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Full Length Research Paper

Climbing beans in Uganda: A perspective of smallholder farmers on their determinants, associated challenges and implications for research

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In many parts of the world including Uganda climbing beans are mostly grown in highland areas where population density is high and land is limiting. The objective of this study was to contribute to understanding the current status of the factors affecting productivity of climbing beans among smallholder farmers in Uganda. Kisoro and Kabale districts in the South West were selected for the study. Primary data was collected based on 150 households selected randomly in each district in January and June, 2014. In both districts, climbing beans was ranked as a major crop enterprise for income (72.7%). Most of the interviewed households (84 and 92%) in Kisoro and Kabale respectively appreciated that the major advantage of climbing beans was suitability to areas with limited land. The study revealed practices that seem to integrate the different factors and the various components within each factor promoting ecological or interrelatedness in the production system. Lack of staking materials was ranked by the majority (Kisoro 45% and Kabale 59%) as the most important constraint. Common bean diseases (49%) and pests (45%) were highly ranked in Kisoro as compared to Kabale (13 and 22%). Labour scarcity was ranked by the majority of farmers in Kabale (49%) as compared to Kisoro (19%). Given the importance of climbing beans in the two districts, the study recommends their continued and sustainable intensification.

Key words: Common bean, cropping system, ecological, food security, highlands, legume, staking.

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is consumed worldwide as a main source of dietary protein, particularly in most Latin-American and African countries CGIAR (2018). In Eastern and Southern Africa, it is an important component of the production systems and a major source of protein (Katungi et al., 2009). In Uganda, it is an

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important staple food for the majority of farmers and consumers (Sibiko, 2012). In addition, it is an important source of income (Opio et al., 2001; Mwesigwa, 2009). Both bush and climbing beans are grown in Uganda (MAAIF (2004) as cited by Sibiko (2012). However, climbing beans were traditionally grown in the high altitude areas (the south-west highlands and the slopes of Mt. Elgon) (Ronner and Giller, 2013). But they are being promoted to other areas of the country with the introduction of the mid-altitude climbers (MACs) by the Uganda National Legumes Research Program (UNLRP) and other development partners. Currently, climbing beans constitute 20% of the total land area under bean cultivation (Ronner and Giller, 2013). Elsewhere in the world climbing beans are also grown; for example Ramaekers (2012) reported that cultivated climbing beans are found mostly in medium to high altitude (2000 to 2800 masl) regions of the Andes and Central America. In East Africa, other areas include Rwanda, Central Kenya highlands, Western Kenya, Burundi and Eastern DR Congo (Ramaekers et al., 2013; Raphaël, 2013; CGIAR, 2018). All these areas are characterized with high population density and over exploitation of land/land scarcity. Musoni et al. (2014) stated that in Rwanda climbing beans provide the best option for intensification and the production of surplus beans where arable landholdings are diminished.

Climbing beans in the South Western highland areas of Uganda were promoted in the 1990s (CIAT, 2008) as cited by Gabiri (2013). Adoption of the climbing bean technology was to cope with the problem of land degradation and land scarcity to reduce on poverty and food insecurity (Gabiri, 2013). Climbing beans are potentially high yielding, capable of giving two to four times the yield of bush varieties (Musoni et al., 2005; Katungi et al., 2009; Ramaekers et al., 2013). In Uganda, the first improved climbing bean varieties introduced from Rwanda through the East and Central African Bean Research Network (ECABREN) were officially released in 1999. These included NABE7C (Vuninkigi), NABE8C (Ngwinurare), NABE9C (Gisenyi) and NABE10C (Umubano/G2333). A number of development partners participated in dissemination of these improved climbing bean varieties such as International Center for Tropical Agriculture (CIAT) through the Pan African Bean Research Alliance (PABRA) and AFRICARE to the Uganda's southwestern and eastern highlands. In 1999, several germplasm of mid altitude climbers (MAC) were introduced from CIAT-Colombia and subjected to participatory evaluation and this resulted into release of MAC31 as NABE12C in 2003. Unlike the earlier released varieties, the mid altitude climbers were designed by CIAT to be early maturing and more heat tolerant and therefore able to grow and perform well in tropical mid-altitude growing conditions, that is, 500 to 1500 masl (Blair et al., 2007). Between 2012 and 2016, more new improved climbing bean varieties have been released and their dissemination is underway.

Unfortunately, compared to bush beans, for a very long time there have been limited deliberate efforts to document the status of the factors affecting climbing bean production in Uganda. But until recently some studies have been initiated but mainly focusing on farmers participating in the N2Africa project with a few non-N2Africa farmers. For example, Breure and Kool (2014) conducted some studies on climbing beans in Kisoro district and selected nine N2Africa farmers in Nyakabande sub-county and nine farmers without an N2Africa demonstration plot in Mutolere sub-county. To this number, they conducted additional interviews with 14 famers from Kisoro district (6 from Nyakabande, 6 from Mutolere and 2 from Busanza). The aim of their studies was to compare farmers' practices of the N2Africa farmers with the non-N2Africa farmers, in terms of inputs (especially labour, seeds and stakes) and outputs (yields). The second aim was to identify the different actors in the climbing bean value chain specifically for Kisoro. In Kabale district in the sub county of Bubaare, they interviewed: six N2Africa farmers, three Non-N2Africa farmers and an owner of a tree plantation. According to Breure and Kool (2014), N2Africa is a research project that works on putting nitrogen fixation to work for farmers growing leguminous crops in Africa and is led by Wageningen University, but implemented and conducted in 13 countries in sub-Saharan Africa, including Uganda. Similarly, Bharathwaj (2015) also conducted an N2Africa study aimed at having a better understanding of adoption constraints for climbing beans in Kashambya sub-county (Kabale district). N2Africa had provided some farmers with different climbing beans varieties and fertilizers in multiple treatments to increase productivity and 67 farmers were selected. Wytze (2015) conducted another study on a total of 32 households both in Kapchorwa district in the Eastern highlands and Kanungu district in the South-western highlands. The main objectives of his study were to describe and explain the opportunities and constraints for climbing bean cultivation by smallholder farmers in an area with good market access (Chema, eastern highlands) and in an area with poor market access (Mpungu, south-western highlands).

The objective of the current study therefore was to contribute more to understanding the current status of the factors affecting productivity of climbing beans among smallholder farmers in Uganda.

MATERIALS AND METHODS

The study area and sampling procedure

The study was conducted in Southwestern Uganda region covering Kabale and Kisoro districts in January and June, 2014. The districts were selected purposively as areas where specifically climbing beans are mostly grown in Uganda (Opio et al., 2001). Kabale altitude ranges between 1,219 m (3,999 ft) and 2,347 m (7,700 ft) above sea level. In terms of geographical co-ordinates, Kabale district is located at latitude: -1° 14' 54.85" S and longitude: 29° 59' 23.75". Kisoro is at an average of 1,980 m (6,500 ft) above sea level at latitude 01°17'S and longitude 29°48'E. This Southwestern region is characterized by a bimodal rainfall pattern, sufficient for two crops per year and intensive farming practices. The households interviewed were selected from five sub-counties in Kisoro district (Kisoro town council, Nyakinama, Nyarushiza, Nyarubuye, and Muramba) and in three sub-counties in Kabale district (Kitumba, Bubare and Kamuganguzi). All the sub-counties in Kisoro were purposively selected mainly because there are major climbing bean production areas. In Kabale, Kitumba sub-county is a major climbing bean producing area. Bubare and Kamuganguzi sub-counties were selected because the national breeding program was conducting participatory variety evaluation and seed dissemination activities. The population of interest was both men and women farmers that are involved in climbing bean production. The sampling unit was the farm household. A total of 150 households were randomly selected and interviewed in each district. The random sampling was based on guidance of the agricultural extension officers and key contact persons or farmers in those sub-counties who knew the different households involved in climbing bean production.

Data collection

Primary data were collected using a standard questionnaire using both open and close ended questions. A systems thinking perceptive was used to view various components of the agro-ecosystems as potential factors affecting climbing bean production. Primary data were collected from households including: (1) demographic variables, mainly gender of the households and household age, (2) human capital variables, mainly education level, (3) physical capital variables, including households' land and non-land assets and income sources, and (4) climbing bean factors of production with the different components of production. Considered also was more detailed information about climbing bean production and consumption, how climbing bean production systems relate to the environment, the benefits of climbing bean production, climbing bean production constraints and copping strategies.

Data processing and analysis

Data was analyzed for a total sample size of 300 respondents. Collected data was cleaned, coded and entered into Microsoft excel and then subjected to analysis using Microsoft excel and the Statistical Package for Social Scientists (SPSS) version 16. Descriptive statistics (means, frequencies, percentages) and qualitative method of data analysis were used to analyze the information gathered during the survey. Chi-square (χ^2) test was used to test for association between the different factors of production, characteristics of cropping systems, and districts from which the farmers come from. Non-parametric statistics especially, Wilcoxcon-matched paired test was also used to compare the characteristics of farmers and cropping systems between the two districts.

RESULTS

Households' socio-economic characteristics (education status, age and source of income)

Results show that the majority of household heads interviewed growing climbing beans have at least attained primary education (Kisoro 95.3%; Kabale 88.7%) (Table 1). Kisoro had high percentage (36.7%) of the household heads that had attained College or University level education as compared to Kabale district (8.7%). In terms of age, the results show that 82.2% of interviewed households from Kisoro were of 21 to 50 years. Whereas in Kabale 67.1% of the households interviewed were also in that same age range.

In the two districts, the majority of the households interviewed (Kisoro 82.7%; Kabale 94.7%) have crop farming as their main source of income. The other alternative sources of income included wages from manual work, business and salary.

Household production and consumption of climbing beans

Overall, most farmers in Kisoro district (77.3%) grow climbing beans as compared to Kabale district (48%) (Table 2). According to the interviewed households, in both districts there is no farmer who does not grow climbing beans. In terms of consumption, results show that climbing bean is an important component of the diet in both districts. In both districts more than 95% of the households eat climbing beans at least once a day (Table 3). However, the proportion of households who eat climbing beans more than once a day, that is, lunch and supper is higher in Kisoro (91.3%) compared to Kabale (68.6%). In both districts in the study area, climbing bean is ranked by the majority of interviewed households as the most important crop enterprise for diet (Table 4). It was highly ranked by more households in Kisoro (94%) compared to Kabale (69%). They mostly eat climbing beans with Irish potatoes and sweet potatoes.

Climbing beans as a source of income

Just like in the case of diet, climbing beans was ranked first by the majority of the households interviewed as a major crop enterprise for income (72.7%, n=109) in both Kisoro and Kabale districts followed by Irish potatoes (Table 5). Only a small proportion (Kisoro 23.2%; Kabale 19.9%) ranked it in the second position. Households explained that climbing bean fresh pods and dry seeds normally fetch high premium prices and have high demand and ready market.

Climbing beans production seasons

This study revealed that most farmers grow climbing beans both in the first and second seasons in both districts. A very strong association (Chi-square = 161, df = 3, p<0.001) was noted between the time of planting and the districts (that is, farmers in Kisoro start their season

Table 1. Socio economic characteristics of interviewed households in Kisoro and Kabale districts in South Western Uganda.

Parameter	Frequency of households (Kisoro)	Proportion (%)	Frequency of households (Kabale)	Proportion (%)
Education status	**n=150**		**n =150**	
Illiterate	7	4.7	17	11.3
Primary	55	36.7	94	62.7
Secondary	33	22	26	17.3
Tertially/College	34	22.7	13	8.7
University	21	14	0	0
Major source of income	**n= 150**		**n=150**	
Crop farming	124	82.7	142	94.7
Salary employment	19	12.7	6	4
Causal labour	4	2.7	1	0.7
Business/Trade	3	2	1	0.7
Age	**n=146**		**n=149**	
21-30	31	21.2	20	13.4
31-40	56	38.4	39	26.2
41-50	33	22.6	41	27.5
51-60	22	15.1	40	26.9
61-70	4	2.7	7	4.7
71-80	0	0	2	1.3

Source: Field Survey Data; at the age variable, n is less than 150 because a few individuals were reluctant to disclose their age.

Table 2. Proportion of farmers that grow climbing beans according to interviewed households in Kisoro and Kabale districts in South Western Uganda

Description	Proportion of interviewed households (%)	
	Kisoro (n=150)	Kabale (n=150)
None	0	0
Few	2	12.7
Average	2	2.7
Many	18.7	36
Most	77.3	48
No response	0	0.6

Source: Field Survey Data.

Table 3. Number of times climbing beans are eaten a day in Kisoro and Kabale districts in South Western Uganda.

No. of times beans are eaten in a day	Proportion (%) of interviewed households	
	Kisoro (n=150)	Kabale (n=150)
0	0.7	4
1	8	27.3
2	81	63.3
3	9	5.3
4	1.3	0

Source: Field Survey Data.

Table 4. Major crops for diet of the interviewed households in Kisoro and Kabale districts in South Western Uganda.

Crop ranking	Percentage of interviewed households ranking the different crops as sources of diet in Kisoro and Kabale districts						
	Climbing beans (*P. vulgaris*)	Irish potatoes (*Solanum tuberosum*)	Maize (*Zea mais*)	Sweet potatoes (*Ipomea batatus*)	Banana (*Musa* spp.)	Bush beans (*P. vulgaris*)	Sorghum (*Sorghum bicolor*)
1st Crop diet	94 (**69**)	6 (**12**)	0 (**0**)	0 (**12**)	0 (**5**)	0 (**1**)	0 (1)
2nd Crop diet	5 (**17**)	44 (**23**)	19 (**2**)	14 (**24**)	11 (**21**)	3 (**1**)	1 (12)
3rd Crop diet	1 (**5**)	18 (**29**)	28 (**5**)	27 (**23**)	9 (**2**)	2 (**10**)	11 (22)

Source: Field Survey Data; Numbers in bold represent Kabale; Only the most important crops are shown in the table; but other crops for the diet such as vegetables; pumpkins and millet were mentioned.

Table 5. Important crops for income for the interviewed households in Kisoro and Kabale districts in South Western Uganda.

Crop ranking t	Percentage of interviewed households ranking the different crops as sources of income in Kisoro and Kabale districts							
	Climbing beans	Irish potatoes	Sorghum	Sweet potatoes	Maize	Passion fruits	Banana	Bush beans
1st Crop income	72.7 (**72.7**)	26 (**12.7**)	0 (**10**)	0 (**0.7**)	1.3 (**0**)	0 (**2**)	0 (**0**)	0 (**2**)
2nd Crop income	23.3 (**19.9**)	26.7 (**28.8**)	2.7 (**17.8**)	8.7 (**25.3**)	30.7 (**2.7**)	0.7 (**1.4**)	3.3 (**0.7**)	0.7 (**2.1**)
3rd Crop income	3.5 (**3.5**)	13.8 (**35.7**)	19.3 (**16.1**)	14.5 (**14**)	26.9 (**2.8**)	0 (**0**)	11 (**2.1**)	2.1 (**21**)

Source: Field Survey Data; *Values in bold in the parentheses are for Kabale district.

much earlier in the year as compared to those in Kabale) (Table 6). The same association between time of planting and district was also noted in the second season (Chi-square =42.19, df =2, p<0.001). Results from the study further suggest that climbing bean production takes place in the whole year, with some seasons starting earlier in the year. The majority of interviewed households in Kisoro district (76.7%) reported that the best season for growing climbing beans is the first season whereas in Kabale district (91.3%) it is the second season.

Climbing bean varieties grown

NABE 12C (Large sugar bean) was the most popular improved climbing bean variety grown in the two districts (Table 7). A number of landraces (local varieties) were also grown. Eibanga lya Kagame (51%) was the most popular landrace grown in Kabale, whereas in Kisoro they were Umwizirahenda (70%) and Nyiramwigondore (70%). Households gave different reasons for preference of different varieties they were growing. In general, in both districts, the main characteristics considered were food security, climbing bean good attributes for high productivity, tolerance to common bean diseases and insect pests, environmental factors with 70 and 64%, 26 and 53%, 25 and 46%, and 22 and 33% households in Kisoro and Kabale, respectively (Table 8). The survey further revealed that in a period of five years (2009 to 2013) some varieties are no longer grown because of lack of desirable attributes for productivity, susceptibility to biotic factors, poor cooking qualities and are not adaptable to local conditions. Other varieties were also abandoned because of their characteristics for example one variety “Gihurabagabo” in the Kifumbira local dialect which means “can be threshed by men” was abandoned due to the fact that it required a lot of strength to thresh and hence could not be easily threshed by women.

Cropping systems in the climbing beans agro-ecosystem

The major cropping systems reported for climbing beans growing in Kisoro and Kabale districts

Table 6. Production seasons for climbing beans in Kisoro and Kabale districts.

Months for growing climbing beans	Proportion of households (%)	
	Kisoro	Kabale
a) In season one		
January- May	6	0
February- July	88	22
March-August	6	57.3
April- August	0	20.7
Chi-square = 161, df = 3, p<0.001		
b) In season two		
July-December	4	0
August-January	38.7	10
September-February	57.3	90
chi-square =42.19, df =2, p<0.001		
Season with the highest climbing bean yield		
First	76.7	7.3
Second	14.7	91.3
Did not give any response	8.7	1.3

Source: Field Survey Data.

Table 7. Climbing bean varieties grown by farmers in Kisoro and Kabale districts in South Western Uganda.

Name of variety	Type of variety	Seed type	% of households	
			Kabale	Kisoro
NABE12C	Improved	Large sugar bean	83	60
Eibanga lyakagame	Landrace	Small Khaki with light red	51	0
Nshemereirwe	Landrace	Large black	19	0
Nyiramwigondore	Landrace	Medium kidney red	1	70
Umwizirahenda	Landrace	Large red kidney	0	70
Nyirakanada	Landrace	Small yellow	0	22
Umwirasi	Landrace	Light orange medium	0	26
Nyirakyigufa	Landrace	Large white with spots	0	15

Source: Field Survey Data.

include crop rotation, intercropping, integrated livestock, agro-forestry and monocropping (Table 9). They explained that climbing beans are mostly rotated with Irish potatoes, sweet potatoes, peas or sorghum. A few who plant bush beans indicated they may rotate climbing beans with either maize/bush bean intercrop or sorghum/bush bean intercrop. In case of intercropping the major crops are maize, sorghum or bananas. Agro forestry involves short term maturing trees such as *Calliandra*, *Sesbania*, *Leucaena* and *Vernonia* species. Each farming household often uses more than one cropping system when growing climbing beans in both districts. Wilcoxon Matched-Paired test showed that there was no significant difference (p=0.188) in the proportion of the farming households practicing the different cropping systems. Households cited several reasons for practicing each type of cropping system while growing climbing beans include the following: crop improvement, controlling biotic factors, avoiding soil degradation, for food security, environment management, inadequate land, and agronomic practices being easily practiced.

Interviewed households were asked to give further explanations about each reason and they reported that crop improvement is realized from the different cropping systems in different ways. For example, when grown as a sole crop, climbing bean yield potential is higher due to reduced competition for nutrients. Some households explained that when climbing beans are intercropped with

Table 8. Reasons for preference and dropping of climbing bean varieties by interviewed households in Kisoro and Kabale districts in South Western Uganda.

Parameter	Explanation given by farmer(s)	% of households	
		Kabale	Kisoro
a) Reasons for preference			
Food security	Good taste and easy to cook	64	70
Environmental	Drought tolerant, tolerant to low soil fertility, improves soil fertility	33	22
Tolerance to insect pests and diseases	Not easily affected by pests and disease	46	25
Good attributes	High yielding, seed/grain size, seed color, stores for a long time	53	26
b) Reasons for dropping varieties			
Biotic factors	Susceptibility to common bean pests and diseases, rodents (rats)	1	21
Lack of acceptable attributes	Low market demand, late maturing, hard to thresh	0	37
Poor cooking qualities	takes long to cook, not palatable	0	11
Not adaptable to local conditions	Do not grow well in hard conditions	0	6

Source: Field Survey Data.

Table 9. Reasons for practicing various cropping systems in the climbing beans agro-ecosystem.

Cropping system	Percentage of households who gave different reasons for practicing various cropping systems in Kisoro and Kabale								
	Crop improvement	Agronomic practices	Control of biotic factors	Avoid soil degradation	Income	Environment management	Food security	In-adequate land	Ecological processes
Mono-cropping	56.7 (79.3)	8 (39.3)	6 (21.3)	30 (18)	3.3 (2)	2.7 (2)	2.7 (1.3)	0 (0.7)	0 (0)
Crop rotation	24 (34.7)	0 (1.33)	25 (36)	47 (51.3)	2.7 (12.7)	5 (1.3)	23 (15.3)	1 (8)	3 (1.3)
Integrated livestock and cropping systems	8 (15.3)	0 (0)	1.3 (1.3)	41.3 (72.7)	21.3 (35.3)	2.7 (0)	3.3 (0)	4 (0)	0 (0)
Agro Forestry	2 (1.3)	0 (0)	0 (0)	10 (14)	1.3 (0)	40.7 (58)	0 (0)	0 (0)	6.7 (0)
Inter-cropping	5 (7.3)	3 (5.3)	4 (6.7)	5 (12)	11 (2.7)	13 (24)	28 (2)	16 (5.3)	0 (0)

Source: Field Survey Data; Values in parentheses are for Kabale.

others crops such as maize, both crops will have improved yields in that the maize will provide the needed stakes for the climber, while the climbing beans will contribute to increased soil fertility for the maize.

All the different cropping systems were important in avoiding soil degradation also in different ways. Climbing beans and agro-forestry trees (such as *Calliandra, Sesbania*) have the ability to restore and maintain soil fertility. They fix nitrogen in the soil and the large biomass from climbing beans provides manure on decomposing. Agroforestry trees also hold the soil firmly and prevent soil erosion. Other households reasoned that climbing beans was a basis for crop rotation for other crops, since it improves soil fertility through N-fixation and biomass production that supports the successive crops. For example, cereals were mentioned to perform well after climbing beans, in a rotation. This system allows the soil to retain its fertility for one to two seasons. Whereas integrated livestock and cropping systems provide farm yard manure/mulches which improve on soil fertility.

For the case of environment management in the climbing bean agro ecosystem, they explained that trees, bananas and coffee plants act as wind breakers. In addition, the trees (agroforestry) will provide the staking material needed for the climbers. Whereas practicing crop rotation and intercropping with cereal crops (such as maize and sorghum), the stalks of the cereal crops after harvesting and live plants respectively also provide the stakes. Consequently, in this era of environmental degradation, intercropping (provides live stakes) reduces on both the cost of staking materials and on the need for conventional stakes hence reducing on deforestation.

On the other hand, control of biotic factors resulted from the fact that some cropping systems involving climbing beans may break the life cycle of pests and diseases. According to households, mono cropping of climbing beans eliminates birds and rats due to reduced congestion. Furthermore, climbing beans have the potential to suppress weeds. This is probably the reason why in Kabale fields after harvesting, climbing beans are weed free and are normally followed by field peas, a crop which is never traditionally weeded by farmers.

As for food security, it was explained that some cropping systems involving climbing beans help in diversifying for a balanced diet (get more food), hedge against total crop loss/risk of complete loss of a particular enterprise.

For in-adequate land, households explained that some systems such as intercropping allow to fully or profitably utilize the land.

Furthermore, cropping systems were important for ecological practices in the sense that different enterprises benefit from each other. For example the trees provide stakes for the beans and are also a source of fuel (fire wood) and charcoal. The tree leaves improve soil fertility and are also used as feed for animals which in turn provide manure to the soil. The climbing bean husks are also very good animal feeds as well as used for mulching in other crops. Re-use or recycling of waste as compost or mulch is assumed to reduce on external input use and improves environmental quality.

Benefits derived from planting climbing beans

According to households interviewed in Kisoro and Kabale, the major benefits from climbing beans production were economic benefits and food security (98.7 and 96.7%) and (94.7 and 92%), respectively (Table 10). They explained that economic benefits result from the fact that climbing bean pods and dry seeds fetch premium prices and have high demand and ready market. This income enables households to meet their basic needs such as payment of school fees, meeting medical bills, buying clothes and improving the general household standard of living.

For food security, they reported that climbing bean is a main source of diet/staple food, is tasty and source of protein and other nutrients especially to young children. The compatibility of climbing beans in the different cropping systems also helps in diversifying for a balanced diet (get more food) and hedge against total crop loss/risk of complete loss of a particular enterprise primarily grown by women farmers and who are involved in food preparations. Social benefits were also reported as being cultural pride, used as a gift to friends, served as a special dish on parties, also exchanged in order to get other food stuffs and that one gains popularity because it improves ones livelihood.

Other households reported that climbing bean production was a source of improving soil fertility and was environmentally friendly. This is because the large biomass decomposes giving manure, provides soil cover and the climbing beans husks are used for mulching. Institutional interaction is also realized since households have a chance to interact with agricultural research institutions such as National Agricultural Research Organisation (NARO) who provide information on improved production technologies in order to improve production and productivity. In addition, National Agricultural Advisory Services (NAADS) provides extension services and advisory roles as well as planting materials. Other development partners such as CIAT, CARE and AFRICARE were also mentioned. Ecological benefits were also reported such as the wooden old staking materials being used for firewood. The byproducts after threshing and cleaning beans are used for mulch/compost, fuel, animal feeds though others may throw them away or burn.

Major constraints in climbing bean production and coping mechanisms

Lack of staking materials was ranked by the majority (45 and 59%) of interviewed households in Kisoro and Kabale, respectively as the most important constraint in climbing bean production (Table 11). They explained that stakes are scarce and are expensive. Common bean diseases (49%) and pests (45%) were significantly ranked as major constraints in Kisoro as compared to Kabale (13 and 22%). Labour scarcity was also another important constraint. According to the results, it was a more important problem in Kabale than in Kisoro. On the other hand, social constraints included theft of stakes in the store and fires set to burn stakes by jealous people.

Table 10. Benefits from climbing bean production as mentioned by households in Kisoro and Kabale in South Western Uganda.

District	Percentage (%) of households ranking benefits from climbing bean production						
	Economic	Food security	Socially acceptable	Improves soil fertility	Environmentally friendly	Ecological	Institutional interaction
Kisoro	98.7	94.7	18.7	13.3	4	2	0
Kabale	96.7	92	13.3	20	`14	4	8

Source: Field Survey Data.

Table 11. Constraints in producing climbing beans in Kisoro and Kabale districts in South Western Uganda.

Constraints	Percentage of households ranking the different constraints	
	Kisoro	Kabale
Diseases	49	13
Pests	45	22
Lack of staking material	45	59
Social factors	39	31
Weather	24	18
In put expensive	21	11
Lack of labour	19	49
Land shortages	19	20
Poor methods of farming	19	17
Lack of funds	7	2
Lack of market	6	5
No problem	5	4
Soil degradation	4	12
Weeds	5.3	0.7
Birds	2	17
Rodent	2	17
Natural hazards	0.7	3.3
Termite	0	2.7

Source: Field Survey Data.

Weather related constraint was heavy rain which leads to rotting of stakes and strong winds that cause stakes to lodge.

In order to overcome these constraints interviewed households reported several coping mechanisms. They included the following: (i) recycling of stakes, where the same stakes are stored properly and can be used for more than two to three seasons, (ii) using strong and mature

Table 12. Merits and demerits of growing climbing beans as perceived by households in Kisoro and Kabale districts, south western Uganda

Parameter	Proportion of households (%)	
	Kisoro	Kabale
a) Merits of growing climbing beans		
Suitable for areas with limited land	84	92
Food security	49.3	28
Possess good marketable attributes	48.7	48
Improve the environment	12.7	46.7
Adaptable to local conditions	4.7	6
b) Demerits of growing climbing beans		
Agronomic characteristics	47	21
Production is expensive	34.7	2
Work load	28	59.3
Susceptible to bird damage and rats	6.7	19.3

stakes and also re-staking of dislodged staking materials due to heavy rain fall or strong wind, (iii) practicing the different cropping systems (agro forestry, intercropping, integrated livestock cropping system), (iv) clearing bushes around the gardens and pruning some plants to control rats from invading the climbing bean garden, (v) use of climbing bean husks for mulching and controlling soil erosion, and (vi) using resistant varieties.

Furthermore, social capital was reported as an important strategy for overcoming labour scarcity. It was explained in terms of farmers forming groups. Others use family labor supplemented with hired labor while others either endure and carry out the activity on their own or involve children. To reduce on drudgery and work load, they also reported that climbing beans may be threshed in the garden and bean husks are not carried home and bicycles are used to reduce the load of carrying stakes on the head. For others, stakes are cut early and allowed to dry for a light weight to be carried to the field.

In the case of lack of seed of any particular climbing bean variety, interviewed households mentioned that they exchange with friends/neighbours. They may also borrow stakes from neighbourss and return them after use. A fear is the social conflict which may arise after failure to return the stakes.

Accessing credit for production of climbing beans from local savings or friends is another important strategy. Others sell climbing bean produce to local markets to get money (capital). Funds are then used to buy seed from the market and/or renting or buying land to expand on climbing bean area of production.

There are special or important strategic interventions that are implemented in order to avoid loss and have continued climbing bean production. Some of the measures implemented include: harvesting and carrying of climbing beans home, while still on their stakes to save the stakes from theft and wild fires, some periodically monitor to ensure security of both beans and stakes or employ people to guard against thieves and scare off birds. To enable longer use of the acquired stakes, they reported storing the stakes on raised beds or under a shade or piling them upside down to expose the part of the stake that had been fixed in the soil to the sun to avoid rotting.

In addition, promoting local practices was also mentioned such as using ropes/strings as staking materials; others said they use stalks of sorghum and maize as staking materials, laying mole rat traps, using scare crows to control birds from pecking young pods and flowers which lowers the production, applying ash in the climbing bean fields to control termites from damaging stakes. For lack of markets, households end up selling in local markets and in case of unfavorable prices they store beans until prices are favorable.

Merits and demerits of growing climbing beans

After analyzing the opportunities and constraints in climbing bean production, households indicated that climbing bean production has several advantages compared to bush beans. In both locations of Kisoro and Kabale, climbing beans were mentioned by the households to be suitable for areas with land shortage (84% , 92%), good for food security (49.3%, 28%), possess good market attributes (48.7%, 48%) and are also adaptable to local conditions (4.7%, 6%) respectively (Table 12). They explained that since climbing beans grow vertically it allows one to maximize the limited space. In terms of food security, farming households explained that climbing beans allow for peace meal harvesting (keep eating pods which developed early as pod loading continues) and are high yielding.

On the other hand, agronomic characteristics of climbing bean was reported a demerit over the bush beans because it requires staking (yield potential is only attained after staking, easily blown by wind after staking because they grow upright). In addition, they are late maturing. The demerits as in order of importance in Kisoro included climbing bean agronomic characteristics 47%, climbing bean production being expensive (34.7%) and work load 28%. While in Kabale, work load (59.3%), the agronomic characteristics 21%, susceptibility to bird and rats damage 19.3%.

In addition, climbing bean production costs are high as explained by households that it requires stakes which are scarce and expensive, as well application of pesticides is very expensive (the crop has too much vegetation). Susceptibility to birds and rat damage was another demerit for climbing beans. They are more liked by birds as well as more affected by rats. Birds affect both flowers and tender bean pods.

Production of climbing beans involves some demanding and cumbersome activities. And if there is no cautious cutting of trees and planting of quick maturing agroforestry trees to provide the needed stakes, it may lead to environmental degradation due to deforestation.

DISCUSSION

First and foremost this study strongly revealed that climbing beans is an important crop in both districts as food and source of income more than the bush beans. In Kisoro, bush beans have not been adopted, whereas in Kabale, climbing beans is a relatively new crop but with potential to replace bush beans because of its several advantages. For food, households mostly eat climbing beans with Irish potatoes and sweet potatoes and this implies climbing beans play a big role in providing proteins in these areas. Climbing bean growth habit leads to staggered harvesting of leaves, pods, and grain, thus providing diversified nutrition and improved household food security throughout the growing season (Sperling et al., 1992 as cited by Musoni et al. (2005)). In terms of income, previous researchers have stated that common bean is considered as an important source of household income in the domestic, regional and international markets (Kimani et al., 2005). In Rwanda, climbing beans are important in raising on-farm productivity and contributing significantly to the gross domestic product (GDP) and replacing the bush type (Musoni et al., 2005). Beebe et al. (2013) stated that beans are becoming increasingly commercial with the trends of urbanization and market globalization.

The observed literacy level among interviewed in Kisoro and Kabale is important because education is assumed to increase the farmers' ability to obtain and use information relevant to the production of crops including climbing beans (Gichangi et al., 2012).

According to Barrett et al. (2001) and Deininger and Okidi (2001) as cited by Walusimbi and Konya (2004), education is a key factor which increases households' opportunities for off farm salary employment, and may increase households' ability to start other various non-farm activities. Similarly, from this study, much as the majority of the households in the two districts depend on crop farming as their main source of income, they also had other alternative sources of income including wages from manual work, business and salary. Related research among maize farmers in Kenya reported that farmers who depend entirely on farming are disadvantaged in terms of farming capital; hence they became less allocatively efficient compared to those who also engage in non-farming activities (Mulwa et al. 2009 cited by Sibiko, 2012).

It was evident from the survey that the interviewed households were generally of active working age, 21 to 50 years. Household demographic composition greatly influences the amount of labor available because in general the very young and very old are not available to work on or off the farm (Puhalla, 2009). Similarly Raemekers et al. (2013) stated that age as a demographic factor is an indicator of labour, that is, household members older than 15 years are (potentially) able to work on the farm (labour endowment). As climbing bean production requires more labour, it is expected that higher labour endowments facilitate the adoption (CIAT, 2004 as cited by Raemekers et al., 2013). This is in addition to the expected experience in production and marketing that is expected of older farmers (Gichangi et al., 2012; Walusimbi and Konya, 2004).

Farmers are able to grow climbing beans both in the first and second seasons in both districts. However, the majority of households in Kisoro reported that the best season for growing climbing beans is the first season whereas those from Kabale indicated it was the second season. There is evidence to support the findings that despite the fact that Kabale and Kisoro districts are both mountainous regions in South Western Uganda, they have differences in climatic conditions.

Wortmann and Eledu (1999) cited by Raussen et al. (2002) stated that much as Uganda's southwest exhibits a good number of common features: bimodal rainfall, hilly terrain, etc., there exists differences in agricultural systems and land-use practices due to local climate, soil and terrain interacted with farmers' traditions, preferences and markets. This probably explains the reported differences in the best seasons for growing climbing beans.

The findings that NABE12C (Large sugar bean) was the only improved climbing bean variety grown presents serious research implications for the Uganda bean research and development program. This indicates that there is still need to continue developing and disseminating more improved climbing bean varieties with related acceptable attributes. Sperling and Muyaneza (1995) in their studies in Rwanda also found majority of farmers growing one improved variety, Umubano (G2333). They stated that such genetic narrowness can compromise production stability and that if yield of improved climbing cultivars are to remain high, research should put emphasis on releasing many and diverse cultivars. Based on households explanations, the major reason for wide adoption of this variety that was released in 2003 is due to its high yield, good seed colour, large seed size, fast cooking, swelling ability on cooking, good taste, and attractive large fresh pods; all these attributes have made it highly marketable. Given the fact that NABE12C fresh pods and dry seeds have high demand and ready market, households are able to get income from this variety. On the other hand, the earlier (1999) released climbing bean varieties (NABE 7C, NABE8C, NABE9C, NABE10C) were high yielding and aimed at addressing the problem of bean root rot disease. Unfortunately, they were not adopted in these districts mainly because their seed type (mainly seed size) and culinary characteristics were not liked by farmers. According to Rausen et al. (2002), all the four climbing bean varieties were rated with moderate to low success rates in Kisoro and Kabale respectively. NABE7C (Vuninkingi) and NABE10C (Umubano) associated problems were low marketability due to small seeds and attack by birds; NABE8C (Ngwinurare) and NABE9C (Gisenyi) were susceptibility to vermin and birds. Surprisingly, NABE10C was adopted in Mbale, Sironko and Kapchorwa. Today, it is very clear that farmers do not only consider yield and resistance to biotic/abiotic factors if they are to adopt any new bean variety, but the seed type and culinary characteristics seem to be even more important than they were thought before. Musoni et al. (2005) stated that improved varieties that lack the desirable culinary (short cooking time, taste, broth colour, and flatulence) and market attributes (seed colour and size, shape and mass) are the least accepted and adopted by farmers and consumers. The assumption to the high rate of dropping different varieties could be because of the fact that households have not integrated the different practices into a whole-farm strategy that involves managing the crop profitably with respect to the environment, in ways that suit local soils, climatic and economic conditions. According to literature in order to enhance farm productivity, farmers need to have access and use bean production practices that combine seed of improved varieties as well as integrated soil fertility management and integrated pest and disease management (IPDM) technologies (Abanga et al., 2012). Other land races are also no longer grown because of lack of desirable attributes for productivity, susceptibility to biotic factors, poor cooking qualities and are not adaptable to local conditions. Similarly, Kimani et al. (2005) stated that urban market forces have caused farmers to specialize in a few varieties and many have been abandoned, although on average, farmers still grow four varieties in different proportions.

Households reported that the important cropping systems for climbing beans growing in Kisoro and Kabale districts include crop rotation with Irish potatoes, sweet potatoes, peas; intercropping with maize, sorghum or bananas, integrated livestock, agro-forestry (C*alliandra*, *Sesbania*, *Leucaena* and *Vernonia* spp.) and mono-cropping. Similarly, studies by Hüskens (2015) on climbing bean diffusion in Kapchorwa district indicated mainly intercropping with perennial crops like coffee, bananas, trees and annual/biennial crops like maize, Irish potatoes, yam, and cassava. Monocropping is also practiced. Other findings by Raphaël (2013) also reveal that in relation to the cropping systems, climbing beans are mainly cultivated in rotation with cereals (92%) in western Kenya. Musoni et al. (2005) reported that multiple cropping systems are the most common practice in Rwanda, where climbing beans are grown along with other crops. When climbing beans are grown in association with other crops, the other crop provides support for the climbing beans. Interviewed households knew the reasons as to why they were practicing each type of cropping system while growing climbing beans. The major reasons included controlling biotic factors, avoiding soil degradation, for food security, environment management, for improved crop production, inadequate land, and improvement of plant vigour and agronomic practices being easily practiced. Gabiri (2013) stated that growing climbing beans has an added advantage of soil and water conservation as an integrated watershed management practice to reduce on watershed degradation apart from being a food security crop. Raemekers et al. (2013) reported that the wealthy biomass of climbing beans can be used as fodder for animals or may provide soil cover, control weeds, and contribute to soil organic matter. According to KARI (2008) as cited by Raphaël (2013), climbing beans can produce up to 17 to 25 tons of leaves per hectare. Since it has elevated nitrogen fixation potential and with a high biomass production, climbing bean plays an important role in improvement of soil fertility. For inadequate land, households explained that some system such as intercropping allow to fully or profitably utilize the land. Studies conducted by Niringiye et al. (2005) revealed that the climbing bean/maize intercrop resulted into yield and economic advantages over pure stands of the component species during 1996 long and 1997 short rain seasons. However, according to their findings in order to maximize yields in a bean intercrop plant population should not exceed 25,000 maize and 67,000 bean planted ha^{-1} in seasons with ample rainfall. Lower plant densities, such as mixtures of 50% of the sole crop density of each species (that is, 22,222 maize and 55,556 bean plants ha^{-1}) may be used in seasons/areas with rainfall deficient. In addition, crop rotation also keeps the land busy and avoids animals trampling and compacting the soil.

Consequently, as reported by Ramaekers et al. (2011), climbing beans production has a potential for ecological integrity that creates a healthy agro-ecosystem. Musoni et al. (2005) stated that in Rwanda monoculture is practiced especially at higher altitudes (2000 to 2300 masl). In monoculture, climbing beans are planted with the support of wood or bamboo stakes or maize stalks, wires or strings (mostly in Africa) (Raemekers et al., 2013; Raphaël, 2013). Whereas in Andean region, trellising is a widespread system; it is an alternative that reduces the need for stakes, but requires an investment in wires and string for tying up bean vines (Sañudo et al. (1999) as cited by Ramaekers (2011).

From this study, it was still pointed out that lack of staking materials was the most important constraint in climbing bean production in Kisoro and Kabale. Previous studies by Wytze (2015) also reported stakes as being the most not easily available inputs for climbing bean cultivation in Chema in Kapchorwa district in Uganda. Similarly, Musoni et al. (2014) stated that shortage of staking wood is a major challenge limiting the wider adoption of climbing beans in Rwanda. Another related study by Raphaël (2013) stated that staking material is the most important climbing bean production constraint according to farmers in Western Kenya. In the Nyanza region of Kenya, Gichangi et al. (2012) also reported lack of stakes as well as sufficient knowledge on the best staking methods. Poor staking or none causes a yield loss of 50 to 90% (Musoni et al., 2014). This therefore calls for a more collective regional effort to address this challenge in order to identify alternative farmer-acceptable and environmentally friendly staking options. There is need to demonstrate some of the recent staking innovations reported by Musoni et al. (2014) in the climbing bean production systems in Kabale and Kisoro districts. Related to staking was labour scarcity arising from a number of cumbersome activities (such as carrying stakes to the field, sharpening, and staking) that are often involved. Labour shortage is the main reason that makes farmers stop growing climbing beans (94%) (Raphaël, 2013). However, it is assumed that with an increasing adoption of the crop and an increasing cultivation experience, farmers would be used to climbing beans, therefore become more efficient and the production would be less time-consuming (Raphaël, 2013). Other important constraints that needed to be addressed by research were the diseases and pest problems that seemed to be more important in Kisoro district. Unfortunately, the current study did not attempt to understand the specific type of diseases and insect pests which were of major importance. Social constraints including theft of stakes heaped after harvest for storage in the garden or at home and fires set to burn stakes by jealous people were observed. Others were weather related constraints mainly heavy rain which leads to rotting of stakes and strong winds that cause stakes to lodge. The study further revealed that farming households had devised different coping mechanisms. One of the most interesting coping mechanisms noted was recycling of stakes, where the same stakes are stored properly and can be used for more than two to three seasons. This was also reported in Rwanda that 88% of the farmers obtain stakes from their own farms having learned to grow fast maturing trees and as well recycle stakes efficiently (Sperling and Muyaneza, 1995). Social capital was another interesting strategy that was reported and is in terms of farmers forming groups. Social capital is important since it allows interaction among individuals of a given community and it empowers the individuals to achieve their goals. When they come together in a group for a collective action they share knowledge on better ways of producing and accessing good services, as well reduce on the work load as they would be working collectively. The family labour is believed to comprise of women, it becomes difficult to carry out timely activities at peak periods and men generally have a lot of leisure (gatherings for local brew). Even where men cooperate, some activities like planting, weeding, harvesting, threshing and winnowing are exclusively for women. Hence, with farmer groups, households pool resources together so as to promote climbing bean and sustain climbing bean productivity. Farmers who belong to farmer associations benefit from better access to inputs and information on improved production practices. In addition, new users learn from the other members in the social network, hence, generating significant technology spillovers and improving their allocative efficiency (Sibiko, 2012).

Overall, interviewed households in Kisoro and Kabale districts confirmed that farmers appreciate and are aware of the advantages of climbing beans over bush type. Some of their advantages compared to bush beans include suitability for areas with limited land, good for food security, possess good market attributes, and adaptable to local conditions. In terms of food security, among other attributes as previously discussed, it allows for peace meal harvesting (keep eating pods which developed early as pod loading continues). Earlier researchers reported that climbing beans maximize use of limited space (both horizontally and vertically), and the yield potential is reported to be of two to four times higher than the bush beans, and more tolerant to heavy rains and wet soils (Katungi et al., 2009; Ramaekers et al., 2013). Nevertheless, according to farming households, some of the major disadvantages of climbing beans seemed to be related to their agronomic characteristics which require them to be staked. Similarly, Gabiri (2013) stated that among the short comings of climbing beans, they require stakes for their potential growth and stakes availability is a challenge. Susceptibility to birds and rat damage was another demerit for climbing beans. They are more liked by birds as well as more affected by rats. Increased labour requirements for staking and bird scaring are some of the disadvantages of climbing beans as perceived by farmers in the central high lands of Kenya (Ramaekers et al., 2013). However, the merits of climbing beans as explained could outweigh the problems. For example, the staggered development of climbing beans which allows utilization in different forms and at different times as previously discussed, attributes more than compensate, for the longer time climbing beans tend to take to attain full maturity. Supposing households got strong mature stakes, these could be recycled for some seasons, as well as giving special care for their maintenance, in addition to the high yields attained cost of production would reduce. Costs considered such as for cutting trees, splitting, sharpening, transportation from the forests and staking activities and frequent replacement of stakes due to breakages as a result of either heavy pod load and/or due to wind/heavy rain effect. In addition, the cumbersome activities (work load), are likely to reduce.

CONCLUSION AND RECOMMENDATIONS

This study highlighted the importance of climbing beans in Kisoro and Kabale districts. Climbing bean productivity in these districts is significantly influenced by the fact that it is a major crop for food, nearly eaten at all meals and also for income. Results further indicated that climbing beans play an important role in the cropping systems and has a sound ecological integrity for improved productivity. However, climbing bean production in the two districts is hampered by several constraints which to a larger extent are similar. For the good marketable attributes of climbing, households seemed to particularly imply the variety NABE12C which has those unique qualities and these have made it to be so far the best climbing bean variety for both home consumption and the market in the study area and in Uganda at large. This therefore suggests the need for more research efforts to develop and release more climbing bean varieties with superior or NABE 12C related attributes. Information generated from this study is therefore particularly useful to scientists and other development partners on the needed interventions in order to intensify climbing bean production in the districts and other parts of the country. This study therefore concludes that there is need for climbing beans agro ecosystem intensification so as to improve genetic diversity in climbing beans in the two districts for increased potential yield so as to minimize the risks of food insecurity as well as increase surplus for sale.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Agriculture and food security under threat of change climate in Benin

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Vulnerability of agriculture to climate change has been a key issue due to its negative effect on human lives for survival. This study aims at determining the threat of climate change on the production of crops in order to draw the attention of plant breeders on the paramount necessity to breed new varieties tolerant to abiotic stress (drought, temperature, salinity and flooding) for the happiness of farmers. Data of the experiments carried out, survey and temperature, rainfall and literature review were used in this work. The results of the study revealed high temperature caused abortion and drying of flowers which resulted in low yield. CL5 (*Solanum pimpinellifolium)* was found more tolerant to heat. The results also showed that there is increase in temperature and decrease in rainfall associated with flooding and violent rainfalls. It has also been demonstrated the delay in the start of the first rain in the central and northern parts of the country, poor distribution of rainfall across the country, drought pocket during rainy season in the central and northern and flooding in the south. There is need to develop new crop varieties that are tolerant to drought, flooding, salinity and temperature.

Key words: Climate change, drought, flooding, crop production, food security, Benin.

INTRODUCTION

Agriculture which constitutes the key activity in Benin Republic and occupies nearly 60% of the workforce has been face with a lot of challenges due to climate change effects. The majority of farmers rely only in rain-fed agriculture to produce crop for their subsistence. It is obvious today that climate change will significantly and harmfully impinge on crop production and food security in the world especially in developing countries by altering the pattern of rainfall (Food and Agriculture Organization (FAO), 2001). Lately, global warming and its effect on crop production has become a very serious issue. Amongst the continents, Africa will go through a severe climate change (Intergovernmental Panel on Climate Change (IPCC), 2007). Lane and Jarvis (2007) reported that many countries where food insecurity is already predominant will be dangerously influenced by the change in climate. Therefore, agriculture is highly sensitive to environmental stresses and weather extremes, such as flood, salinity, high temperature (heat), and drought. Our actions have already modified the

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atmospheric features and this will continue as years go by which will be a great problem to agricultural production and farmers will be faced with a lot of challenges.

Society for the Advancement of Education (2002) reported that, every year yield losses of crops due to abiotic stresses are more significant than those caused by insects and weeds. In Africa and Asia, most of economic important crops will decrease in yield due to the deleterious effect of climate change (Calzadilla et al., 2009). They further stated that the obvious effect of change in climate on food production will be more felt and more severe in Sub-Saharan Africa and South Asia. It was foreseen that the global warming will cause the rise in sea level ranging from 0.1 to 0.5 m (4 to 20 inches) according to present estimates of the Intergovernmental Panel on Climate Change (IPCC, 2007). The increase in the level of sea and the high irrigation of water will definitely bring out high salinity in the coastal regions of Benin.

Besides, the growing world population requires more food, while the prospect of global warming threatens to make agricultural growing conditions more demanding (FAO, 2004). Climate change will seriously affect crop production as years goes on (IPCC, 2007). More erratic rainfall and high temperature patterns and increased salinity and flooding caused by climate change will consequently be expected to further reduce crop productivity, and developing countries in the tropics are particularly vulnerable (de la Peña and Hughes, 2007). In these areas, increasing salinity and flooding will be major limiting factors in sustaining and increasing vegetable production (de la Peña and Hughes, 2007). Climate changes have impact on Benin agriculture, especially in the coast, valley of Ouémé, Mono.

In addition, our study on the impact of salinity on tomato production along the coastal regions of Benin Republic revealed that salinity is increasing due to the rise in the sea level which causes yield loss up to 60% in the regions (Ezin et al., 2012). Due to repeated yearly yield loss to salinity some producers were compelled to abandon their field. In the village called Avlo in Benin Republic, farmers have stopped growing vegetable crops in the field due to high salinity of their soil unsuitable for vegetable production. Farmers were asking for new varieties tolerant to salinity and flooding. Henceforth, breeders must assist farmers in coping with the climate change risk by developing adaptation strategies to abate its negative impacts on crop productivity.

Most of the varieties farmers use is bred for tolerance to pest and diseases while abiotic stresses are the main cause of crop-yield declines reducing by more than 50% the average yield (Boyer, 1982; Wang et al., 2003). Thus, measures to adapt to the climatic changes, particularly development of salinity and flooding tolerant varieties, are critical in tropical agricultural production systems. Therefore, to lessen or overcome climate change effect, it is imperative to breed new varieties for improved tolerance to drought, high temperature, salinity and flooding. Developing countries are in dire need for new crop varieties tolerant to severe climate conditions. In view of the magnitude of the predicted climate change impact on crop productivity more attention must be given to breeding.

The objective of the present study was to use the data of the conducted experiments, survey, temperature, rainfall in Benin and literature review to project the threat of climate change on the production of crops in Benin Republic in order to draw the attention of plant breeders on the paramount, necessity to breed new varieties tolerant to abiotic stress (drought, temperature, salinity and flooding) for the happiness of our farmers.

MATERIALS AND METHODS

Description of study area

This study was carried out in Benin Republic. Benin latitude ranges from 6°3°' to 12°3°'N and its longitude from 10° to 3°4°'E. The climate is of equatorial type with two rainy and two dry seasons.

Experiment on high temperature

Three genotypes CA4 (*S. lycopersicum),* CL5 (*Solanum pimpinellifolium),* and CL5xCA4 (hybrid) were used in this study. The experiment was laid at randomized complete block design (RCBD) with 8 replicates. Treatments consist of two different temperatures: 40°C as high temperature and 27°C as normal temperature.

Other data collected

Two different data were used: one based on survey carried out amongst producers and the other ones from the meteorological data collected from different institutes namely Africa Rice, IITA, and ascena. Daily data of temperature and daily rainfall were collected from weather data recorded by, automatic weather recorders installed nationwide.

Three different stations were chosen: one in the south (Cotonou), two in the Central part (Bohicon and Zagnanado) and one in the North (Natitingou).

Statistical analysis

Data collected from the heat experiment were subjected to variance analysis using SPSS16.0, and then the determination of the differences among treatments was carried out. Means separation was performed.

The meteorological data collected were subjected to descriptive statistics to determine means, min, maxi and standard deviation. The processing of data collected was performed with the aid of EXCEL 2007, and XLTAT. In depth, statistic analysis was carried out such as trend analysis, T Test, confidence test, co-efficient of variation and Mann-Kendall analysis.

Statistical approach used to analyze trends

Trends of variables of water quality for the period 1999 to 2008 were analyzed using SAS version 9.1 software. Monthly median concentrations were used to perform various tests. The test of Kruskal-Wallis was used to determine the presence of seasonality in the data, and that of Durbin-Watson to verify the presence of autocorrelation. The trend test of Mann-Kendall was used when there was no seasonality or autocorrelation. The test of seasonal Mann-Kendall was chosen when the data included seasonality without autocorrelation and that of LettenMaier Spearmann when there was autocorrelation and absence of seasonality.

Finally, the approach of Hirsch-Slack was retained when there was seasonality and autocorrelation. For this test, missing data were replaced by the monthly median value calculated over the entire period. Trends were not considered significant when the probability level (p) was greater than or equal to 0.05. In the absence of seasonality, the slope of the regression line was estimated using the method of Sen, whereas in the presence of seasonality, it was estimated using the Seasonal Kendall Slope Estimator.

Mann-Kendall analysis: The Mann-Kendall statistic S (Mondal et al., 2012) is given as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k)$$

The application of trend test is done to time series x_i which is ranked from i = 1,2,3,……n-1 and x_j, is ranked from j = i+1,2,3,….n. Each of the data point x_i is taken as a reference point which is compared with the rest of the data point x_j so that,

$$sign(x_j - x_k) = 1 \; if \; x_j - x_k > 0$$
$$= 0 \; if \; x_j - x_k = 0$$
$$= -1 \; if \; x_j - x_k < 0$$

The variance statistic is calculated by the following equation:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5)\right]$$

Where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value) and t_p is the number of data points in p^{th} group. A normalized test statistic Z was computed as follows:

$$Z = \frac{S-1}{[VAR(S)]^{1/2}} \; if \; S > 0$$
$$= 0 \qquad if \; S = 0$$
$$= \frac{S+1}{[VAR(S)]^{1/2}} \; if \; S < 0$$

Sen's slope estimator test: The magnitude of trend is predicted by the Sen's estimator. Here, the slope (Ti) of all data pairs is computed as (Sen, 1968; Mondal et al., 2012):

$$T_i = \frac{x_j - x_k}{j - k} \qquad for \; i = 1, 2, \ldots \ldots \ldots \ldots, N$$

Where x_j and x_k are considered as data values at time j and k (j>k) correspondingly. The median of these N values of T_i is represented as Sen's estimator of slope which is given as (Sen, 1968, Mondal et al., 2012):

$$Q_i = \begin{cases} T_{\frac{N+1}{2}} & N \; is \; odd \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N \; is \; even \end{cases}$$

Sen's estimator is calculated as Q_{med} = T (N+1)/2 if N appears odd, and it is regarded as Q_{med} = [TN/2+T (N+2)/2]/2 if N appears even. At the end, Q_{med} is computed by a two sided test at 100 (1-α) % confidence interval and then a true slope can be obtained by the non-parametric test. Positive value of Q_i indicates an upward or increasing trend and a negative value of Q_i gives a downward or decreasing trend in the time series.

RESULTS AND DISCUSSION

The life conditions of farmers relying mostly on rainfed agriculture in Benin have been affected due to climate change

Climate change impact

The following abiotic stress; Drought, temperature, heat, salinity and flooding are the consequences resulted from climate change; though those abiotic stresses have always posed a significant menace to crop production even before the change in climate concept is known and glaring to everyone across the globe. It is obvious that as years go on, the effect climate change will increase in abiotic stress. Abiotic stress cause wide-ranging losses to crop production in the world. Developing countries like ours have contributed least to the atmospheric buildup of carbon dioxide and greenhouse gases associated with recent global warming but unfortunate we are most at high risk from climate change and we will be the most to undergo its negative effects.

Pierre (1997) reported that, there would be a sharp difference in impact of climate change which is due to two main causes between the less developed countries (LDCs) and the developed countries (DCs). Firstly, the "physical" factor will be in favor of the DCs because of their geographical position on the planet which will benefit their agriculture owing to the longer growing seasons that a warmer climate will bring, while most LDCs would be negatively affected. Secondly, the "eco-structural" factor bound to the fact that the DCs have much greater resources that can be devoted to helping farmers adjust to climate change. Besides, the institutional structures of DCs appear to be more outstanding and efficient than those in LDCs in mobilizing resources need to pursue

Table 1. Kendall's analysis and estimated sen's slope.

Variable	Mean	Stdev	Confidence Test	S	Kendall's tau	p-value	Sen's slope
Rainfall N	1189.60	161.85	161.85±95.64	-15.00	-0.27	0.28	-21.13
Rainfall B	1100.02	224.23	224.23±72.25	182	0.28	0.02	8
Rainfall Z	985.30	204.56	204.56±73.20	37	0.09	0.52	2.43
Temp N	33.48	0.23	33.48±0.14	17	0.38	0.16	0.04
Temp B	27.9	0.39	27.90±0.39	197	0.47	0.0001	0.03

Rainfall N = rainfall of Natitingou, Rainfall B= rainfall of Bohicon, Rainfall Z= rainfall of Zagnanado, Temp N= temperature of Natitingou, Temp B= temperature of Bohicon, Stdev= standard deviation.

Table 2. Effect of temperatures on flowers and number of fruits from cluster 2 to 6.

Genotypes	Number of flowers		Number of fruits	
	T1	T1	T1	T2
CL5	50.67a	49.13a	31.83a	28.13a
CL5XCA4	44.63a	41.38a	39.11a	30.13a
CA4	28.29a	31.86a	10.15a	1.13b

social objectives, whether they are adjustments to climate change or anything else. Therefore, the poorest countries in the world are the most vulnerable and the richest countries will face the least harm from climate change due to the fact that they are also well equipped to deal with the little harm to encounter. In addition to problem attached to climate change we need to develop sustainable agricultural systems in Africa in general and Benin Republic in particular.

MEHU-PNUD (2008) in its planned assessment of vulnerability to climate change in the most susceptible geographic areas in the Republic of Benin pointed out environmental factors as a result of climate change namely (1) drought, inundation, late and violent rainfalls as three major climatic risks in Benin; (2) the occurrence of violent winds and high temperature heat as climatic risks capable of being serious in some areas, in some situations; and (3) the existence of localized climatic risks such as coastal erosion. They further stated that tributary basin, subsistence farming, small farmers, vegetable gardeners, biodiversity; fishers are highly exposed to climatic risks in Benin.

African countries will face more shortages of food, poverty, and hunger. This has started gradually because the price of all commodities has been increased in the past three years due to low yield of crops in the field. Currently, climates of most parts of the country have changed: delay in the arrival of the first rain, poor distribution of rainfall, drought pocket during rainy season, flooding, etc.

Increase in the temperatures

Table 2 shows the effect of temperature on tomato production. High temperature can cause low yield and even death of crops. Among the genotypes used CA4 variety was the most sensitive. CL5 genotype could be regarded as heat tolerant based on the fact that it produced better yield under high temperature. There was significant difference in number of flowers and fruit number among genotypes and within genotype. This indicates that high temperature impinged high yield. Our results are consistent with those of Maman et al. (2003), Firon et al. (2006), Wahid et al. (2007) and Blanc (2012). Hall (2001) reported that heat stress due to high ambient temperature is a serious threat to crop production worldwide.

The trend analysis of Natitingou in the northern part, Bohicon in the central part has been performed using Mann-Kendall and Sen's Slope Estimator. Table 1 demonstrates that the Sen's Slope of temperature in Natitingou and Bohicon is increasing in trend. This results projects that temperatures are on rising. The results of the present study is similar to the report of IPCC (2007). Mondal et al. (2012) also reported that research of various time series data provided evidence that trend is either decreasing or increasing, both in case of temperature and rainfall.

Figure 1 show that from 1971 to 2000 temperature varies around the overall average, 27.9°C in Bohicon. The average over this period was 27.84°C which is slimly lower than average temperature recorded in Bohicon. The average in the second period from 2001 to 2008 is 28.15°C. The last decade is warmer. The peak of annual average temperature was observed in 2000. In the second period from 2001 to 2008, the average annual temperature was always above 28°C. The average temperature recorded in Natitingou ranges from 33.1 to

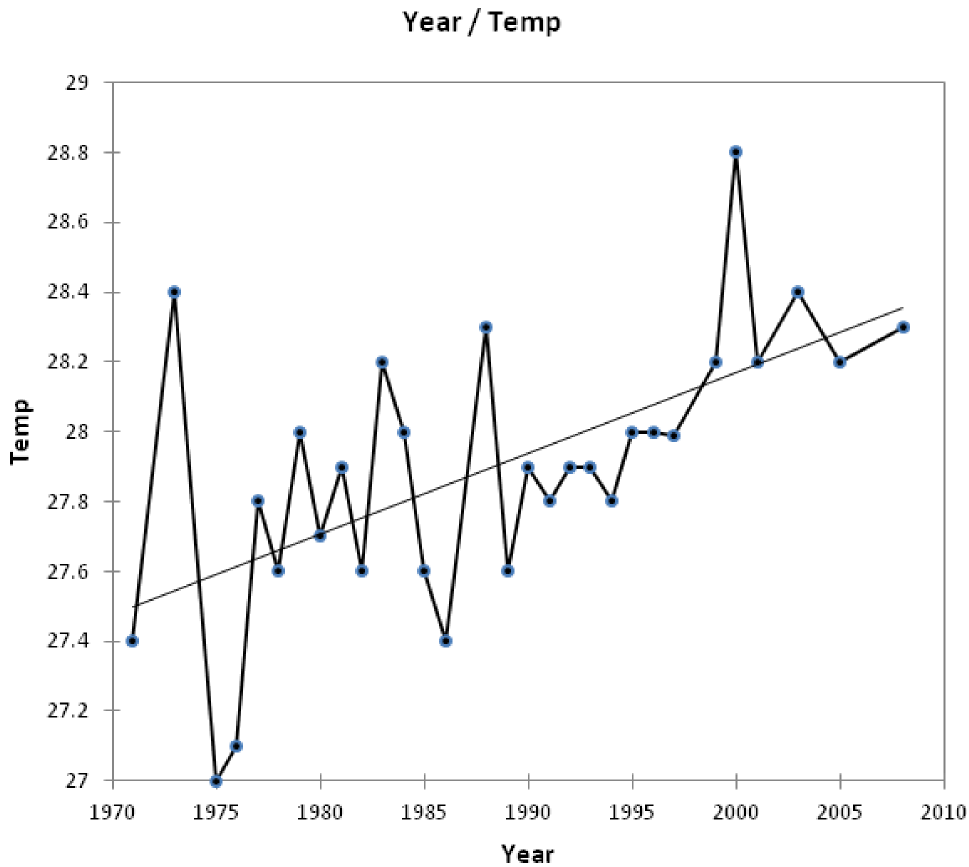

Figure 1. Annual average temperature from 1971 to 2000 in Bohicon.

33.6°C between 1993 and 2000 but from 2001 to 2004 there was slight increase (0.3°C) in average temperature and varies between 33.7 and 33.9°C.

It is obvious that the temperature actually increases each year. The trendline is an up trendline with positive slope indicating that the temperature rises as we move from left to right on the figure. As long as the trend is up, temperature will increase as years go by. But, it should be noted that there is break below the up trendline (Figures 1 and 2). Based on observations of increases in average temperature recorded from meteorological stations in our country, the deleterious effect of global warming is undeniable. According to ECOWAS-SWAC/OECD/CILSS (2008) in West Africa, observed temperatures have been increasing faster than global warming and the increase varied between 0.2 and 0.8°C since the end of the 1970s. IPCC (2007) reported that temperature of the earth is likely to increase by 1.1 to 6.4°C. It is also said that land area will warm than ocean in part due to the water ability to store heat. They further stated that most of North America, all of Africa, Europe, Northern and Central Asia, and most of Central and South America are likely to warm more than the global average.

Therefore, the rising temperature will have negative effect on crop yield. Peña and Hughes (2007) reported that temperature limits the range and production of many crops, and that in the tropics crops will be subjected to increased temperatures stress. Greater climate variability which incorporates the later onset, higher temperatures and increased potential evapotranspiration will make farming systems more highly vulnerable to climate change (Sarr, 2012) Temperature primarily affects the photosynthetic functions of higher plants (Weis and Berry, 1988). Plant development, growth, yield and crop production even seed germination will definitely and negatively respond to climate change. In our study, on effect of heat on tomato production under controlled environmental conditions (personal communication). we concluded that high temperature caused decrease in plant height, dropping of flowers and yield loss even total yield loss in some tomato varieties. It can also cause significant losses in tomato productivity due to reduced fruit set, and smaller and lower quality fruits (Stevens and Rudich, 1978). Pre-anthesis temperature stress is associated with developmental changes in the anthers, particularly irregularities in the epidermis and endothecium, lack of opening of the stromium, and poor pollen formation (Sato et al., 2002).

Hazra et al. (2007) summarized the symptoms causing

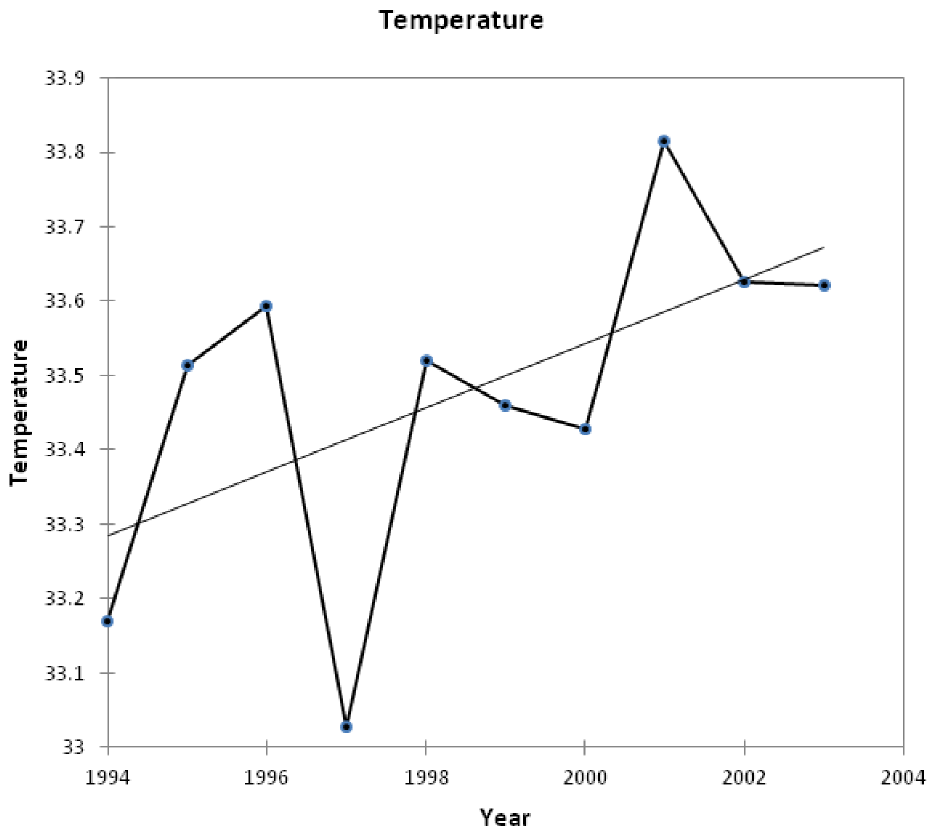

Figure 2. Annual average temperature from 1994 to 2004 in Natitingou.

fruit set failure at high temperatures in tomato; this includes bud drop, abnormal flower development, poor pollen production, dehiscence, and viability, ovule abortion and poor viability, reduced carbohydrate availability, and other reproductive abnormalities. This is similar to the results presented in Table 1 owing to the fact that despise the high number of flowers recorded especially in the sensitive, one few fruits were recorded. This demonstrates the fact that there was flower drop. In addition, significant inhibition of photosynthesis occurs at temperatures above optimum, resulting in considerable loss of potential productivity. Challinor et al. (2005) reported that brief periods of high temperature which occur near flowering can severely reduce the yield of annual crops such as wheat and groundnut.

Challinor et al. (2007) observed that high temperature stress was not a major determinant of simulated yields in the current climate, but affected the mean and variability of yield under climate change in two regions which had contrasting statistics of daily maximum temperature. Changes in mean temperature had a similar impact on mean yield to that of high temperature stress in some locations and its effects were more widespread (Challinor et al., 2007). Where the optimal temperature for development was exceeded, the resulting increase in duration in some simulations fully mitigated the negative impacts of extreme temperatures when sufficient water was available for the extended growing period. For some simulations, the reduction in mean yield between the current and future climates was as large as 70%, indicating the importance of genotypic adaptation to changes in both means and extremes of temperature under climate change (Challinor et al., 2007).

Drought

Drought is an abiotic factor which limits crop yield. It will increase in importance with climate change. IPCC (2007) reported that, between 75 and 250 million across Africa could face more severe shortage of water by 2020. The monthly data collected on rainfall from ascena shows that yearly rainfall period has been reduced in the last five years in the center and northern parts of the country; it ranges from 5 to 4 months, respectively. Irrigation systems are most practiced in the north of Benin due to lack of rain and inconsistent frequency of rainfalls. Thus, flooded irrigation could lead to salinity of soils in the regions due to the buildup of sodium chloride. To avoid an addition of salinity of soils where drought is almost settle and predominant, our farmers must be taught about drip irrigation which is one of the best irrigation system

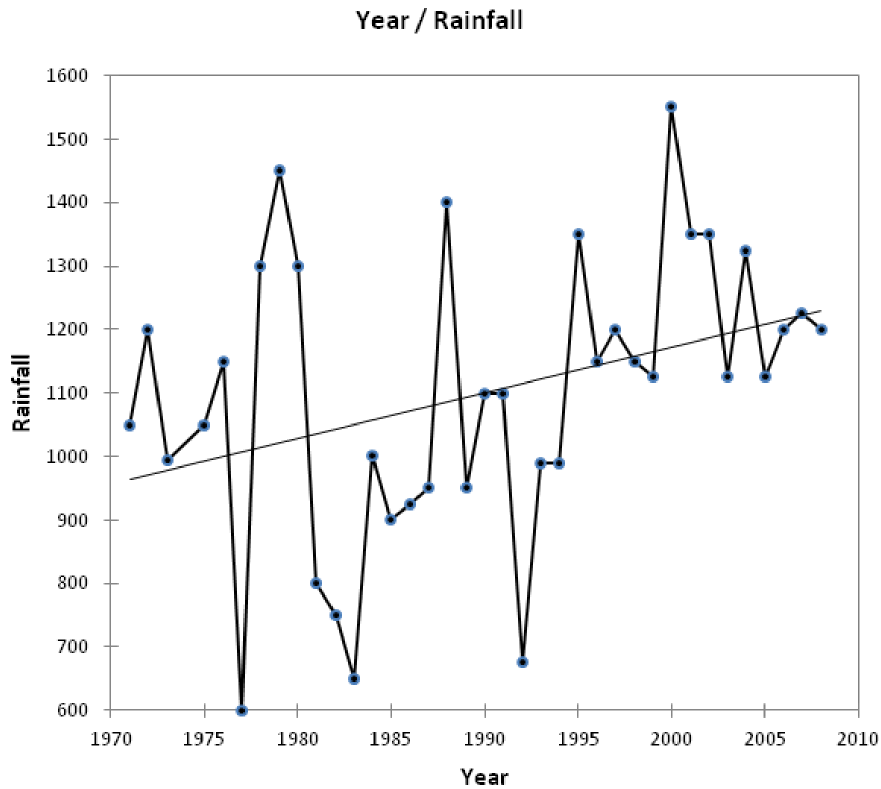

Figure 3. Annual average of rainfall from 1971 to 2005 in Bohicon.

but very expensive when compared to the flooded irrigation practiced to date. In one way or the other we are beginning to feel the effect of climate change because, farmers reported that the rain is not frequent and has become unpredictable, resulting to decrease yield in crop production. These are the sign of hunger and food security problems.

In some part of Africa such Somalia, Soudan, and Ethiopia drought rate has been increased lately and many have left their countries to seek refuge elsewhere. Millions face death due to the ravaging horn of Africa drought. It is therefore expected that many crops will not be able to be resilient to drought with the increase in temperature of the climate as time goes on. Country STAT-Benin reported that annual variation of yield from 1987 to 1997 and 1997 to 2007 are 5.7 and 3.2% for cassava, 0.5 and 0.1% for yam, 7.0 and 1.1% for maize, respectively. This results show that there is yield reduction in cassava, yam and maize due to the effect of climate change in crop production in Benin.

Drought stress causes the solute concentration of plant cells to increase, thus lowering water potential and disrupting membranes along with essential processes like photosynthesis. These water-stresses affect plant, making them exhibit poor growth and resulting to plant death in severe cases. Water stress also causes abortion of flower bud and then reduction in fruit setting.

Rainfall variability

In the non-parametric Mann-Kendall test, there is variability in the trend of rainfall recorded across the country as shown in Figure 3, 4, 5 and 6 respectively.

The rainfall during 1971 to 2000 (Figure 4) fluctuated around the overall average (1100.02 mm) in Bohicon. It rained an average of 1078.52 mm / year over this period. On the other hand, from 2001, we observe that the rainfall exceeded the average. The average rainfall was 1231.66 mm against 1078.52 mm during the first period. From 2001, it began with more rain than usual in Bohicon. It is also warmer than in previous years. The periods 1971 to 2000 and 2001 to 2008 therefore deserve to be taken apart, to show the actual existence of climate change. This result is consistence with those of IPCC which reported that the current climate changes have been observed from the 2000s.

The average rainfall in Natitingou (Figure 4) was 1270.33 mm per year between 1994 and 1999 against 1098.4 from 2000 to 2004. These results showed that from 2000 the precipitation has significantly reduced in this locality. The same trend of results was obtained with meteorological data from ascena on rainfall at Zagnanado (Figure 5). In this locality, from 1986 to 1989, 1994 to 1998, and 1999 to 2000 the graph 5 show that there was high precipitation but from 2000 significant

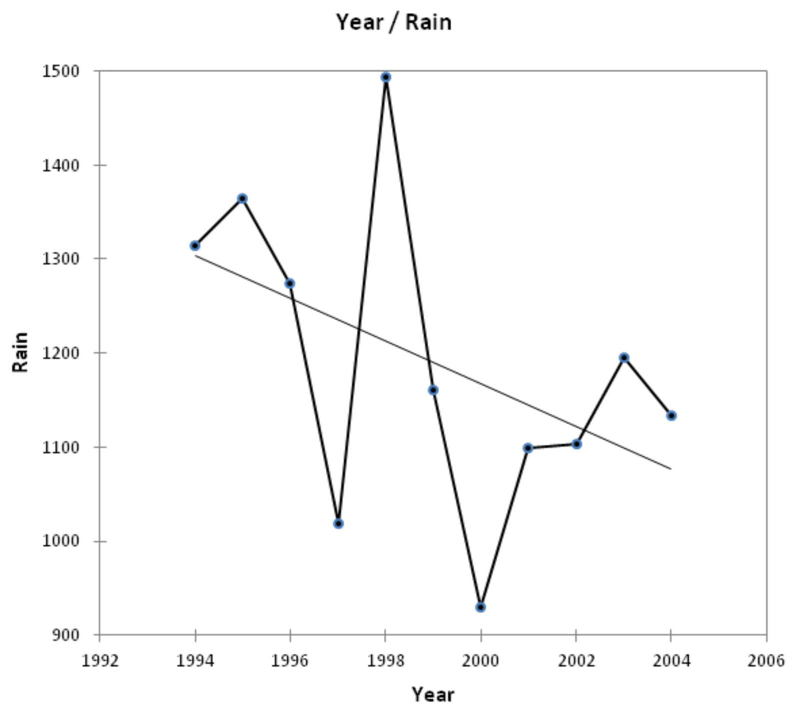

Figure 4. Annual average rainfall from 1994 to 2004 in Nattitingou.

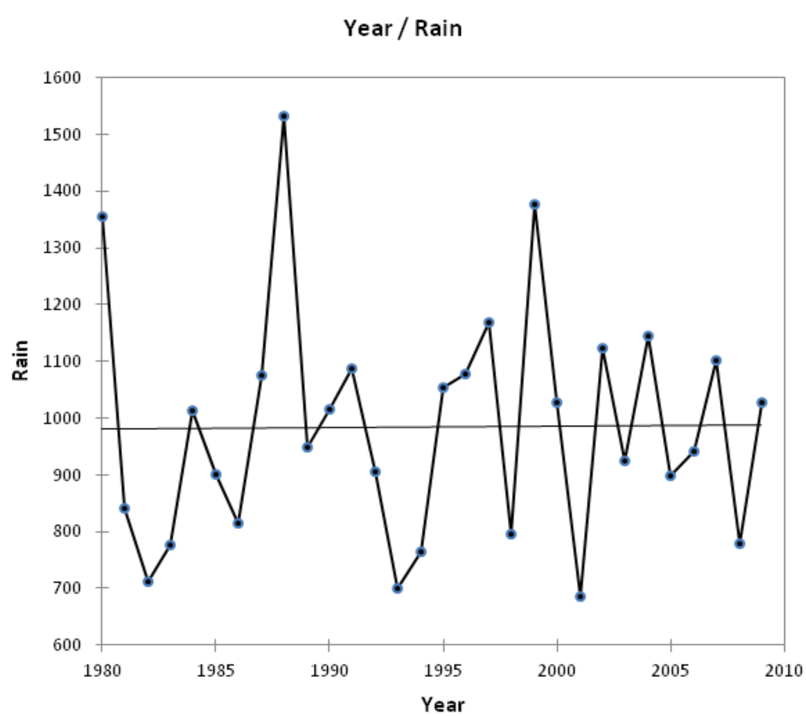

Figure 5. Pluviometric diagram of ASECNA data from Zagnanado (1980 to 2009).

reduction in rainfall was observed. The Figure 6 shows monthly rainfall in 2007, 2008, 2009, and 1968 to 2008. The total rainfall in March 2009 was 32.2 mm in 3 days VS 72 mm as the total rain in the month of March 2008. The total rainfall from January to March 2009 was 48mm VS 75.5mm in 2008. The average rainfall from 1968 to

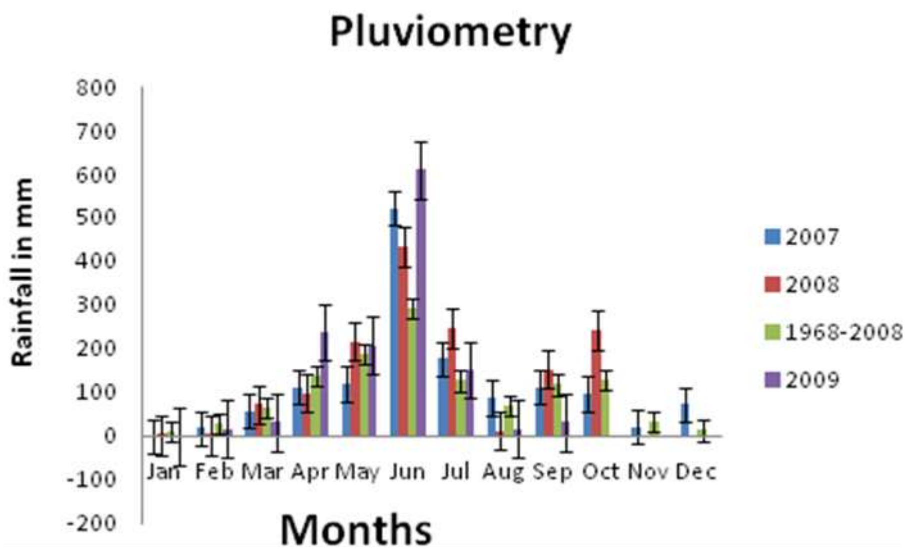

Figure 6. Monthly Rainfall 2007 versus2008 versus 2009 versus 38years in cotonou.

2008 was 34.84mm. There was heavy rain in June 2009 when compared to other years but the rainy season was short (4months) compared to others years. The results demonstrate that the annual rainfall decreased as the years go on.

The Observations on rainfall in the Save (central part of the country) this year is alarming because the rainfall stopped in June and most farmers who grew maize, tomato, other crops lost their production to the drought which came suddenly. The rain started again in late September to last for just three weeks. Absence of rain leads to drought which implies significant losses of yield and production. This year, there is no water in the rivers for irrigation in order to grow crops in dry season.

Salinity

In our previous study on impact of salinity and flooding along the coastal areas of Benin it was revealed that: (1) The coast of Benin lies on a wide bay in the Gulf of Guinea called the Bight of Benin, about 125 km between Togo and Nigeria covers part of the cultivable lands of the country; (2) salinity and flooding cause unfavorable conditions that restrain the normal crop production (personal communication).

The factors that contribute significantly to salinity were soil salinity, wet breeze from high tide especially between June and September, and direct watering of crop with saline water. The wetted foliage of growing tomato absorbed the salts directly. The results also show that salinity in the coastal areas of Benin affects tomato growth, leaf length, and number of leaves, which reduces yields and in severe cases total yield is lost. Producers in the areas affirmed that wet breeze has been increased and are compelled to move far away from the sea for those who have much land to avoid crop failure.

Meanwhile those who were not indigenes continue to face the problem but by providing some temporary solution through the setting of palisades and avoidance of planting crops during the period when the wet breeze is high. Due to heavy loss in crop production some producers have abandoned their fields in favor of fishing. Producers have been self-observed the changes in climate over a period of time i.e. they mentioned a significant differences between nowadays climate and past climate. Global warming is predicted to lead to thermal expansion of sea water resulting in a rise of sea level which may range from 0.1 to 0.5 m (4 to 20 inches) according to present estimates of the Intergovernmental Panel on climate change (IPCC, 2007). The increase in the level of sea and the high irrigation of water will definitely bring out high salinity in the coastal regions in Benin.

The producers in the areas were not educated enough to predict climate change and agricultural extension officers have not been able to teach them adaptive measure to overcome adverse effects of climate change on crop production and train farmers on how to adjust timing of sowing in the field.

Owing to the short period of rain in the northern parts (Kandi, Karimama, Malanville districts etc) of the country, irrigation system has been extensively applied to agricultural lands which will result in salinity in a long run due to the accumulation of toxic compounds in the soils. Moreover, the survey carried out on soil salinity showed that the entire Avlo district and part of Gbahoué district in the commune of Grand Popo have high soil salinity unfavorable to the production of market gardening and other crops.

Henceforth, producers in the regions do not grow vegetable any more. François and Maas (1994) reported that it is estimated that worldwide about 20% of cultivated lands and 33% of irrigated agricultural lands are affected by high salinity. The causes of salinity can be natural, clearing of the natural vegetation, or irrigation. Plant sensitivity to salt stress is reflected in loss of turgor, growth and yield reduction, wilting, leaf curling and epinasty, leaf abscission, decreased photosynthesis, respiratory changes, loss of cellular integrity, tissue necrosis, and potentially death of the plant (Jones 1986; Cheeseman, 1988). Salinity also affects agriculture in coastal regions which are impacted by low-quality and high-saline irrigation water due to contamination of the groundwater and intrusion of saline water due to natural or man-made events.

Flooding

Flooding has been a major factor contributing to total and complete loss of production of crops in the recent years in our country. Many efforts have been made to develop crops resistant to biotic factors such as fungi, virus, and bacteria; at the same time nothing is done to breed crops tolerant to drought, flooding, heat, and salinity. It should be noted that breeding crops take many years before its release, thus much attention must been given to the breeding of crops tolerant to abiotic stress which will go on causing massive crop-yield losses every year as a result of climate change.

In our study carried out in the six departments of the south, in Benin Republic namely: Plateau, Ouémé, Littoral, Atlantique, Mono, Couffo, producers affirmed that there is always total crop-yield losses during flooding even waterlogging. None of the producers were able to harvest his crops after flooding. Excess rainfall causes 100% yield losses of crops such tomato, pepper, carrot, maize, beans according to the farmers. But unfortunately, this recurrent problem has not been drawing breeders 'attention in the country to tackle it in order to provide lasting solution or mitigate it to a certain extent. For instance, Benin Republic that is thought previously not to be vulnerable to flooding has been devastated by 2010 flooding. The two-third of the country has been affected and all the growing crops in the regions were swept off by flooding. There has been flooding which has more rains fall in short periods and with longer gaps between, this is observed in the center of the country. The increase in soil erosion which results from heavy rainfalls will negatively affect soil fertility.

Vegetable production is often limited during the rainy season due to excessive moisture brought about by heavy rains (Peña and Hughes, 2007). Most vegetables are highly sensitive to flooding and genetic variation with respect to this character is limited, particularly in tomato. In general, damage to vegetables by flooding is due to the reduction of oxygen in the root zone which inhibits aerobic processes. The severity of flooding symptoms increases with rising temperatures; rapid wilting and death of tomato plants is usually observed following a short period of flooding at high temperatures (Kuo et al., 1982).

Conclusion

Climate change will negatively impact agriculture and reduce food supply. Drought, salinity, flooding, high temperature will consequently reduce crop productivity. Necessary steps must be taken to lessen the effect of climate change and avoid food insecurity in our country. To achieve this, new varieties capable of resisting drought, salinity, high temperature, and waterlogging even flooding must be created. Wild relative species are thought to be rich in resilient genes to abiotic stresses, thus a program to identify, collect and preserve the wild relative species of our crops must be carried out in order to prevent them from extinction under a variable climate.

It should be noted that, a single method is unlikely to overcome the effect of climate change. Integrated methods will be the most appropriate, effective and durable so as to mitigate the effect of climate change in Sub-Sahara Africa, the most vulnerable parts of Africa to change in climate. All hands must be on desk to hope avoiding food insecurity in our country because change in climate is real and will worsen as years go on. A thick collaboration amongst policymakers (government), farmers, and researchers is needed to put in place adaptive measures adequate for risks associated with climate change.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Assessment of soil characteristics under four cropping and land management systems in south west Nigeria

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Soil degradation and desertification pose a major threat to agricultural production in sub-Saharan Africa. The influence of cropping systems which had been established on selected physical and chemical properties of soil were investigated in Akinyode-Okinni community in Egbedore Local Government Area (LGA) of Osun State, Nigeria. The cropping systems included agri-silviculture (SCM), silvi-pasture (SPC), agri-horti-silviculture (PAH) and agroforestry (AFT) selected from existing farms in the community. The selected plots had cocoa (*Theobroma cacao*), oil palm (*Elais guineensis*) and kola-nut (*Kola nitida*) as permanent crops; coco-yam (*Coco nucifera*), guinea grass (P*anicum maximum*), plantain (*Musa spp*), maize (*Zea mays*), and cassava (*Manihot utilissima*) were the annual crops. The experiment was carried out for two cropping seasons. Results showed that in the AFT system bulk density (BD) decreased slightly from 1.22 to 1.16 g/cm^3 in the top soil and from 1.18 to 1.09 g/cm^3 in the subsoil after two seasons of crop growth. The pH varied between 6.40 and 7.05 in the first season and between 7.05 and 7.29 after two seasons. On average, the topsoil contained more organic carbon (OC) in the SPC (38 g kg^{-1}) and SCM (36 g kg^{-1}) systems than in the PAH and AFT systems. Similarly, the total phosphorus content was higher in the topsoil of SPC and SCM systems than in the other systems. There was a slight reduction in soil acidity and no significant changes occurred in the concentrations of exchangeable bases after two cropping seasons. Conclusively, these cropping systems have the potential to reduce soil deterioration and thus, further studies to develop appropriate management strategies are necessary.

Key words: Cropping systems, exchangeable bases, organic carbon, silviculture, soil degradation.

INTRODUCTION

The influence of soil management practices on sustainable agricultural production could be related to the readiness of farmers to adopt improved agricultural practices. One of the goals of effective soil management practices is to create farming systems that mitigate environmental degradation associated with inappropriate

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activities of man (Sustainable Agriculture, 2001). Sustainable agriculture is part of a larger movement toward sustainable developmental processes, which recognize natural resources as being finite; it acknowledges limits on economic growth, and encourages equity in distribution of resources (Horrigan et al., 2002). The adoption of certain agricultural technologies which are believed to be yield-enhancing and development oriented can bring ecological, socio-economic, and cultural benefits if based on a holistic scientific approach (Madden and Chaplowe, 1997). Potential sustainable agricultural practices that may have impact on some developmental processes on soil management include organic farming, crop rotation, planting of cover crops, conservation tillage, integrated soil fertility cum nutrient management, enhancement and conservation of bio-diversity, integrated pest management, rotational grazing, and agro-forestry (Factsheet of Tropical Forages, 2015; Lamidi, 2013; Michel, 2010; Alabadan et al., 2009; Sustainable Agriculture, 2001; Allan, 1996).

This study focused on four soil management systems which are considered important in the quest to develop sustainable agricultural production systems. These systems include agri-silviculture, agri-silvipasture, agri-horti-silviculture, and agroforestry. In agri-silviculture farmers in dryland grow field crops in combination with forest trees; the silvi-pastoral system involves raising grasses instead of field crops in the spaces between forest trees (Balasubramaniyan and Palaniappan, 2005). Agri-silvipasture is the combination of agri-silviculture and silvi-pastoral systems whereas agri-horti-silviculture is a system where fruit trees are grown along with crops and multipurpose tree species. Agri-horti-silviculture is highly diverse in vegetation and its productive capacity is expected to be relatively high. For example, crops such as rice, mustard, soybean and/ or vegetables may be grown in between banana or guava (Balasubramaniyan and Palaniappan, 2005). The general assumption is that these agricultural systems have the capacity to restore and balance ecosystems naturally (Factsheet of Tropical Forages, 2015; Ifeanyi et al., 2013).

Thus, it was hypothesized that farmers' adoption of developmental soil management practices could have an impact on the physical and chemical properties of the soil. Therefore, this study examined the influence of four cropping and land management systems on selected physical and chemical properties of the soil after two cropping seasons in South West Nigeria.

MATERIALS AND METHODS

The study was conducted at Oluyeyin Akinode-Oke Farm (5.56°N, 4.56°E) in Okinni village located at Egbedore Local Government Area of Osun State, Nigeria. The soil is well drained and sandy loam in texture. The mean annual rainfall is between 300 and 350 mm. The area is prone to soil erosion. Four agricultural systems which had been established by farmers were selected for the study. These systems were agri-silviculture, silvi-pastural, agri-horti-silviculture, and agroforestry.

Agri-silviculture is a system of agriculture where the land is used to produce both forest trees and agricultural crops either simultaneously or alternately (Balasubramaniyan and Palaniappan, 2005). Silvi-pastural system is where trees are planted for wood production as well as fodder for feeding domestic animals. Agri-horti-silviculture is a system of agriculture where annual crops, fruit trees and multipurpose tree species are planted on a piece of land simultaneously or alternately. The agroforestry system was taken as a system having tree species as a major feature or a combination of all the other systems already described. The size of each of the selected cropping systems was 1 ha which was divided into four segments to serve as replicates.

The agri-silviculture system had three-year old cocoa trees which served as forest tree crop and plantain at the commencement of the study; maize (*Zea mays*) was grown in between the rows for two cropping seasons and the system was tagged SCM. The silvi-pastural system also had three-year old cocoa trees with guinea grass (*Panicum maximum*) grown between the rows and was tagged SPC; grazing was discouraged during the period of the experiment. The agri-horti-silviculture system, tagged PAH, had oil palm (*Elais guineensis*) and cocoa trees; maize was grown in the rows of the tree crops. In PAH system, cocoa served as a fruit tree crop, oil palm as a multipurpose tree species, and maize as a field crop. The agro-forestry system tagged AFT, had fully grown kola-nut (*Kola nitida*) trees which were regarded as forest tree species. A nearby field (same neighbourhood, of similar size) with secondary regrowth of vegetation (bush fallow) was selected as the control plot.

Soil samples were taken from each plot at two depths, 0 to 15 and 15 to 30 cm, prior to commencement of the study and after two cropping seasons. Soil samples were also taken from the control field for comparison. The samples were air-dried, sieved (2 mm) and analysed for physical and chemical characteristics. The parameters measured included particle size fractions, pH, total P, organic carbon, total N and exchangeable cations (Essington, 2004; Davidson and Ackerman, 1993; IITA, 1982). Core soil samples were also taken for determination of bulk density (BD) (Hamza and Anderson, 2005; Hakansson and Lipiec, 2000). The data obtained were subjected to One-way analysis of variance (ANOVA), the treatment means of the data were separated with least significant difference (LSD).

RESULTS AND DISCUSSION

Physical properties (bulk density (BD) and particle size fractions)

Generally the influence of the cropping systems on BD of the topsoil was not visible during the experimental period as shown in Table 1. However, when considered on absolute terms, a slight decrease was observed in some systems. For example, in the topsoil of the AFT system BD decreased from 1.22 to 1.16 g/cm^3. Similarly the BD of the subsoil tended to decrease slightly in PAH (1.22 to 1.06 g cm^{-3}) and SCM (1.21 to 1.17 g cm^{-3}) systems.

The relatively low BD values after two seasons suggest

Table 1. The bulk density (BD) and pH of the soil samples at different depths before and after two cropping seasons.

Treatment	Depth			After two seasons	
		BD (g cm^{-3})	pH (H_2O)	BD (g cm^{-3})	pH (H_2O)
SCM	Topsoil	1.23	7.00	1.22	7.05
	Subsoil	1.21	6.80	1.17	7.30
SPC	Topsoil	1.28	7.01	1.20	7.29
	Subsoil	1.20	6.70	1.18	7.29
PAH	Topsoil	1.24	7.00	1.22	7.19
	Subsoil	1.22	6.40	1.06	7.05
AFT	Topsoil	1.22	6.95	1.16	7.27
	Subsoil	1.18	6.80	1.09	7.22
Control	Topsoil	1.18	7.00	1.16	7.12
	Subsoil	1.20	7.05	1.18	7.07

some improvement in this soil property which apparently, would have influenced some other properties of the soil. The slight decrease in BD could be attributed to the no-till strategy adopted for cropping systems with permanent crops. The absence of trampling by grazing animals may have contributed to the slight reduction in BD since grazing was discouraged in the experimental fields during the period of the study. In essence, the agricultural development systems used for this study could be described as being environmentally friendly because of their perceived lowering effect on BD which translates to occurrence of little or no soil compaction. It is common knowledge that soil compaction causes physical impedance of roots and thus limits access to water and nutrients by reducing the volume of soil exploited by plant roots.

This attribute is particularly important since compaction destroys the structural units of the soil and, thus alters the pore spaces which invariably affect aeration and water infiltration negatively (Taylor and Brar, 1991). Moreover, when BD is high (≥ 1.5 g cm^{-3}) root growth and development can be depressed (Hassan et al., 2007).

Data on particle size fractions of the surface and subsurface layers are given in Table 2. At the commencement of the experiment, the amount of sand particles varied from 704 to 760 g kg^{-1} in the top soil while the silt particles ranged from 123 to 182 g kg^{-1}. In the subsoil, the sand fraction varied from 694 to 762 g kg^{-1} whereas the silt fraction varied from 113 to 192 g kg^{-1}. The quantity of the clay fraction was, on average, 114 g after two cropping seasons were, more or less, similar to the initial values (data not shown) indicating little or no kg^{-1} for the topsoil and 122 g kg^{-1} for the subsoil. The soils in

Table 2. Distribution of particle size fractions in the top- (0-15 cm) and sub-soil (15-30 cm) layers.

Treatment	Depth	Sand	Silt	Clay
		←-------------	g kg^{-1}	-------------→
SCM	Topsoil	722.3	167.2	110.5
	Subsoil	713.4	161.4	125.2
SPC	Topsoil	722.3	174.2	103.5
	Subsoil	704.3	167.2	128.5
PAH	Topsoil	713.0	157.4	129.6
	Subsoil	704.3	171.2	124.5
AFT	Topsoil	704.5	182.4	113.1
	Subsoil	694.8	192.0	113.2
Control	Topsoil	760.0	123.0	117.0
	Subsoil	762.0	113.0	125.0

(sandy loam). The particle size fractions measured change during the period of study. In general, there was no evidence of change in their distribution after two cropping seasons.

This observation is encouraging since the cropping systems were established by farmers to reduce erosion conserve to the soil. As the cropping systems contained plant species which shed some of their the various cropping systems had same textural class leaves regularly, the resulting litter may have reduced surface

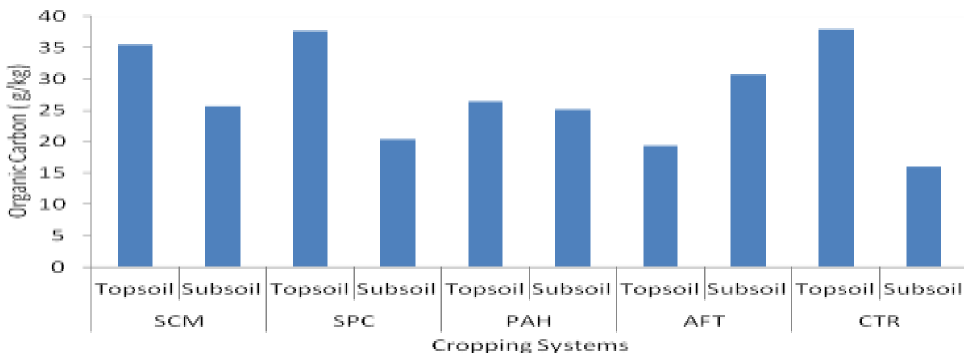

Figure 1. The amount of organic carbon (OC) in the topsoil (0-15 cm) and subsoil (15-30 cm) as influenced by the cropping systems.

runoff and prevented dislodgement and removal of fine soil particles. In addition, the no-till strategy adopted may have contributed in preserving the soil.

Chemical properties (organic carbon, pH, exchangeable bases, total phosphorus, and total nitrogen)

The organic carbon content of the topsoil of the SPC or SCM system was similar to the control which had secondary vegetation that remained untouched during the experimental period but higher than that of the PAH or AFT system (Figure 1). More organic carbon was measured in the topsoil than in the subsoil in all the cropping systems except AFT whose topsoil contained the lowest amount.

The value of organic carbon is an indication of the soil organic matter (SOM) content in agricultural soils (Obigbesan, 2000). The observed organic carbon content suggests that SOM was not negatively affected by the activities conducted in these cropping systems. Both SPC and SCM systems had 3-year old cocoa trees at the beginning of the experiment which may have contributed to the replenishment or maintenance of the organic carbon content through its litter. The reason for the relatively low amount of organic carbon measured in the topsoil of the AFT system is unclear since it contained kola nut trees that would shed its leaves and contribute to SOM upon decomposition; the amount of litter in each of the cropping systems was, however, not quantified in this study.

It was observed that the pH the topsoil at the commencement of the study was either slightly acidic or nearly neutral in all the cropping systems while that of the subsoil of all the systems varied from neutral to slightly alkaline except the control field which had a near neutral pH (Table 2). However, results showed that after the two cropping seasons, the pH of the subsoils of all the cropping systems had become neutral or slightly alkaline. Although it has been reported that agricultural practices such as zero tillage which contribute to SOM build up also promote soil acidity (Adepetu et al., 2014), the no-till strategy adopted in this study did not reduce the pH of the soil. For example, in the systems (SPC and SCM) where the amount of organic carbon in the topsoil was relatively high and comparable to the control, and given that zero tillage was employed, the soil did not become acidic. This assertion is supported by the pH (measured in water) of the soil which ranged between slightly acid to neutral before cropping and ranged between neutral to slightly alkaline after cropping.

Data on exchangeable bases and acidity measured on samples taken just before the commencement of the experiment are shown in Table 3. In the topsoil, exchangeable Ca varied from 4.5 to 12 Cmol kg^{-1} among the cropping systems whereas the variation in quantity of exchangeable Mg was not wide. The cropping systems also had similar amounts of exchangeable K and Na in the topsoil. The amounts of these nutrients in the cropping systems did not change appreciably after two cropping seasons (Table 4). Thus, the concentrations of these nutrient elements were somewhat stable during the study period probably due to addition of organic matter to the soil through fallen leaves and dead roots. However, the concentrations of most of the measured cations generally fall within the low range (Adepetu et al., 2014) except those of the SPC (topsoil) and AFT (subsoil) cropping systems that were within the medium class. Considering the critical limits of soil nutrients reported by Aderonke and Gbadegesin (2013), the amount of exchangeable K was generally in the medium range. Nevertheless, the low levels of exchangeable cations indicate the need for adequate soil management in all the cropping systems to boost the productive capacity of the soil. Cation exchange is important in soil as it controls

Table 3. Levels of exchangeable cations and acidity in the top-soil (0 - 15 cm) and sub-soil (15 - 30 cm) layers before the experiment.

Treatment	Depth	Ca	Mg	K	Na	Acidity
		←--------------------- Cmolc kg^{-1} --------------------→				
SCM	Topsoil	8.38	1.20	0.38	1.20	0.38
	Subsoil	6.28	1.20	0.30	1.30	0.80
SPC	Topsoil	12.2	1.19	0.48	1.48	0.95
	Subsoil	3.20	0.90	0.20	1.20	0.71
PAH	Topsoil	6.80	1.10	0.42	1.60	0.70
	Subsoil	6.61	1.80	0.92	1.51	0.32
AFT	Topsoil	4.56	1.82	0.50	1.40	0.32
	Subsoil	10.62	3.18	0.60	0.90	0.35
Control	Topsoil	10.00	0.98	0.42	1.36	1.20
	Subsoil	10.10	1.06	0.42	1.36	1.20

Table 4. Levels of exchangeable cations and acidity in the top-soil (0 -15 cm) and sub-soil (15-30 cm) layers after the two seasons.

Treatment	Depth	Ca	Mg	K	Na	Acidity
		←--------------------- Cmolc kg^{-1} --------------------→				
SCM	Topsoil	8.41	1.17	0.42	1.31	0.40
	Subsoil	6.34	1.18	0.23	1.48	0.30
SPC	Topsoil	13.07	1.21	0.52	1.62	0.60
	Subsoil	3.18	0.81	0.18	1.10	0.60
PAH	Topsoil	6.89	1.13	0.46	1.54	0.60
	Subsoil	6.66	1.93	0.85	1.54	0.30
AFT	Topsoil	4.52	1.93	0.46	1.38	0.40
	Subsoil	11.65	3.13	0.63	0.84	0.34
Control	Topsoil	10.10	1.12	0.54	1.42	1.16
	Subsoil	9.89	1.24	0.44	1.44	1.20

availability of nutrients to plants, prevents leaching of the nutrients, and ensures their release for plant uptake; low levels of exchangeable cations are usually attributed to leaching and soil erosion (Negassa, 2001). But in this study, soil erosion was minimal as there was no significant redistribution of particle size fractions.

The topsoil of the SPC and SCM systems contained more total P than the topsoil of the other systems as well as the control (Figure 2). The amount of total P in the subsoil was generally lower than in the topsoil in all the cropping systems except AFT. The results indicated that total P varied between 0.068 to 0.273% (mean = 0.184%) in the topsoil and between 0.095 to 0.147% (mean = 0.118%) in the subsoil. These mean values could translate to 1.84 g kg^{-1} for the topsoil and 1.18 g kg^{-1} for the subsoil. The amounts of total P in the topsoil of the

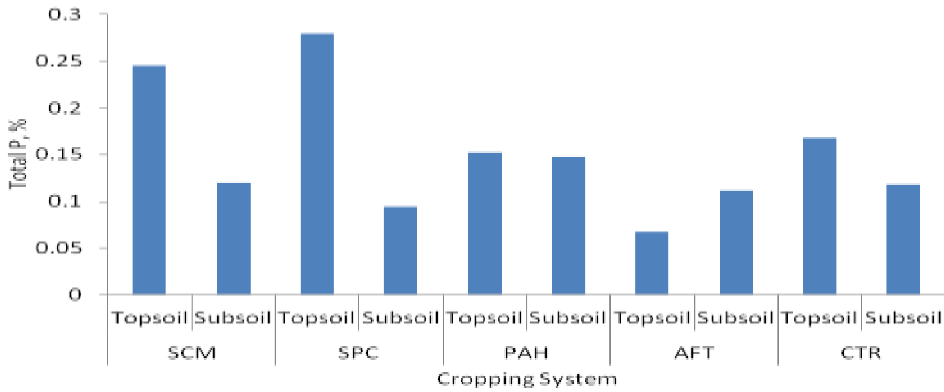

Figure 2. The amount of total P in the topsoil (0-15 cm) and subsoil (15-30 cm) as influenced by the cropping systems.

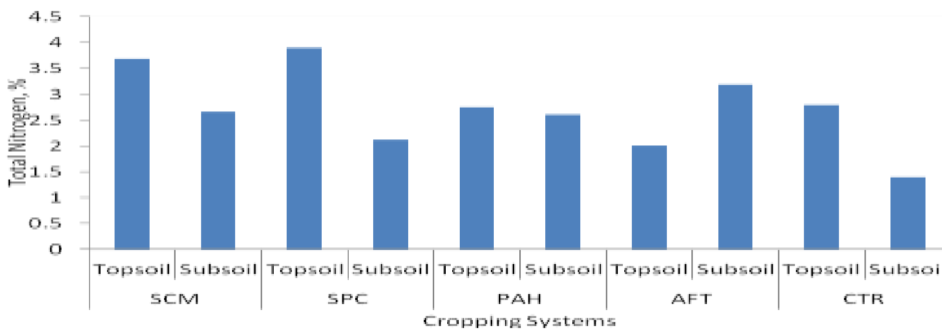

Figure 3. The amount of total nitrogen in the topsoil (0-15 cm) and subsoil (15-30 cm) as influenced by the cropping systems.

studied cropping systems are relatively high when compared with other soils. For example, the amount of total P in the top layer of some soils in the study region has been reported to vary from 90 to 198 mg kg^{-1} (Nwoke et al., 2004). The relatively high total P content observed in this study might be due to organic matter input from the associated trees and could buffer P in soil solution for uptake by growing crops.

The concentration of total N in the topsoil of the cropping systems varied from 0.201 to 0.390% while 0.212 to 0.319% in the subsoil (Figure 3). The trend was similar to that of total P; similar amounts were measured in the topsoil of the SPC and SCM systems and these were higher than the amount measured in the other systems. The results indicated that soil nitrogen is relatively high in these cropping systems based on a scale for maize production reported by Aderonke and Gbadegesin (2013). The authors had classified soil nitrogen > 0.15% as high, and the total N content of the topsoil in the present study was greater than this even in the control treatment probably due to addition of organic matter (that is plant litter).

Conclusion

Data on soil nutrient concentrations and the apparent stable particle size fractions after two cropping seasons suggest that, these cropping systems have the potential to minimise erosion and reduce soil deterioration. However, the differences in the total N and P, and organic C contents among the cropping systems necessitate further studies to develop appropriate management strategies to optimise the benefits that might be derived from the cropping systems.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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