^{-1} ha^{-1} per year), concluding that the ADF concentrations were not affected by N fertilization. Similarly, Ribeiro et al. (1999), working with Elephant grass found little or no influence of N fertilization on the NDF and ADF concentrations of forage. Rocha et al. (2002) also found no significant difference for the ADF values obtained, when working with grasses of the genus *Cynodon,* and with N rates (30, 60 and 120 kg ha^{-1}). In this study, no significant differences for the sources of N were found. However, Costa et al. (2004) found lower concentrations of the ADF in Tanzania guineagrass in the rainy season with the application of 450 kg N ha^{-1} compared to 300 and 150 kg ha^{-1}, which did not differ among them. It should be noted that ADF concentrations above 400 g kg^{-1} are considered as limiting for digestibility (Soest, 1994). In this work, regardless of the rates or sources of N, ADF concentrations less than 400 g kg^{-1} of DM were obtained (Table 2). Thus, in this study, it can be inferred that the Mombasa guineagrass is good digestibility forage.

Conclusions

1. Dry matter production increased with the application of N rates only in the second harvest, of the five harvests performed. Sources of N provided the same behavior.
2. Crude protein concentration increased with N rates in four of the five harvests; however, the sources of N did not affect it. Nitrogen rates did not influence the ADF and NDF concentrations, as well as the sources used.
3. Due to the fact there are no differences among sources, in all evaluations, the use of urea is recommended, as this is the most affordable at a dose of 50 kg ha^{-1} of N, as maintenance and guarantee for good CP concentrations.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Study of the influence of physico-chemical characteristics of cassava (*Manihot esculenta* Crantz) stem on its varietal vulnerability to termites ravaging cuttings *Odontotermes* sp. aff. *Erraticus*

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Cassava (*Manihot esculenta Crantz*) includes a multitude of varieties different by several parameters, each of them with specific characteristics. Some of these varietal specificities may constitute the seat of an influence on the vulnerability of this plant to stresses. In this present study, we proposed to assess the impact of physico-chemical parameters of the cassava stem on its varietal sensitivity to termites ravaging cuttings *Odontotermes* sp. aff. *erraticus* in Senegal. At the end of experiments conducted in laboratory, we have seen that the cassava varieties in which the stem bark was thick and hard with a reduced diameter of the marrow were more tolerant to the action of these pests, while those with thin and fragile bark and large stem marrow were more sensible. However the pH of the cassava stem did not affect the incidence of attack of the cuttings by the termites.

Key words: Cassava, cuttings, tolerance, physico-chemical parameters, *Odontotermes* sp.

INTRODUCTION

Cassava (*Manihot esculenta*) is a plant of the *Euphorbiaceae* family native to Latin America. It is grown mainly for its starchy tubers which constitute the basis of food and the main source of energy of many populations across the world (FAO, 1990). Cassava world production of was estimated in 200 at 184 million tons with 55% in Africa (FAO, 2000).

It is a very undemanding plant in relation to the fertility of the soil, rainfall and cultural practices (Raffailac, 1993). The starch content of roots is high and that of protein of leaves is too important (FAO, 2000).

With an annual production of about 90 million tons, cassava is the most important of the R & T (Roots and Tubers) in Africa. About 200 million Africans consume

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cassava as staple food. Almost all of the African production is consumed locally, and is therefore a subsistence crop. Cassava is a strategic product in the fight for food insecurity in Africa. Many products derived from its tubers (flour, starch, *gari*, *attieke*, pellets, *tapioca*, etc.) relate its importance (Coraf, 2010).

In Senegal, the importance of cassava cultivation continues to increase in these recent years and research is more and more interested. It accounts for 25% in the total vegetables production (Aïchatou, 2007).

However, this plant is attacked by several pests and diseases that cause extensive damage on its culture. Indeed, in addition to, between other enemies, the Cassava African Mosaic Disease and the floury cochineal that cause yield losses respectively from 20 to 90% and up to 100% (Mbaye, 1991), termites ravaging cuttings constitute also a major threat against the cultivation of this plant. In the Department of Tivaouane (Senegal) where its culture is strongly practiced, the attack of termites *Odontotermes* sp. among other species on cuttings planted in fields, wins more and more scale (Faye et al., 2014).

To remediate to that biotic stress, the use of tolerant and resistant varieties is the best way of controlling pests and diseases and may be an attractive alternative to the use of pesticides which residues are harmful for the consumers' health and the environment (Renoux, 1997). Varietal tolerance is considered here as inheritable capability of certain varieties within a plant species to limit development and damage caused by insects. Unlike resistance to diseases that often includes genes, varietal tolerance of plants to pests is rather, according to Painter (1951), linked with physical, mechanical or chemical intrinsic parameters and may involve different tissues of the plant (cuticle, mesophyll, phloem, etc). Thus, a study conducted in rural cassava plantations in the department Tivaouane showed that certain varieties were, more than others, tolerant to termites ravaging cuttings in the area (Faye et al., 2014).

In this present study, it was to study the impact of physical and chemical parameters of the cassava stem on its vulnerability to *Odontotermes* sp. aff. *erraticus* termites' action. Specific objectives included evaluating the effects of the bark thickness and hardness, the marrow diameter and the pH of the cassava stems on the incidence and severity of attack of cuttings by these termites in different varieties.

MATERIALS AND METHODS

Plant material

The plant material was cuttings of caliber 18 mm and 20 cm long from 8 varieties of cassava grown in the Department of Tivaouane (Senegal) including 6 local (*Soya*, *Kombo*, *Niargi*, *Cololi*, *Nigeria* and *Wallet*) and 2 from Brazil (*Cacau* and *Cacau roja*). The mother plants were grown in experimental plot for 8 months prior to collection of the cuttings.

Experimental device

36 plastic trays large of 70 and 50 cm deep, at 2/3 filled of previously sterilized soil have been used as culture media. Sterilization of the substrate was made by heating to 80°C over a wood fire in a large metal container, after being wetted. Each tray was then infested by introduction of 200 individuals of termites *Odontotermes* sp. aff. *erraticus* previously collected in farms and identified in the laboratory. In order to put these termites in activity before planting, vegetable debris were placed on the surface of the culture substrate until signs of attack were observed.

Cuttings of each variety were thus planted into 4 infested trays at the rate of 8 cuttings per tray and watered every 2 days with 5 L during 2 months of culture.

Other cuttings of the same dimensions were used for the measurement of physical and chemical parameters of the stem in each variety of cassava.

Evaluation of the physico-chemical parameters of the stem of the different varieties of cassava

The physico-chemical parameters evaluated in the different cassava varieties were the thickness and hardness of the stem bark, the diameter of the stem marrow and their pH. Each of these intrinsic parameters was measured in each variety on cuttings from different plants, with 4 repetitions. For what concerns the bark thickness and diameter of the stem marrow, measurements were made on cuttings' cross-sections using a graduated rule. Concerning the bark hardness, it was measured in cuttings emptied of their marrow, by measuring the breakthrough pressure using a hardness meter. The pH of the stems have been evaluated on bark and marrow v/v solutions in distilled water maintained at 28°C for 24 h before measuring it with a pH meter.

Evaluation of sensitivity parameters of different varieties of cassava to the *Odontotermes* sp. aff. *erraticus* termites' action

The sensitivity parameters assed in the different varieties of cassava were the incidence and the severity of attack of cuttings by termites and the mean number of individuals of insects from each cutting per variety. The assessments of the incidence of attack and the number of individuals of termites extracted were conducted on exhumed cuttings after 2 months of culture. The incidence of attack (I) was determined using the following formula:

$$I(\%) = \frac{NA}{32} \text{x}\, 100$$

in which NA is the number of attacked cuttings and 32 the total number of cuttings for a considered variety.

The average number of termites per cutting was determined on the 32 exhumed cuttings of each variety through a count of individuals of termites (N) extracted from, reporting N/32.

For the severity of attack (S) of the cassava cuttings by the termites, it was evaluated every 15 days during one month and half using the formula:

$$S\,(\%) = \frac{X1(1-1) + X2(2-1) + X3(3-1) + X4(4-1) + X5(5-1)}{Y(5-1)}\, X\, 100$$

where xi = number of cuttings of the class I; i = 1: no attack; i = 2: low attack; i = 3: medium attack; i = 4: severe attack. i = 5: mortal attack; Y = total number of cuttings of the variety.

Table 1. Influence of the bark thickness and the marrow diameter of the stem on the degree of attack of cuttings by termites *O.* sp. in the 8 varieties of cassava after 2 months of culture.

Varieties	Means of		
	Marrow diameter	Bark thickness	Number of termites/cutting
Soya	9.8 [g]	5.2	3.2
Kombo	16.3 [a]	1.7	16.4
Niargi	11.4 [e]	4.6	3.6
Cololi	10.2 [f]	4.8	2.8
Nigeria	13.8 [c]	3.2	8.3
Wallet	15.8 [b]	2.2	13.1
Cacau	13.1 [d]	3.9	3.9
Cacau roja	9.9 [g]	5.7	2.5

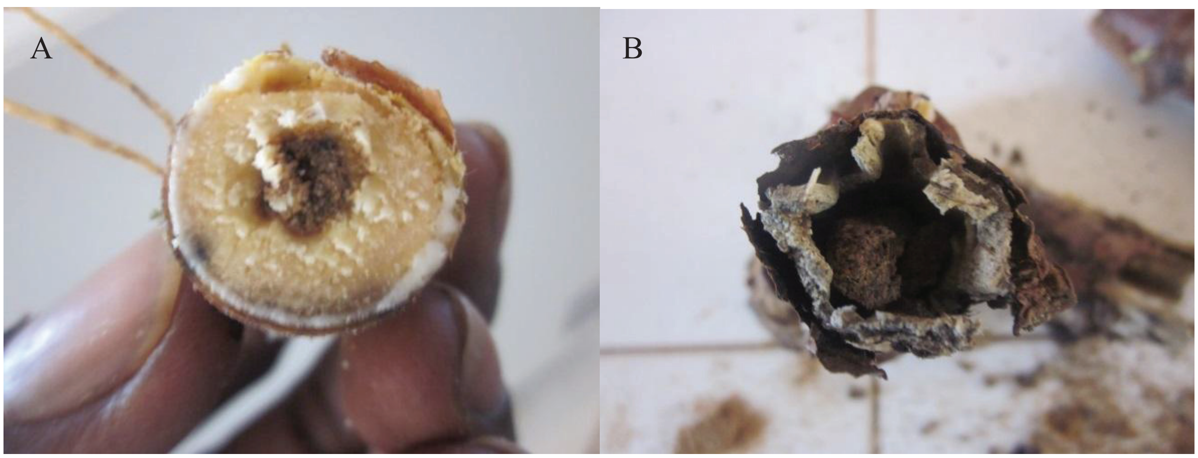

Figure 1. Showing *Soya* (A) and *Kombo* (B) cuttings' cross-sections attacked by termites O. sp., after 60 days of culture.

Statistical analyses

Data collected on this study were entered on Excel and analyzed with software Costat. They have been subjected to analysis of variance (ANOVA) and comparison of means of the Student, Newman and Keuls test at the 0.05 probability.

RESULTS

Influence of the bark thickness and the marrow diameter of the cassava stem on the degree of attack of the cuttings by the termites

A correlation could be established between the diameter of the cassava stem marrow and the number of termites extracted from cuttings. Indeed, the varieties with a large stem marrow presented a low thick bark and vice versa. Table 1 show that cuttings with large marrow diameter have been penetrated by greatest numbers of termites. On the other hand, the varieties which cuttings have a thick bark and a reduced marrow were less attacked. Thus we could count in varieties *Soya* (marrow diameter = 9.8 mm; bark thickness = 5.2 mm) and *Cacau roja* (marrow diameter = 9.9 mm; bark thickness = 5.1 mm) 1.96 and 1.46 against 9.25 and 7.12 in varieties *Kombo* (marrom diameter = 16.3 mm; bark thickness = 1.7 mm) and *Wallet* (marrow diameter = 15.8 mm; bark thickness = 2.2 mm) of average numbers of termites extracted from each cutting respectively (Table 1 and Figure 1).

Analysis of variance showed that the variations in the bark thickness (F = 2.14; P = 0.05), the marrow diameter (F = 0.34; P = 0.05) and the number of termites per cutting (F = 0.194; P = 0.05) were very significant between the 8 cassava varieties studied. The comparison of means allowed to class them in 7 homogeneous groups (a, b, c, d, e, f and g).

Influence of the hardness of the cassava stem bark on the severity of attack of the cuttings by the termites

Figure 2 show that the hardness of the cassava stem bark has an impact on the vulnerability of the cuttings to

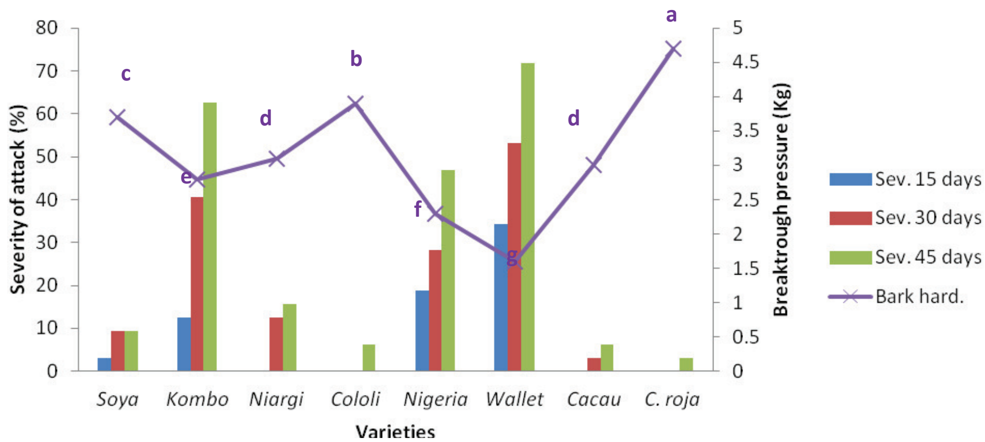

Figure 2. Influence of the stem bark hardness on the severity of attack of the cuttings by termites *Odontotermes* sp. in the 8 varieties of cassava for 45 days of culture.

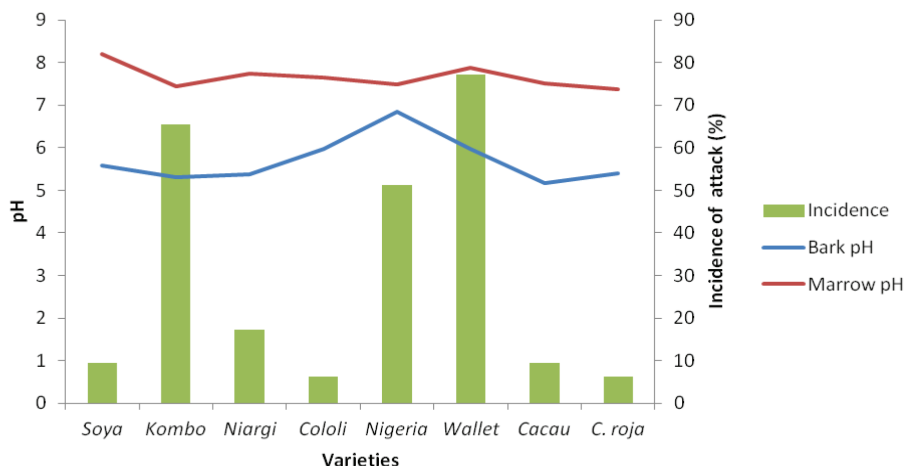

Figure 3. Influence of the stem pH on the incidence of attack of cuttings by termites *Odontotermes* sp. in the 8 varieties of cassava after 2 months of culture.

the action of termites *Odontotermes* sp. We could note a correlation between the hardness of the cuttings bark and their severity of attack by these insects. Indeed, the varieties *Cacau rosa*, *Cololi* and *Soya* with 4.7, 3.9 and 3.7 kg of breakthrough pressure of the bark have been proved more tolerant to the action of termites with respectively 3.12, 6.25 and 9.37% of severity of attack of their cuttings after 45 days of culture (Figure 2). However the varieties *Wallet*, *Kombo* and *Nigeria* which stem bark were relatively more fragile with 1.6, 2.8 and 2.3 kg of breakthrough pressure showed high vulnerability to termites with respectively 71.87, 62.5 and 46.87% of severity of attack of cuttings. According to the ANOVA, the variation in the stem bark hardness ($F = 1.05$; $P = 0.05$) as well as the severity of attack of cuttings by termites after 45 days of culture ($F = 2.107$; $P = 0.05$) were very significant between the 8 cassava varieties studied. These could be classified, according to the bark hardness variation, into 7 homogeneous groups (a, b, c, d, e, f and g) through the comparison of means.

Influence of the pH of the cassava stem on the incidence of attack of cuttings by the termites

No correlation could be established between the pH of the cassava stem bark or marrow and the incidence of attack of its cuttings by the termites *Odontotermes* sp. among the different varieties put in experience. Figure 3 shows that the attack of these insects on cuttings is not related to the acidity or basicity of the stems. Indeed, we have seen that varieties *Kombo* (I = 65.5%) and *Niargi* (I = 17.3%) with respectively 5.31 and 5.7 on one hand and the varieties *Wallet* (I = 77.07%) and *Cololi* (I = 6.25) with respectively 5.97 and 5.98 on the other hand, presented lowly variable bark pH. Similarly, the stem marrow that was less acidic than the bark in the 8 varieties of cassava, did not vary lot between these different varieties.

DISCUSSION

The thickness and the hardness of the stem bark would be the main parameters related to varietal tolerance of cassava to the action of termites ravaging cuttings *Odontotermes* sp. aff *erraticus*. Indeed, these two parameters of the stem that characterize the tolerant varieties would constitute a physical barrier to the activity of these xylophagous termites that use their mouthparts to gradually dig cassava cuttings. This observation perfectly agrees with the findings of Sauvion et al. (2013) that against xylophagous insects, several types of passive defenses can play the roles of physical barrier. According to these authors, the thickness of the bark can be a system of effective resistance to beetles such as *Pityogenes chalcographus* (*Coleoptera*, *Curculionidae*) on spruce and *Ips acuminatus* (*Coleoptera*, *Curculionidae*) on pines, which usually attack the upper portions of the trunk and the branches of the trees. On the other hand, a research by Rahbe and Giordanengo (2013) has shown that the liber and the outer bark of various conifer species contain structures called "stony cells" which are piles of lignin. Thus, when these structures were abundant at the level of the stem bark, their hardness could disrupt the action and development of beetles drilling galleries, as in the case of *Dendroctonus micans*. In this sense, Lieutier and Haddan (2007) cited by Sauvion et al. (2013) have observed a negative correlation in eucalyptus between the thickness of the liber and the proportion of larvae of the beetle *Phoracantha recurva* (*Coleoptera*, *Cerambycidae*) which could access to the sapwood after laying on the bark surface.

In our experimental conditions, we can therefore explain the cassava tolerance to termites ravaging cuttings *Odontotermes* sp. observed in varieties *Soya, Cololi*, *Cacau*, *Cacau roja* and *Niargi* by their relatively hard and thick stem unlike in varieties *Kombo*, *Wallet* and *Nigeria* which were more vulnerable to the activity of these insects.

Like the bark thickness and hardness, the diameter of the stem marrow also would be in relation to the varietal vulnerability of cassava to termites ravaging cuttings. Thus, high degree of infestation as severity of attack observed in varieties *Kombo*, *Wallet* and *Nigeria* would be also due to their relatively large stem marrow with bark consequently reduced. Indeed, a large diameter of this stem marrow includes a possibility of penetration of a great number of individuals of termites inside the cuttings and therefore an increase of their activity.

Chemically, the pH of the cassava stem varies from one variety to another and would be linked to its latex or cyanhydric acid contents. Indeed, the stem of the variety *Soya* is very rich in latex (a cut stem actually cast lot) while the *Nigeria* variety is poor (any drop from a cut stem). This stem latex essentially located at the level of the bark would be responsible for the acidity of this cortical part. Its abundance in a variety would however not act on termites ravaging cuttings. Our results have also shown that the marrow of cassava stem were less acidic than the bark. The basicity of this medullar part would be due to its poverty in latex and cyanogenic glycosides. Thus, these toxic composts mainly represented by linamarine and the lautostraline in cassava, are present in all parts of this plant and which content diminishes from the periphery to the middle of each organ, according to Alves (2012). In the stem, these acids would therefore be more present in the bark than in the marrow, and would be at the origin of the difference in pH between these two components of this organ. However, the pH of the cassava stem would not have repulsive or attractive effect on termites ravaging cuttings *Odontotermes* sp. aff. *erraticus*.

Conclusion

This study proposed to evaluate the influence of physico-chemical properties of the stem of cassava on its varietal tolerance to termites ravaging cuttings *Odontotermes* sp. aff. *erraticus*. Registered results have shown on one hand that the cassava varieties *Soya*, *Niargi*, *Cololi*, *Cacau* and *Cacau roja* are more tolerant to the action of these insects than those *Kombo*, *Wallet* and *Nigeria*. On the other hand, they have shown that the thickness and the hardness of the bark and the diameter of the marrow of the cassava stem are physical parameters influencing the vulnerability of this plant to the action of these pests. Indeed, a correlation could be established between the hardness of the bark and the severity of attack of cuttings by the termites on one hand and on the other hand between the diameter of the marrow and the number of individuals of termites which penetrated attacked cuttings of the different varieties of cassava. However the pH of the stem has not been proved influencing the attack of termites *Odontotermes* sp. aff. *erraticus* on cassava cuttings.

Conflict of Interest

The authors have not declared any conflict of interest.

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Agronomic performance of soybean according to stages of development and levels of defoliation

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Insect pests have led to decreases in grain yield; yet this occurrence depends on the level of defoliation and the reproductive stage of the plant when defoliation occurs. Thus, the aim of this study was to evaluate the agronomic performance of the cultivar BRS Favorita RR® according to the stages of reproductive development of the plant at defoliation and the levels of defoliation. A randomized block experimental design was used in a 6 × 3 + 1 factorial arrangement, composed of six reproductive stages at the time of defoliation [R_1 (Beginning flowering), R_2 (Full flowering), R_3 (Beginning pod formation), R_4 (Full pod formation), R_5 (Beginning seed filling), R_6 (Full seed filling -100% pod filling), and three levels of defoliation (33, 66 and 99%), as well as one additional treatment without defoliation, with three replications. The following features were evaluated: Plant height, number of pods per plant, number of grains per pod, harvest index, thousand seed weight, and grain yield. It was observed that all the levels of defoliation had a significant effect on the other variables studied, with the exception of plant height. The phenological stages at the time of defoliation had a significant effect on plant height, number of pods per plant, harvest index, and grain yield. There was a decline in grain yield with levels of defoliation as of 66%, and this decline was more significant with defoliation at the more advanced stages of the crop reproductive cycle.

Key words: Leaf area, BRS Favorita RR®, *Glycine max* (L.) Merrill, damage level.

INTRODUCTION

Soybean (*Glycine max* (L.) Merrill] is the main oilseed crop grown in the world. Brazil is the second largest producer and exporter worldwide, with a planted area of 30173.1 thousand ha^{-1} and mean grain yield of 2854 kg ha^{-1} in the 2013/2014 crop year (CONAB, 2014). The Brazilian soybean production chain has gone through modernization processes, which have led to an increase in grain yield.

Among the factors that have brought about declines in yield, the occurrence of insect pests stands out. This constitutes one of the main problems faced by soybean producers in achieving high grain yields (Sediyama, 2009). Significant pests are the velvetbean caterpillar (*Anticarsia gemmatalis*, Lepidoptera: Noctuidae), the soybean looper (*Chrysodeixis includens*, Lepidoptera: Noctuidae), and some species of Spodoptera, due to

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Table 1. Chemical and physical composition of the dystrophic red latosolsoil (0-0.20 m) before setting up the experiment. Lavras, MG, Brazil. 2013/2014 crop season.

pH	Ca^{2+}	Mg^{2+}	Al^{3+}	$H^{+}+Al^{3+}$	SB	CEC	P	K	OM	V
H_2O			$cmol_c\ dm^{-3}$				mg dm^{-3}		dag/kg^{-1}	%
6.4	5.0	1.4	0	2.9	6.7	9.6	11.46	118	3.41	69,82
Zn	**Mn**	**Cu**	**B**	**Fe**	**S**	**Clay**	**Silt**	**Sand**	**Texture class**	
		mg/dm^3					dag/kg			
4.97	31.70	1.40	0.17	34.81	4.75	64	20	16	Clayey	

H + Al, Potential acidity; SB, sum of bases; CEC, cation exchange capacity at pH 7.0; OM, organic matter; V, base saturation.

their wide distribution in Brazilian territory (Hoffman-Campo et al., 2012). Recently, the caterpillar *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) has led to expressive damage in the crop (Czepak et al., 2013; Specht et al., 2013).

Under field conditions, the leaf-eating pests cause damage by reducing leaf area and, consequently, the photosynthetic capacity of the plant. The level of damage depends on the time the pest remains on the plant, the percentage of defoliation, and the phenological stage of the plant (Hoffman-Campo et al., 2012).

Thus, producers have adopted the use of chemical products as a means of control so as to minimize the damage arising from leaf-eating insects. Nevertheless, according to Barros et al. (2002), the use of chemical products should be avoided, due to environmental consequences and the increase in production costs. Thus, identifying the period(s) of greatest sensitivity of the crop to defoliation is of great relevance in planning applications of these agricultural chemicals.

Some studies have been carried out regarding the behavior of soybean cultivars in response to damage caused by these pests (Jesus et al., 2013). A general rule is to control the leaf-eating pests when they cause 30% damage in the vegetative phase or 15% damage in the reproductive phase (Hoffmann-Campo et al., 2000), considering that above these levels, the pests cause economic losses. Therefore, agronomic performance of soybean plants undergoing defoliation is a function of the reproductive stage of the soybean and the levels of defoliation since, in some studies (Bahry et al. 2013; Souza et al. 2014), it was observed that defoliation up to 66.7% in the vegetative stages does not lead to loss in grain yield. Yet, in other studies (Diogo et al., 1997; Pelúzio et al., 2004), defoliation at any level led to reduction in yield and in yield components.

A more detailed study is necessary in respect to plant stages and the levels of defoliation tolerated by the cultivar BRS Favorita RR® (chosen for being among the cultivars most used in the south of the Brazilian state of Minas Gerais) so as to increase the effectiveness of current technologies of pest control and reduce losses.

Thus, the aim of this study was to evaluate the agronomic performance of the soybean cultivar BRS Favorita RR® under defoliation in accordance with the stages of reproductive development and levels of defoliation.

MATERIALS AND METHODS

The experiment was carried out at the Crop and Livestock Scientific and Technological Development Center – Muquém Farm/UFLA (Universidade Federal de Lavras) in the municipality of Lavras, MG, Brazil (21°14' latitude south, 45°00'W longitude west, and altitude of 918 m), in the 2013/2014 crop season. Soil in the experimental area is classified as dystrophic red latosol. The chemical and physical composition of the soil is shown in Table 1.

Climate in the region is type Cwa (wet moderate subtropical), according to the Köppen classification, with mean annual temperature of 19.3ºC and normal annual rainfall of 1530 mm (Dantas et al., 2007). The climatic data were collected at the meteorological station of the Instituto Nacional de Meteorologia (INMET) at the Universidade Federal de Lavras - UFLA and are shown in Figure 1.

A randomized block experimental design was used in a 6 × 3 + 1 factorial arrangement, composed of six reproductive stages at the time of defoliation [R_1 (Beginning flowering), R_2 (Full flowering), R_3 (Beginning pod formation), R_4 (Full pod formation), R_5 (Beginning seed filling), R_6 (Full seed filling - 100% pod filling), and three levels of defoliation (33, 66 and 99%), as well as one additional treatment without defoliation, making for a total of 19 treatments, with three replications. Defoliation was characterized by the removal of one part (terminal leaflet), two parts (opposed leaflets), and three parts (all the leaflets) of all the leaves developed on the plant, with the aid of a scissors. Each plot consisted of 4 planted rows of 5 m length, spaced at 0.50 m, for a total area of 10 m^2 (5 m × 2 m) for each plot. The two center rows were considered as a useful area for the experiment, excluding a 1 m border area from each extremity.

Soybeans were planted on December 15, 2013 and the seeds were treated with pyraclostrobin + thiophanate methyl + fipronil at the commercial product rate of 2 mL kg^{-1} of seed, and inoculated with *Bradyrhizobium japonicum* at the commercial product rate of 3 mL kg^{-1} of seed using the strains SEMIA 5079 and 5080. Fertilization consisted of 350 kg ha^{-1} of formulaic $N-P_2O_5-K_2O$ (02-30-20) applied in the plant furrow according to recommendations of the Comissão de Fertilidade do Estado de Minas Gerais (1999). The soybean cultivar used was BRS Favorita RR® at a planting density of 12 plants/meter, which was subjected to the established levels of defoliation.

The following management was used during plant development: (i) Application of the herbicide Glyphosate (Roundup Ready®) at the rate of 1080 g e.a. ha^{-1} after crop emergence, 25 days after emergence (DAE); (ii) Preventive applications of fungicides, pyraclostrobin + epoxiconazole (Opera®) at the commercial

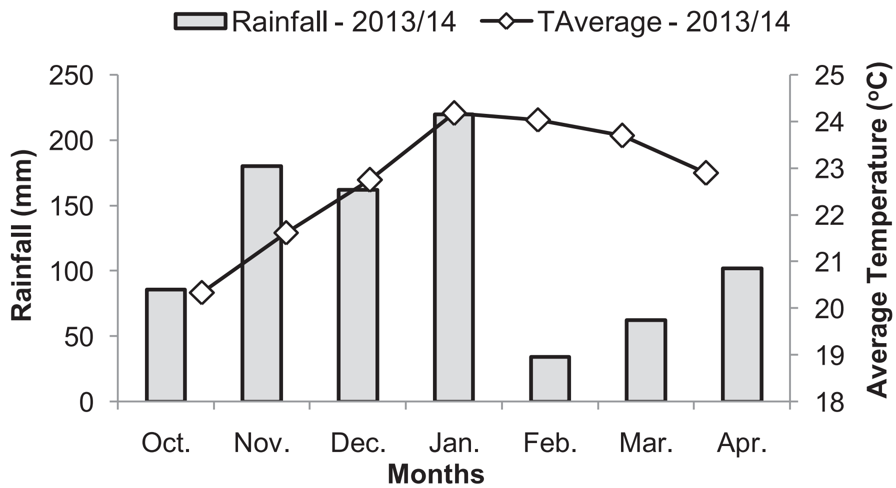

Figure 1. Monthly averages of rainfall and air temperature in Lavras during 2013/2014 cropping season. Lavras, MG, Brazil in the 2013/2014 crop season.

product rate of 500 mL ha^{-1}, applied in the R_1 stage, and azoxystrobin + cyproconazole (Priori Xtra®) at the commercial product rate of 300 mL ha^{-1} + an additional 0.5% of the adjuvant Nimbus, applied in the R_3 stage (beginning pod formation) and iii) three applications of insecticide, Teflubenzuron (Nomolt®) at the commercial product rate of 50 mL ha^{-1}, Cypermethrin (Nortox 250 EC®) and Chlorpyrifos (Fersol 480 EC®) at the commercial product rates of 120 and 250 mL ha^{-1}, respectively.

At the time of harvest (R_8 stage) the following observations were made: Plant height - determined from the soil surface to the apex of the apical meristem with the aid of millimeter ruler; after that, ten plants were collected per plot to evaluate first pod height, number of pods per plant, number of grains per pod, and thousand seed weight. The plants with in the useful area of the plot were collected manually, and threshed mechanically. The yield was transformed into kg ha^{-1} of grain, at standard 13% moisture. The grain harvest index (GHI) was also determined in the following manner: GHI = grain yield/ biological yield.

After collection and tabulation of the data, analysis of variance was carried out on the data obtained in all the parameters evaluated. For comparison of the defoliation treatments, the Tukey test at 5% probability was used. Each mean value of the defoliation treatment and the value in the additional treatment (control) were compared by the Scott-Knott test at 5% probability. The statistical program Sisvar® (Ferreira, 2011) was used to carry out the analyses.

RESULTS AND DISCUSSION

With the exception of plant height, it may be seen that the levels of defoliation had a significant ($p \leq 0.01$) effect on the other variables studied (Table 2). The phenological stages at the time of defoliation had a significant effect on the number of pods per plant, the harvest index, and grain yield. The effects of the level of defoliation and of the phenological stage at the time of defoliation on soybean production components were documented by Barros et al. (2002) and Pelúzio et al. (2002). Significant interaction between both factors occurred for grain yield. Thus, with the exception of grain yield, an isolated study of the factors of level of defoliation and the stage of the plant at defoliation was carried out for the other parameters.

Plant height

According to Table 3, this trait was not affected by the factors evaluated. Upon comparing the mean values of the treatments with the control, no statistical difference is seen. These results differ from those obtained by Diogo et al. (1997); these authors observed reductions of 26.75% in plant height when the mean values were compared with the control.

The fact that the level of defoliation and the stage of the plant at defoliation did not affect the soybean plants was expected since the cultivar used has a determined growth habit and the cultivars with these particular features tend to define this growth habit during the vegetative cycle. Therefore, after this period, the photo-assimilates produced are redistributed mainly for pod and grain formation, and a smaller portion for plant maintenance.

Number of pods per plant

Upon comparing the mean values of the treatments with the control, a significant reduction is seen for this trait at all levels of defoliation and stages in which defoliation was carried out (Table 4). The greatest reduction in the number of plant pods (51.38%) in relation to the control occurred at the 99% level of defoliation in the R_4 stage, when the pods were already completely developed. These results are similar to those seen in the study of Pelúzio et al. (2002), who also verified a significant

Table 2. Analysis of variance of the data in regard to plant height (PH), number of pods per plant (NPP), number of grains per pod (NGP), harvest index (HI), thousand seed weight (TSW),and grain yield (GY)obtained in the trials of levels of defoliation and different reproductive stages at the time of defoliation in the soybean crop of the cultivar Favorita. Lavras, MG, Brazil. 2013/2014 crop season.

Sources of variation	DF	Mean squares					
		PH	NPP	NGP	HI	TSW	GY
		cm	unit			g	Kg ha^{-1}
Blocks	2	4.73	6.50	0.16	0.0003	46.02	91048.09
Defoliation (D)	2	57.45^{ns}	352.28**	0.76**	0.30**	1827.80**	6012007.84**
Stage (S)	5	30.14^{ns}	74.09**	0.14^{ns}	0.01**	186.49^{ns}	253877.79**
D x S	10	18.50^{ns}	16.67^{ns}	0.17^{ns}	0.001^{ns}	109.22^{ns}	104324.64*
Factorial *vs* Additional	1	116.28**	591.75**	591.75*	1284.48**	599.21*	1387275.47**
Treatments	18	31.97^{ns}	138.19**	0.23^{ns}	0.05**	347.39**	870450.96**
Residue	36	24.06	10.61	0.11	0.002	125.42	45349.94
Corrected Total	56	-	-	-	-	-	-
CV (%)	-	5.37	7.77	18.56	11.55	8.06	11.80

** and * significant at the level of 1 and 5% probability by the F test, respectively. ^{ns}, not significant; DF, degrees of freedom; CV, coefficient of variation.

Table 3. Mean values of plant height (cm) obtained in the trials of levels of defoliation and different reproductive stages at the time of defoliation in the soybean crop of the cultivar FavoritaRR. Lavras, MG, Brazil. 2013/2014 crop season.

Defoliation (%)	Reproductive stages						Mean
	R_1	R_2	R_3	R_4	R_5	R_6	
33	82.26	99.66	93.46	93.33	92.20	90.53	93.48^{A}
66	89.46	96.00	90.40	86.06	92.46	86.53	90.71^{A}
99	91.80	92.26	89.53	89.60	92.66	90.40	90.68^{A}
Mean	91.17^{a}	94.86^{a}	91.13^{a}	89.66^{a}	92.44^{a}	90.48^{a}	91.62

In the column, mean values followed by the same uppercase letter, and in the row, by the same lowercase letter belong to the same group by the Tukey test at 5% probability.* Mean values statistically different from the mean value of the control without defoliation (85.00 cm) by the Scott Knott test at 5% probability.

Table 4. Mean values of the number of pods per plant (unit) obtained in the trials of levels of defoliation and different reproductive stages at the time of defoliation in the soybean crop of the cultivar Favorita. Lavras, MG, Brazil. 2013/2014 crop season.

Defoliation (%)	Reproductive stages						Mean
	R_1	R_2	R_3	R_4	R_5	R_6	
33	51.80*	44.53*	41.93*	43.33*	44.44*	56.53*	45.41^{A}*
66	46.13*	42.40*	42.66*	42.96*	43.46*	43.86*	43.58^{A}*
99	40.53*	36.46*	32.33*	30.60*	40.30*	41.86*	37.00^{B}*
Mean	45.16^{a}*	41.13^{bc}*	38.97^{c}*	38.96^{c}*	42.66^{ab}*	44.08^{ab}*	41.99

In the column, mean values followed by the same uppercase letter, and in the row, by the same lowercase letter belong to the same group by the Tukey test at 5% probability. *Mean values statistically different from the mean value of the control without defoliation (62.93 unit) by the Scott Knott test at 5% probability.

reduction in the number of pods per plant in the total defoliation carried out in the R_4 stage.

Furthermore, significant differences are detected between the levels of defoliation and the stages at which defoliation was carried out. Namely, when carried out in the R_3 and R_4 stages, greater reduction occurred for this variable, although no statistical difference occurred in the R_2 stage. Upon analyzing the levels of defoliation, it may be seen that total defoliation has the most severe impact on formation of the number of plant pods. Nevertheless,

Table 5. Mean values of the number of grains per pod (unit) obtained in the trials of levels of defoliation and different reproductive stages at the time of defoliation in the soybean crop of the cultivar Favorita. Lavras, MG, Brazil. 2013/2014 crop season.

Defoliation (%)	Reproductive stages						Mean
	R_1	R_2	R_3	R_4	R_5	R_6	
33	1.97	2.13	2.26	2.12	1.96	1.95	2.07^{A}
66	2.33	1.96	1.99	1.31	1.67	1.80	1.85^{AB}
99	1.62	1.83	1.49	1.70	1.41	1.87	1.65^{B}
Mean	1.98^{a}	1.97^{a}	1.91^{a}	1.71^{a}	1.68^{a}	1.87^{a}	1.86

In the column, mean values followed by the same uppercase letter, and in the row, by the same lowercase letter belong to the same group by the Tukey test at 5% probability. *Mean values statistically different from the mean value of the control without defoliation (2.09 unit) by the Scott Knott test at 5% probability.

Table 6. Mean values of thousand seed weight (g) obtained in the trials of levels of defoliation and different reproductive stages at the time of defoliation in the soybean crop of the cultivar Favorita. Lavras, MG, Brazil. 2013/2014 crop season.

Defoliation (%)	Reproductive stages						Mean
	R_1	R_2	R_3	R_4	R_5	R_6	
33	154.36	152.50	156.90	156.90	152.00	148.83	153.58^{A}
66	148.16	145.63	136.56*	133.66*	129.22*	148.60	140.31^{B}*
99	143.20	139.90*	137.76*	131.00*	125.83*	125.16*	133.81^{B}*
Mean	148.57^{a}	146.01^{a}	143.74^{a}	140.52^{a}*	135.70^{a}*	140.86^{a}*	142.57

In the column, mean values followed by the same uppercase letter, and in the row, by the same lowercase letter belong to the same group by the Tukey test at 5% probability. *Mean values statistically different from the mean value of the control without defoliation (154.36 g) by the Scott Knott test at 5% probability.

all the levels of defoliation negatively affect this trait. Working with the same levels of defoliation in soybean, Barros et al. (2002) observed significant reductions for this trait only at a 99% level of defoliation.

Reduction in the number of pods per plant is nothing more than a reflection of reduction in leaf area because it is in this structure that photosynthesis occurs for production of photo-assimilates, which, during the reproductive phase, are prioritized for the formation of pods and filling of grain. Thus, since there are fewer photo-assimilates, the plant tends to reduce the sinks (pods) to complete its cycle. Soybean has good capacity for leaf expansion (Procópio et al., 2003), but under total defoliation conditions, this capacity is not sufficient to compensate for defoliation. In addition, Pelúzio et al. (2002) report the occurrence of peaks of photosynthetic activity, which indicates greater demand of photo-assimilates in the reproductive stages for the plant to produce pods.

Number of grains per pod

This trait was significantly affected only for levels of defoliation (Table 5). Comparing all the defoliation treatments with the control, statistical differences were not observed for the number of grains per pod. These data corroborate those obtained by Diogo et al. (1997), in which the authors observed a smaller number (1.90) of seeds per pod in total defoliation (99%).

In light of these results, it may be seen that plants under defoliation were subject to reductions in the number of pods per plant compared to the control (Table 4). Nevertheless, upon reducing the number of sinks (number of pods) at all the plant stages and levels of defoliation, even with reductions in their leaf area, plants managed to produce photo-assimilates in a sufficient quantity to meet the demands of grain filling. In contrast, the control obtained a greater number of pods and, consequently, greater sinks for distributing its photo-assimilates. Thus, the number of grains was identical to the defoliation treatments. For Mauad et al. (2010), the total number of grains per pod is related to the total number of pods per plant. Therefore, a reduction in the total number of pods directly affects the number of grains per pod. However, that behavior was not observed in this study (Table 6).

Thousand seed weight

For this variable, a significant decrease was observed in the thousand seed weight in relation to the control for the treatments with 66% defoliation in the R_3, R_4, and R_5

Table 7. Mean values of the harvest index obtained in the trials of levels of defoliation and different reproductive stages at the time of defoliation in the soybean crop of the cultivar Favorita. Lavras, MG, Brazil. 2013/2014 crop season.

Defoliation (%)	Reproductive stages						Mean
	R_1	R_2	R_3	R_4	R_5	R_6	
33	0.70*	0.60*	0.61*	0.57*	0.55*	0.61*	0.60^{A}*
66	0.50*	0.47*	0.45*	0.45*	0.46*	0.48*	0.47^{B}*
99	0.42*	0.36*	0.32*	0.31*	0.33*	0.31*	0.34^{C}*
Mean	0.54^{a}*	0.48^{ab}*	0.45^{c}*	0.44^{c}*	0.45^{c}*	0.47^{ab}*	0.47

In the column, mean values followed by the same uppercase letter, and in the row, by the same lowercase letter belong to the same group by the Tukey test at 5% probability. *Mean values statistically different from the mean value of the control without defoliation (0.80) by the Scott Knott test at 5% probability.

stages. For total defoliation, in addition to the stages mentioned, defoliation carried out in the R_2 and R_6 stages also resulted in lower thousand seed weight (Table 7). The results of thousand seed weight as a function of levels of defoliation and plant stages for defoliation are contradictory in the literature since Pelúzio et al. (2002) observed reduction in this trait at the levels of 66 and 99% of defoliation only in the R_5 and R_6 stages, whereas Barros et al. (2002) observed reductions at all levels (33, 66 and 99%) and all stages (R_4, R_5, R_6) evaluated. Both results partially corroborate those obtained in this study.

Upon considering the mean values of levels of defoliation, a reduction is detected in thousand seed weight when there was removal of 66 and 99% of the leaves. Nevertheless, differences are not observed among the plant stages in which defoliation is carried out (Table 7).

Such findings are probably related to the low production and translocation of photo-assimilates during grain filling, which occurs in the R_4, R_5, and R_6 stages, requiring a greater quantity of leaves to increase efficiency during this process. For Sediyama et al. (1985), the increase in sinks in the reproductive period causes an increase in photosynthetic activity, highlighting the importance of leaves as a source of photo-assimilates. Therefore, the greater the percentage of defoliation occurring in the R_4, R_5, and R_6 stages of the crop, the lower the efficiency of grain filling. These observations reaffirm the importance of the presence of leaves during these stages, having a direct impact on crop yield.

Grain harvest index

The values obtained for this characteristic exhibit response patterns similar to those observed for the number of pods per plant. All the treatments showed significant difference from the control, indicating changes in plant biomass conversion to grain (Table 7). These changes may lead to losses in productive potential and utilization of resources during soybean growth, as well as losses in yield. It should be noted that even the lowest level of defoliation applied caused significant changes in the mean values of both the variables reported, and these parameters are directly related to grain yield. According to Petter et al. (2012), the grain harvest index expresses crop efficiency in converting plant biomass into grain yield, that is, there is positive correlation between the index and the harvest (Fageria and Santos, 2008).

Grain yield

The values obtained for grain yield exhibited the same tendency of response to treatments observed for thousand seed weight (Table 8). Nevertheless, only the treatments with defoliations of 66 and 99% differed significantly from the control (Table 7). These results are similar in part to those obtained by Diogo et al. (1997), who observed reductions from the defoliations of 66% in the R_4 and R_5 stages, and from total defoliation in all the reproductive stages studied (R_2, R_4, and R_6). Ribeiro and Costa (2000) also observed drastic reductions in yield with defoliations greater than 67% at all the developmental stages evaluated, and yields were even weaker if defoliations were applied in the reproductive stages of development. Likewise, in similar trials, Fontoura et al. (2006) observed that the treatment with 100% defoliation in the R_5 stage led to the lowest grain yield, with reduction of 76% in relation to the control.

It is important to highlight that this variable is dependent on the other parameters already evaluated, such as number of pods per plant, number of grains per pod, and the seed weight. Thus, it is possible to observe that the variation shown for grain yield may be explained by the variations observed previously for the other traits. Any variation not explained by the previous parameters may be related to the Defoliation X Plant Development Stage interaction (D x S), which was significant for grain yield.

The soybean plant is characterized by high compensation capacity (Hoffman-Campo et al., 2012), especially when the damage levels are low, and its

Table 8. Interaction effect between levels of defoliation and different reproductive stages at the time of defoliation for grain yield (kg ha^{-1}). Lavras, MG, Brazil. 2013/2014 crop season.

Defoliation (%)	Reproductive stages						Mean
	R_1	R_2	R_3	R_4	R_5	R_6	
33	2638.44Aa	2498.48 Aa	2238.44 Aa	2295.10 Aa	2194.56 Aa	2421.27 Aa	2381.05
66	2084.86 Ba*	1828.31 Ba*	1779.55 Ba*	1801.66 Ba*	2067.73 Aa*	1913.77 Ba*	1912.65
99	1774.48 Ba*	1310.60 Cab*	1295.33 Cab*	1193.91 Ca*	1008.04 Ba*	807.99 Ca*	1231.72
Mean	2165.92	1879.13	1771.11	1763.56	1756.78	1714.34	1841.81

In the column, mean values followed by the same uppercase letter, and in the row, by the same lowercase letter belong to the same group by the Tukey test at 5% probability. *Mean values statistically different from the mean value of the control without defoliation (2526.26 kg ha^{-1}) by the Scott Knott test at 5% probability.

Table 9. Percentage variation of grain yield (%) obtained due to in the trials of levels of defoliation and different reproductive stages at the time of defoliation in the soybean crop of the cultivar Favorita. Lavras, MG, Brazil. 2013/2014 crop season.

Defoliation (%)	Reproductive stages					
	R_1	R_2	R_3	R_4	R_5	R_6
33	+ 4.44	- 1.09	- 11.31	- 9.15	- 13.13	- 4.15
66	- 17.47*	- 27.62*	- 29.55*	- 28.68*	- 18.15*	- 24.24*
99	- 29.75*	- 48.12*	- 52.74*	- 52.74*	- 60.09*	- 68.01*

Mean values statistically different from the mean value of the control without defoliation according to the mean values shown in Table 8.

recovery without losses in grain yield is possible. It shows good plasticity, which allows it to change its morphology in accordance with the damages that occur.

This behavior of defoliation at a lower intensity carried out at the beginning of the reproductive cycle may be softened by the compensation effect of the plant, which puts forth new leaflets. In contrast, upon analyzing the yield of the control (2526.26 Kg ha^{-1}), it may be seen that performance is below the mean yield for the crop in the state of Minas Gerais (2687 Kg.ha^{-1}) achieved in the 2013/2014 crop season (CONAB, 2014). This is related to the low rainfall amounts, which probably hurt recovery of the plants that received the most severe defoliations (Figure 1).

According to Larcher (2004), plant cover functions as an assimilation system in which layers of leaves are overlaid and provide mutual shading and in which solar radiation arrives in the plant cover in various manners: directly through openings in the plant cover or from the margins, and as diffuse radiation derived from reflection of the leaves and the soil surface, or even as radiation transmitted through the leaves.

Thus, small levels of defoliation do not affect plant production. This occurrence is probably based on the increase in photosynthetic production of the plant promoted by greater penetration of radiation at the lower layers of the plants. For Bueno et al. (2010) and Souza et al. (2014), depending on the intensity of the attack of leaf-eating insects, the leaf area of the remaining leaves are able to carry out photosynthesis at a sufficient level to ensure energy production for the plant, in addition to remobilization of the reserves.

Regardless of the stage at which defoliation takes place, the treatments involving total removal of the leaves showed greater yield reductions (Table 9). At this level of defoliation, greater losses in yield are observed to the extent that leaf removal was carried out in more advanced stages, especially evident in the loss of 68.01% of grain yield with defoliation in the R_6 stage. These results are in agreement with those observed by Diogo et al. (1997), Pelúzio et al. (2002), Barros et al. (2002) and Carvalho et al. (2012), who also detected greater reductions in grain yield upon carrying out total removal of the leaves at more advanced reproductive stages of the crop.

It should be emphasized that the decreases in yield at the levels of defoliation of 66 and 99% reflects the lower number of pods per plant (Table 3), and reduction in the thousand seed weight at these levels of defoliation (Table 6). The reduction in yield as a result of defoliation of 66% in the R_3, R_4, and R_6 stage, and in total leaf removal in these stages mentioned plus the R_2 stage is directly related to the thousand seed weight (Table 6).

The results show a large impact from the plant reproductive stage at the time of defoliation and the level of defoliation on the agronomic development of the crop and on yield. However, there are some practices suggested in the literature for the purpose of lessening the damages. According to Costa and Daros (2006), reduction in the spacing between plant rows may decrease the effects caused by defoliation. From the results, it is possible to see that the cultivar BRS Favorita® exhibits sensitivity to defoliation, with alteration in all the traits evaluated, except for plant height.

There was a decrease in grain yield as of levels of defoliation of 66%, and these losses were more significant when defoliation occurred at the more advanced stages of the reproductive cycle of the crop.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Quantity-intensity characteristics of Potassium (K) in relation to potassium availability under different cropping system in alluvial soils

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Potassium availability to the plant is influenced by internal soil properties and other external properties. Quantity intensity characteristics are one of the satisfactory measures of potassium dynamics and its availability. So quantity intensity characteristics of potassium were studied to quantify the potassium availability in three different cropping systems viz., paddy-paddy, banana and paddy-pulse based. Three soil profiles were studied in each cropping system and soil samples were collected horizon wise for laboratory analysis. Q/I parameters were estimated by the method adopted by Beckett (1964a). Analysis of variance was performed to compare the impact of cropping system and pedons on different chemical and nutrient properties of soils. Significantly high organic carbon (0.47%) and available nitrogen (271.10 kg/ha), medium available phosphorus (17.00 kg/ha) and available potassium (230.50 kg/ha) recorded in paddy-pulse cropping system compared with other cropping system. Banana based cropping system recorded significantly higher clay (41.2%), soil reaction (8.24) and potassium fixing capacity (84.32%). The results of Quantity-Intensity (Q/I) dynamics studies shows that paddy-pulse based cropping system recorded high labile K K_L (0.49 c mol (p+)/kg) and Potential buffering capacity PBC^K (45.67 c mol (p+)/kg) whereas paddy-paddy cropping system recorded PBC^K of 16.81 c mol (p+)/kg which needs frequent potassium fertilization. The results showed that most of the soil properties including K dynamics were greater extent influenced by changes in cropping systems which consecutively affects the potassium availability.

Key words: Quantity intensity (Q/I) characteristics, cropping systems, soil properties, K dynamics.

INTRODUCTION

The Q/I relation of soil describes the relation between K availability or intensity (I) in soil to the amount (Q) present in soil, that is, changes of K sorbed to changes of K in solution concentration (Uddin et al., 2011). The potassium content in soil depends mainly on type and degree of soil weathering and the forms in which it exist

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in the soil (Havlin et al., 1999). Hence the K availability in the soil solution (intensity) and the inherent capacity of the soil to buffer this concentration against changes are among the important parameters that determine effective availability of K to plants (Grimme, 1976; Raheb and Heidari, 2012). In some cases even though the soil contain considerable amount of total K, the availability to plants are negligible. This is because the availability of K to plants depends not only on its availability but also on its dynamics viz., intensity, capacity, and renewal rate in soils. Finally, knowing the equilibrium constants is vital for predicting the status and supply of K for plant (Lindsay, 1979). Misunderstanding of theses dynamics leads to mismanagement of soil fertility. Potassium potential (PP) is one of the intensive characteristics of soil potassium dynamics which describes the intensity of potassium release from the soil solid phase into the soil solution. Lamm and Nafady (1971). However, to assess the conditions of potassium uptake by plants, the extensive parameters, that is, the contents of potassium and other soil properties (Ca+Mg) are also required (Woodruff, 1955). In this case, the activity ratio AR_e^K or aK/ √a (Ca+Mg)/2 described by Beckett (1964) is one of the satisfactory measures of the K dynamics and its availability because it measures both the chemical potential of labile K present to the chemical potential of labile (Ca+Mg) in the same soil.

The same time different soil having same AR_e^K values may not possess the capacity for maintaining AR_e^K when soil K is depleted (Diatta et al., 2006). The PBC^K characterizes soil capacity to resist changes in the content of available potassium under the impact of natural and anthropogenic factors (Zharikova, 2004).

Soil properties vary in vertical and lateral directions with landscape position, soil forming factors and land use (Momtaz et al., 2009). Land use systems significantly affected the clay, the silt and the sand fractions and affect the distribution and supply of soil nutrients by directly altering soil properties like exchangeable basic and acidic cations (Stutter et al., 2004), soil exchange chemistry (Chien et al., 1997) and water retention characteristics (Malgwi and Abu, 2011). The forms and dynamics of soil potassium greatly influenced by changes in land use which is often involve changes in vegetative cover and biomass production (Awdenegest et al ., 2013). Since K is largely required for paddy (*Oryza sativa*) crop next to nitrogen, major paddy growing alluvial soils of Thamirabarani command area of Tamil Nadu was identified to measure the potassium dynamics in relation to K availability. A good knowledge of the spatial variability of soil as it relates to topography and land use is essential for good land evaluation, which is a prerequisite for sound land use planning (Amusan et al., 2006). With this background an attempt was made to relate the potassium availability parameters with the quantity intensity characteristics under three differentcropping systems in alluvial soils of Thamirabarani command area of Tamil Nadu.

QUANTITY-INTENSITY ISOTHERMS - INTERPRETATION AND RELEVANCE

Figure 1 typically represents the relation between changes in the amount of soil labile K (Quantity factor) and the activity ratio (AR_e^K) (Intensity factor). It means that it measures changes in the amount of labile K in the soil to the amount held in the soil.

ΔK represents the difference between the K concentrations of a solution before and after the addition of soil. It is convenient to measure changes in the amount of labile K in the soil, not against a zero state of the soil with no labile K, but relative to the amount held in the field soil.

The intercept of the curve with the activity ratio axis (ΔK=0) gives the value of the activity ratio of potassium (AR_e^K) in soils. It is a measure of availability or intensity of labile K in soil. Schouwenburg and Schuffelen (1963) theorized that if the AR_e^K value is less than 0.001 moles lit^{-1}, the adsorbed K will be at edge positions and if it is > 0.01, K will be adsorbed at planar positions.

It has upper linear part and lower curved part. The lower curved part appears to describe, the exchange reactions of labile K held at sites (edges of clay particles and to wedge sited of weathered micas) which shows more specific affinity for K. The lower curvature at the low values of AR_e^K was due to the release of fixed K from the soil particle. The upper linear portion of the curve has been ascribed to non specific sites (planar surface) for K.

ΔK° is the measure of potassium adsorbed on p-positions (non specific positions on outer crystal surfaces) and considered to be available for plants. Kx represents the capacity of the specific sites, that is, potassium adsorbed on e-positions (specific exchange positions occur on the edges, bends and projected parts of crystal surfaces) is less available for plants (Medvedeva, 1975).

The amount of ΔK at AR_e^K=0 represents labile potassium (K_L) in adsorption curves. It characterizes the total pool of labile potassium in particular soils (ΔK°+Kx). This parameter showed the amount of K which is readily available and is capable of ion exchange during period of equilibrium between soil colloids and soil solution.

The slope of ΔQ/ΔI measures the amount of labile K that can be removed before AR_e^K falls by more than a given amount that is gradient of the linear part of the graph has been generally represents Potential Buffering Capacity (PBC^K) of the soil. It is generally a measure of the ability of the soil to maintain the intensity of K in the soil solution. The PBC^K is related to sorption–desorption processes acting in the soil. The range of its values is divided into very low (<20), low (20–50), medium (50–100), elevated (100–200) and high (> 200). Soils with highest PBC^K values were characterized by the lowest percent K saturation, indicative of higher potential to replenish K concentration in soil solution. Removal of adsorbed K from the non specific planner surface sites by cropping increased the buffer capacities, indicating that

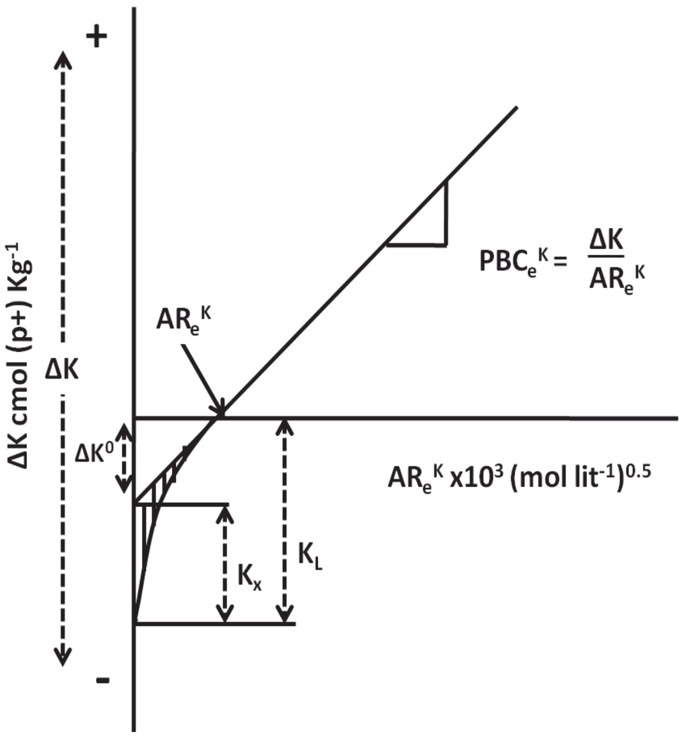

Figure 1. Quantity-Intensity isotherms - Interpretation and relevance.

higher energy sites became involved as the number of cropping increased.

MATERIALS AND METHODS

Study area and sample collection

The study was conducted in Thamirabarani command area of Tamil Nadu, India located between 76° 24' and 78° 24' East longitude and 8° 20' to 9° 0' North latitude. The geology is granite gneiss. This area has a typical monsoonic climate with a mean annual precipitation is 75.9 cm. The mean annual temperature is 33.5°C and it is lowest in the month of December (29.9°C) and highest in May (37.1°C). The mean soil temperature is about 22°C. The difference between the mean summer and mean winter soil temperature is more than 5°C. The soil temperature regime is megathermic. The soil map of Tamil Nadu prepared by NBSSLUP was used as a base map for selection of sampling sites. From that five major soil units were identified representing ninety per cent of the study area. The cropping pattern in the study area is paddy-paddy, paddy-pulses and banana based cropping system and the length of growing period is 90 to 120 days. Soil survey followed by sample collections was carried out representing all the cropping system in the study area following standard procedure. Three sites were identified for each cropping system and soil profile was studied for its morphological characters and ten surface samples were collected randomly from each cropping system for laboratory analysis (Soil survey staff, 2008). Soil samples were analyzed for physico chemical properties using standard methods (Jackson, 1973). Water soluble K was determined by Mac Lean (1960) method and the exchangeable K (Kex) was assessed by the method adopted by Stanford and English (1949).

Potential buffering capacity (PBC_K)

For the determination of K potential the method developed by Beckett (1964a) and as adopted by Palaniappan (1972) and Ramanathan (1977) was adopted. To a series of 100 ml shaking bottles 5 g soil samples were taken. To each shaking bottle with soil, 40 ml of 0.0125 M $CaCl_2$ solutions was added. To these, 10 ml portions each of varying KCl concentrations were added to make up the final concentrations of $CaCl_2$ to 0.01 M. The concentrations of KCl used were 0, 0.25, 0.5, 1.0, 2.0, 3.0 and 5.0 milli moles. Another sample of 0.5 g was also weighed into the shaking bottle and 50 ml of 0.01 M $CaCl_2$ was added. The bottles with contents were shaken for 1 h, kept overnight and centrifuged at 2000 rpm from 10 min. The supernatant solution was filtered and analyzed for K using flame photometer. Calcium and magnesium were estimated by the versenate titration method. From the concentrations of K, Ca and Mg, the activity ratio ^aK / ^aCa+Mg was calculated by Debye – Huckel formulae as proposed by Beckett (1964).

The difference between the amount of K added and recovered in the extract solution in me per 100 g of soil was also calculated (ΔK). The AR^K was then plotted against ΔK. The Q / I curve resolves into lower curved part and the upper linear part. The difference between the lower and upper part represents the K held at specific sites (K_X) at zero activity ratio. Further an extension of the lower curved part to the ΔK axis given the total amount of K in labile pool (K_L). The linear part of the curve was interpolated to the X-axis and this X intercept would represent the equilibrium activity ratio (AR_e^K) when ΔK is zero.

The linear part was also interpolated to intersect the Y-axis and this Y-intercept would represent the amount of K held in the soil on sites, or surfaces of which the exchange equilibrium is described by the linear part of Q/I Relation (-ΔK). The other Q/I parameters calculated are as follows.

$$PBC^K = \frac{-\Delta K^0}{AR_e^K}$$

Where,
PBC^K = Potential buffering capacity
$-\Delta K^0$ = Labile K (Quantity of K released or the part of labile K that is located on the planar surface)
AR_e^K = Equilibrium activity ratio to K.

RESULT AND DISCUSSION

Soil properties

There are three types of soils found in the study area. One is deep imperfectly drained cracking clay soils occurring on gently sloping lands with moderate erosion (Fine montmorillonitic vertic ustropepts) and utilized only for banana. Whereas in lowlands the soils are deep imperfectly drained calcareous gravelly clay soils (Fine loamy mixed typic ustropepts) and it is associated with paddy followed by paddy cropping system. Deep, well drained gravelly loam soil found on gently sloping lands (Fine loamy mixed typic ustrothents) has land use of rice followed by pulses (Table 1). The soil of all the three cropping systems found as alkaline with the mean range between 8.01 to 8.59. Even though the soils are having high pH they are not saline soil because the EC was found < 2.5 dSm^{-1} with the mean range between 0.17-

Table 1. Different soil unit under three different cropping system.

S/N	Cropping system	Soil Unit	Description
1	Paddy-pulses	Fine loamy mixed typic ustrothents	Deep, well drained gravelly loamy soils on gently sloping lands, moderately eroded
2	Banana	Fine montmorillonitic vertic ustropepts	Deep imperfectly drained cracking clay soils on gently sloping lands with moderate erosion
3	Paddy-paddy	Fine loamy mixed typic ustropepts	Deep imperfectly drained calcareous gravelly clay soils on nearly level lowlands, slightly eroded

Table 2. Soil properties under three different cropping system.

Cropping system	Statistical parameters	pH	EC (dS m^{-1})	OC %	Available nutrients (kg ha^{-1})		
					N	P	K
	Mean	8.59	0.43	0.38	194.60	15.40	186.90
Paddy-paddy	SD	0.41	0.33	0.12	69.54	4.31	26.93
	CV	**4.80**	**80.39**	**30.17**	**35.54**	**27.96**	**13.72**
	Mean	8.24	0.26	0.43	245.00	13.20	208.60
Banana	SD	0.57	0.17	0.31	61.33	4.21	31.25
	CV	**6.97**	**66.56**	**73.08**	**25.03**	**31.87**	**14.98**
	Mean	8.01	0.17	0.47	271.10	17.00	230.50
Paddy-pulses	SD	0.48	0.11	0.21	49.95	4.94	23.74
	CV	**5.96**	**51.62**	**46.44**	**19.31**	**27.61**	**9.66**

0.43 dSm^{-1}. Soil organic carbon content was low (< 0.5%) in all the cropping sequence and it is comparatively high in paddy-pulse cropping sequence (0.47%) might be organic residue addition from pulses (Table 2). Same wise all the available major nutrients were found high (N: 271 kg ha^{-1}, P: 17 kg ha^{-1} and K: 230 kg ha^{-1}) in paddy-pulse cropping system. The biological nitrogen fixation by nodules in pulses and addition of huge biomass might be the reason for the increased amount available nutrients under paddy-pulse cropping system.

Q/I parameters

Equilibrium activity ratio of K (AR_e^K)

The AR_e^K values are the status of immediately available K (Taiwo et al., 2010) and its pattern under three different cropping systems (Tables 3 and 4) shows that the AR_e^K value was high in paddy-paddy cropping system followed by banana and paddy-pulse. Equilibrium activity ratio of the soils studied were ranged from 5 to 10 × 10^3 $(mol/lit)^{0.5}$ which was low but higher than the suggested minimum of 5 × 10^{-4} $(mol\ L^{-1})^{½}$ by Beckett and Webster (1971). From that it can be theorized that K was preferentially held at inner positions of the clay particles because the AR_e^K values are between than 0.01 to 0.001 moles lit^{-1} (Schouwenburg and Schuffelen, 1963). The high amount of clay content (> 40%) in soil banana cropping system increases the K fixation and thereby reduced the AR_e^K values (Sharma and Mishra, 1989). The higher value (9.2 × 10^3 $(mol/lit)^{0.5}$) of labile K (AR_e^K) in paddy-paddy cropping system might be due to greater K release into soil solution because these soils contain comparatively low amount of exchangeable calcium and magnesium values which intern increase the AR_e^K values.

K held at specific sites (K_X)

K_X indicates the number of sites showing specific affinity for K, and it was higher in paddy-pulse cropping system (0.29 c mol (p+)/kg). Even though soils of paddy-pulse cropping system contain less clay content, one of the reasons for its higher Kx value is because of its organic matter content (0.47%). The lower amount of labile K (0.41 c mol (p+)/kg) in soils of banana cropping system is due to the more retention of K because of the presence of montmorillonite nature of clay. The K_X value of paddy-paddy cropping system exceeds 50% of K_L, probably because of percolative water regime as well as because of biogenic potassium uptake (Zharikova, 2001).

Labile K (K_L)

The labile K represents the amount of K capable of ion

Table 3. Different fraction of potassium under three different cropping system.

Cropping system	Statistical parameters	K Fractions (ppm)					
		H2O sol K	Kex	Boiling 1N HNO_3 K	Knex	Lattice K	Total K
Paddy-paddy	Mean	22.1	70.4	810.9	740.6	2776.6	3517. 1
	SD	3.6	11.4	143.2	151.9	681.8	620.1
	CV	**16.2**	**16.2**	**17.5**	**20.3**	**27.1**	**18.8**
Banana	Mean	24.7	78.5	780.2	701.8	3336.6	4038.0
	SD	3.1	9.9	95.8	95.5	915.2	923.8
	CV	**12.7**	**12.7**	**12.3**	**13.6**	**27.4**	**22.9**
Paddy-pulses	Mean	26.1	83.1	818.7	735.6	5309.3	6044.9
	SD	4.6	14.5	117.8	118.4	544.8	570.9
	CV	**17.5**	**17.5**	**14.3**	**15.9**	**13.2**	**11.5**

Table 4. Quantity-intensity parameters under three different cropping system.

Soil unit	ARe^K x10^3 $(mol/lit)^{0.5}$	K_X	K_L	ΔK^0	PBC^k	Kex	Ex.Ca	Ex.Mg	K Fixed (%)	Clay (%)
		c mol (p+)/kg								
Paddy-paddy	9.20	0.23	0.44	0.15	16.81	2.26	15.7	7.35	82.94	38.8
Banana	7.40	0.24	0.41	0.18	24.32	1.74	17.0	11.4	84.32	41.2
Paddy-pulse	5.50	0.29	0.49	0.25	45.67	1.85	17.6	9.20	73.30	24.2
SD	1.9	0.0	0.0	0.1	15.0	0.3	1.0	2.0	6.0	9.2

exchange during the equilibrium between soil solids and solution. The total amount of K in the labile pool ranged from 0.41 to 0.49 c mol (p+)/kg in soil. The higher levels of labile K indicate that higher amount of loosely bonded K^+ ions present in exchangeable site. The lower amount of labile K in soils of banana cropping system (0.41 c mol (p+)/kg) than others is due to the more retention of K because of the presence of montmorillonite nature of clay minerals. In all the cropping system, K_L values were lower than the exchangeable K (Kex) (1.74 to 2.26 c mol (p+)/kg) indicating there by that potassium of these soils should be released basically via exchange processes than solubility or diffusion. This implies that any addition of K in these soils could result a significant partition of K to the soil exchangeable portion and tend to have less capacity to fix potassium (Poudel and west, 2005).

ΔK^0

Traditionally, change in solution K (ΔK) has been attributed to the change in the amount of K adsorbed by or released from the soil solid phase. In paddy-pulse cropping system, the ΔK^0 generally became more negative (0.25 c mol (p+)/kg) because there was a greater release of soil K into soil solution resulting in large pool of labile K. The result indicates the soil had high power of K release compared to other soils. The lower value in paddy-paddy cropping system (0.15 c mol (p+)/kg) indicates it had a strong ability to absorb K. The contents of both easily exchangeable and labile potassium (ΔK^0 and $-K_L$, respectively) are also high in the paddy-pulse cropping system.

Potential buffering capacity (PBC^K)

Potential buffering capacity is a measure of the ability of a soil to maintain a given K and this suggest that in higher range the soils would be able to maintain relatively higher activity ratio of the soil K when there is any K stress, whereas the lower value would be susceptible to rapid changes in the AR_e^K, signifying frequent K fertilization (Wang et al., 2004). It was ranged from 16.81 c mol (p+)/kg in paddy-paddy cropping system to 45.67 c mol (p+)/kg in paddy-pulse cropping system. Zharikova (2004) divided the values of PBC^k into very low (20 cmol kg^{-1} $(molL^{-1})$ ½) to high (> 200 cmol kg^{-1} $(molL^{-1})$ ½). The high soil PBC^k value is an indication of good K availability, whereas a low PBC^k soil would suggest a need for frequent K fertilizer application (LeRoux and Sumner, 1968). Consequently this study concluded that application of K fertilizer is necessary in paddy followed by paddy cropping system in split levels. In addition it was found that there is no relationship between soil clay content and PBC^K. Even though the paddy-paddy

Table. 5. Correlation between different soil Q/I characteristics.

Soil characteristics	ARe^K	K_x	K_L	ΔK^0	PBC^K
K_x	0.411				
K_L	0.478	0.602			
ΔK^0	-0.922*	-0.035	0.777		
PBC^K	0.979**	-0.317	0.557	0.946*	
WS-K	0.069	-0.130	-0.131	-0.061	-0.112
Ex. K	0.631	-0.210	0.392	0.655	0.751
Clay	-0.549	0.694	0.214	-0.279	0.542
Sand	0.602	-0.570	-0.062	0.371	-0.576
pH	-0.187	0.517	0.384	0.074	-0.004
OC %	0.705	-0.200	0.377	0.629	0.682
CEC	0.491	0.914*	0.434	-0.177	0.476
Ca	-0.223	0.637	0.767	0.458	0.231
$CaCO_3$	-0.240	0.673	0.874	0.563	0.272

cropping system has registered high clay content (38.8%) the PBC^K was found low (16.81 c mol (p+)/kg). It might be because of the influence organic matter content. Organic matter may possess a lower surface area than previously thought, and the interaction between organic matter and inorganic clays tends to reduce the surface area of the latter (Pennell et al., 1995). This implies that it is not the available total area of exchange surface that controls the PBC^K, as originally suggested by Beckett and Nafady (1967, 1968). Rather, it is the available total area of high K-affinity surfaces that determines the PBC^K in the soil.

Correlation

There was a positive correlation between AR_e^K with exchangeable K (0.631) and water soluble K (0.069) (Das et al., 1993). It is because of increased available potassium saturation gives rise to increase in AR_e^K. The same time AR_e^K had significant negative correlation with Ca (-0.223) and $CaCO_3$ (-0.240) (Table 5). It is because of the fact that higher Ca and $CaCO_3$ activity decreased the activity of K in soil, thereby decreasing AR_e^K. The Kx value of soil had positive correlation with clay content (0.694) and negative correlation with sand content of soil (-0.570). Soils with higher clay content have higher exchange surface offered a selective or specific binding sites for K compared to other soils which were light in texture (Dutta and Joshi, 1990). K_L was positively correlated with soil organic carbon (0.377), exchangeable potassium (0.392) and clay (0.214) (Scott, 1968).

The PBC of different soils is roughly proportional to CEC which is seen from the small positive (0.476) value to CEC, and clay (0.542) which increases as the K–depletion is prolonged. Beckett and Nafady (1968) pointed out that the buffering capacity of a soil depends primarily on the surface area available for ion exchange and, to a lower degree, on the character and charge density of soil surfaces. Since major exchange surfaces in soils include inorganic clays and organic humic substances, it is expected that soils which receive more crop residues would exhibit higher PBC values than others. Correlation showed that whenever exchangeable sites are more in soils, intendancy and capability of them for K adsorption is more. As result, potential buffering capacity of soil also will increase.

Conclusion

The present study revealed that cropping systems are significantly affecting most of the soil properties and intern affecting the availability of soil potassium in the study area. Paddy followed by pulse cropping system had better potassium availability compared to others because of high biomass return from the pulse crop which facilitates high labile potassium. In addition the PBC^K of paddy followed pulse cropping system suggested less frequent application potassium fertilizer compared to paddy-paddy cropping system has low PBC^K require frequent application of potassium fertilizer. So apart from amount of potassium present in the soil, the availability of potassium to plants is mostly influenced by the soil properties. So identifying, quantifying and monitoring these properties and its changes are necessary to prevent soil degradation and to improve soil and land management. So estimation of available potassium by quantity intensity parameters will give better estimation of plant available potassium and its causes.

Conflict of Interest

The authors have not declared any conflict of interest.

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Review

Approaches and methods used in analyzing compliance with fishery regulations

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This paper reviews existing literature on analytical framework and methodological approaches to study noncompliance with fishery regulations. The causes of the problem of illegal fishing and noncompliance with fishery regulations are analysed and reasons behind the failure of current management regimes to promote sustainable management and exploitation of fishery are investigated. Several deterrence models have been developed to study this problem in static and dynamic decision frameworks. The shortcomings of static model versus dynamic are specified and the static model found to be limited. Dynamic model on the other hand, consider allocation of resources overtime and hence account for the effect of discount future benefits and the repeated nature of the crime and detection. Extensions of both models are also discussed in details. Results from theoretical models are tested empirically using survey data. Different econometric models have been specified to conduct empirical deterrence analysis on determinants and extent of the decision to violate. Intensity of violation and frequency of violation as measures of violation rate are compared. Non-compliance determinants variables include socio-economic attributes, deterrence, and social and legitimacy factors. Empirical studies estimate both violation rate and extent of violation. Deep understanding of how fishers behave and their reaction to regulations is very crucial to tackle the problem and help policy makers to formulate policies accordingly.

Key words: compliance, dynamics, fishery, fisher's behavior, inconstant probability, management, static.

INTRODUCTION

Future viability and benefits from fisheries have been negatively affected by the practicing of illegal fishing and noncompliance with fishery regulations. This has become a global problem, presenting serious threats to fish stock rebuilding (MEA, 2005; Sumaila et al., 2006). Serious decline in inland water stocks has been reported in developing countries; the number of un-harvested inland fish stocks has been steadily decreasing; from 40% in 1990 to 23% in 2004 (MED, 2005). Despite the existence of fisheries management policies, fisheries in developing countries are encountering a serious threat of over-fishing (Allan et al., 2005). Particularly, African tropical fresh water lakes are believed to be fully exploited and even over-fished in many parts (MEA, 2005). This presents a big threat to the capacity of these fishery ecosystems to continue providing for the livelihood of many communities that are highly dependent on them. Many

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factors are believed to contribute to this problem; among them are difficulties in enforcing regulations and inefficient institutions to handle the problem.

The practice of illegal fishing leads to stock collapse and fishery closure. For instance the use of small mesh sizes removes small fish before they can finish their life span and hence limits the opportunity for reproduction (Clark, 1990). This calls for urgent action to reduce noncompliance with fishery regulations. Noncompliance with regulations also contributes to lack of accurate statistics about the status and potential role of fishery resources (World Fish Centre, 2003). It is believed that the actual catch from inland water is 2 to 3 times larger than what is reported in official statistics due to illegal fishing and noncompliance with regulation (FA0, 2003; Welcome et al., 2001). Failure to account for illegal fishing therefore gives incorrect estimates of the resource and misleads fishery policy formulation and management decisions based on this information (Atta-mills et al., 2004; Hatcher and Pascoe, 2006). Achieving compliance with fishery regulations is accordingly becoming an issue of serious concern to managers and policy makers worldwide.

Despite its major role in the failure of fishery management, illegal fishing has received little attention in the past (Sutinen and Hennessey, 1986; Anderson, 1989), particularly in the field of fishery economics and policy making studies (Charles et al., 1999). However, illegal fishing behaviour has gained considerable attention recently in both fields because of the increasing recognition of the damage and loss associated with this problem (Sumaila et al., 2006). Many studies have argued that fishery regulation failure is attributed to costly and weak enforcement and monitoring of compliance with laws and regulations, in addition to tolerance to corruption and cheating (Charles et al., 1999; MEA, 2005). The lack of effective enforcement and monitoring mechanisms also encourages corruption and creates a good environment for illegal fishing (Eggert and Lokina, 2010). Thus, fisheries' sustainability has been far more difficult to achieve although many efforts have been made to rebuild fish stocks. For instance, official limits on the size of fishing nets and harvests, as well as other management measures, have been used to help stock recovery and reduce over-fishing and consequently illegal fishing (FAO, 2003).

Many theoretical and empirical studies have been conducted to analyse reasons for noncompliance with fishery regulations by adapting different static, dynamic and policy oriented approaches. Different types of noncompliance with fishery regulations are cited in the literature such as: fishing in closed areas, catching with non-prescribed mesh size or fishing in a prohibited zone or any behaviour against the law (Furlong, 1991; Charles et al., 1999; Hatcher et al., 2000; Srinivasa, 2005; Sumaila et al., 2006; Akpalu, 2008a). Therefore good understanding of the motives for illegal fishing is necessary to help policy makers and managers design appropriate intervention measures that would improve effectiveness and efficiency of enforcement of regulations and ensures sustainability of the resource use. This can be achieved by reviewing the existing analytical frameworks and methodological approaches to study noncompliance with regulations worldwide. Next is a review of the approaches for analysis of determinants of noncompliance with fishery regulations under static and dynamic formulations, followed by empirical approaches to analyse factors influencing violation rate.

APPROACHES AND METHODS USED IN COMPLIANCE ANALYSIS

Noncompliance with fishery regulations has important implications for the welfare of fishing communities. The framework schema of Figure 1 is adapted from Sutinen and Kuperan (1999) and extended to include determinants of noncompliance with fishery regulations in dynamic approaches. The various components of the compliance modelling framework presented in Figure 1 are subsequently reviewed.

Static approach to study noncompliance with fishery regulations

Becker (1968) was the first who studded the behaviour of law breakers. He developed the first theoretical deterrence model to analyse the choice between legal and illegal options for a criminal to maximise his/her utility from illegal activities. Static deterrence models assume that a violator faces a single time period decision problem of maximising expected utility from illegal fishing, that is, the choice of either to follow fishery regulations or not. The model's implicit assumption is that a fisher has a fixed amount of time to be allocated to both legal and illegal fishing. The gain from violation is not guaranteed because of the probability of enforcement leading to detection and consequent punishment. This motivated the use of expected utility in deterrence models.

In the static context, the main determinants of the choice of an illegal option are the profit that an offender gains from the illegal practice and the low probability of detection combined with a small fine (punishment). Many studies have followed Becker's model of the economics of crime and punishment under static formulations (Furlong, 1991; Kuperan and Sutinen, 1998; Charles et al., 1999; Sutinen and Kuperan, 1999; Hatcher and Gordon, 2005; Sumaila et al., 2006).

The high profit that fishers gain by violating national laws is the main incentive for noncompliance (Charles et al., 1999; Hatcher and Gordon, 2005; Sumaila et al., 2006; King and Sutinen, 2010). Sumaila et al. (2006) estimated gains from illegal fishing to amount to about 24

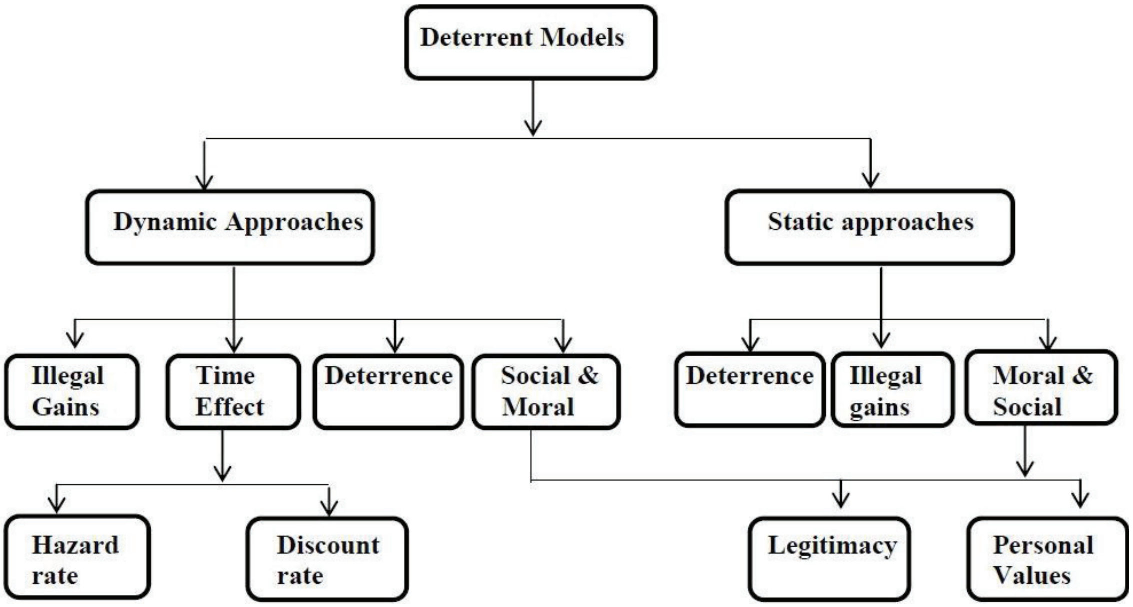

Figure 1. Approaches and factors considered in analyses of determinants of noncompliance with fishery regulations. Source: Modified/extended from Sutinen and Kuperan (1999).

times the fine paid as a punishment. King and Sutinen (2010) estimated it to be 5 times the penalty paid. The recommendation from the pure deterrence model is that detection should be made eminent and penalties should be high to offset gains from violation. On the other hand, Furlong (1991) conducted a self-reported survey among Canadian fishers and found that fishers are more sensitive to increases in likelihood of detection than increases in penalties.

Static model extensions and limitations

Some studies have argued that the policies suggested by the purely traditional deterrence model cannot be applied to real life and also do not give a complete explanation of compliant behaviour. One major extension of the static model is the attempt by Charles et al. (1999) and subsequently Sumaila et al. (2006) to consider effects of avoidance activities (any mechanism fisher use to avoid detection. for instance in Sudan fisher tie the illegal net to a big stone and let it think deep when regulator office shows, and try to recover it later, when feeling secure). Charles et al. (1999) applied a micro-economic static model to determine the level of enforcement a policy maker should allocate in presence of evasion activities for optimal management of a fishery. The study showed that fishers react to enforcement by focusing more on avoidance behaviour than reducing violation rate. This means that improvement of law enforcement in fisheries needs to be grounded in good understanding of avoidance behaviour.

Kuperan and Sutinen (1998) pointed out that profit from and cost of illegal behaviour, are not enough to describe fishers' decisions. Based on this last argument, some studies have extended the traditional deterrence model to account for moral, social and legitimate dimensions, known as normative factors that are believed to be important in determining violation among fishers (Kuperan, Sutinen, 1998; Hatcher et al., 2000; Akpalu, 2008a,b; Eggert and Lokina, 2010; Abusin and Hassan, 2014). These factors measure a fisher's behaviour and beliefs towards his peer violators and how that influences his values. It also measures a fisher's perception of the violation itself and his perception of regulations as effective or fair.

The influences of social and moral factors have been accounted for in theoretical and empirical applications to examine their impact on compliance. Results of empirical investigations revealed that such factors can have either positive or negative influences. Positive influence implies supporting or encouraging compliance and considering violation of regulations to be bad behaviour. On the other hand, negative influence result from the perception that violation is not a wrong attitude making noncompliance dominant and a normal part of their regular job. However, the normative effect was found to be smaller in comparison to the deterrence effect in a study by Hatcher and Gordon (2005).

One of the shortcomings of the static model is the assumption that two different agents have an equal set of constraints and the only factor that differentiates them is their affinity for taking risks. This distinction was argued to be immeasurable by Davis (1988), which makes the static model limited. The static model also does not account for the effect of discounting future benefits, that is, discount rates (Davis, 1988), which proved to be of significance especially among poor fishers (Akpalu, 2008a/2009). Static models by nature cannot measure the optimal rate of violation over time.

Dynamic compliance modelling approaches

Dynamic models have been developed to consider allocation of resources over time (that is, to study inter-temporal allocation decisions). In dynamic formulations, the fisher will be optimising his gains over time until he gets caught, because the crime is committed repeatedly. The two periods dynamic deterrence model (DDM) as developed by Davis (1988), postulates that violators seek to maximise expected discounted profit over both periods. In the first period, offenders gain from illegal activities until the time they get caught and pay a fine. Violators will then comply and engage only in legal activities thereafter, concluding the model' second period.

Justifications for using a dynamic model for illegal fishing analysis are motivated by many legitimate considerations, most important of which are the repeated nature of the crime (that is, violation occurs repeatedly), the change in the danger of getting caught over time (detection time evolves), and differences in fishers' time preference towards the future (discount rates). These factors imply a temporal objective of not analysing single period gains but rather maximising the sum of the stream of net benefits over time (at least over two periods). It also motivates inclusion of evasion efforts with the aim of prolonging the time before getting caught.

The difference in skippers' time preference is also a very important factor in deterrence analysis since it gives information about their patience (choice between consumption now or in the future). A study by Akpalu (2008a) found impatient (high discount rate) fishers have higher violation rates. It also provides information on skippers' poverty levels, given the fact that that poorer fishers are found to have higher discount rates.

Conclusions from the current dynamic model with constant probability of detection reveal that noncompliance is more likely to be deterred by increasing the probability of being caught than by raising the fine (Davis, 1988; Akpalu, 2008a; Leung 1991). The DDM adds the effect of the discount rate and modifies probability of detection from being subjective in the static model to a conditional probability that explains the fact that the profit from violation is conditional on the violator's survival.

Violation rates in DDM have been mainly specified only as "intensity of violation" (Akpalu, 2008a) whereas "frequency of violation" has been used only in static deterrence models (Furlong, 1991; Sutinen and Kuperan, 1999; Eggert and Lokina, 2010).

Dynamic compliance modelling extensions

As explained by Abusin et al. (2012). The DDM has been extended in three ways as follows:

Introduction of time as a random variable into the model to split the two periods

Although the DDM calculates profits from violation into two periods, namely, before and after getting caught, all previous literature using this model formulates the choice problem to be optimised over finite time horizon. The transition between the two periods is therefore not clear. Therefore the time of detection is introduced as a random variable that defines the end of the first period and the start of the second period, which then extends to infinity in period two. Splitting the two periods would then result in an easier distinction between the violation and compliance periods within the time horizon.

Frequency instead of intensity as measure of violation rate

Implementing frequency rather than intensity in the dynamic deterrence model due to four factors: First, intensity of violation may fit developed countries but is highly unlikely to work well in developing countries where property rights are less well defined and it is relatively easier for fishers to escape being caught. Second, by not employing frequency as a measure of violation rate, one misses the opportunity of capturing the direct link between violation rates and opportune time periods for illegal fishing (seasonality). This is due to the fact that, during productive months the quantities of small fish are high, which encourages illegal fishing compared to months of no breeding. Thirdly, the use of frequency also helps to classify fishers into categories of violators, a typology that will help policy makers and managers design policy measures and instruments suited for each group (Sutinen and Kuperan, 1999) for more details). Finally illegal catches are not sold on formal fishing markets, but are rather concealed and sold out of monitors' notice, outside formal channels.

Probability of detection depends on time

Standard DDM formulations have been limited by the case of probability of detection that does not depend on time assumptions (Akpalu, 2008a; Davis, 1988, Lueng, 1991). The model extended to allow for non-constancy (depend on time) of probability of detection by employing the Cox proportional hazard function, which defines probability of detection to be a function of the multiple of two terms, a constant individual characteristics function and a time-variant hazard function.

Empirical studies based on static and dynamic approaches

To design more effective deterrence mechanisms, more research is needed to gain better understanding of fishers' noncompliant behaviour. Illegal fishing, however, is difficult to observe, and information about it cannot be obtained from government and fisheries departments' statistics but is mostly based on surveys and interviews King and Sutinen (2010). Generally, there is little published research on empirical regulatory compliance. Some empirical studies of noncompliance with fishery regulations have been conducted in many parts of the world, generating results that differ across countries.

Measuring violation rate and extent of violation

Some studies analysed the extent of violation by looking at how frequently fishers violate (Furlong, 1991; Sutinen and Kuperan, 1999; Eggert and Lokina, 2010; King and Sutinen, 2010; Abusin and Hassan, 2014) and hence provide information on violators' degrees of violation. Studies that classified violators according to their violation rate believe that classification will help managers understand each group and hence formulate policy accordingly. Frequency of violation (as measure of violation rate) has been measured in different ways in studies conducted in different countries. Both studies of fishers in Lake Victoria (Tanzania) and Jebel Aulia reservoir (Sudan) measured violation of minimum mesh size regulations by the number of months when such illegal fishing was practiced within the year (Eggert, 2010; Abusin, 2014). In these studies, the surveyed fishers were asked about the type of net they own/use. Those who indicated that they own only legal net sizes were classified as non-violators and those who only owned illegal nets as chronic violators. Occasional violators are those fishers who owned both legal and illegal nets. Violation rates were measured by asking fishers about how frequently they have used an illegal size net in the past year in number of months (where zero stand for non-violator and 12 for chronic violator).

Furlong (1991) used proportion of violation (proportion of regulatory regimes violated) in a typical fishing trip in a specific season as a measure of frequency of violation. Hatcher and Gordon (2005) measured violation rate as the percentage of landings over quota in the previous year, whereas Kuperan and Sutinen (1998) measured violation rate by the number of days a fisher has fished in a prohibited zone.

In analysing factors affecting compliance with output restrictions (quotas) among fishers in the United Kingdom, Hatcher et al. (2000) measured violation rate by a fisher's decision to violate or comply. On the other hand, in a dynamic formulation Akpalu (2008a) measured the rate of violation of fishers in Ghana by looking at the intensity of violation, calculated as the value of juvenile fish in an illegal catch per day averaged over the past week's catch.

Hatcher et al. (2000), Kuperan and Sutinen (1998) and Akpalu (2008a) all investigated fishers' decision on whether to violate or comply using binary Probit models. Kuperan and Sutinen (1998); Akpalu (2008a) subsequently used the Tobit model. Their logic is to use a simultaneous probit-tobit method. The probit hypothesized, a "yes" violation occurs when the unobserved latent variable exceeds a threshold level of zero, and a "no" violation occurs otherwise. Then, violation group are explained by the Tobit model; violations are observed when an unobserved "propensity to violate, exceeds 0. When the propensity to violate is positive, actual violations equal the propensity to violate; when the propensity to violate is negative, a zero violation is observed. As some fishers do not violate for reasons other than their moral standing, like high cost of illegal nets.

The number of violators also differs across countries. For example, Eggert and Lokina (2010) found that about half of the surveyed fishers in Tanzania were violators. On the other hand, Furlong (1991) surveys reported about two thirds of fishers violate while Kuperan and Sutinen (1998) reported 75% violation rates among fishers in Malaysia. Generally, non-violators are found to be significant in numbers in many countries which support the positive influence of normative factors (Furlong, 1991; Kuperan and Sutinen, 1998; Sutinen and Kuperan, 1999; Eggert and Lokina, 2010; King and Sutinen, 2010).

Econometrics specification of violation to fishery regulations

Different econometric models have been employed to suit the different ways in which violation rates are measured. Eggert and Lokina (2010); Hatcher and Gordon (2005) and Abusin and Hassan (2014) used ordered Probit models to analyse determinants of violation with fishery regulation because of the ordered nature of the latent dependent variable. In these studies, the ordered likelihood function was used to predict changes in the probability of violation in response to changes in considered determining factors. Eggert and Lokina (2010), further measured the extent of violation within one fishers' typology (occasional violators) by truncating the data to exclude both no-violators and chronic violators. However, truncating creates data problems since it limits information and changes the sample. Abusin and Hassan (2014) measured extent of violation within violators only (occasional and chronic violators) by employing zero-truncated negative binomial model (ZTNB).

Furlong (1991), when conducted a survey of Canadian

Table 1. Different estimations of POD.

Estimation of POD	Econometric estimation	Relevant studies
exogenously determined	Y= X β+μ* POD is not included in X, it is estimated separately. But variables that determine POD (enforcement and avoidance activity) are included in X	Akpalu, 2008
Joint estimation	X include a variable say z that estimates POD jointly Z= probability of detection, the probability of an arrest given detection, the probability of being taken to court given arrest, and the probability of being found guilty given that the fisher is taken to court	Hatcher and Gordon (2005), Furlong (1991); Kuperan and Sutinen (1998); Hatcher et al. (2000)
As one variable	X includes a variable measuring POD.	Abusin and Hassan, (2014) Sutenin and Kuperan 1999

*Y is independent variable measuring violation, *X is a vector includes all determinants of violation, *μ is the error term, POD: probability of detection.

fishers, found some personal characteristics such as age, income from fishing and other employment are important in compliance analysis. This is confirmed by Sutinen and Gauvin (1989) who found, in their estimation of compliance in the lobster fishery of Massachusetts, that the effect of all three (that is, age, experience and fishing as source of income) on noncompliance to be statistically significant.

There has been a lot of debate in literature about the probability of detection and the way it enters the model and how to measure it. Probabilities of detection are either estimated separately or jointly in an econometric model as explained by Kuperan and Sutinen (1998). They considered probability of detection to be a salient issue of compliance and hence better understanding of how this variable behaves is very important. Probability of detection itself is the joint estimation of probabilities, which include probability of detection, the probability of an arrest given detection, the probability of being taken to court given arrest, and the probability of being found guilty given that the fisher is taken to court (Furlong, 1991; Kuperan and Sutinen, 1998; Sutinen and Kuperan, 1999; Hatcher et al., 2000; Akpalu, 2008; Eggert and Lokina, 2010). This implies that probability of detection by itself is a function of a number of factors. Kuperan and Sutinen (1998) suggested measuring the overall probability of detection variable in three different ways. They firstly proposed an exogenously determined probability of detection, which makes the overall probability of detection not included in the main violation model directly. Instead, exogenous determinants such as enforcement and avoidance activity enter the deterrence model.

The second way is to jointly estimate probability of detection as part of the violation model. For example, the overall probability of detection is treated as an explanatory variable and used in the main deterrence function. In a study by Furlong (1991), the probability of detection was jointly determined in the model and divided into four stages, probability of detection, prosecution, conviction and punishment in the function. The mentioned study encountered problems of both co-linearity and simultaneity due to the joint estimation of the overall probability of detection and violation function.

The third method entails an estimation of the probability of detection by one variable measuring the number of times the violator has been seen by the police landing an illegal catch or using unauthorised gear or by the perceptions of fishers about the chances of detection as increasing or decreasing. In a study by Hatcher and Gordon (2005), the probability of detection is measured by including the subjective probabilities as a regressor in the violation function. Table 1 explains the three possibilities of estimation by simple econometrics equation.

Almost all these studies (except Hatcher and Gordon, 2005) faced the problem of endogenity due to reasons explained in the preceding paragraphs (Sutinen and Gauvin, 1989; Furlong, 1991; Kuperan and Sutinen, 1998; Hatcher et al., 2000; Akpalu, 2008a; Eggert and Lokina, 2010). Hatcher and Gordon (2005) argued that the reason for not having endogenity is due to the fact that the violation rate and probabilities of detections were not estimated in the same time period (fishers were asked about their previous year's violations). This means correlation between violation and probability of detection is not contemporaneous, which made it still consistent based on the assumption that the perceived risk has not changed significantly within the time under consideration. Hence, the simultaneity problem falls away.

Kuperan and Sutinen (1998) argued that there is an inconsistency in the performance of variables measuring the probability of detection. This inconsistency stems from the fact that the probabilities are subjective and are difficult to analyse because of the lack of knowledge about the factors affecting their generation. Furthermore, the respondents may not understand the concept of probabilities.

Another problem related to compliance analysis is the strong correlation between variables measuring normative factors. The close link and interdependency between social, moral and legitimate factors usually create this type of problem (Hatcher et al., 2000; Akpalu, 2008a, b; Hatcher and Gordon, 2005; Abusin and Hassan, 2014).

Determinants non-compliance with fishery regulations

Some factors in the empirical model cannot be measured directly and hence proxies are used. For instance, probability of detection is measured by asking respondents about their perception of probability of detection, ranking on a five-point scale ranging from very high to very low (Hatcher et al., 2000). Akpalu (2008a) for example, measured the discount rate using experimental choice design. The skippers were asked to choose between two hypothetical fishery projects. Project A that supposed to increase skipper's income once by an amount at the end of the month in which the data were collected, and Project B which increased it once by twice the amount in six months' time. After the choice was made, the respondent was asked to indicate the value for Project B that would make him indifferent between the two projects. Depending on the fisher's choice, the discount rate was calculated as the amount quoted by the skipper over the amount that the project offered.

Enforcement is measured by asking fishers whether they perceive the current enforcement to be adequate and fair (Sutinen and Kuperan, 1999). The moral variables refer to the fisher's beliefs about violation given the fact that some people are impressionable and act according to others' standards (Tyran and Feld, 2002). Moral variables are also measured by the fisher's moral standing in the community, that is, when fishers are keen about their moral standing in the fishing community and how it might psychologically impact them (Sumaila et al., 2006). Moral aspects such as acceptance of bribes by police when violators are arrested have been found to be very significant in Tanzanian fisheries, where corruption and poverty make it difficult for fishers to comply with regulations (Eggert and Lokina, 2010).

The different measurement of the social and moral factors as explained above makes the effect of normative factors differ or may have both negative and positive effects on compliance with fishery regulations. The measure of the normative factors that one should choose in the model depends on the current fisheries environment in terms of the social relations within the fishing community under study and how fishers value violation and the way regulations are enforced, considering their fairness and effectiveness (Abusin and Hassan, 2014).

Empirical results from compliance studies are different. Some papers found that to deter violation, deterrent variables are the most important factors (Hatcher and Gordon, 2005) while others found both deterrence and non-monetary variables such as social and moral standards to be equally important (Kuperan and Sutinen, 1998; Hatcher et al., 2000; Akpalu, 2008; Eggert and Lokina, 2010; Abusin and Hassan, 2014). For instance, Eggert and Lokina (2010) tested for exclusion of either the deterrence or normative factors from the model and the results showed that both deterrence and normative factors are very important in explaining violation behaviour. It may also happen that the regulation officer could be socially excluded from the community in his or her efforts to enforce the regulations. This creates an incentive for a regulator to accept bribes in order to continue keeping social ties with his community and avoid shame-based sanction.

Empirical studies generally suffer from data accuracy and difficulties in obtaining quality and reliable information. This may refer to misreporting, not understanding concepts and giving misleading answers since reporting own violation is not an easy task. The concepts of probabilities and perceptions are new to fishers, who are most likely to have only primary education. In addition, some variables in compliance analysis cannot be measured directly; hence proxies are used, which may also have some effect on model parameters' estimates.

Management regimes associated with compliance with fishery regulation

There is a strong view in the empirical literature that for compliance to be applied in a proper way, a good management system should be designed and put into effect since the management regime has a direct influence on compliance (Hardin, 1968). Quite divergent view on which management system is most effective for better compliance with regulations exists in literature. For instance, many authors agree that the most suitable management system to ensure compliance is a properly implemented co-management system (Ostrom, 1990; Jentoft, 2000; Eggert and Ellegård, 2003; Hanna, 2003; Nilsen, 2003, Nielsen and Mathiesen, 2003). Jentoft (2000) attributed perfect compliance under this regime to the improvement of the legitimacy of fisheries management system such as sharing decisions, creating a feeling of fairness and justice and greater understanding of regulations. He further indicated, though, that if co-management is not handled carefully it may lead to loss of legitimacy. Nilsen (2003) ascribed the success of compliance to the fact that managers and decision makers lack knowledge about the factors that affect compliance and legitimacy within the fishers' communities. Legitimacy is defined as the perception of the fishers about regulations. He concluded that if there are large numbers of fishers involved in regulation formulation, legitimacy is more easily achieved. A survey of Swedish commercial fishers on regulation compliance (Eggert and Ellegård, 2003) found that the majority of Swedish fishers are in favour of co-management on a regional basis.

Hatcher et al. (2000), on the other hand, argued that co-management as a fishery management system is unlikely to result in high levels of compliance as long as output controls are concerned. They pointed out that it is not co-management *per se* but the flexibility in the management system that brings about efficient fishery management in many regulatory regimes. The management approaches that are currently applied in most developing countries are based on centralised government intervention and have proven inadequate to deal with the issue of compliance with fisheries regulations (Sterner, 2000).

CONCLUSION

Fisheries are experiencing serious over-harvesting stress and often consequent collapse of fish resource stocks due to many market and policy failure situations such as poor management and open access conditions. The stress is even worsened by the practice of illegal fishing and noncompliance with regulations, which has serious negative consequences on the resource. Accordingly, policy makers need to evaluate the extent of violation, understand and give more attention to fishers'behaviour and reasons for not complying with regulations in order to achieve an adequate level of compliance and save this important renewable source from collapse.

This paper review analytical framework and methodological approaches used in the literature. The static deterrence model assumes the fisher faces one-period binary decision of either to obey or violate specific regulations. This found to be limited since it ignores the dynamic nature of the detection time, the repeated nature of the crime and discounting the future benefits. It also ignores the fact that violators might get away from being detected and therefore wants to know how much money will accumulates through time from violation. This model extends to incorporate normative aspects to give a complete picture for compliance analysis.

On the other hand, the two periods dynamic deterrence model assumes that violators enjoy incremental profit in the first period from fishing illegally, get caught at random time, punished and forced to behave legally thereafter. The DDM modified to include frequency measures of violation and therefore inconstant probability of detection. Although the two periods DDM found to be the most advanced model, it suffers the limitation of not to account for recidivism which found to be very common especially among chronic violators.

Future research should not limit the applications of the modified DDM model to the fishery case but can be generalised to management and regulation of other natural resources such exploitation of common property forest, water and grazing lands and hunting of wildlife. Future research can also empirically measure inconstant probability of detection by regression analysis to test hypotheses on influences of identified determinants of probability of detection as demonstrated in medical and criminology fields applications of the Weibull proportional hazard regression model.

Empirically, determinants of noncompliance are found to be, mere deterrence factors and normative factors. Reviewing of such studies confirm the importance of both deterrence and normative factors to be accounted for when analysing compliance with fishery regulations. Introduction of such factors, advocates for co-management regime mechanism to manage the fishery.

Government intervention is crucial and important policy reforms to control the fishery from collapse. Some polices include investment in better education of fishermen, provision of alternative income and employment opportunities other than fishing especially during reproductive season, improvement of the credit market for ownership of legal net will be necessary for enhancing compliance with mesh size regulation. It is also necessary to promote community level organization and awareness campaigns among fishers about the dangers for future fish stocks of eroding small fish quantities through the use of illegal nets.

Conflict of Interest

The authors have not declared any conflict of interest.

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