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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 (training 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 existing 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 vector spread BXW. In a few extreme cases, deployment of cultivars such as scabmia 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, rougeing 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 bury 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 3 months 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 important to note that the survival of the bacterial is dependent on ecological conditions of different areas therefore it may be necessary to validate this recommendation 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 empha-
sized 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 techno-
lologies are generated and promoted together with institu-
tional 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 Uni-
versities (Tushemereirwe et al., 2006). Other stakehol-
ders from Government and Non-Government Organisa-
tions involved in rural development also contributed to the
planning, generation and promotion of these technolo-
gies. In some locations, farmers sometimes modified
recommended practices to suit their conditions (Bagamba
et al., 2006). Experiments were established to scienti-
fically 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 re-
commended practices may have region-wide applica-
bility, most of them were ecology specific and may there-
fore need to be validated for customization to the local
ecological conditions.

Accessibility to improved technologies for disease con-
rol 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.

<table>
<thead>
<tr>
<th>Goal</th>
<th>Objectives</th>
<th>Activities</th>
<th>Time frame</th>
<th>Target</th>
<th>Resp. Person</th>
<th>Budget unit cost</th>
<th>Source of funds</th>
</tr>
</thead>
<tbody>
<tr>
<td>To eradicate BBW from Rugando Sub-county</td>
<td>Create awareness about BXW in Rugando</td>
<td>Conduct sensitization workshops</td>
<td>March - June 2005</td>
<td>Technical staff/local leaders</td>
<td>DPC &amp; DAO</td>
<td>100,000=</td>
<td>District</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Training farmers</td>
<td>X</td>
<td></td>
<td></td>
<td>20,000=</td>
<td>NGOss/county</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>Community</td>
<td>AO &amp; SC leaders</td>
<td>50,000=</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mobilize and organize farmers for community action for effective control of BXW</td>
<td>Formulate and enforce community bye-laws - village meetings</td>
<td>July - September 2005</td>
<td></td>
<td></td>
<td>60,000=</td>
<td>NGOss/county</td>
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<tr>
<td></td>
<td></td>
<td>Organize farmers to effect BBW control – village meetings</td>
<td>October - December 2005</td>
<td></td>
<td></td>
<td>60,000=</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Effectively supervise and monitor the BXW control activities</td>
<td>Formulation of Taskforces</td>
<td>January - June 2006</td>
<td></td>
<td></td>
<td>100,000=</td>
<td>S/county</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supervise implementation of control measures</td>
<td></td>
<td></td>
<td></td>
<td>30,000=</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tracking new outbreaks/infections</td>
<td></td>
<td></td>
<td></td>
<td>15,000=</td>
<td>S/county</td>
</tr>
<tr>
<td></td>
<td>Ensure sharing of information</td>
<td>Organize exchange visits</td>
<td></td>
<td></td>
<td></td>
<td>60,000=</td>
<td>S/county</td>
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<td></td>
<td>40,000=</td>
<td>APEP</td>
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<td>10,000=</td>
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</tbody>
</table>

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.
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

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**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.
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.

REFERENCES


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 LD50/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 determine 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 Whatman 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, dichloromethane, 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 sacrificial of the animals were in accordance with the Euro-

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 LD₅₀, LD₅₀ and LD₉₅ 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 LD₅₀ (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 DL₅ and DL₉₅ are respectively 1118 and 6425 mg/kg body weight (Figure 1). The quotient DL₅ / DL₉₅ reports 0.17. This result is far from 1.

DISCUSSION

The study of the acute toxicity of dichloromethane fraction showed that the LD₅₀ 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.

<table>
<thead>
<tr>
<th>Dose (mg/kg body weight)</th>
<th>Acute toxicity signs mobility</th>
<th>Death</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>+</td>
<td>_</td>
</tr>
<tr>
<td>1000</td>
<td>+</td>
<td>_</td>
</tr>
<tr>
<td>2000</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>3000</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>4000</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>5000</td>
<td>_</td>
<td>+</td>
</tr>
<tr>
<td>6000</td>
<td>_</td>
<td>+</td>
</tr>
<tr>
<td>7000</td>
<td>_</td>
<td>+</td>
</tr>
</tbody>
</table>

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

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

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$_{50}$ (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$_{50}$ 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.

**ACKNOWLEDGEMENTS**

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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 (Manning 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 physical 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 (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 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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pre-planting Ikenne</th>
<th>Pre-planting Ibadan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand (%)</td>
<td>80.6</td>
<td>77.5</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>8.9</td>
<td>9.2</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>10.4</td>
<td>13.5</td>
</tr>
<tr>
<td>pH (H₂O)</td>
<td>5.1</td>
<td>5.3</td>
</tr>
<tr>
<td>Org. C (g kg⁻¹)</td>
<td>4.22</td>
<td>4.16</td>
</tr>
<tr>
<td>Total N (g kg⁻¹)</td>
<td>0.76</td>
<td>0.63</td>
</tr>
<tr>
<td>Avail. P (MgKg⁻¹)</td>
<td>5.12</td>
<td>5.33</td>
</tr>
<tr>
<td>Exchangeable bases (cmolkg⁻¹)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>0.17</td>
<td>0.14</td>
</tr>
<tr>
<td>Ca</td>
<td>1.37</td>
<td>1.77</td>
</tr>
<tr>
<td>Mg</td>
<td>0.12</td>
<td>0.09</td>
</tr>
<tr>
<td>Zn</td>
<td>0.78</td>
<td>0.67</td>
</tr>
</tbody>
</table>

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 applied, there were no significant differences for stalk lodging both at Ibadan and Ikenne.

**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, stalk diameter and stalk lodging 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 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).
Parameters of maize at Ibadan and Ikenne.

Higher height and highest percentage stalk lodging at 106,670 plants ha$^{-1}$, higher nutrient uptake which lead to better nutrient translocation from source to sink in hybrid maize could amount to 217.3 g and 3.6 t/ha for Obasuper (hybrid) maize variety recorded highest maize and maize grain yield at both locations (Table 3). 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$_2$O$_5$ 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

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

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ibadan location</th>
<th>Ikenne location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plant height (cm)</td>
<td>Stalk diameter (cm)</td>
</tr>
<tr>
<td>Fertilizer rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120 kg N ha$^{-1}$</td>
<td>150.8b</td>
<td>2.28b</td>
</tr>
<tr>
<td>150 kg N ha$^{-1}$</td>
<td>157.5a</td>
<td>2.34a</td>
</tr>
<tr>
<td>180 kg N ha$^{-1}$</td>
<td>160.9a</td>
<td>2.37a</td>
</tr>
<tr>
<td>Population density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>53,335 plants/ha (75 x 50cm)</td>
<td>137.6c</td>
<td>2.78a</td>
</tr>
<tr>
<td>88,880 plants/ha (90 x25cm)</td>
<td>184.3b</td>
<td>2.17b</td>
</tr>
<tr>
<td>106,670 plants/ha (75 x 25cm)</td>
<td>210.8a</td>
<td>1.87c</td>
</tr>
<tr>
<td>Variety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QPM</td>
<td>148.8a</td>
<td>2.30a</td>
</tr>
<tr>
<td>Suwan 1 SR</td>
<td>145.5a</td>
<td>2.31a</td>
</tr>
<tr>
<td>Obasuper</td>
<td>140.9a</td>
<td>2.33a</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ibadan location</th>
<th>Ikenne location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cob weight (g)</td>
<td>Cob diameter (cm)</td>
</tr>
<tr>
<td>Fertilizer rates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120 kg N ha⁻¹</td>
<td>222.4b</td>
<td>13.6b</td>
</tr>
<tr>
<td>150 kg N ha⁻¹</td>
<td>236.7a</td>
<td>17.2a</td>
</tr>
<tr>
<td>180 kg N ha⁻¹</td>
<td>237.7a</td>
<td>19.0a</td>
</tr>
<tr>
<td>Population density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>53,335 plants/ha (75 x 50 cm)</td>
<td>217.3a</td>
<td>15.8a</td>
</tr>
<tr>
<td>88,880 plants/ha (90 x25 cm)</td>
<td>212.4a</td>
<td>14.8a</td>
</tr>
<tr>
<td>106,670 plants/ha (75 x 25 cm)</td>
<td>200.6b</td>
<td>11.6b</td>
</tr>
<tr>
<td>Variety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QPM</td>
<td>213.1b</td>
<td>14.8a</td>
</tr>
<tr>
<td>Suwan-1 SR</td>
<td>211.4b</td>
<td>15.9a</td>
</tr>
<tr>
<td>Obasuper</td>
<td>227.5a</td>
<td>15.6a</td>
</tr>
</tbody>
</table>

Numbers within the same column with different letter(s) are significantly different at P<0.05.
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 decreas-
ed row spacing may be attributed to reduced competi-
tion 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. Decreas-
ing 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 fertili-
zer 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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