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Pitout JDD, Church DL, Gregson DB, Chow BL, McCracken M, Mulvey M, Laupland KB (2007). Molecular epidemiology of CTXM-producing Escherichia coli in the Calgary Health Region: emergence of CTX-M-15-producing isolates. Antimicrob. Agents Chemother. 51: 1281-1286.

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Review

Approaches for the control of banana *Xanthomonas* wilt in East and Central Africa

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The livelihoods of millions of banana farmers in East and Central Africa have been threatened by the devastating epidemic of banana *Xanthomonas* wilt (BXW) caused by *Xanthomonas campestris* pv. *musacearum*. The disease is widespread and has been reported in East and Central Africa. The economic impact of the disease emanates from loss of yield and cost of control measures. All banana cultivars grown in the region are susceptible to BXW and no source of resistance has been identified. Cultural interventions are therefore the most practical and recommended practices for BXW control. A number of approaches: farmer field schools, community action, going public and top-down conventional approaches (traning of trainers, mass media and posters) have been used to mobilize stakeholders in Kenya, Uganda, Rwanda, Tanzania and Democratic Republic of Congo. Different approaches have been used in different countries with varied success in controlling BXW. This review discusses approaches, which have been successfully used in the management of BXW in some areas of East and Central Africa with a view of evaluating them individually or in combination under local conditions. This hopefully will help scale-out the promising approaches and contribute to more effective BXW control in the region.

Key words: Banana *Xanthomonas* wilt, disease management approaches, Eastern and Central Africa.

INTRODUCTION

The communities of the Great Lakes of Eastern and Central Africa have traditionally depended on a perennial banana cropping system for food and income (Karamura et al., 2008). This slow-changing farming system has ensured regional food security for many centuries. The system has come under stress due to progressive decrease in farm size, land fallow periods and production. This is mainly due to biotic threats particularly weevils, nematodes, fungal and viral diseases. On farm, such pests and diseases were traditionally managed by

exploiting exisiting differences in cultivar tolerance. Although there was reduced productivity, farmers maintained reasonable levels of food and income security. However, following the arrival of banana *Xanthomonas* wilt (BXW) caused by *Xanthomonas campestris* pv. *Musacearum*, in the great lakes region in 2001, entire crop holdings were wiped out in some areas where highly susceptible genotypes were dominating the farming systems ((Tushemereiwe et al., 2004, Karamura et al., 2006). Different approaches have been used

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across the region to control BXW with varied success. For example, in the major banana growing areas in Uganda, BXW incidence remained below 5% for about 4 years (Tushemereirwe et al., 2006). In addition, in areas around the lake Victoria zone of Tanzania and Northern Rwanda, the spread of BXW was relatively reduced. Successful control of disease and pest epidemics is only possible if effective technologies are deployed together with institutional approaches that efficiently mobilise stakeholders. This review documents technological and institutional approaches that contributed to successful control of BXW in some areas, which may be validated and scaled out in the region.

Technical aspects of BXW control

There is no resistance to BXW so far reported among the local *Musa* germplasm in East and Central Africa (Ssekiwoko et al., 2006; Ndungo, unpublished). Therefore, the control strategies for BXW are based on cultural practices. However, the design and successful implementation of disease control programme based on cultural practices requires a clear understanding of the etiology and epidemiology of the disease (Thresh, 1980). Furthermore, critical factors that influence pathogen reproduction, survival, propagation, selection and evolution of more virulent strains must be understood (Jeger, 2004). This review provides a detail of the technologies used for control of BXW together with underlying epidemiological logic, which the farmers or other recipient stakeholders need in order to make informed decisions.

Prevention of introduction of BXW into uninfected fields

Introduction of pathogens to new locations and fields may be attributed to the use of pre-infected planting material or movement of vectors from remote infected sources (Cabaleiro and Segura, 1997). Currently, there are no quick screening techniques in the region for the planting materials (Karamura et al., 2008). Therefore, in locations where bananas have completely been cleared especially by BXW, strategies for large scale production of affordable clean planting materials are urgently needed to supplement the limited macro and micro-propagation technology already available.

Early removal of the malebud is an effective means of preventing the spread of BXW by insect vectors (Tinzaara et al., 2006). Removal of malebuds is recommended for both affected and unaffected fields. Using a forked stick, the malebud is removed as soon as the last cluster on banana flower is formed, that is, at about two weeks after emergence of the inflorescence. A forked stick rather than the commonly used cutting tool should be used because the stick can only contaminate should

the broken bud. As such, there is no exchange of plant sap between banana plants on which the forked stick has been used and therefore no risk of spreading BXW between the plants. This technique is a preventive measure that effectively blocks the spread of BXW infection via insect vectors from within and without field.

Some banana cultivars do not have persistent neuter flowers. Other cultivars have persistent or semi-persistent bracts which do not easily break and thus escape insect vectored BXW spread. In a few extreme cases, deployment of cultivars such as scambia which do not have a male bud, but are tested for juice production, yield and farmer acceptability, may reduce the cost of removal of male buds and therefore the control of BXW cost effectively.

Management of initial inoculum from the banana field

Once BXW infection has been detected in a banana field, infected plants are the source of inoculum. In addition to removal of malebuds, farmers are advised to remove infected plants and disinfect tools that have had contact with infected plants (Tushemereirwe et al., 2004). Some farmers rouge the whole stool once they find an affected plant on them. Others remove the only infected plants from the affected stool. At the beginning of the BXW epidemic in Uganda, rouging the whole affected stool was recommended (Tushemereirwe et al., 2004). Overtime the recommendation changed to single stem removal (that is, removing infected plants only from the stool). This was after it became evident that the process of rouging whole stools was extremely labour intensive and it was possible to only remove infected plants from the affected stool and save the remaining uninfected plants from disease infection on the same stool. This was possible because most BXW infection starts from the upper parts of the plant on the inflorescence and takes some time to get to the lower parts of the plant (Ssekiwoko et al., 2006). If the infected plant is carefully removed from the stool before infection gets to the corm, it is possible to save other plants on the stool from BXW infection (Turyagyenda et al., 2006). Single stem removal has also been evaluated and found to be effective in control of BXW in Kenya and DRC (Kubiriba et al., 2014). Furthermore, after cutting infected banana plants, farmers may leave banana refuse on the ground. It had been previously recommended to burry all banana refuse (Tushemereirwe et al., 2004). However, no *Xcm* was isolated from refuse of infected banana plants after 5 days even when they were left on the ground (Mwebaze et al., (2006). As long as rotting conditions are created, Xcm seems to compete poorly with other organisms involved in the rotting process of the banana refuse. This suggests that formerly affected fields can be replanted after 3months without risk of reinfection from old inoculum. However, a minimum of 6 months have been recom-

mended to completely remove the risk of reinfection in previously infected fields. It is impotant to note that the survival of the bacterial is dependent on ecological conditions of different areas therefore it may be necessary to validate this recomendation before its application.

Management of incubating BXW infection

In tool-mediated infection, movement of the disease within the plant is dependent on the site of infection and this can be the roots, leaves, the inflorescence or the stem. During the incubation period, suspending the use of cutting tools in infected fields was key in the control of BXW (Tushemereirwe et al., 2006). The epidemiological basis for this practice is that, when a plant is infected with BXW, it shows symptoms within 3 months. Meanwhile, if infected plants are continuously removed, the number of infected plants will gradually reduce until no more infected plants are identified. During the 3 months incubation period, if pruning is discontinued, *Xcm* will not spread from infected plants with incubating BXW infection to unaffected plants. As a result, the disease outbreak is then effectively controlled. However, all preventive measures have to be applied continuously to prevent reintroduction of the bacteria.

Disinfection of tools

Disinfection of cutting tools used for pruning trash off the plants or after removing infected plants limits mechanical spread of BXW. The Xcm was detected on cutting tools kept at room temperature up to 22 days (Buregyeya, 2010). During that period, BXW is spread from the tools to banana plants up to 18 days. This implies that if traders who collect bananas from fields that are hundreds of kilometres apart do not disinfect the tools between plants and farms, they can spread BXW over long distances. Cutting tools may be disinfected by burning directly on a fire flame or cleaning with commercial JIK (sodium hypochloride).

Institutional approaches for stakeholder mobilisation

Conventional approaches

Every stakeholder in the banana value chain should be engaged in the battle against BXW. Subsistence farmers, who form the majority of farmers in the region, have substantial difficulty in managing plant diseases (Sherwood, 1997). This is partly because they cannot see the organisms that cause the plant diseases (Nelson et al., 2001). It is therefore important to package the message in a clear and concise manner stating the epidemiological underpinnings, negative impact of failure to implement the

intervention as well as the benefits of such interventions to the individual farmer and the larger community. The choice and design of the communication strategies should take into account the dynamics of the target area such as literacy levels, numbers of radio receivers and availability of extension support. The strategies would include training of trainers, posters, pamphlets, leaflets, brochures and billboards designed to suit the levels of literacy and other socio-economic dynamics in the target community. Whereas this approach, which is widely used in the region is instrumental in swiftly raising awareness of stakeholders about the disease across countries, it is ineffective in triggering actions to control the disease (Tushemereirwe et al., 2006).

Participatory approaches

In the conventional approaches of stakeholder mobilization, pest and disease epidemic control programmes begin with generation of technologies and most often stop at dissemination of information to the farming communities, hoping that the recipients will use the information to control the epidemics (Hawkins et al., 2009). The awareness campaign deployed in Uganda was successful with more than 85% of the banana farmer knowing how to identify BXW, how it spreads and how it is controlled (Bagamba et al., 2006). However, only 30% of the farmers were undertaking BXW control (Tushemereirwe et al., 2006). It is possible to improve on the proportion of farmers that adopt control measures at community level using participatory approaches.

Participatory development communication

Participatory development communication (PDC) is the use of communication to facilitate community participation in a development initiative such as control of BXW (Bessette, 2004). Deploying PDC facilitates dialogue among the different stakeholders around a common problem has the aim of developing and implementing an action plan to solve the problem. The approach follows the following steps:

1. Members of the community and their leaders are brought together to discuss the BXW problem with facilitation of a PDC resource person.
2. The community members explore and discuss alternative ways of controlling BXW and identify the appropriate practices they can implement.
3. The community members develop an action plan to tackle the BXW problem.
4. The community agrees on the mechanism for implementing the formulated action plan.
5. The action plan is executed with various stakeholders in the community given roles and responsibilities to see

that the agreed action plan is properly implemented in time and space.
6. The community also agrees on how to monitor and evaluate activities for disease control as part of the action plan.
7. The community agrees on how to share successful outcomes.

The key output of the above process is the formulation and implementation of an action plan for the control of BXW (Table 1). The action plans may be at community level, sub-county, district and national levels. In locations where PDC approaches were religiously implemented, the incidence of BXW was drastically reduced (Figure 1). In the communities of Lake zone, Tanzania, PDC or its modification was also used with some success in controlling BXW (Mgenzi et al., 2006).

Farmer field schools (FFS)

Farmer field schools empower farmers to learn in an informal setting within their own environment. The FFSs are schools without walls where groups of farmers meet weekly with facilitators. It is a participatory method of learning, technology development and dissemination based on adult learning principles. The approach uses experiential learning and a group approach to facilitate farmers in making decisions, solving problems and learning new techniques. The concept is based on farmer participatory discovery approach for improving decision-making capacity of farming communities and stimulating local innovation for sustainable agriculture. The school involves 25 – 30 farmers. The group dynamics contribute towards team building and organizational skills. The FFS approach has successfully been used in Kenya, Uganda and Tanzania (Davis, 2008)

Farmer field schools with BXW control

The FFS approach was employed in controlling BXW in Uganda between 2006 and 2008. The process started with training of trainers (TOT). In this TOT, it was emphasized to the facilitators that:

1. It is not possible to improve banana production with their farmers' groups unless BXW was eradicated. It was agreed that BXW is enemy number one to the banana crop; which should be eradicated quickly to allow the FFS time to deal with other banana constraints.
2. The cultural package for control of BXW is effective, giving experiences of successful control.
3. The farmers should know how to identify infected plants and how BXW is spread through Agroecosystem analysis (AESA). This then would help them to explain the logic behind the recommended practices, not only for

enhanced adoption but also modification of the practices where applicable.

The FFS were thereafter established in 50 subcounties in five banana growing districts of Mbarara, Kiboga, Mukono, Kamuli and Lira. By April 2008, BXW had been significantly reduced in all the groups of participating farmers (Figure 2). In subcounties or districts hosting FFS, other farmers soon started controlling BXW thus spreading the efforts. In areas such as Lira district, where control of BXW had been difficult for the national disease control efforts, FFS were islands of effective control in a sea of no compliance in BXW control. The FFS approach is invaluable where some recommended technologies may not work in new locations and therefore must first be tested, validated and adapted locally. The FFS approach has potential benefits because it is cheap, flexible, incorporates farmers' aspirations and empowers them. In addition, FFS approach has an in-built monitoring and evaluation mechanism and it can be integrated with other research/development approaches.

DISCUSSION

Effective disease control is possible if effective technologies are generated and promoted together with institutional approaches that effectively mobilise stakeholders who use the technologies (Kubiriba et al., 2012). The cultural practices reviewed in this paper were formulated with information generated from epidemiological studies in Uganda with participation of various partnerships from both local and International Research Institutes and Universities (Tushemereirwe et al., 2006). Other stakeholders from Government and Non-Government Organisations involved in rural development also contributed to the planning, generation and promotion of these technologies. In some locations, farmers sometimes modified recommended practices to suit their conditions (Bagamba et al., 2006). Experiments were established to scientifically validate such technologies and valuably improved development of appropriate technology e.g. single stem removal (Ssekiwoko et al., 2006). The technologies for the control of BXW proved effective in all areas where they have diligently and consistently been deployed (Tushemereirwe et al., 2006). Although most of the recommended practices may have region-wide applicability, most of them were ecology specific and may therefore need to be validated for customization to the local ecological conditions.

Accessibility to improved technologies for disease control influences a farmers' knowledge and their decision to control plant diseases (Sherwood, 1997). The farmers should be provided with correct information that enables them to make more effective action decisions. Bentley and Thiele (1999) showed that too much information would cause needless confusion, while oversimplification of concepts would not be effective in improving disease

Table 1. Action plan executed by communities to control BXW in Rugando, Mbarara District.

Goal	Objectives	Activities	Time frame				Target	Resp. Person	Budget unit cost		Source of funds
			March - June 2005	July – September 2005	October - December 2005	January - June 2006			Item	Amount	
To eradicate BBW from Rugando Sub-county	Create awareness about BXW in Rugando	Conduct sensitization workshops	X				Technical staff/local leaders	DPC & DAO	Facilitation Stationery Announcements	100,000= 20,000= 50,000=	District
		Training farmers	X	X	X	X	Community	AO & SC leaders	Fuel SDA Stationary Posters	60,000= 60,000= 15,000=	NGOs S/county
	Mobilize and organize farmers for community action for effective control of BXW	Formulate and enforce community bye-laws - village meetings	X	X			Affected villages	AO & Community leaders, TF	Fuel SDA Stationary	50,000= 40,000= 10,000=	S/county
		Organize farmers to effect BBW control – village meetings	X	X			Affected villages	AO & Community leaders, TF	Fuel SDA JIK Posters	100,000= 60,000= 9,000=	S/county APEP
	Effectively supervise and monitor the BXW control activities	Formulation of Taskforces	X				Affected villages	AO & community leaders, TF	Fuel SDA Stationary Posters	100,000= 30,000= 15,000=	S/County
		Supervise implementation of control measures	X	X	X		Affected villages	AO & community leaders, TF	Fuel SDA Stationary	60,000= 40,000= 10,000=	S/County APEP District
		Tracking new outbreaks/ infections	X	X	X	X	All villages	Community	-	-	-
	Ensure sharing of information	Organize exchange visits			X	X	Community and other stakeholders	Community	Fuel SDA Stationary	100,000= 80,000= 20,000=	NGOs S/County
									Total	**884,000=**	

DPC = District Production Coordinator; DAO = District Agricultural Officer; AO = Agricultural Officer; TF = Taskforce; NGOs = Non-governmental Organization; S/county = Sub-county. The action plan was totally facilitated by funds locally mobilized. To date no plant infected with BXW has been sighted in the Rugando sub-county, Mbarara for over 12 months.
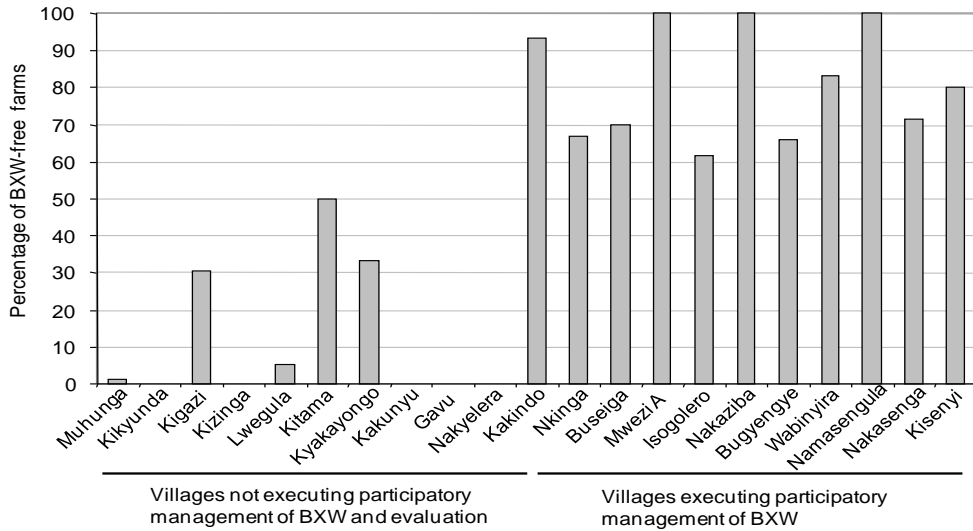
Figure 1. Success of participatory management of banana *Xanthomonas* wilt within one year in different villages in Uganda.
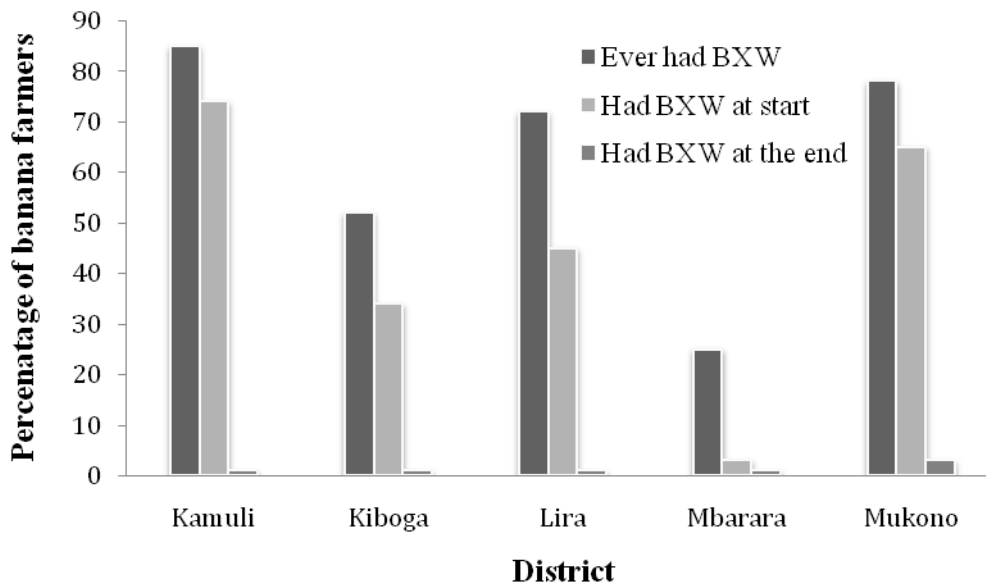
Figure 2. Level of BXW control in communities hosting farmer field schools in Uganda.

management. Research and extension agents too often use scientific terminology-laden approaches in information dissemination; they do not attempt to explain the disease life cycles to farmers, thereby underestimating the farmers contribution as key to unlocking the mystery of the disease. This problem was circumvented by involvement of various stakeholders (including the end users) in packaging information and selecting dissemination pathways (Ngambeki et al., 2006). Following the massive and aggressive awareness campaigns in Uganda, over 80% of the banana farmers knew BXW - its diagnosis, spread and means of control (Muhangi et al., 2006).

Information materials developed from this process have been revised and further translated into different languages including Swahili and French used in all the 6 ECA countries (Karamura et al., 2006). The impact of using such information should be assessed to enable more appropriate modifications where necessary.

Despite the fact that most banana farmers knew how to control BXW from the awareness campaigns, only 30% utilized the knowledge to effect BXW control (Tushemereirwe et al., 2006). In order to address this problem, participatory approaches reviewed in this paper were used. The key elements of participatory approaches

included getting communities together, facilitating them to formulate and implement action plans, mobilizing political and other leaders to support community efforts and ensuring their effective monitoring and evaluation were all important BXW control.

As a result, it was possible to control BXW to below 5% in important banana growing areas in Uganda for over 3 years while more than 90% of the farmers participating in FFS controlled the disease in their fields and their communities (Kubiriba et al., 2012). In future, the stakeholders in ECA who may use these participatory approaches needed to continuously evaluate their effectiveness and to make the necessary modifications to suit end user situation without compromising the key principles.

CONCLUSION

A number of management options and approaches for the control of BXW have been explored. However, no single management option can effectively control the disease. Successful control of BXW and possibly other epidemics is only possible by deploying effective technologies together with participatory approaches that effectively mobilize stakeholders for the control of the epidemic. While generation of technologies that effectively control BXW is mainly the role of researchers, other elements for successful control of BXW are roles of different stakeholders including local leaders (political and opinion leaders), extension officers (both governmental and non-governmental organizations) and farmers.

The East and Central African regional partners under the Crop Crisis Control Project (C3P), Association for strengthening Agricultural Research in Eastern and Central Africa (ASARECA) project used these approaches to control BXW in 6 countries: Uganda, Tanzania, Kenya, Rwanda, Burundi and Democratic Republic of Congo. A remarkable reduction in the incidence of BXW has been recorded in most of the pilot areas. Approaches that have registered successful disease control need to be carefully evaluated and scaled out in order to effectively control BXW in the region. This will only be possible with the support of all key stakeholders including policy makers at regional and national levels.

Conflict of Interests

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

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Full Length Research Paper

Acute toxicity effects of dichloromethane fraction of ethanol extract of stem bark of *Piliostigma reticulatum* on rats

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The aim of this study was to investigate the oral acute toxicity effects of dichloromethane fraction of ethanol extract of stem bark of *Piliostigma reticulatum* on rats using conventional methods. The rats were divided in nine groups. The control group received normal saline. The others groups received the order of doses of 800, 1000, 2000, 3000, 4000, 5000, 6000 and 7000 mg/kg body weight. However, the rats showed signs of immobility with the dichloromethane fraction at doses of 5000 mg/kg body weight and mortality at doses of 2000 mg/kg body weight. The LD50 was 3000 mg/kg body weight and the quotient LD5/LD95 was 0.17. This value shows that the toxic dose and the therapeutic dose were not distant. Phytochemical screening revealed the presence of tannins, flavonoids, polyphenols and reducing sugars in the stem bark of *P. reticulatum*. These results suggest that dichloromethane fraction of the ethanol extract of stem bark of *P. reticulatum* could be used with some degree of safety especially by oral route.

Key words: Acute, toxicity, stem, bark, *Piliostigma reticulatum*, rats.

INTRODUCTION

Hundreds of years ago, plants were known to play mainly nutritional roles. Today they play an additional important function in treatment of diverse pathologies. Plants, although pharmacologically active, are used without knowledge of toxicological parameters. For this reason, the World Health Organisation approved the use of herbal products for national policies and drug regulatory measures in order to strengthen research and evaluation of the toxicity of these products (Saxena, 2001). Thus, the toxicity of certain plants has been shown in many studies. For example, the acute toxicity of *Anogeissus leiocarpus*, *Daphnia magna* and *Cansjera rheedii* has

been studied respectively by Agaie et al. (2007), Altindag et al. (2008) and Mounnissamy et al. (2010).

Piliostigma reticulatum which is the object of our study is traditionally used in Côte d'Ivoire for diarrhoea including bacterial diarrhoea (Yelemou et al., 2007; Dosso et al., 2012). Thus Babajide et al. (2008) have shown that the piliostigmol (6-C-methyl-2-p-hydroxyphenyloxychromonol), a substance isolated in *P. reticulatum,* inhibited *Escherichia coli* with a MIC equal to 2.57 µg/mL. In our previous study, results showed that an ethanol extract of the stem bark of *P. reticulatum* significantly reduced the gastrointestinal transit, the number, volume and weight of faeces of rats (Dosso et al., 2012). Also, the extract was not toxic in rats. In the present study, the aim of the current investigation was to determinate the toxic effects of the dichloromethane fraction of a crude ethanol extract of the stem bark of *P. reticulatum* on rats as well as to screen its phytochemical constituents.

MATERIALS AND METHODS

Plant collection

Stem barks of *P. reticulatum* (DC.) Horscht (Ceasalpiniaceae) were collected in Abidjan (South region of Côte d'Ivoire) in October 2007. The plant was identified and authenticated by Pr AKE-ASSI Laurent. A voucher specimen (No. 18033) of the plant has been deposited in the herbarium of the National Centre of Floristic of University of Cocody-Abidjan.

Preparation of dichloromethane fraction

Stem barks of *P. reticulatum* were washed with distilled water, cleaned, cut into smaller pieces and kept at room temperature for two weeks. Then they were ground into a fine powder. The powder (100 g) was extracted with two liters of a solution of ethanol (96%) / water (80:20) for 24 h under constant stirring (this operation was repeated twice).

The extract was filtered twice through cotton wool, then through Whattman filter paper (No 1). The filtrate was evaporated to dryness using a rotavapor (Buchi R110/NKE6540/2) at 45°C, and dried under reduced pressure. Percentage yield was found to be 13.6%.

After successive liquid-liquid fractionations, five fractions (heptane, dicloromethane, ethyle acetate, butanol and water) were obtained from the crude ethanol extract (Harborn, 1984; Samsam-Shariat, 1992).

Animals

Healthy young adult albino Wistar rats (weighing 150-200 g) of both sexes that were provided by UFR Biosciences (University of Cocody-Abidjan, Côte d'Ivoire) were housed in standard metal cages. They were kept under standard laboratory temperature conditions one week before the experiments for acclimation. The animals were fed with a diet of commercial pellets (Ivograin®, Abidjan, Côte d'Ivoire) and were given water *ad libitum*. They were deprived of food for at least 18 h prior to experiments but allowed free access to drinking water. The equipment usage and handling and sacrificing of the animals were in accordance with the Euro-

pean Council legislation 87/609/EEC for the protection of experimental animals (Mitjans, 2008).

Acute toxicity studies

Fifty forth albino rats were divided into nine groups of six rats each and were given graded doses (800, 1000, 2000, 3000, 4000, 5000, 6000 and 7000 mg/kg body weight) of the fraction by oral route. The rats were observed for signs of toxicity and death over a period of 72 h as described by Lorke (1983). The first group received single oral dose of 2 ml of normal saline through the same route. The LD_5, LD_{50} and LD_{95} of the fraction were calculated using the arithmetic method of Karber as modified by Aliu and Nwude (1982).

Phytochemical analysis of the fraction

The dichloromethane fraction was screened for the presence of tannins, flavonoids, alkaloids, sterols, saponins, polyphenols, polyterpenes and anthraquinones. Detection of these constituents was performed according to Bekro et al. (2007).

RESULTS

Phytochemical analysis of the fraction

Phytochemical screening tests of dichloromethane fraction for various constituents revealed the presence of major components such as tannins, polyphenols and flavonoids. Reducing sugars were present, and anthraquinones, alkaloids, coumarins, polyterpenes and sterols were absent.

Acute toxicity studies

The results in the Table 1 show that with the dichloromethane fraction at doses of 800 to 4000 mg/kg body weight, the survival animals are mobile. At the dose of 5000 mg/kg body weight, we observed the immobility of rats. Also the animals began to die at dose of 2000 mg/kg body weight. At dose of 1000 mg/kg body weight, we had 0% of mortality. The LD_{50} (50% of mortality) is 3000 mg/kg body weight. Also, at the dose of 7000 mg/kg body weight, 100% of animals did not survive with dichloromethane fraction (Tables 1 and 2). The DL_5 and DL_{95} are respectively 1118 and 6425 mg/kg body weight (Figure 1). The quotient DL_5 / DL_{95} reports 0.17. This result is far from 1.

DISCUSSION

The study of the acute toxicity of dichloromethane fraction showed that the LD_{50} is equal to 3000 mg/mL body weight. Animals showed toxicity signs in a dose-dependent manner. Also, at a dose of 7000 mg/mL, there were no survivors. The results obtained with the dichloromethane fraction, are consistent with those of Diallo and

Table 1. Acute toxicity signs observed in rats after treatment with dichloromethane fraction.

Dose (mg/kg body weight)	Acute toxicity signs	
	mobility	Death
800	+	–
1000	+	–
2000	+	+
3000	+	+
4000	+	+
5000	–	+
6000	–	+
7000	–	+

Table 2. Percentage of mortality in rats treated with dichloromethane fraction.

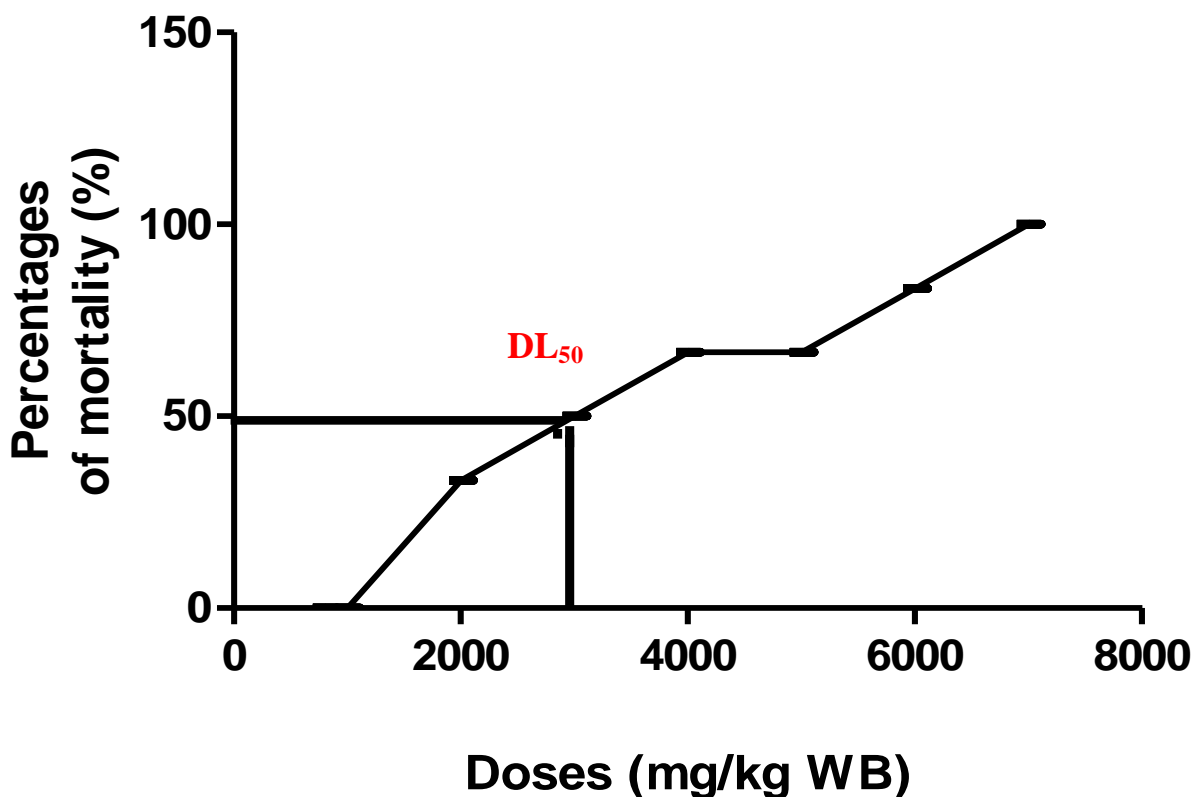| Group	Number of animals	Dose (mg/kg body weight)	Number of death	Mortality (%)
1	6	800	0	0
2	6	1000	0	0
3	6	2000	2	33.33
4	6	3000	3	50
5	6	4000	4	66.67
6	6	5000	4	66.67
7	6	6000	5	83.33
8	6	7000	6	100

Figure 1. Evolution of mortality percentage in rats treated with dichloromethane fraction.

Diouf (2002) which showed that the LD_{50} of the aqueous extract of *Piliostigma reticulatum* leaves in rats was 1700 mg/mL body weight. The leaves of this plant therefore center more toxic substances in the leaves than stem bark. The LD_{50} obtained with our active fraction is higher than that obtained with the aqueous extract of the leaves. Agaie et al. (2007) studied the acute toxicity of aqueous extract of leaves of *Anogeissus leiocarpus* rats and was near 1200 mg/kg body weight like LD_{50}. This plant is more toxic than that used in our studies with a low LD_{50}. The study of the toxicological properties of the latex of *Calotropis procera* yielded approximately a LD_{50} like 2611.75 mg/kg body weight (Lohoues et al., 2006). The latex of *Calotropis procera* focuses more toxic substances than the dichloromethane fraction.

The quotient DL_5 / LD_{95} (0.17) is far from 1. These results indicate that the use of this fraction is not safe in its therapeutic use with the understanding that the therapeutic dose is not distinct from its toxic dose (Tamboura et al., 2005). These results are contrary to those obtained by Lohoues et al. (2006). According to these authors, the DL_5 / DL_{95} quotient in the study of the acute toxicity of the latex of *C. procera* was 0.71 - 1. The therapeutic dose of this product is distinct from the toxic dose. The latex of this plant is probably non toxic.

After administration of the fraction of plant, immobility and death of animals are observed at high doses. These clinical manifestations had been also reported by Lohoues et al. (2006) in the study of the acute toxicity of the latex of *C. procera* in Côte d'Ivoire.

The phytochemical screening of dichloromethane fraction showed the presence of flavonoids, tannins, polyphenols and reducing sugars. Our tests have not revealed the presence of alkaloids, quinones, coumarins, saponins, sterols and polyterpenes. Phytochemical studies by Kubmarawa et al. (2007) on the aqueous extract of the roots of *P. reticulatum* showed the presence of chemical compounds such as saponins, tannins and flavonoids. Contrastingly, chemical compounds in the same plant could be explained by the different organs used in the studies or the difference of natural environments. Thus, we observed a variation of secondary metabolites in the same plant according the living environment (Sofowora, 1996).

The active compounds observed in the stem bark of *P. reticulatum* could explain the toxicity signs in rats. Thus, when in excess in the body, certain chemical compounds may exceed their therapeutic activities, incite some malfunctions or lethal disorders (Lohoues et al., 2006). For example, astringent tannins have a role in reducing foods in animals (Alldredge, 1993; Agaie et al., 2007). This causes weakness in animals leading to immobility. Polyphenols are endowed with surfactant and hemolytic properties (Lohoues et al., 2006).

Thus, according to the same authors, compounds that are swallowed or even inhaled, are known to cause, among others, digestive tract burns, cyanosis, hypoxia and seizures.

Schultz and Riggin in 1985 stated in this regard that the phenol poisoning lead to death by acute respiratory failure. These could have caused immobility and death of the animals in our study.

Conclusion

Our results show that the stem bark of *P. reticulatum* contains toxic natural substances. These could be due to chemical constituents observed in dichloromethane fraction like tannins, flavonoids, reducing sugars and polyphenols.

It will be necessary to eliminate the probable toxic substances in dichloromethane fraction. Thus, the fraction could be used to treat diarrhea without risk. Also, the use of aerial parts of the plant could represent an alternative to the utilization of its roots, therefore limiting the biodiversity degradation.

Conflict of Interests

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

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Full Length Research Paper

Effect of different population densities and fertilizer rates on the performance of different maize varieties in two rain forest agro ecosystems of South West Nigeria

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The study aimed at identifying the influence of different plant population density and fertilizer rates on three different maize varieties, it was carried out in two cropping seasons (2007/2008 and 2008/2009) at Ibadan and Ikenne in South-western Nigeria. The experiment was a split-split-plot design with three replications. Maize variety (Swan 1-SR an open-pollinated, Obasuper a hybrid and Quality Protein Maize, an improved) was used as the main plot, the sub-plot comprised three plant population densities determined from spacing combinations which are 53,320 plants ha^{-1} (75 x 50cm), 88,880 plants ha^{-1} (90 x 25cm) and 106,640 plants ha^{-1} (75 x 25cm) while the sub-sub-plot was NPK 20:10:10 fertilizer (applied at 120, 150 and 180 kg N ha^{-1}). The results showed that there were significant differences (P≤0.05) for plant height, stalk diameter, stalk lodging, maize cob weight, cob diameter, cob length and grain yield due to influence of different rates of fertilizer and plant population density at both locations. Irrespective of the rates of fertilizer applied, there were no significant differences for stalk diameter at Ibadan and Ikenne. Also, maize variety did not significantly affect (P≤0.05) maize growth performances. However, the results indicated that, the application of 180 kg N ha^{-1} gave the highest grain yield of 3.8 and 3.5 ha^{-1} at Ibadan and Ikenne, respectively, which was not significantly different from the application of 150 kg N ha^{-1}. Thus, the plant population density of 88,880 plants ha^{-1} gave the highest maize grain yield while the lowest yields were recorded for plant population density of 106,670 plants ha^{-1} at both locations. The hybrid maize (Obasuper) variety gave the highest maize grain yield.

Key words: Plant population density, fertilizer rates, maize varieties, NPK fertilizer, south west.

INTRODUCTION

Plant population densities (PPD) have a significant impact on growth and yield of crops, including maize, a popular C4 cereal crop (Hunter, 1978; Cox, 1996). Therefore, understanding how plants regulate their growth in response to plant population densities has problems, such as determination of optimal sowing density (Cox, 1996). Increased plant populations could lead to increased yields under optimal climatic and

and management conditions due to greater number of smaller cobs per unit area (Bavec and Bavec, 2002).

Plant population is the prime factor for getting maximum yield which is decided by inter and intra row spacing of crops. Decreasing the distance between neighbor rows at any particular plant population has several potential advantages. First, it reduces competition among plants within rows for light, water and nutrients due to a more equidistant plant arrangement (Olson and Sander, 1988; Porter et al., 1997). The more favorable planting pattern provided by closer rows enhances maize growth rate early in the season (Bullock et al., 1988), leading to a better interception of sun light, a higher radiation use efficiency and a greater grain yield (Westgate et al., 1997).

Secondly, the maximization of light interception from early canopy closure also reduces light transmittance through the canopy (McLachlan et al., 1993). The smaller amount of sun light striking the ground decreases the potential for weed interference, especially for shade intolerant species (Gunsolus, 1990; Teasdale, 1995; Johnson et al., 1998). Thirdly, the quicker shading of soil surface during early part of the season results in less water being lost by evaporation (Karlen and Camp, 1985). This is especially important under favorable soil surface moisture conditions because it allows maize plants to maximize photosynthesis and the proportion of water that is used in growth processes rather than evaporated from the soil (Lauer, 1994). Furthermore, the earlier crop cover provided by smaller row width is instrumental to enhance soil protection, diminishing water runoff and soil erosion (Mannering and Johnson, 1969; Sangoi et al., 1998). The nutrient use efficiency can be improved with the use of optimum plant population (Srikanth et al., 2009). In addition, Carena and Cross (2003) had suggested that higher plant population densities are encouraged for germplasm improvement in order to facilitate foraging of the unwanted plants.

However, according to Duncan (1984) plant population above critical density has a negative effect on yield per plant due to the effects of inter plant competition for light, water, nutrient and other potential yield-limiting environmental factors. Similarly, the majority of farmers do not follow the recommended plant population density. Higher plant densities affect leaf area index (LAI), grain yield, ear size and yield negatively (Wiyo et al., 1999). As population increases, the crushing strength, stalk section mass, stalk diameter and rind thickness decreases, allowing for more complications from stalk rot and stalk lodging (Cox, 1996).

Most soils contain an abundance of elements essential for the plants development but majority of these elements are rarely available for plant use due to nutrient loss. Nutrient depletion and soil degradation have become serious threat to agricultural productivity in Nigeria. According to Mba (2006) vast areas of tropical lands that were once fertile have been rendered unproductive due to continuous cultivation and erosion which caused physi-

cal degradation, loss of soils organic matter and decrease cation exchange capacity (CEC) as well as increased Al and Mn toxicity. These soils suffered multi-nutrient deficiencies; application of mineral fertilizers has become mandatory to increase crop yields in such soils (Adeniyan and Ojeniyi, 2005).

According to Srikanth et al. (2009), among the plant nutrients, primary nutrients such as nitrogen, phosphorus and potassium play a crucial role in determining the growth and yield. The nitrogen use efficiency can be improved with the use of hybrids, optimum plant population and application of nitrogen coinciding with peak need by the crop. Optimum nitrogen requirement will vary with plant density. Hence, an attempt was made to study the effect of different plant population densities and fertilizer rates on the growth and yield of different maize varieties.

MATERIALS AND METHODS

The field trials were conducted in 2007 and 2008 at Ibadan (7.38° N, 3.84° E) and Ikenne (6.87° N, 3.72° E); two of the research farms of the Institute of Agricultural Research and Training (IAR&T) Moor Plantation Ibadan, to determine the effect of fertilizer rates and planting maize at different spacing on the performance of different maize varieties. Ibadan (transitional rain forest agro-ecology) is located in the dry rainforest area while Ikenne (high rain forest agro-ecology) is located in the wet rainforest agro ecological zone of South-western Nigeria. Before planting at both locations, surface (0 – 15 cm) soil samples were collected from the experimental sites and were then bulked based on locations. The collected soil samples were air-dried, crushed and allowed to pass through 2 mm sieve. Analyses were carried out according to Juo (1975).

The experiment was a split-split-plot design with three replications. Maize variety (Swan 1-SR an open-pollinated, Obasuper a hybrid and Quality Protein Maize an improved) was the main plot, the sub-plot comprised three plant population densities determined from spacing combinations which are 53,320 plants ha^{-1} (75 x 50cm), 88,880 plants ha^{-1} (90 x 25cm) and 106,640 plants ha^{-1} (75 x 25cm) while the sub-sub-plot was NPK 20:10:10 fertilizer (applied at 120, 150 and 180 kg N ha^{-1}).

Planting was done at the onset of rains in the early planting season of the cropping year. Four seeds were planted in each hole and later thinned to two plants per hole soon after emergence. The two locations received the same standard field management routine for optimum grain yield (fertilizer application, herbicide use, manual and mechanical operations). The entire doses of phosphorus and potassium were applied basally. The nitrogen was applied in two splits; after first weeding operation and at tasselling. The N, P and K fertilizers were applied in the form of compound fertilizer NPK 20:10:10. Urea (46%) was applied to top up for nitrogen. Data were collected on percentage lodging; this was estimated by subtracting the number of plants at harvest from the total number of plants that supposed to be on each of the plots based on population density combinations. Plant height and stalk diameter at harvest were measured for each plot. Percentage stalk lodging was calculated at maturity by counting the number of plants that lodged on weekly basis as from 8 weeks after planting. Only those plants that had produced at least one normal cob were counted. The percent lodged stalks were calculated on plot basis. Stalk diameter and plant height at harvest were measured by randomly selecting 20 plants from the center rows of each plot. Stalk diameter were determined by measuring the middle of the first elongated internodes using calipers. The average stalk diameter by variety and population den-

Table 1. Initial soil chemical and physical characteristics of the 0 - 20 cm layer of the soil before planting of maize in 2007.

Parameter	Pre-planting	
	Ikenne	Ibadan
Sand (%)	80.6	77.5
Silt (%)	8.9	9.2
Clay (%)	10.4	13.5
pH (H_2O)	5.1	5.3
Org. C (g kg^{-1})	4.22	4.16
Total N (g kg^{-1})	0.76	0.63
Avail. P (MgKg^{-1})	5.12	5.33
Exchangeable bases (cmolkg^{-1})		
K	0.17	0.14
Ca	1.37	1.77
Mg	0.12	0.09
Zn	0.78	0.67

sities was calculated. Average cob weight and length were determined from the twenty plants randomly selected. All data collected were subjected to analysis of variance (ANOVA). Significant means were separated using Duncan multiple range test (DMRT).

RESULTS

Physico-chemical characteristics of the study areas

The physical and chemical properties of the soils of the study areas, Ibadan and Ikenne are presented in Table 1. The texture of the soils in Ibadan and Ikenne was sandy loam. The soil reaction was acid; pH 5.1 and 5.3 for Ikenne and Ibadan, respectively. Organic carbon was 4.22 and 4.16 g kg^{-1} for Ikenne and Ibadan, respectively, such levels of organic C could translate to corresponding low organic matter contents. Total N in both locations was marginally low; 0.76 and 0.63 g kg^{-1} for Ikenne and Ibadan, respectively. The available P and exchangeable bases were generally low in both locations (Table 1).

Combined maize growth performances as influenced by fertilizer rates at Ibadan and Ikenne for 2008 and 2009

There were significant differences (P≤0.05) for plant height and stalk diameter due to the application of different rates of fertilizer at Ibadan and Ikenne irrespective of plant population density and maize variety (Table 2). The highest values recorded at Ibadan (160.9 cm) and Ikenne (157.5 cm) for plant height were recorded for application of NPK fertilizer at 180 kg N ha^{-1}. These were not significantly different from the application of 150 kg N

ha^{-1}. The same trends were observed with stalk diameter; it was the application of 180 kg N ha^{-1} that recorded the highest values: 2.37 and 2.38 cm at Ibadan and Ikenne, respectively. Irrespective of the rate of NPK fertilizer app-lied, there were no significant differences for stalk lodging both at Ibadan and Ikenne.

Combined maize growth performances as influenced by population density at Ibadan and Ikenne for 2008 and 2009

There were significant differences (P≤0.05) for plant height, stalk diameter and stalk lodging due to plant popu-lation density at Ibadan and Ikenne irrespective of fertilizer rates and maize variety (Table 2). Plant population density at 106,670 plants ha^{-1} recorded the highest plant height of 210.8 and 204.5 cm at Ibadan and Ikenne, respectively. The reverse was the case with stalk diameter. It was the plant population density at 53,335 plants ha^{-1} that recorded the highest stalk diameter of 2.78 and 2.57 cm at Ibadan and Ikenne, respectively. The highest stalk lodging of 27.5 and 35.9% were recorded for plant population density at 53,335 plants ha^{-1} at Ibadan and Ikenne, respectively.

Combined maize growth performances as influenced by maize variety at Ibadan and Ikenne for 2008 and 2009

There were no significant differences (P≤0.05) for plant height, stalk diameter and stalk lodging due to planting of different maize varieties at Ibadan and Ikenne irrespective of fertilizer rates and plant population density (Table 2).

Combined maize yield and yield parameters performances as influenced by fertilizer rates at Ibadan and Ikenne for 2008 and 2009

There were significant differences (P≤0.05) for maize cob weight, cob diameter, cob length and grain yield due to the application of different rates of fertilizer at Ibadan and Ikenne (Table 3). At Ibadan, highest values; 237.9 g, 19.0 cm, 28.1 cm and 3.8 t ha^{-1} were recorded for cob weight, cob diameter, cob length and grain yield, respectively, with the application of 180 kg N ha^{-1} which was not significantly different from 150 kg N ha^{-1} (Table 3). The same trend was observed for Ikenne where highest values; 230.3 g, 18.9 cm, 27.6 cm and 3.5 t ha^{-1} were recorded for cob weight, cob diameter, cob length and grain yield, respectively, with the application of 180 kg N ha^{-1} which was not significantly different from 150 kg N ha^{-1}. The lowest values were recorded for 120 kg N ha^{-1} at both locations (Table 3).

Table 2. Effect of fertilizer rates, spacing and variety on growth parameters of maize at Ibadan and Ikenne.

Treatment	Ibadan location			Ikenne location		
	Plant height (cm)	Stalk diameter (cm)	Stalk lodging (%)	Plant height (cm)	Stalk diameter (cm)	Stalk lodging (%)
Fertilizer rate						
120 kg N ha^{-1}	150.8b	2.28b	8.2a	144.6b	2.20b	23.1a
150 kg N ha^{-1}	157.5a	2.34a	9.5a	151.9a	2.35a	25.2a
180 kg N ha^{-1}	160.9a	2.37a	8.5a	157.5a	2.38a	23.9a
Population density						
53,335 plants/ha (75 x 50cm)	137.6c	2.78a	8.70b	133.9c	2.57a	14.8c
88,880 plants/ha (90 x25cm)	184.3b	2.17b	15.8b	180.9b	2.40b	22.6b
106,670 plants/ha (75 x 25cm)	210.8a	1.87c	27.5a	204.5a	1.31c	35.9a
Variety						
QPM	148.8a	2.30a	8.2a	154.6a	2.30a	23.1a
Suwan 1 SR	145.5a	2.31a	9.5a	151.9a	2.35a	25.2a
Obasuper	140.9a	2.33a	8.5a	149.5a	2.33a	23.9a

Numbers within the same column with different letter(s) are significantly different at P<0.05.

Combined maize yield and yield parameters performances as influenced by plant population density at Ibadan and Ikenne for 2008 and 2009

Population density significantly affected (P≤0.05) cob weight, cob diameter and cob length at both locations (Table 3). Highest values: 217.3 g, 15.8 cm, and 20.7 cm for cob weight, cob diameter and cob length, respectively, were recorded at Ibadan for plant population at 53,335 plants ha^{-1}. While at Ikenne, highest values: 233.1 g, 16.1 cm and 20.1 cm for cob weight, cob diameter and cob length respectively were recorded for plant population density at 53,335 plants ha^{-1} (Table 3). These values were not significantly different from values recorded for plant population density at 88,880 plants ha^{-1} at both locations. However, the significantly lowest values were recorded for plant population density at 106,670 plants ha^{-1} for Ibadan and Ikenne (Table 3). The significantly highest values; 3.3 and 3.5 t/ha were recorded at Ibadan and Ikenne, respectively for grain yield at plant population density of 88,880 plants ha^{-1}. The significantly lowest values were recorded for plant population density of 106,670 plants ha^{-1} at both locations.

Combined maize yield and yield parameters performances as influenced by maize variety at Ibadan and Ikenne for 2008 and 2009

Maize variety significantly affected (P≤0.05) cob weight and maize grain yield at both locations (Table 3). Obasuper (hybrid) maize variety recorded highest maize cob weight (227.5g) and 3.8 t/ha was recorded for maize grain yield at Ibadan. The same trend was observed at

Ikenne, where the highest values: 225.1 g and 3.6 t/ha were recorded for cob weight and grain yield, respectively, for Obasuper (hybrid) maize variety (Table 3).

DISCUSSION

The results clearly indicated that, successive increase in fertilizer from 120 to 180 kg N ha^{-1} had marked influences on the growth parameters of maize but after 150 kg N ha^{-1}, the increase in the growth parameters was comparatively low. The increase in fertilizer levels increased the growth and yield attributes by better uptake of nutrients. The increased fertilizer levels increased the yield attributes by better uptake of all the nutrients and increased translocation of photosynthetic materials from source to sink in hybrid maize could amount to 200 kg as also reported by Parthipan (2000) and up to 225 kg by Singh et al. (1997). Saleem et al. (2003) observed in hybrid maize that response was up to 150 kg P_2O_5 ha^{-1}. Increased doses of phosphorus increased the forage activity, accumulation of food reserves, increased functional leaves and LAI, higher nutrient uptake which lead to higher yield attributes and yield. Ali et al. (2004) reported that with higher dose of K, there is enhancement of LAI, better nutrient translocation from source to sink and better nutrient uptake, hence these factors ultimately result in increase in yield attributes and finally the yield.

The highest plant height and highest percentage stalk lodging that were recorded with the population density of 106,680 plants ha^{-1} could possibly be explained by the added stress from population density pressure. Higher plant population densities increase stress and competition for nutrients, sunlight and water. Increased plant

Table 3. Effect of fertilizer rates, spacing and variety on yield and yield parameters of maize at Ibadan and Ikenne.

Treatment	Ibadan location				Ikenne location			
	Cob weight (g)	Cob diameter (cm)	Cob length (cm)	Grain yield (t/ha)	Cob weight (g)	Cob diameter (cm)	Cob length (cm)	Grain yield (t/ha)
Fertilizer rates								
120 kg N ha^{-1}	222.4b	13.6b	21.8c	2.2b	215.6b	14.4b	21.6c	2.2b
150 kg N ha^{-1}	236.7a	17.2a	26.6ab	3.4a	227.7a	18.6a	25.3ab	3.2a
180 kg N ha^{-1}	237.7a	19.0a	28.1a	3.8a	230.3a	18.9a	27.6a	3.5a
Population density								
53,335 plants/ha (75 x 50 cm)	217.3a	15.8a	20.7a	2.6b	233.1a	16.1a	20.1a	2.9b
88,880 plants/ha (90 x25 cm)	212.4a	14.8a	18.6b	3.3a	232.3a	15.2a	18.6a	3.5a
106,670 plants/ha (75 x 25 cm)	200.6b	11.6b	13.2c	3.6a	205.6b	12.6b	13.1b	3.7a
Variety								
QPM	213.1b	14.8a	20.7a	3.2b	215.1b	14.2a	22.1a	3.2b
Suwan-1 SR	211.4b	15.9a	22.1a	3.2b	218.3b	14.9a	22.6a	3.1b
Obasuper	227.5a	15.6a	23.7a	3.8a	225.1a	15.3a	23.1a	3.6a

Numbers within the same column with different letter(s) are significantly different at P<0.05.

stress followed by increased plant height and reduced stalk diameter resulting from high plant population densities could have led to higher stalk lodging. Cox (1996) had stated that, as population increases, the crushing strength, stalk section mass, stalk diameter and rind thickness decreases, allowing for more complications from stalk rot and stalk lodging. The observed decreased maize cob weight, cob diameter and cob length under increased population densities may be attributed to the statement according to Duncan (1984) that plant population above critical density has a negative effect on yield per plant due to the effects of inter plant competition for light, water, nutrient and other potential yield-limiting environmental factors.

Similarly, Wiyo et al. (1999) had also indicated that higher plant densities affect leaf area index

(LAI), grain yield, ear size and yield negatively. The results confirmed that grain yield increased with increasing plant population densities in the order of 20 and 22% for 53,335, 88,880 plants ha^{-1}, respectively but later decreased to 13.3% for 106,670 plants ha^{-1}. Decreased row spacing implies high plant density, which is concomitantly equal to high yield with every successful ear formation per plant so long as critical population density is not exceeded. This finding is supported by Bavec and Bavec (2002) when they reported that increased plant populations could lead to increased yields under optimal climatic and management conditions due to greater number of smaller cobs per unit area. This finding is in contrast to research findings in Argentina by Maddonni et al. (2006) which shows that maize

grain yield was stable in response to changes in plant spatial arrangement at all plant population densities. Also, in contrast, Tollenaar et al. (2006) in their research finding argued that a moderate increase in plant-spacing variability does not influence maize grain yield at the canopy level because reductions in grain yield of plants that experience enhanced crowding stress is compensated, in part, by increased yield of plants that experience reduced crowding stress.

However, according to the observation made by Owino (2009), it is worth mentioning that, decreesing row spacing has socio economic implications; high plant population densities mean upward adjustment of the amount of agro inputs used (seed rate and fertilizer). Manual weeding, harvesting and other agronomic maintenance operations would

take more labour and time, as it is difficult working through the dense crop stand.

Conclusion and recommendation

The observed increased maize grain yield under decreased row spacing may be attributed to reduced competition among plants within rows for light, water and nutrients due to a more equidistant plant arrangement leading to a better interception of sun light, a higher radiation and nutrients use efficiency, and a greater grain yield if the critical population density is not exceeded. However, understanding how plants regulate their growth in response to plant population densities has problems such as determination of optimal sowing density. Decreasing row spacing seems to be an alternative that can be used to intensify crop production per unit land area. It has been clearly indicated that, successive increase in fertilizer from 120 to 180 kg N ha^{-1} had marked influences on the growth parameters of maize but after 150 kg N ha^{-1}, the increase was comparatively low. Planting at row spacing of 90 x 25 cm at 2 plants/hole giving 88,880 plants ha^{-1} and application of 150 kg N ha^{-1} is hereby recommended for the farmers.

Conflict of Interests

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

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