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Full Length Research Paper

The effect of nitrogen supply on potato yield, tuber size and pathogen resistance in *Solanum tuberosum* exposed to *Phytophthora infestans*

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Little is known about the effects of nitrogen supply on plant productivity and defensive response to pathogen exposure. Here, tuber yield and resistance to the fungal pathogen *Phytophthora infestans* were investigated in potato plants supplied with four different nitrogen levels (N1: 45 kg-hm^{-2}, N2: 90 kg-hm^{-2}, N3: 135 kg-hm^{-2}, and N4: 180 kg-hm^{-2}). The N2 level of nitrogen promoted the highest tuber yield and largest tubers under pathogen-free conditions. However, N3 promoted the strongest pathogen resistance and highest potato production in response to *P. infestans* exposure. Also, the highest level of chlorophyll accumulation was observed with N3 relative to the other treatment groups under pathogen-infected but not pathogen-free conditions. Further study showed that, in response to pathogen infection, the N3 level of nitrogen induced the highest activity levels for the defensive enzymes polyphenol oxidase and phenylalanine ammonia-lyase (but not chitinase and β-1,3-glucanase) and the most abundant accumulation of phenolic and flavonoid compounds. Our data demonstrated that modest increases in the nitrogen supply provided potato plants with optimum growth and defensive capability in response to *P. infestans* exposure.

Key words: Nitrogen, tuber yield, pathogen resistance, *Phytophthora infestans*, *Solanum tuberosum*.

INTRODUCTION

Because plants are sessile in nature and provide a rich source of nutrients for many organisms in the environment, they have developed a wide array of structural, chemical, and protein-based defenses designed to detect invading organisms and protect themselves from extensive damage. Defensive structures and chemicals are expensive because they absorb resources that could otherwise be consumed by plants to promote growth and reproduction. However, a trade-off between strategies that maximize growth and minimize losses is a central property of evolving biological entities existing under conditions of limiting resources (Coley et al., 1985; Hamilton et al., 2001). While it is clear that all defenses incur costs, our understanding of the complex interactions between defense and growth remains rudimentary.

Nitrogen (N) is typically the most limiting factor for plant growth and crop yield (Kraiser et al., 2011; Kant et al., 2011). Thus, nitrogenous fertilizer is used to stimulate higher biomass yields. Plants require nitrogen for growth

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but both excess and limited nitrogen negatively affects plants. Nitrogen is a mobile nutrient in the soil, and nitrogen levels have a significant impact on tuber yield and size in a potato crop (Saeidi et al., 2009). Successful colonization of plants by pathogens requires the efficient use of nutrient resources available in host tissues (Dordas, 2008). Over- or under-application of nitrogenous fertilizer can lead to a higher susceptibility for plants to fungal pathogens (Snoeijers et al., 2000; Hoffland et al., 2000). Phytophthora *infestans* is an important fungal pathogen for potato plants and the cause of the late blight disease in potato, which can result in a significant reduction in tuber yield (Moller et al., 2006).

Interestingly, many studies have shown that insect resistance or abiotic stress tolerance is often not compatible with fast growth. Crops selected for high biomass accumulation may also possess low natural resistance to environmental stress, and vice versa (Coley et al., 1985; Hamilton et al., 2001; Zhu, 2001; Züst et al., 2011). However, fast growth and enhanced drought stress tolerance has been observed simultaneously in some transgenic plants (Deng et al., 2013). In addition, nitrogen levels can have a significant impact on potato yield and tuber size (Saeidi et al., 2009). However, few studies have addressed the effect of nitrogen on defensive and productive capacity when plants are exposed to pathogens. In the current study, we have addressed two connected problems. First, how does *P. infestans* affect potato tuber yield and size and the defense response with different nitrogen levels? Second, we investigated whether strong resistance to pathogens would be compatible with high yield in potato plants with the rise of nitrogen availability. This work provided us with insight into the relationship between *P. infestans* resistance and plant yield under various nitrogen conditions.

MATERIALS AND METHODS

Plant growth and nitrogen treatment

Experiments were performed under greenhouse conditions in Daqing city, Heilongjiang province, China, in 5 L pots containing 4 L of nutrient soil (pH = 6.6; N: 62.8 mg kg^{-1}' P: 42.3 mg kg^{-1} and K: 151.6 mg kg^{-1}), a depth of 40 cm and a hole at the bottom to drain water excess.

Experiments were performed with a completely randomized design and 5 replications. Treatments were performed with four levels of N supply (N1, N2, N3 and N4). Nitrogen (urea dissolved in tap water) was added 20 d after seedling emergence, and an amount equivalent to 45 (N1), 90 (N2, the mean level of N supply for potato cultivation in Northeast China), 135 (N3) and 180 kg-hm^{-2} (N4) was applied. Each pot was considered to be an experimental unit and five pots were used for each treatment. The potato cultivar Kexin 1 (from Keshan Farm, Potato Research Institute of Heilongjiang Province) was used in this experiment to investigate the effect of nitrogen application on potato yield and pathogen resistance. Kexin 1 is a hybrid potato cultivar that was bred and selected for in China from a cross of the maternal *374-128* with the paternal *Epoka* in 1958 (registration number: GS05009-1984). This potato cultivar was planted on June 15^{th}, 2011 at a depth of 15 cm using one seed tuber per pot. Seed tubers had a diameter between 45 and 50 mm and vigorous shoots. Isolated potato seedlings of the same size and from healthy plants were selected for further experimentation.

Tuber yield assay under exposure to a pathogen

The crop cycle lasted 90 d for the potato yield assay and was ended when 90% of the infected plants showed stalk yellowing. The tuber yield (kg hm^{-2}) was evaluated 10 d after the stalks dried completely. Tubers were separated into four size groups (small < 50 g; 50 ≤ medium < 100 g; and large ≥ 100 g) for counting. Tubers were weighed to determine their fresh weight (kg hm^{-2}). Uninfected plants were used as a control.

Pathogen resistance assay

Whole-plant disease resistance assays were repeated five times. Three Kexin 1 plants were inoculated and scored for each replication. Four-week old seedlings with the same size were isolated and placed in a closed greenhouse with a misting system that maintained greater than 90% relative humidity. Greenhouse temperatures were set at 25°C during the day and 15°C at night with 14 h of light. Each plant was sprayed with ~2 ml of a suspension containing zoospores and sporangia (approximately 5×10^4 ml^{-1}) of *P. infestans* D08-7 (a strain from our laboratory), on the underside and topside of the leaves.

The pathogen resistance score was measured by visual inspection of plants using a scale developed by Kuhl and his co-authors (2001). Leaves were scored at 7, 14, and 21 days after inoculation using disease severity indices based on the percentage of leaf area affected: 0 = no symptoms, 1 = 0 to 5%, 3 = 6 to 25%, 5 = 26 to 50%, 7 = 51 to 75% and 9 = 76 to 100%. Also, infected leaves were collected 0, 1, 2, 3 and 4 days after inoculation (the third and the fourth leaf from top) for defense enzyme and compound assays.

Chlorophyll content assay

Potato plant leaves were collected for chlorophyll content assay after pathogen inoculation for 0, 7, 14 and 21 days. Total chlorophyll was extracted and measured according to the method of Lichtenthaler (1987).

Enzyme protein extraction and assays

Potato plant leaves were collected for enzyme assays 0, 24, 48, 72 and 96 h after pathogen inoculation. One gram of leaves was homogenized in liquid nitrogen and extracted with 5 ml PBS (pH =7.2) at 4°C. Samples were then centrifuged at 10,000 rpm for 15 min at 4°C. Supernatants were used as an enzyme source after 10-fold dilution in the same buffer. PAL and PPO activities were measured according to the method of Pal et al. (2011). β-1, 3-glucanase and chitinase enzyme activity were measured according to the method of Fink et al. (1988). Soluble protein content was measured according to the method of Bradford (1976) using BSA as a standard.

Phenolic and flavonoid compound assays

Potato plant leaves were collected to assay phenolic and flavonoid compound content after pathogen inoculation. The content of total

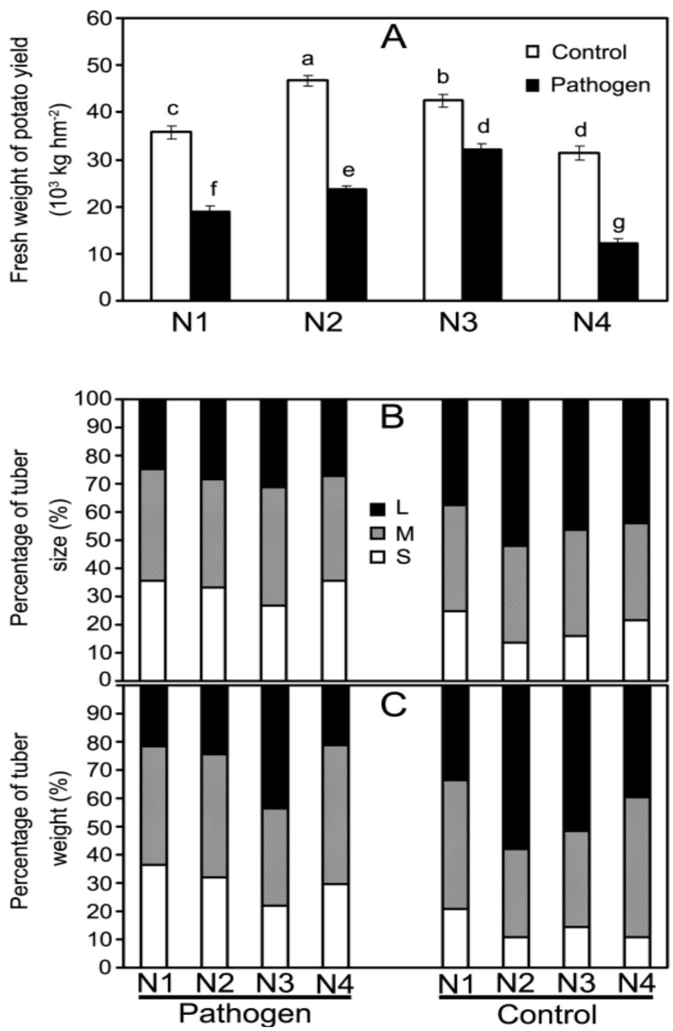

Figure 1. The effect of nitrogen on total potato yield and tuber size. The effect of nitrogen content on total potato yield (A), size distribution (B) and weight distribution (C) in potato plants under stress-free or stressful conditions. Data are presented as the means of five independent experiments. Means followed by the same letter were not significantly different between the four nitrogen supply levels (Duncan's multiple range; test $P < 0.05$). Bars show mean ± SE (n = 5).

phenolic or flavonoid compounds was extracted and measured using the method of Pirie and Mullins (1976). The aluminum chloride colorimetric method was used to determine flavonoid content with some modifications (Chang et al., 2002). One milliliter of plant extract in methanol was mixed with 1 ml of methanol, 0.5 ml of aluminum chloride (1.2%) and 0.5 ml of potassium acetate (120 mM). The mixture was incubated for 30 min at room temperature, and the absorbance of the reaction mixture was measured at 415 nm using a spectrophotometer with rutin as a standard (flavonoid content was expressed as mg g^{-1} quercetin dry sample).

DATA ANALYSIS

All data were analyzed using SPSS 13.0 software. Means followed by the same letter were not significantly different (Duncan's multiple range test $P < 0.05$). For each treatment, five replicates were analyzed.

RESULTS

The effect of nitrogen on potato yield and tuber size

We first measured the effect of nitrogen availability on total tuber yield and related indices in the Kexin 1 potato cultivar with pathogen exposure (Figure 1). Compared to the low nitrogen group (N1), the medium nitrogen groups (N2 and N3) increased the total tuber yield, while a high level of nitrogen (N4) impaired it (Figure 1a). The highest potato yield was observed in the N2 group under stress-free conditions and in the N3 groups with pathogen exposure (Figure 1a). Disease damage significantly reduced the tuber yield for potato plants exposed to *P. infestans*. For example, there was an approximately 89 (in N1), 98 (in N2), 32 (in N3) and 159% (in N4) reduction in tuber yield relative to their respective pathogen-free groups (Figure 1a).

In addition, tubers were classified as small, medium and large in size for further analysis (Figure 1b and c). Larger numbers of large tubers and fewer small tubers were found in the medium nitrogen group (N2 and N3) relative to the low (N1) or high (N4) groups (Figure 1b). A similar percentage of medium sized tubers were detected among plants treated with the four nitrogen levels (Figure 1b). And, there was a significant reduction in the percentage of large tubers and an increase in the percentage of small tubers in the four groups treated with pathogen relative to the pathogen-free groups (Figure 1b). Similar patterns were also observed in tuber weight (Figure 1c). These data suggest that nitrogen availability significantly affected total tuber yield and size.

The effects of nitrogen on pathogen resistance

In this experiment, the effect of nitrogen on *P. infestans* resistance was characterized in potato plants 7, 14 and 21 days after inoculation (Figure 2). The disease index showed that the N3 nitrogen level (135 kg hm^{-2}) provided plants with the strongest pathogen resistance, irrespective of the time of inoculation. For example, the disease index decreased by approximately 27% for the N3 group (135 kg hm^{-2}) and rose by approximately 78% for the N4 group (180 kg hm^{-2}) when compared with N1 (45 kg-hm^{-2}) treated plants 14 days after inoculation. These data suggested that a nitrogen supply of 135 kg hm^{-2} was required for strong defense against *P. infestans* exposure in the Kexin 1 potato cultivar.

The effect of nitrogen on the chlorophyll level

The chlorophyll level of potato leaves was measured with

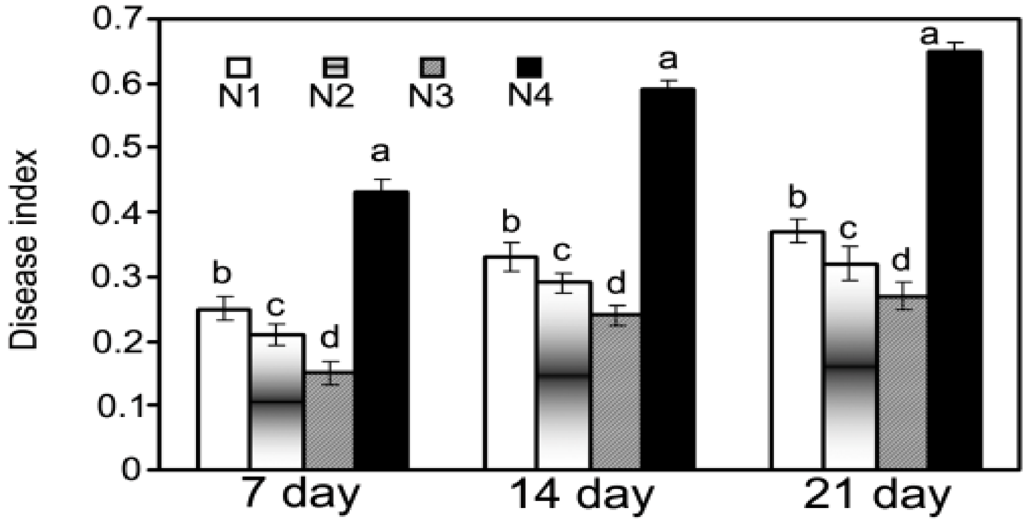

Figure 2. The effect of nitrogen on pathogen resistance. The effect of nitrogen supply on pathogen resistance as evaluated by the disease index was monitored in potato plants after inoculation. Data are presented as the mean of five independent experiments. Means followed by the same letter were not significantly different (Duncan's multiple range test; P < 0.05). Bars show mean ± SE (n = 5).

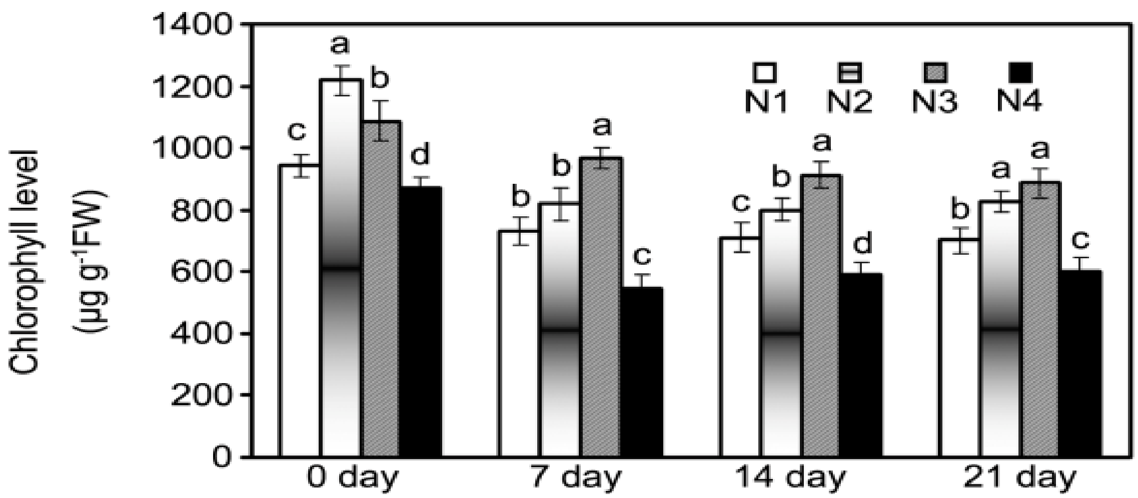

Figure 3. The effect of nitrogen on chlorophyll levels during pathogen exposure.The effects of nitrogen availability on chlorophyll content were observed in potato plants after inoculation. The data are presented as the mean of five independent experiments. Means followed by the same letter were not significantly different (Duncan's multiple range test; P < 0.05). Bars show mean ± SE (n = 5).

pathogen exposure or under stress-free conditions (Figure 3). The highest chlorophyll content level was observed in the N3 group relative to the other groups 7, 14 and 21 days after pathogen inoculation. However, the N2 level of nitrogen supply also conferred the highest accumulation of chlorophyll under pathogen-free conditions on day 0 (Figure 3). In addition, the chlorophyll content was higher in the N1 group than that in the N4 group (Figure 3). This suggests that the chlorophyll level was linked to pathogen resistance and tuber yield.

The effect of nitrogen on defensive enzyme activity

The activity of defensive enzymes such as PPO, PAL, Glu and Chi was measured during the first 4 days (Figure 4). Significantly higher levels were detected for these enzymes in N3 treated plants relative to other nitrogen conditions under pathogen free conditions (Figure 4). Pathogen infection significantly affected enzymatic activity, causing it to first ascend and then descend. N3 conditions conferred plants with the strongest defensive

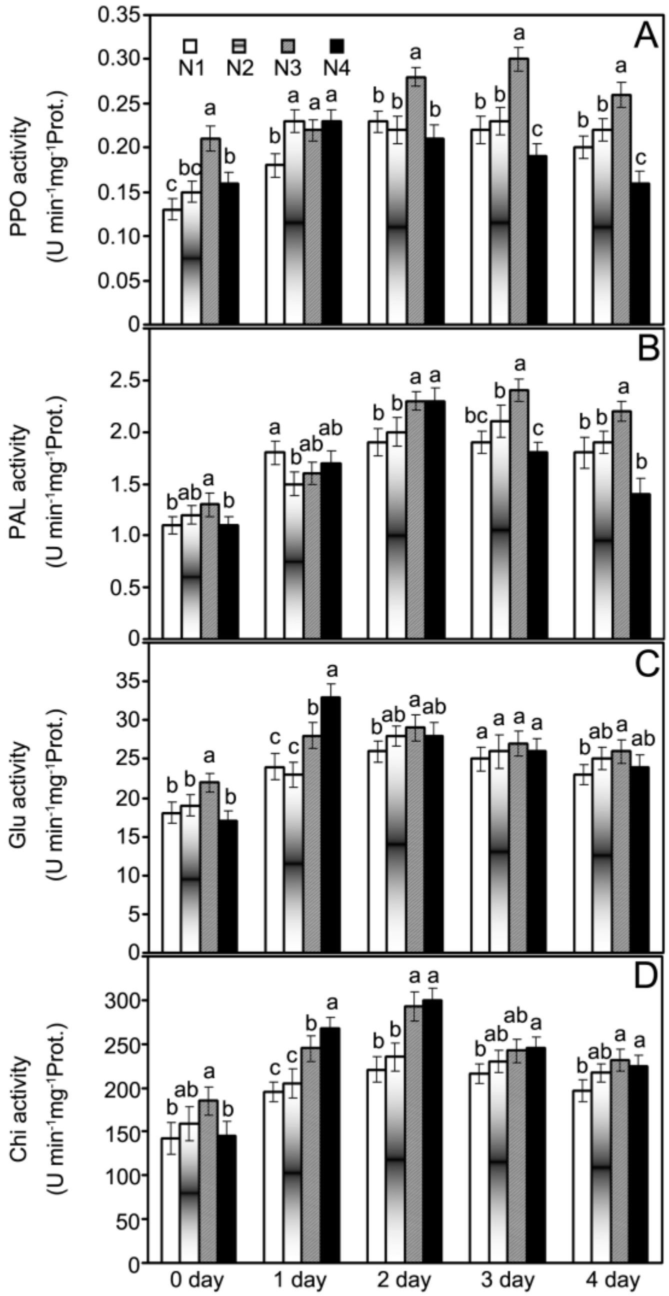

Figure 4. The effect of nitrogen on defense enzyme activity. The effect of nitrogen availability on PPO (A), PAL (B), Glu (C), and Chi (D) activity was observed in potato plants 4 days after inoculation. Data are presented as the mean of five independent experiments. Means followed by the same letter were not significantly different (Duncan's multiple range test $P < 0.05$). Bars show mean ± SE ($n = 5$).

(PPO and PAL) activity of the four groups after 48 hpi (Figure 4). For example, a 70 and 43% rise in PPO activity was detected in the N3 treated plants on day 0 and 3, respectively, compared with N1 treated plants (Figure 4a). A similar pattern was also observed for PAL enzyme activity (Figure 4b). However, no significant differences were found in the high N- relative to the low N-treated plants for Glu or Chi enzyme activity at 24 hpi (Figure 4c). These data suggest that optimum nitrogen availability is important for activating defensive enzymes in potato plants in response to *P. infestans* challenge.

The effect of nitrogen on defensive compound accumulation

Defensive compounds play key roles in pathogen defense for plants. Here, we measured phenolic and flavonoid compound content in infected leaves under different levels of nitrogen supply (Figure 5). With pathogen exposure, N3-treated plants produced the highest levels of phenolic and flavonoid compounds 2 days after inoculation (Figure 5). For example, there was a 42% rise in phenolic compounds in the N2 group and 107% rise in the N3 group on day 3 compared to day 0.
However, under pathogen free conditions, a higher accumulation of total phenolic and flavonoid compounds was observed in N1-treated plants relative to the N2, N3 or N4 groups. For example, we detected a 25 and 36% increase in total phenolic content in N1-treated plants relative to the N3 and N4 nitrogen supply groups, respectively. These data suggest that both excess and limiting nitrogen levels impair the synthesis and accumulation of defensive compounds in potato plants upon exposure to *P. infestans*.

DISCUSSION

Nitrogen supplies crops with the energy to grow foliage and set fruit and provides balance to the metabolic processes of plants. We observed that 90 $kg\text{-}hm^2$ was the most popular nitrogen concentration in use in Northeast China for Kexin 1 potato cultivation due to the high levels of tuber production achieved (Figure 1a). However, our data suggests that 90 $kg\text{-}hm^{-2}$ is not optimum for potato production in the presence of *P. infestans* (Figures 1 and 2).

In this study, four different nitrogen levels were applied to the Kexin 1 potato cultivar. We demonstrated that low (N1) and high nitrogen (N3 and N4) supply can impair tuber yield when compared with plants treated with intermediate (N2) nitrogen levels under pathogen free conditions (Figure 1a). The highest level of potato production with pathogen exposure was observed in the N3 and not the N2 nitrogen supply group (Figure 1a). Interestingly, we observed a significant effect of nitrogen on tuber size in this work. N3 levels of nitrogen favored the highest weight and percentage of large tuber size relative to the low and high nitrogen-treated groups under pathogen-exposure conditions. However, an excess and limited nitrogen supply resulted in a greater abundant of

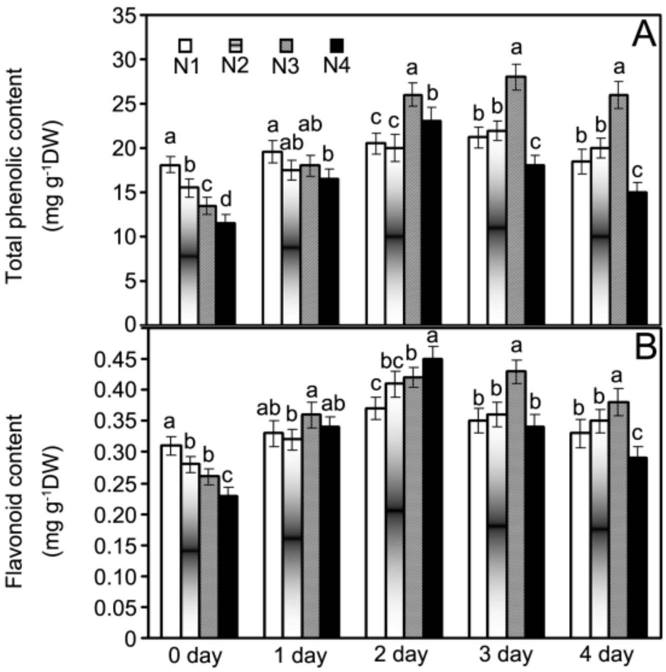

Figure 5. The effect of nitrogen on defensive compound accumulation. The effect of nitrogen availability on total phenolic (A) and flavonoid compound accumulation (B) was observed in potato plants after 4 days of inoculation. The data are presented as the mean of five independent experiments. Means followed by the same letter were not significantly different (Duncan's multiple range test; $P < 0.05$). Bars show mean ± SE (n = 5).

small tubers under the same conditions (Figure 1c-d). From an ecological standpoint, these data suggest an optimal reproductive strategy for the plant. The production of larger tuber with more nutrient storage would enhance potato reproduction (asexual reproduction in this case) under favorable conditions. On the other hand, producing a larger number of small tubers would enhance plant survival under adverse conditions.

The chlorophyll level in a plant is closely associated with photosynthesis. Interestingly, previous reports have demonstrated there is a positive correlation between chlorophyll levels and pathogen resistance (Ou, 2007; Yan et al., 2009). Here, we quantified chlorophyll levels of pathogen-infected potato plants under four levels of nitrogen availability (Figure 3). Our data demonstrated that the N3 level of nitrogen supply conferred potato plants with the highest chlorophyll content under pathogen-exposure (but not pathogen-free) conditions (Figure 3). So, both chlorophyll level and tuber yield peaked with the N3 levels of nitrogen supply (Figure 1).

Our data demonstrated that yield and pathogen resistance in Kexin 1 were biphasically regulated by the nitrogen supply. As is shown in Figure 2, a low level of nitrogen application gradually elevated pathogen resistance, which was then reversed by high-nitrogen treatment. Defensive capacity determines pathogen resistance in potato plants. Plant phenolics are formed through phenylpropanoid metabolism, and free phenolics can be cytotoxic in the cytoplasm. In the cell wall, they may be ester- or ether-linked to polysaccharides or be polymerized into lignin (Lewis and Yamamoto, 1990). Also, flavonoids are important secondary compounds that play a key role in pathogen resistance (Treutter, 2005). Defense enzymes, such as PAL and PPO, link phenols to cell-wall materials and promote the formation of lignin-like polymers (Pal et al., 2011). Other defensive enzymes from plants, such as chitinase and β-1,3-glucanase, are required for the degradation of the cell wall of fungal pathogens (Fink et al., 1988). Nitrogen increases the activity of defensive enzymes but suppresses the synthesis of defensive compounds in plants (Ibrahim et al., 2012; Nguyen and Niemeyer, 2008; Hamilton et al., 2001).

In this study, a higher activity for defense enzymes such as PPO and PAL and the abundant accumulation of defense compounds (such as phenolic) were found with intermediate (N2 and N3) but not low (N1) and high (N4) nitrogen supply levels (Figures 4 and 5). These data suggest that pathogen resistance was partly dependent on the provision of N in suitable amounts. Also, the enzymes PPO and PAL, which are associated with phenolic metabolism, were more important than cell wall-degrading enzymes, such as Chi and Glu (which attack the cell wall of the pathogen), in these plant-microbe interactions (Figure 4). Our results suggest that phenolic-associated metabolism made a greater contribution than degradative enzymes in potato plants, at least in this Kexin 1 cultivar.

In conclusion, the nitrogen supply can significantly affect defensive enzyme activity, the synthesis of defense compounds, and tuber yield and size during pathogen exposure. In addition, defense capacity can be regulated biphasically by nitrogen with an "ascend first and then descend" pattern with pathogen exposure. To our knowledge, this is the first report in potato plants of the defense response and tuber yield in response to pathogen exposure. Also, a modest increase in the nitrogen supply level (from 90 to 135 kg-hm^{-2}) raises the tuber yield and pathogen resistance in potato plants during *P. infestans* exposure. This work provides us with a better understanding of the correlation between nitrogen-mediated growth and defensive metabolism during pathogen exposure.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

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Abbreviations: PPO, polyphenol oxidase; **PAL,** phenylalanine ammonia-lyase; **Chi,** chitinase; **Glu,** β-1,3-glucanase; **N,** nitrogen; **K,** potassium; **P,** phosphorus; **hpi,** hours post inoculation.

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Full Length Research Paper

An alternative procedure for evaluating the quality of castor seeds by the tetrazolium test

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The use of fast technologies, which also permit efficient decisions on seeds lots quality, is fundamental to the seed industry. Five seeds lots of "IAC 80"and five seeds lots "AL Guarani 2002" cultivars were used to test an alternative procedure for evaluating the seed quality of castor seeds by the tetrazolium test. Seeds lots characteristics were determined by tests of germination, first count germination, seedling emergence, speed emergence index and initial stand. The seeds were imbibed in water at 30°C for 3 h for the tetrazolium test and submitted to three preparation methods: (1) a bevel cut in the region opposite to the caruncle; (2) removal of the coats and a bevel cut in the region opposite to the caruncle; (3) removal of the coats and lateral cuts in the seed. After preparation, the seeds were immersed in 0.5 and 1.0% tetrazolium solutions for 6 h at 30°C. Imbibitions in water at 30°C for 3 h, followed by removal of the coats and lateral cuts in the seeds, with immersion in a 1% tetrazolium solution at 30°C for 6 h, is a suitable methodology for evaluating castor seed quality.

Key words: *Ricinus communis* L., seed technology, seed analysis.

INTRODUCTION

The launching of the Probiodiesel program, which aims at the substitution of 2% of the diesel produced from petroleum by biodiesel from vegetable oils, has resulted in Brazil relaunching castor seed production (*Ricinus communis* L.- Euphorbiaceae) in bunches. This production will bring in foreign exchange for Brazil and play an important social role in the development of family agriculture (Holanda, 2004). To supply this new demand, castor seeds have become scarce and expensive, consequently favoring a market of poor quality "pirate" seeds.

Research on castor seed quality is essential for crop establishment and is justified by the potential of the plant and the scarcity of information on the seed production technology. Considering that the seed is the basic input in agricultural production and its quality the starting point for a successful crop, it is necessary to develop technologies which permit a rapid and efficient evaluation of seeds lot quality.

Among the available methods for evaluating seed viability is the tetrazolium test, which is based on the activity of dehydrogenase enzymes in tissue respiratory

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processes. During respiration, hydrogen ions are liberated, which react with the 2,3,5 triphenyl chloride salt of tetrazolium forming an insoluble, red compound, called formazam (Delouche et al., 1976). The test has some specific characteristics: It is unaffected by conditions which can alter the results of the germination test, such as seed dormancy; evaluation of the viability and vigor at different levels is fast; a diagnosis of the causes of seed viability losses is possible (Delouche et al., 1976; França-Neto et al., 1998; França-Neto, 1999). Tissues dead or damaged presented discolored. The pattern of staining of tissues can be used to identify viable seeds, non-viable and within the viable category of the high and low vigor (Vieira and Von-Pinho, 1999).

The speed with which the tetrazolium salt is absorbed by seed tissues depends on the physical barriers present (Piña-Rodrigues and Santos, 1988). Many species require preparation of the seeds to allow penetration of the solution and activation of the respiratory system. Among the preparation methods most used are puncturing, cuts and removal of the coats (Brasil, 2009).

Apart from the preparation, other factors, such as solution concentration and staining time, may influence test efficiency and the methodology may have to be adjusted for each species. *Amburana cearensis* seeds, for example, require a 0.05% tetrazolium solution for 3 h (Guedes et al., 2010); whereas Jatropha curcas only needs a 0.5% tetrazolium solution for 120 min to evaluate seed quality (Pinto et al., 2009).

The rules for seed analysis - RSA (Brasil, 2009) provide information on the methodologies for evaluating the seeds of many species. Castor seeds require an 18 h period for seed preparation and 6 to 24 h immersion in a 1% tetrazolium solution, totaling around 42 h for a test evaluation. However, due to the need for a rapid analysis of seed quality, this period may be considered too long. Also, the possibility of reducing the concentration used would be an advantage since lower concentrations would have a lower salt cost and provide a better observation of staining differences to identify different types of injury (França-Neto et al., 1998).

The objective of this study was to develop an alternative methodology for evaluating the quality of castor seeds (*R. communis* L.) with the tetrazolium test.

MATERIALS AND METHODS

The analysis was conducted at the Central Laboratory of Seed Analysis Laboratory of the Federal University of Lavras (Universidade Federal de Lavras). Five seeds lots of “IAC 80” and five seeds lots “AL Guarani 2002” were produced during the 2005/2006 crop cycle. The seeds were collected from different plants, cleaned and naturally dried in a warehouse, after which the seeds lots were sent to the Seed Laboratory for evaluation. The physiological potential of the seed lots was evaluated using the: Seed Water Content (SWC): Determined by the oven method at 105°C for 24 h, using two replications of approximately 5 g per sample kept in aluminium capsules. The data were expressed as a percentage (Brasil, 2009). Germination test (G) was done with four replications of 50 seeds, in a rolled paper towel, moistened with distilled water 2.5 times the weight of the dry substrate. The rolls were kept in a germinator at 20 to 30°C (16 to 8 h) and counts were made seven (First Count Germination - FCG) and 14 days after the test was initiated, according to criteria established by the Rules for Seed Analysis-RAS (Brasil, 2009). Seedling Emergence Test (SE) was done in nursery beds with an earth-sand substrate (1:1) with four replications of 50 seeds. Seedling emergence was evaluated at seven days (Initial Stand- IS) and 21 days after test initiation. The Speed Emergence Index (SEI) was calculated according to Maguire’s (1962) formula with data from the daily counts of the emergence test.

For the tetrazolium test (TZ) were used four replications of 25 seeds for each treatment. The seeds from the different castor seeds lots were imbibed between paper moistened in water at 30°C for three hours before being tested with the three different preparation methodologies: (1) With coats: The seed coats were maintained and a bevel cut was made in the opposite region to the caruncle; (2) Lateral cuts: The seed coats were removed and lateral cuts were made in the endosperm; (3) Bevel cut: The seed coats were removed and a bevel cut was made in the opposite region to the caruncle (Figure 1).

After preparation, the seeds were immersed in 0.5 and 1% tetrazolium solutions in plastic recipients and kept in the dark in a BOD chamber at 30°C, for six hours, constituting six treatments (three preparation methodologies x two concentrations of tetrazolium solution). The seeds were examined individually and according to the extension and intensity of the red staining and presence of milky-white areas, tissue appearance and location of the these colorations with respect to the essential growing areas, they were classified as viable or unviable, according to the standards published by Grabe (1976) and Moore (1972), for various agricultural and forest species.

All the data were submitted to an analysis of variance and the means compared using the Tukey test at the 5% probability level. The results in percentages were transformed into arc sine $\sqrt{x/100}$ and those of the emergence speed index into log(x+5). Pearson’s simple correlation was calculated between the results of the germination and tetrazolium tests.

RESULTS

The mean values for the seed water content were 7.8% for the “IAC 80”and 6.5% for the “AL Guarany 2002” cultivars. The coats were observed to hinder penetration of the tetrazolium solution, independently of the concentration used, masking the evaluation of seeds lot quality for both cultivars. This was confirmed by the lower percentage of viable seeds obtained from these treatments (TZ1 and TZ4) compared to the other treatments and tests (Tables 1 and 2). The main objective of the preparation was to facilitate penetration of the tetrazolium solution, and although only imbibition and cuts are sufficient for some species, such as *Jatropha elliptica* seeds, which should be imbibed in water followed by removal of the caruncle and a longitudinal cut of the seeds (Añez et al., 2007), for castor seed complete integument removal is necessary to stain the viable organs. Similar results were obtained by Gaspar-Oliveira et al. (2009a) for castor seeds, who said that for the evaluation of their physiological potential with the tetrazolium test, the recommended preparation is the removal of the coats followed by posterior longitudinal

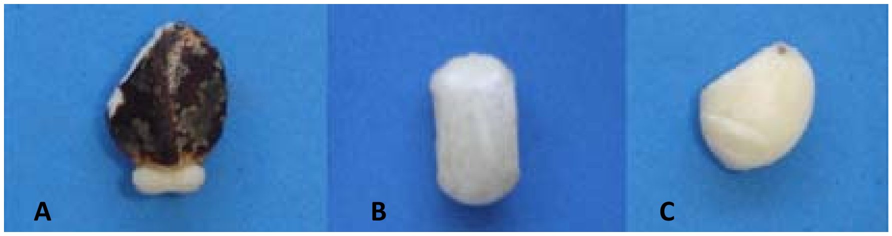

Figure 1. Methods of preparation in castor bean seeds for tetrazolium testing. A, With coats; B, lateral cuts; C, bevel cut.

Table 1. Speed emergence index (SEI), Seedling emergence (SE), initial stand (IS), First count germination (FCG) Germination (G) and tetrazolium (TZ1 - With coats and 0,5% tetrazolium solutions; TZ2 - Lateral cuts and 0,5% tetrazolium solutions; TZ3 - Bevel cut and 0,5% tetrazolium solutions; TZ4 - With coats and 1% tetrazolium solutions; TZ5 - Lateral cuts and 1% tetrazolium solutions e TZ6 - Bevel cut and 1% tetrazolium solutions) of seed lots of castor “Guarani AL 2002” cultivar.

Lots	SEI	SE	IS	FCG	G	TZ1	TZ2	TZ3	TZ4	TZ5	TZ6
		----------%----------									
1	43.64^{b}	84^{a}	18^{a}	72^{b}	84^{a}	02^{b}	49^{b}	45^{b}	04^{a}	58^{a}	48^{a}
2	44.80^{b}	87^{a}	16^{a}	89^{a}	94^{a}	03^{b}	60^{ab}	41^{b}	03^{a}	74^{a}	66^{a}
3	52.42^{a}	90^{a}	30^{a}	81^{ab}	87^{a}	01^{b}	78^{a}	55^{ab}	03^{a}	70^{a}	65^{a}
4	53.43^{a}	91^{a}	33^{a}	82^{ab}	90^{a}	26^{a}	71^{ab}	55^{ab}	03^{a}	74^{a}	67^{a}
5	53.88^{a}	90^{a}	32^{a}	87^{a}	95^{a}	01^{b}	71^{ab}	69^{a}	00^{b}	62^{a}	61^{a}
CV (%)	1.62	4.70	27.88	7.19	8.44	34.98	14.94	13.84	18.73	18.16	20.77

*Comparison of means within each column (Tukey test, P ≤ 0.05); CV (%) = coefficient of variation.

Table 2. Speed emergence index (SEI), Seedling emergence (SE), initial stand (IS), First count germination (FCG) Germination (G) and tetrazolium (TZ1 - With coats and 0,5% tetrazolium solutions; TZ2 - Lateral cuts and 0,5% tetrazolium solutions; TZ3 - Bevel cut and 0,5% tetrazolium solutions; TZ4 - With coats and 1% tetrazolium solutions; TZ5 - Lateral cuts and 1% tetrazolium solutions e TZ6 - Bevel cut and 1% tetrazolium solutions) of seed lots of castor “IAC 80” cultivar.

Lots	SEI	SE	IS	FCG	G	TZ1	TZ2	TZ3	TZ4	TZ5	TZ6
		----------%----------									
1	3.58^{b}	23^{c}	01^{b}	04^{c}	07^{b}	01^{c}	12^{b}	11^{b}	05^{b}	09^{b}	07^{b}
2	17.38^{a}	52^{b}	00^{b}	10^{c}	55^{a}	04^{b}	38^{a}	39^{a}	04^{b}	36^{a}	20^{a}
3	17.89^{a}	51^{b}	01^{b}	13^{bc}	22^{b}	11^{a}	34^{a}	29^{ab}	18^{a}	23^{a}	28^{a}
4	29.88^{a}	81^{a}	07^{a}	27^{ab}	59^{a}	06^{ab}	45^{a}	37^{ab}	05^{b}	38^{a}	18^{ab}
5	19.62^{a}	58^{b}	01^{b}	31^{a}	58^{a}	02^{bc}	36^{a}	17^{b}	26^{a}	35^{a}	21^{a}
CV(%)	8.99	12.48	83.18	25.55	24.36	28.49	12.23	10.84	14.66	15.74	20.08

*Comparison of means within each column (Tukey test, P ≤ 0.05); CV (%) = coefficient of variation.

and median cuts in the embryo and endosperm. However, Costa and Santos (2010) observed that the tetrazolium test is efficient for evaluating leucaena seed viability using a lateral cut followed by the seed coat removal.

Similarly, staining was only observed in the region close to the cut in some seeds, which had had their coats removed and were bevel cut, due to the greater exposure of this region to the tetrazolium solution (Figure 2). This result agrees with that of Gaspar-Oliveira et al. (2009a), who observed that only the peripheral regions of castor seeds, which had direct contact with the tetrazolium solution, were stained. Considering that the embryo is located in the internal part of the seed and is the principal structure to be analyzed in quality evaluation in the tetrazolium test, this preparation method may be considered inefficient.

On the other hand, the preparation method involving the removal of the coats and lateral cuts permitted the penetration of the tetrazolium solution up to the

Figure 2. Staining of castor bean seeds submitted to the tetrazolium test. A, With coats; B, bevel cut; C, lateral cuts.

Table 3. Simple correlation coefficients between the results of the germination (G) and tetrazolium (TZ1 - With coats and 0,5% tetrazolium solutions; TZ2 - Lateral cuts and 0,5% tetrazolium solutions; TZ3 - Bevel cut and 0,5% tetrazolium solutions; TZ4 - With coats and 1% tetrazolium solutions; TZ5 - Lateral cuts and 1% tetrazolium solutions e TZ6 - Bevel cut and 1% tetrazolium solutions) in the seed lots of castor “AL Guarani 2002” (GUA) and “IAC 80”(IAC) cultivars.

Tests/cultivars	TZ1	TZ2	TZ3	TZ4	TZ5	TZ6
G (GUA)	-0.018^{NS}	0.354^{NS}	0.407^{NS}	-0.775^{NS}	0.340^{NS}	0.595^{NS}
G (IAC)	-0.069^{NS}	0.8594*	0.572^{NS}	0.131^{NS}	0.976*	0.362^{NS}

NS = not significant; * Significant at P ≤ 0.01 level.

embryonic axis and cotyledons, which facilitated quality analysis due to contact of the whole seed with the solution. Seed imbibition followed by seed coat removal and cuts was also an efficient preparation method for the seeds of other species, such as *J. curcas* (Gris et al., 2007) and Albizia hasslerii (Zucareli et al., 2001).

The numerical results of the germination tests, first germination count, initial stand, emergence and emergence speed index, showed that the seeds lots from the “AL Guarany 2002” cultivar had a higher physiological quality compared to those from the “IAC 80”cultivar (Tables 1 and 2). There were no significant differences between the seeds lots of the AL Guarani 2002 cultivar for emergence, initial stand and germination tests. Similar results were obtained from the treatments with lateral cuts and the 1% solution (TZ5) and the bevel cut and the 1% solution (Table1). However, as mentioned previously, the difficulty of making an evaluation should be noted when the seeds are submitted to a bevel cut. For the “IAC 80”cultivar, the IAC1seeds lot can be classified as having a worse quality compared to the rest based on the numerical results of the tests. The inferior quality of the seeds lot compared to the others may also be observed in the lateral cut and 0.5% (TZ2) and 1% (TZ5) treatments (Table 2). Therefore, the removal of the coats and lateral cuts in a 1% solution (TZ5) permitted a differentiation of the seeds lots of castor seeds corresponding to the results obtained in the other tests for both cultivars (Tables 1 and 2). The results from this treatment were also correlated with those from the germination test for the “IAC 80”cultivar, but this was not observed for the AL Guarani 2002 cultivar (Table 3).

Although the 1% tetrazolium solution intensely stained the seed tissues of some species, as observed by Wetzel et al. (1992) in rubber tree seeds and by Añez et al. (2007) in *J. elliptica* seeds, this concentration can be recommended for castor seeds, as verified in the present study and according to the description in the Rules for Seed (Brasil, 2009). Other methodologies have been recommended for castor seeds, such as that of Gaspar-Oliveira et al. (2009b), who observed that to evaluate the physiological potential using the tetrazolium test, the castor seeds should be immersed in a 0.2% tetrazolium solution for 120 min at 35°C. Three categories of viable and five of unviable seeds were found and described from the tetrazolium test (Table 4). The classification of the seeds submitted to the tetrazolium test into viable and unviable classes facilitates future seed quality evaluations. Another important factor to be considered when doing the tetrazolium test on seeds is the time taken since a rapid evaluation has advantages, such as the possibility of discarding seeds lots of unsuitable quality. The germination test needs 14 days for castor beans whereas the results of the tetrazolium test were available in only one day.

Thus, to be able to differentiate seed seeds lots in a similar way to most of the tests used, to facilitate test evaluations and correlate with the results of the germination test, the methodology using seed imbibitions in water at 30°C for three hours, followed by removal of

Table 4. Categories of castor seeds submitted to the tetrazolium test.

Category	Description
1 (viable)	Embryo completely stained with firm tissues
2 (viable)	Embryo with damage to the embryonic axis without affecting the central cylinder. Cotyledons with a normal color or with less than 50% of the tissues affected
3 (viable)	Embryonic axis with a normal color and less than 50% of the cotyledons stained an intense red.
4 (unviable)	Embryo with damage to the reserve translocation region
5 (unviable)	Embryo with damage to the embryonic axis reaching the central cylinder. Cotyledons with a normal color or with more than 50% of the cotyledons damaged
6 (unviable)	Embryonic axis intensely stained and less than 50% of the cotyledons with intense staining
7 (unviable)	More than 50% of the cotyledons with an intense red stain, embryonic axis with a normal color
8 (unviable)	Embryo completely discolored or with more than 50% discolored, with flaccid tissues

Source: Adapted Moore (1972) and Grabe (1976).

the coats and lateral cuts and the immersion in a 1% tetrazolium solution at 30°C for six hours was suitable for evaluating castor seed quality.

Conclusions

Imbibition in water at 30°C for three hours followed by the seed coat removal and lateral cuts in the seeds with immersion in a 1% tetrazolium solution at 30°C for six hours is a suitable methodology for evaluating castor seed quality.

Conflict of Interest

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

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Full Length Research Paper

Effect of tillage system and nitrogen fertilization on the pH, extractable phosphorus and exchangeable potassium of Nitisols in Western Ethiopia

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Maize production in Western Ethiopia is constrained by non-sustainable cropping practices, particularly repeated conventional tillage and insufficient N fertilization. A change in these cropping practices have usually a profound influence on soil chemical properties of which some may affect crop performance. Field trials were therefore conducted to determine the integrated effects of tillage system and nitrogen fertilization on the pH, extractable phosphorus and exchangeable K of Nitisols at five sites using maize as test crop from 2000 to 2004 in Western Ethiopia. Three tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) and three N levels (the recommended rate and 25% less and 25% more than this rate) were combined in factorial arrangement with three replications. After five years the influence of the tillage systems on pH, extractable P and exchangeable K was confined to the upper 0-7.5 cm. The soil was acidified much more with MTRR than with either MTRV or CT. However, MTRR resulted in higher contents of extractable P and exchangeable K than MTRV and CT. Application of N fertilization for five consecutive years significantly decreased pH irrespective of tillage system. Neither extractable P nor exchangeable K were affected by N fertilization. The enhanced soil acidification that coincides with MTRR may impact negatively on maize production in the long run without a proper liming program. Liming is currently not a common practice in Western Ethiopia because of resource poor farmers. This aspect should be taken into account when the replacement of CT with MTRR is recommended. The findings of this study could be useful to other highland regions in Africa where cropping on Nitisols is common.

Key words: Conventional tillage, crop residues, minimum tillage, plant nutrients, soil acidity.

INTRODUCTION

The western part of Ethiopia has a high maize production potential because of favourable environmental conditions. However, maize production is constrained by non-sustainable cropping practices, particularly plough- or hoe-based cultivation (Bezuayehu et al., 2002), soil and water loss due to erosion, as well as N deficiency (Tolessa et al., 2002). This necessitated a proper investigation into the integrated effects of tillage system and N fertilization on the performance of the maize crop and the change in soil properties. The ultimate aim with

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this investigation was to obtain substantiated information whether the sustainability of the current cropping systems can be improved with minimum tillage. Results of the investigation concerning effects on yield and yield components (Tolessa et al., 2007) and efficacy of applied nitrogen (Tolessa et al*.,* 2009) have already been reported but not that of changes in soil fertility indicators.

Tillage systems have a profound effect on the chemical properties of soils that ultimately may influence crop growth and development. It is especially pH and content of immobile nutrients such as P and K that are substantially affected by different tillage systems (Juo and Lal, 1979; Dick, 1983; Ismail et al*.,* 1994; Kotzé and Du Preez, 2008; Lopex -Fando and Pardo, 2009).

The pH in the upper few centimeters of a soil usually decreases rapidly under minimum tillage compared to conventional tillage, especially when high rates of N fertilizer are used (Moschler et al*.,* 1973; Blevins et al., 1983; White, 1990; Yadvinder-Singh et al., 2005). This drop in pH is attributed mainly to the H^+ released through the nitrification of NH_4^+. The NH_4^+ originates from the surface-applied nitrogenous fertilizers and the N mineralized from the crop residues (Ismail et al*.,* 1994). Organic acids released during the breakdown of crop residues could also contribute to the pH reduction (Stevenson and Cole, 1999). Weil and Magdoff (2004), however, pointed out that the organic matter which usually accumulates near the surface of minimum tilled soils tend to ameliorate the acidity. Thus, changes in pH resulting from tillage systems may have a bearing on fertilizer application strategies.

Accordingly, it has been found that minimum tillage in comparison with conventional tillage increased the concentration of plant nutrients like P and K in the surface layers of soil but decreased concentrations in deeper soil layers (Shear and Moschler, 1969; Lal, 1976; Juo and Lal, 1979; Ismail et al*.,* 1994; Du Preez et al., 2001; Wright et al., 2007). Robbins and Voss (1991) for example reported that extractable P and exchangeable K in the 0-5 cm layer of minimum tilled soil were on average 3.5 times higher than in the 5-15 cm layer. Thus it is not surprising that these two plant nutrients are usually higher in the surface layers of minimum tilled soil than in conventionally tilled soil. For example, in a 20-year old trial it was found that extractable P and exchangeable K in the 0-5 cm layer of minimum tilled soil exceeded those in conventionally tilled soil by 1.5 and 1.8 times, respectively (Kotzé and Du Preez, 2008). This stratification of the two nutrients on account of minimum tillage can be attributed *inter alia* to: (1) no incorporation of surface-applied fertilizer P and K into soil; (2) uneven extraction of soil P and K by crop roots; (3) release of plant P and K from crop residues that decompose on the soil surface; and (4) little movement of P and K in soil due to their immobility (Dick, 1983; Unger, 1991; Lupwayi et al., 2006).

Stratification of other nutrients such as Ca, Mg, Cu, Fe Mn and Zn has also been associated with the adoption of minimum tillage (Lal, 1976; Blevins et al., 1983; Shuman and Hargrove, 1985). However, in a few instances no stratification of P (Juo and Lal, 1979; Lal, 1997), K (Hargrove et al., 1982) and Ca (Blevins et al*.,* 1977) were found with minimum tillage. Reasons for these exceptions to the rule are given by the aforementioned authors.

The growth and development of a crop can be affected if the introduction of a tillage system results in a severe decrease of pH and increase of either extractable P or exchangeable K in the surface layers of soil (Matawo et al*.,* 1999). Quantification of these processes are therefore of great importance in the evaluation of a tillage system before being advocated.

We are not aware of any research in Western Ethiopia on the temporal and spatial dynamics of soil fertility indicators for maize production under different tillage systems. Due to a lack of *inter alia* such information neither extension officers recommend nor smallholder famers apply conservation agriculture practices like minimum tillage generally. Thus it is not surprising that the sustainability of maize production in Western Ethiopia is questioned. This scenario can be reversed when sound experimental knowledge is available concerning changes in soil fertility indicators that coincide with the introduction of conservation tillage systems. The temporal and spatial effects of tillage system and N fertilization on the pH, extractable P and exchangeable K of Nitisols in Western Ethiopia are therefore reported in this paper.

MATERIALS AND METHODS

Experimental sites

The field trials for this study were conducted under rainfed conditions at Bako Agricultural Research Center, and on farmers' fields at Shoboka, Tibe, Ijaji and Gudar. These five sites were selected to be representative of the major maize producing areas of Western Ethiopia in terms of climate and soil. Bako is located at 09° 01'N and 37° 02'E, Shoboka at 09°06' N and 37°21'E, Tibe at 09°29'N and 37°32'E, Ijaji at 09°43'N and 37°47'E, and Gudar at 08°09'N and 38°08'E latitude and longitude, respectively.

The altitudes for Bako, Shoboka, Tibe, Ijaji and Gudar are 1650, 1695, 1730, 1820 and 2000 m above sea level, respectively. Only climatic data of the Bako site with the lowest altitude and the Gudar site with the highest altitude as obtained from nearby weather stations is given in Table 1 since there are no weather stations close to the other three sites. Based on these data the mean annual rainfall over a 15-year period (1990-2004) ranged from 1042.2 mm at the higher lying Gudar site to 1239.6 mm at the lower lying Bako site, viz. a difference of 197.4 mm. For the cropping season (May to October) the average minimum temperature was 3.5°C lower and maximum temperature 0.9°C higher at the Bako site compared to that of the Gudar site. At all five sites the soil was classified as a Nitisol (FAO, 1998). Some physical and chemical topsoil characteristics of these Nitisols before commencement of the trials are summarized in Table 2.

The textural class of the Nitisols differed from loam at the Ijaji site to clay at the Shoboka site. Similar differences of 0.61 units in pH, 1.08% in organic C, 0.04% in total N, 3.9 mg kg^{-1} in extractable P and 85 mg kg^{-1} in exchangeable K were recorded between the five sites. The aforementioned differences in climate and soil justified therefore the selection of the five sites for this investigation.

Table 1. Climatic data for the Bako and Gudar sites as obtained from nearby weather stations.

Bako	May	Jun	Jul	Aug	Sep	Oct	*CS	Annual
Rainfall (mm)								
1990-1999	146.1	214.1	254.1	231.7	141.4	70.8	1058.2	1243.7
2000	135.1	278.2	236.9	289.6	162.0	103.4	1205.2	1345.5
2001	161.3	219.3	328.9	264.3	96.7	92.7	1163.2	1354.2
2002	68.3	236.0	239.2	205.9	42.1	0.0	791.5	1040.9
2003	5.7	265.1	420.6	434.4	39.9	11.5	1177.2	1355.1
2004	14.1	268.6	225.5	257.8	85.2	43.5	894.7	1061.3
2000-2004	76.9	253.4	290.2	290.4	85.2	50.2	1046.3	1231.4
Temperature (°C)								
Minimum	15.0	14.7	14.6	14.5	14.0	12.6		
Maximum	28.6	25.9	23.9	24.1	25.1	27.2		
Mean	21.8	20.3	19.3	19.3	19.6	19.9		
Gudar	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	***CS**	**Annual**
Rainfall (mm)								
1990-1999	111.4	150.4	258.5	163.3	100.7	74.6	858.9	1069.0
2000	109.9	123.8	207.5	237.5	166.6	19.4	864.7	994.4
2001	194.0	166.6	301.5	209.7	61.0	17.8	950.6	1139.4
2002	29.5	216.2	211.6	131.0	30.2	17.8	636.3	881.8
2003	2.0	185.9	167.3	153.2	55.9	7.5	571.8	975.9
2004	37.4	110.0	293.5	172.1	147	28.9	788.9	951.5
2000-2004	74.6	160.5	236.3	180.7	92.1	18.3	762.5	988.6
Temperature (°C)								
Minimum	11.6	11.1	11.1	11.2	10.3	9.6		
Maximum	28.4	25.3	23.1	22.6	24.5	25.7		
Mean	20.0	18.2	17.1	16.9	17.4	17.7		

*CS = Cropping season.

Table 2. Some physical and chemical topsoil characteristics of the Nitisols at the study sites before commencement of the trials.

Sites	Sand	Silt	Clay	pH (H_2O)	Organic C	Total N	P	K
		--------%-------			-------%-------		---- mg kg^{-1}----	
Bako	35.1	31.6	33.3	5.59	1.77	0.15	12.6	192
Shoboka	34.7	23.3	42.0	5.52	1.65	0.14	11.5	155
Tibe	26.7	35.2	38.1	5.41	1.46	0.12	8.7	146
Ijaji	44.7	32.3	23.0	5.69	1.93	0.16	10.3	231
Gudar	18.8	42.5	38.7	6.02	1.69	0.14	9.6	159

Field trial layout

At each of the five sites a field trial was laid out in a randomized complete block design. The layout consisted of two factors namely, three tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal, and CT = conventional tillage) and three N fertilization levels (69 kg ha^{-1}, 92 kg ha^{-1}, and 115 kg ha^{-1}) replicated three times in a complete factorial combination. Every field trial had therefore 27 plots. An application of 92 kg N ha^{-1} is the recommended fertilization rate for conventional maize production at the study sites, implicating the two other rates are 25% less and 25% more than this recommended rate. These experiments were conducted from 2000 until 2004. The experimental plots were kept permanent to observe the carry-over effects of the treatments for the five cropping seasons.

Agronomic practices

Before initiation of the trials the fields at all sites were under conventional maize production for many years. During the entire trial period immediately after harvesting the plants were cut at ground level and uniformly spread on the CT and MTRR plots, and removed from the MTRV plots. For the MTRR and MTRV treatments soil disturbance was restricted to the absolute minimum, *viz.* the soil was disturbed only to place the seed in the soil at the time of sowing. In contrast, the soil was ploughed three times with the local oxen-plough 'maresha' prior to sowing to obtain a suitable seedbed for the CT treatments.

Urea and triple super phosphate were used as the sources of N and P, respectively. The application of urea was split and therefore half of the urea and all of the triple super phosphate were band placed 5 cm below the seed at sowing. At 35 days after sowing when maize was at knee-height the other half of the urea was band placed next to the row at 5 cm depth. The fertilizer in the small furrows was covered with soil soon after application. All treatments received the recommended phosphorus rate of 20 kg ha^{-1} annually.

Weed control in the MTRR and MTRV treatments was done by applying Round-up (glyphosate-isopropylamine 360 g a.i. L^{-1}) at a rate of 3 L ha^{-1} prior to planting and Lasso/Atrazine (alachlor/atrazine 336/144 g a.i. L^{-1}) at a rate of 5 L ha^{-1} as a pre-emergence application. The recommended weed control practice for CT in Ethiopia is hand weeding at 30 and 55 days after sowing followed by slashing at milk stage.

The standard cultural practices as commonly recommended to the farmers were adopted for the study. Therefore, from 2000 to 2004 the planting dates varied from 5 May to 5 June at all the sites. A late maturing commercial maize hybrid, BH-660 was planted. The plant density aimed for was 50 000 plants ha^{-1} as the 5.0 x 4.8 m plots consisted each of six rows, 5.0 m in length and the inter- and intra-row spacing was 0.8 and 0.25 m, respectively.

Data collection

Soil samples were collected, just before the trials commenced, from the 0-30 cm layer of all five sites for their characterization. A 5 cm diameter auger was used to sample 20 randomly selected spots per site. These subsamples were thoroughly mixed, dried at room temperature, sieved through a 2 mm screen and stored until analysis. Since the trials started soil samples were collected annually after harvesting from the 0-30 cm layer of all plots at each site. At the end of the trial period the 0-7.5 cm, 7.5-15 cm, 15-22.5 cm and 22.5-30 cm layers were sampled additionally. In both instances an auger with a 2 cm diameter was used to sample five randomly selected spots per plot. These subsamples were prepared for analysis as described earlier. Standard procedures (The Non-affiliated Soil Analysis Work Committee, 1990) were used to determine particle size distribution (Hydrometer), organic C (Walkley-Black), total N (Kjeldahl), pH (1:2.5 water), extractable P (Bray 2) and exchangeable K (NH_4OAc) of the relevant composite soil samples.

Statistical analysis

Experimental data were analyzed through analyses of variance using the MSTATC statistical package (Michigan State University, 1989). Means for each parameter were compared by the least significant difference (LSD) test at P = 0.05.

RESULTS AND DISCUSSION

pH

Both tillage system and N fertilization had a significant effect on the pH of the 0-30 cm soil layer for the year 2000 to 2004 but there was no significant interaction between the two main effects. The effect of tillage system on pH in this soil layer is illustrated in Figure 1. At all five sites pH decreased over the experimental period regardless of the tillage system applied. This decrease in pH was least severe with CT, followed by MTRV and then MTRR. Differences in pH between tillage systems were initially small and inconsistent but as the experiments progressed it become more apparent. The magnitude of pH differences between CT and MTRR was surprisingly similar for the five sites, namely in the order of 0.07 units.

The pH of the 0-30 cm soil layer at all five sites decreased from 2000 to 2004 irrespective of the N application level (Figure 2). This decrease was least severe with the 69 kg ha^{-1} N level, followed by the 92 kg ha^{-1} N level and then the 115 kg ha^{-1} N level. The differences in pH between the three N application rates were only significant from the year 2003. This is probably due to the accumulative effect of the H^+ released with the continued use of urea at the three fixed rates. In the year 2004 pH differed between the lowest and highest N application level from 0.08 units at the Tibe site to 0.14 units at the Ijaji site. This is an indication that the buffer capacity of the Nitisols in this investigation was not similar.

As shown in Figure 3, the pH differences that evolved in the upper 30 cm of the Nitisols from either tillage system or N fertilization are attributable to their effects in the 0-7.5 cm layer. In this layer the highest pH was recorded in the CT soil, followed by the MTRV soil and then the MTRR soil. At the five sites the difference in pH between the CT and MTRR soils ranged from 0.15 to 0.25 units. The pH of the next three soil layers was not affected significantly by the three tillage systems at any of the sites.

The increase of pH with depth is common in the Nitisols of the study area. However, acidification of the upper 7.5 cm of these soils at all the sites appeared to be occurring faster with MTRR than with MTRV or CT. This phenomenon could be attributed to the nitrification of NH_4^+ released from either the fertilizer or residues at or near the soil surface (Blevins et al., 1983; Ismail et al., 1994) since the process produces acidifying hydrogen ions (Fox and Bandel, 1986). Similar changes in pH on account of tillage systems were reported by other researchers (Shear and Moschler, 1969; Blevins et al., 1983; White, 1990; Du Preez et al., 2001; Kotzé and Du Preez, 2008).

Extractable P

Extractable P of the 0-30 cm soil layer was significantly affected by tillage system and not by N fertilization. The effect of tillage system on extractable P in this soil layer is displayed in Figure 4 for the year 2000 to 2004. Regardless of year MTRR exhibited a higher extractable P level than MTRV while CT was intermediate. These

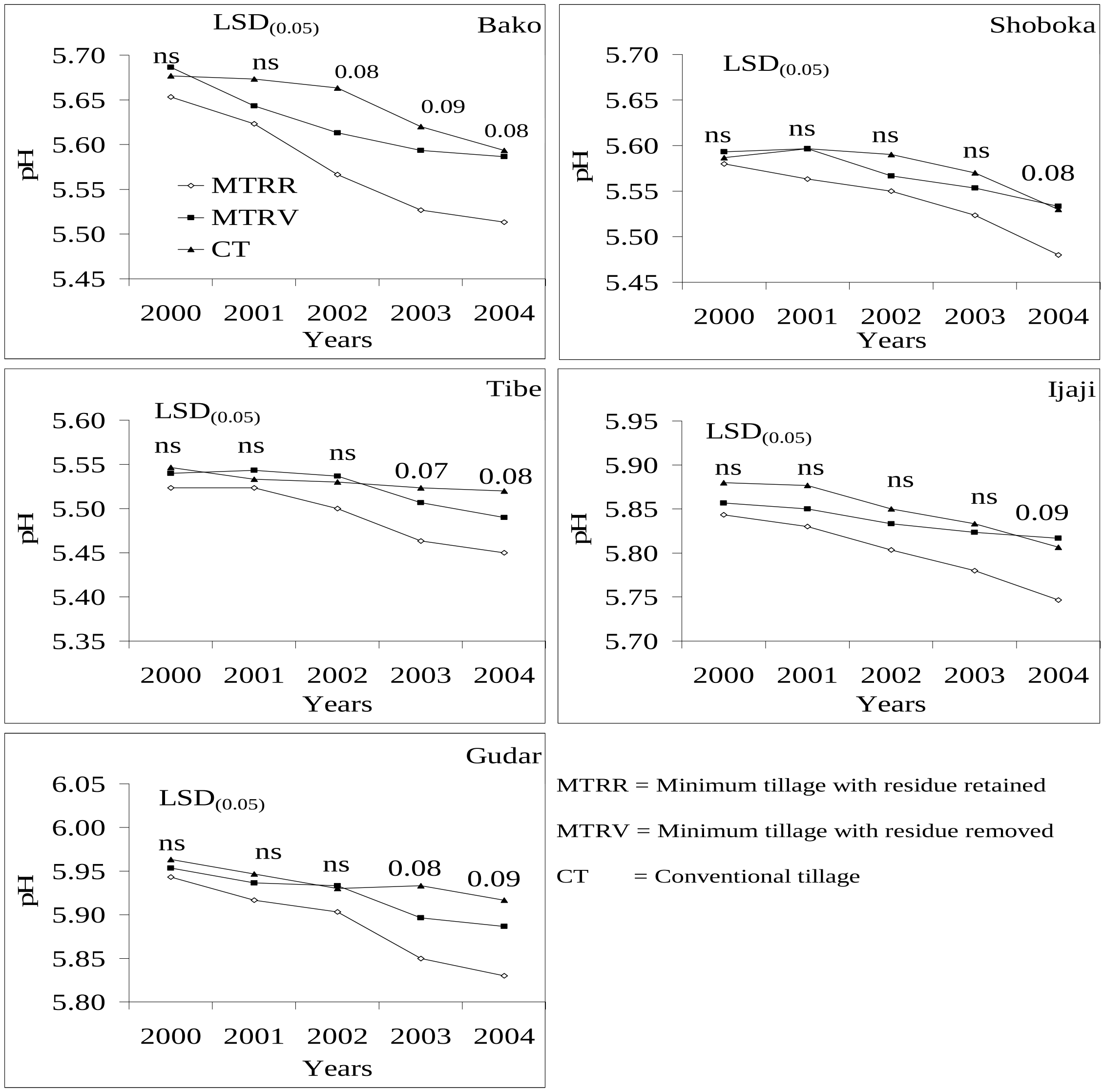

Figure 1. Effect of tillage system on pH measured after harvesting in the 0-30 cm layer of Nitisols at the five experimental sites in 2000 to 2004.

differences in extractable P levels between tillage systems were only significant from 2002 at Gudar, 2003 at Baka and Ijaji, and 2004 at Shoboka. However, the differences of extractable P between MTRR and MTRV soils at these four sites were relatively small in the year 2004, ranging from 0.9 mg kg^{-1} at Gudar to 1.3 mg kg^{-1} at Ijaji. Differences of this magnitude should not have any influence on the growth and development of maize.

The above mentioned differences in extractable P originated in the upper 15 cm soil layer as no significant differences were found below this depth (Figure 5). In 2004 irrespective of site, the extractable P level of the 0-7.5 cm layer was significantly higher in the MTRR soil than in either the MTRV or CT soils. The differences ranged from 2.5 mg kg^{-1} at Tibe to 5.1 mg kg^{-1} at Gudar which are probably large enough to affect maize growth and development. However, the extractable P level of the 7.5-15 cm layer was higher in the CT soil than in either the MTRV or MTRR soils although not significant at all sites.

The higher extractable P levels recorded especially in the 0-7.5 cm soil layer and to a lesser extent in the 7.5-15 cm layer of the Nitisols regardless of the tillage system can be attributed to the immobility of this nutrient. However, as indicated the tillage systems caused after five consecutive years of practice different extractable P levels in the upper 7.5 cm layer. The higher extractable P levels in this layer of the MTRR than the CT soils can be attributed to the applied P fertilizer and the retained maize residues which were not mixed with the soil to the

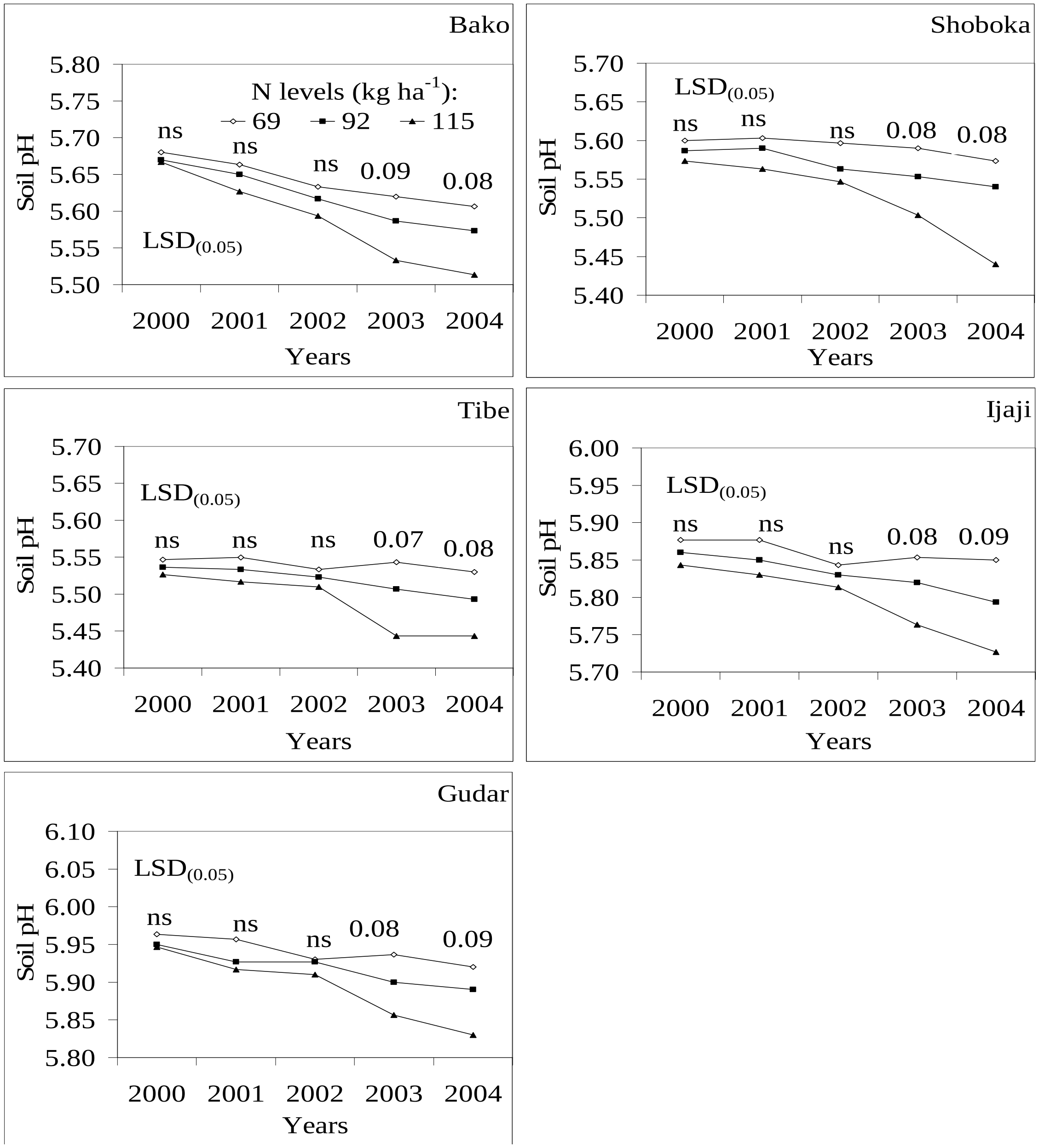

Figure 2. Effect of nitrogen fertilization on pH measured after harvesting in the 0-30 cm layer of Nitisols at the five experimental sites in 2000 to 2004.

same degree due to the nature of the two tillage systems. It seems however that the retention of maize residues contributed largely to this phenomenon as the extractable P levels in the upper 7.5 cm layer of the MTRV and CT soils were almost similar. The retained maize residues on the soil surface enhanced organic matter formation and in this process some of the P taken up by the crop from deeper layers is released in an inorganic form (Ismail et al., 1994; Thomas et al., 2007). This released inorganic P is probably less subject to fixation as organic matter can protected it to some degree (El-Baruni and Olsen, 1979).

Exchangeable K

Exchangeable K of the 0-30 cm layer was significantly affected by tillage system and not by N fertilization. The effect of tillage system on exchangeable K in this soil layer is shown in Figure 6 for the year 2000 to 2004. During the first three years exchangeable K differed not significantly among the three tillage systems which was not the case in the last two years at Bako, Shoboka, and Tibe when significantly higher levels of exchangeable K were recorded in the MTRR than MTRV and CT soils.

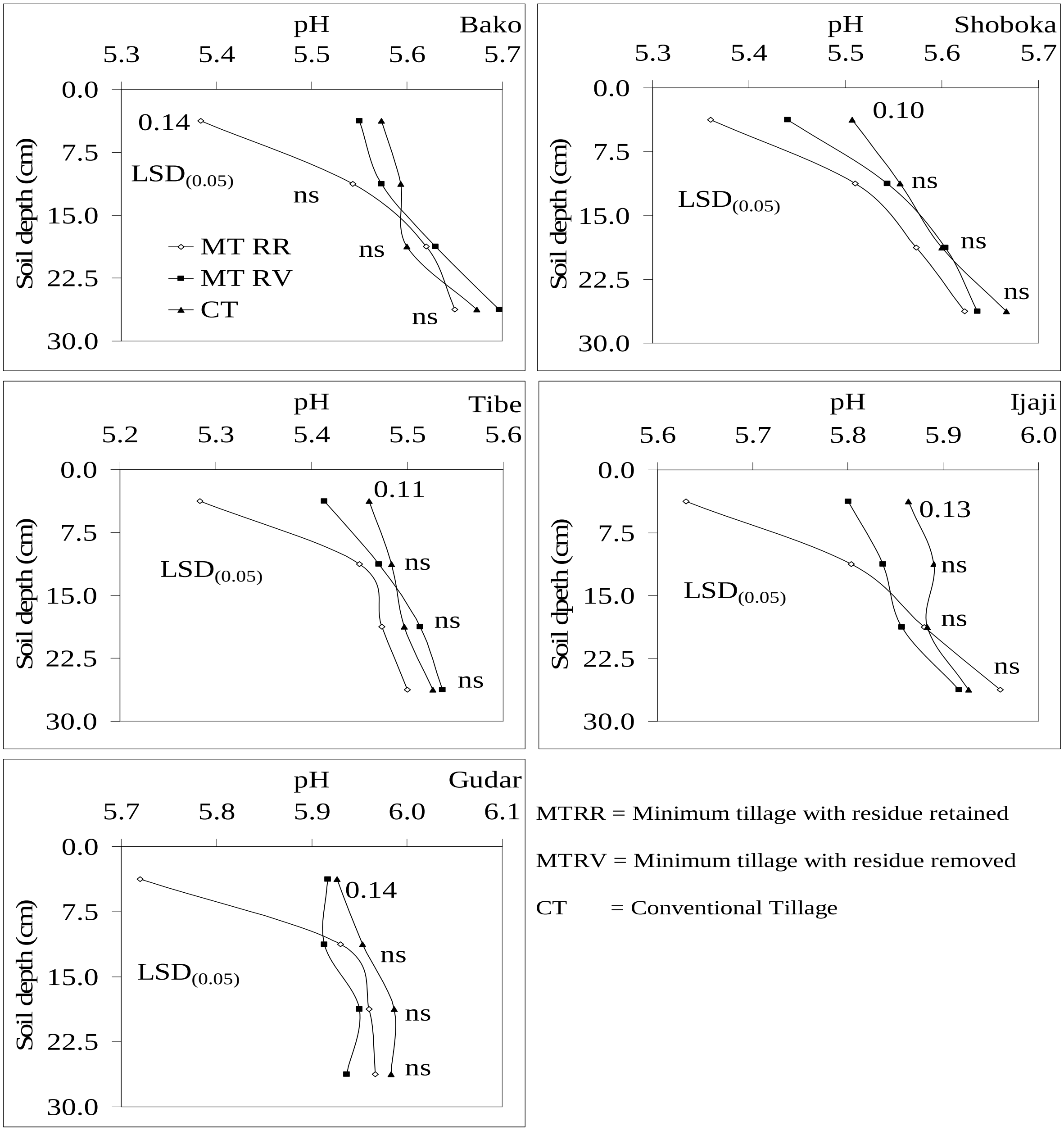

Figure 3. Effect of tillage system on pH measured after harvesting in the 0-7.5 cm, 7.5-15 cm, 15-22.5 cm and 22.5-30 cm layers of Nitisols at the five experimental sites in 2004.

However, throughout the experimental period the MTRR soils and to a lesser extent also the CT soils exhibited higher levels of exchangeable K than the MTRV soils. Thus at termination of the trials at the five sites in the year 2004 exchangeable K averaged 176 mg kg^{-1} for MTRR soils, 169 mg kg^{-1} for the CT soils, and 139 mg kg^{-1} for the MTRV soils.

The above mentioned differences in the exchangeable K originated in the upper 15 cm soil as no significant differences were recorded below this depth (Figure 7). In 2004 after five consecutive years of practice, MTRR resulted in the highest exchangeable K level in the 0-7.5 cm soil layer at all sites, followed by MTRV and CT. The exchangeable K levels for this layer averaged therefore over the five sites at 233 mg kg^{-1} in the MTRR soils, 202 mg kg^{-1} in the CT soils, and 187 mg kg^{-1} in the MTRV soils. However, in the 7.5-15 cm soil layer at all sites, the exchangeable K levels with MTRR and CT were almost similar but higher than that of MTRV.

A decline of exchangeable K with depth in the Nitisols is common to the study area. However, the differences in exchangeable K that evolved in the upper 15 cm of the

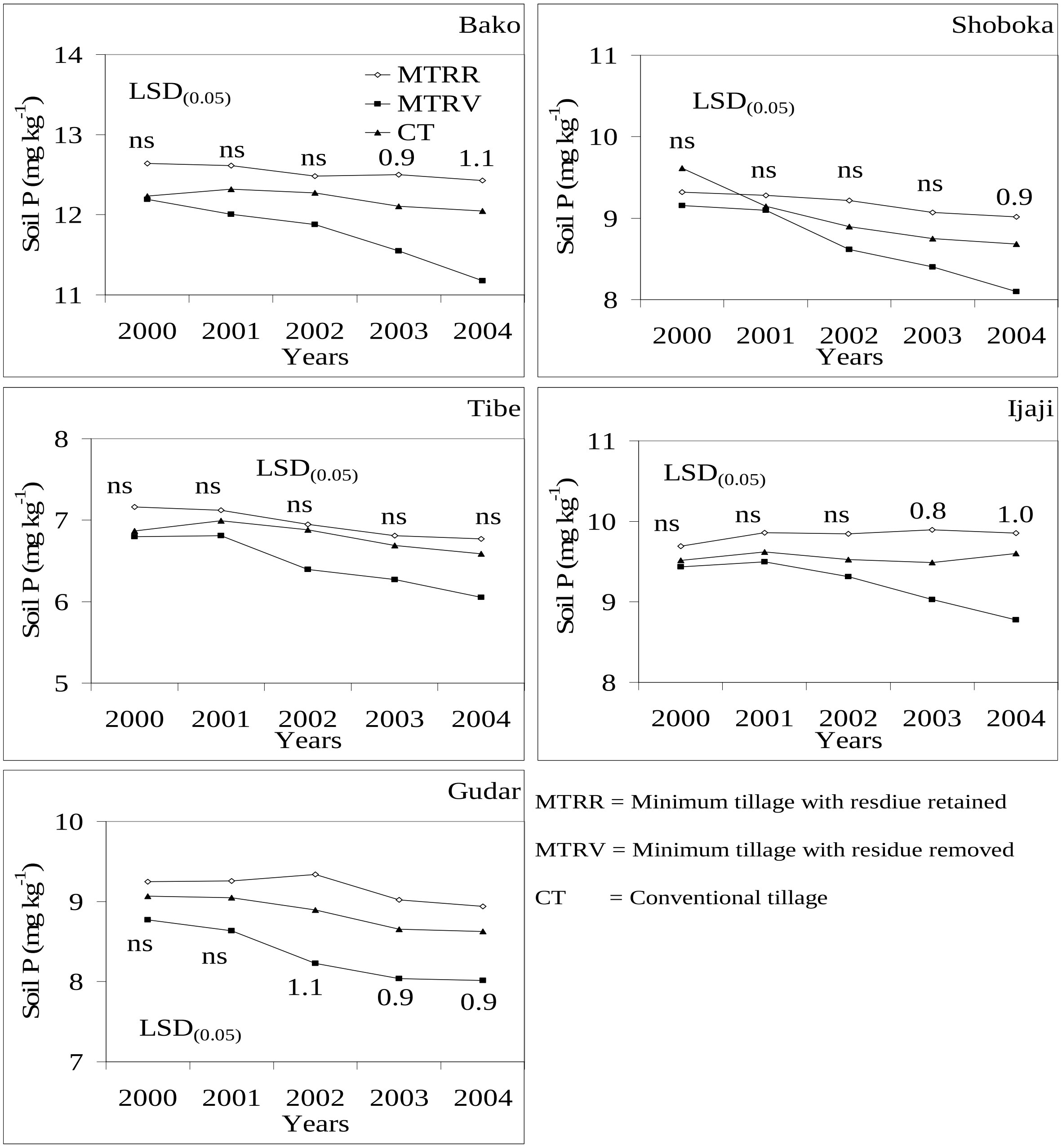

Figure 4. Effect of tillage system on extractable P measured after harvesting in the 0-30 cm layer of Nitisols at the five experimental sites in 2004.

Nitisols on account of tillage systems are a consequence of the concomitant residue management since no K fertilizer was applied. Several researchers (Triplett and Van Doren, 1969; Fink and Wesley, 1974; Addiscott and Dexter, 1994; Du Preez et al., 2001; Ben Moussa-Machraoui et al., 2010) showed that the fate of maize residues had a large influence on exchangeable K in soils as the residues contain a large amount of K.

The decrease of pH and increase of extractable P and exchangeable K in the 0-7.5 cm layer of MTRR soils with respect to MTRV and CT soils had probably no negative effect on the grain yield of maize during the final two years of the trial period. In this period there was no significant difference in grain yield between MTRV and CT and both were significantly inferior to MTRR (Tolessa et al., 2007). However, it can be expected that the changes of pH, extractable P and exchangeable K resulting in the Nitisols within five years of MTRR will proceed with continuous application of this tillage system. Prolonged application of MTRR may have eventually a

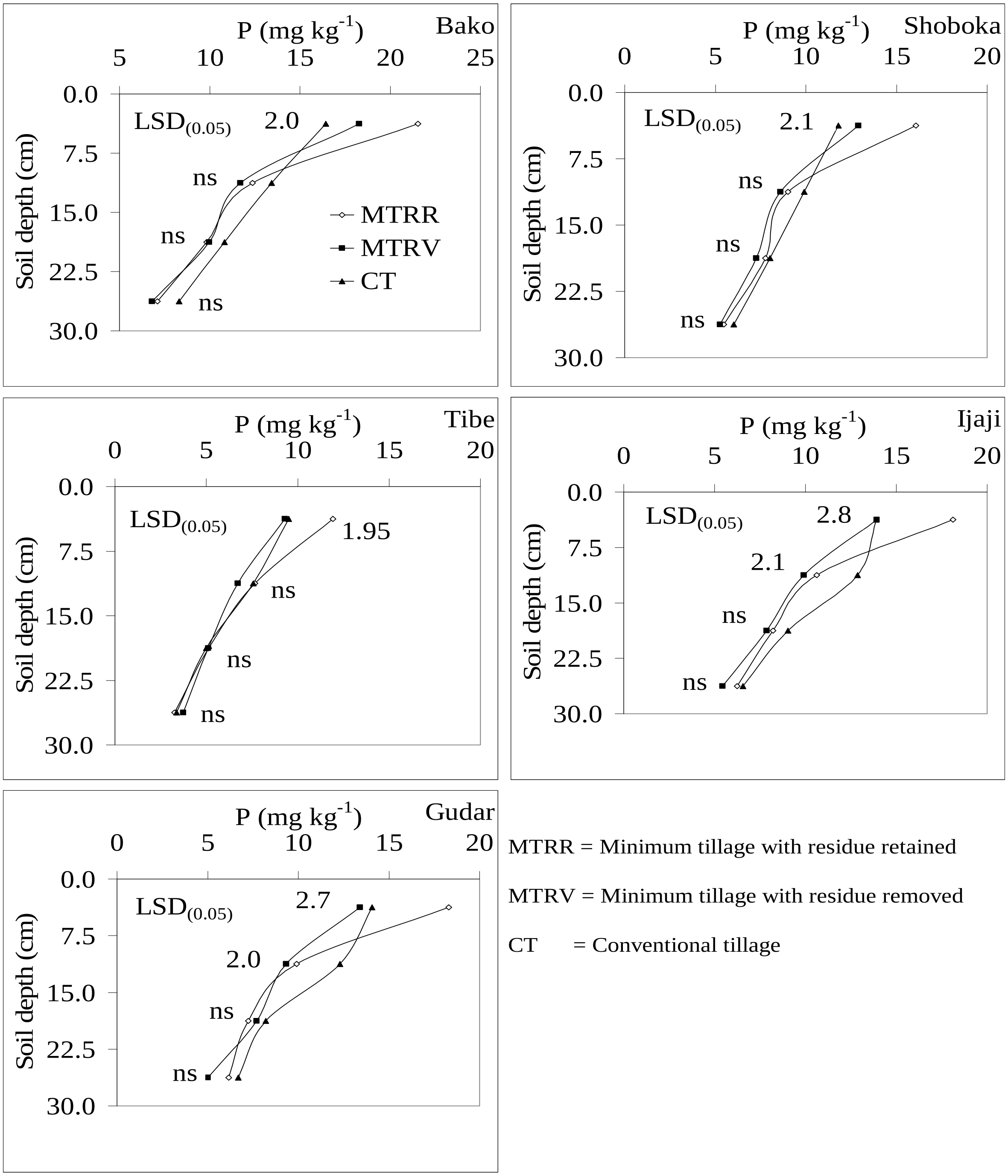

Figure 5. Effect of tillage system on extractable P measured after harvesting in the 0-7.5 cm, 7.5-15 cm, 15-22.5 cm and 22.5-30 cm layers of Nitisols at the five experimental sites in 2004.

negative impact on the performance of the maize crop, especially through enhanced soil acidification. The rectifying of soil acidity through liming is currently not a common practice in Western Ethiopia because most of the resource poor farmers cannot afford it. This aspect should be taken into account when the replacement of CT with MTRR is advocated. Compared to CT, MTRR resulted in more efficient use of applied N by maize (Tolessa et al., 2009).

We are of opinion that the findings of this study will be applicable also to the remaining highland regions of Ethiopia as well as those of other African countries like Cameroon, Congo and Kenia. In these countries are cropping on Nitisols common, notably at altitudes of more

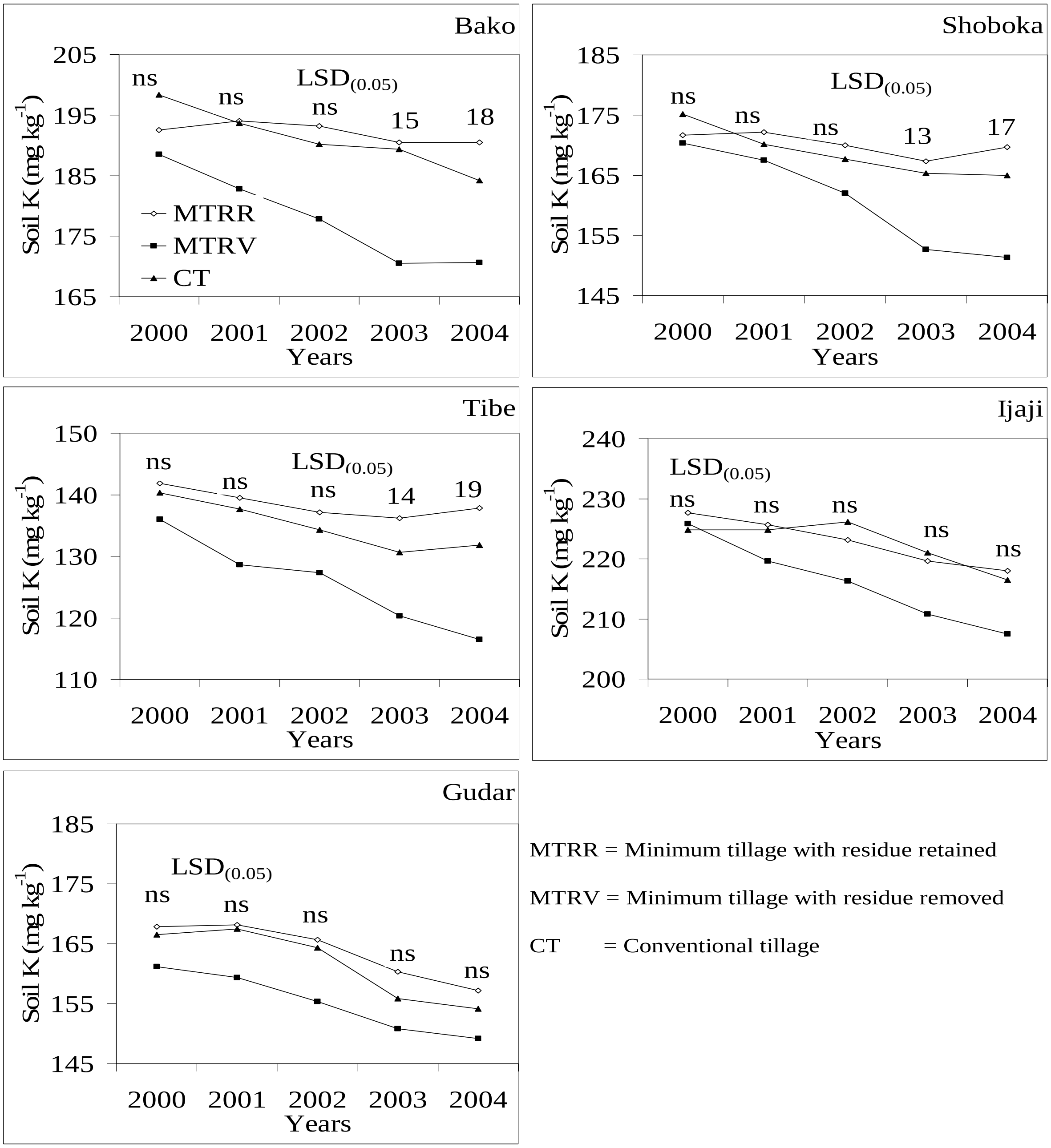

Figure 6. Effect of tillage system on exchangeable K measured after harvesting in the 0-30 cm layer of Nitisols at the five experimental sites in 2000 to 2004.

than 1200 m above sea level. The estimated area of Nitisols in the higlands of Africa is 100 million ha.

Conclusions

Tillage systems and concomitant residue management showed profound effects on the pH, extractable P and exchangeable K in especially the 0-7.5 cm layer of the studied soils. Acidification was more pronounced with MTRR than with MTRV and CT. This was also found with an increase of N fertilization from 69 to 115 kg ha^{-1}. The extractable P and exchangeable K contents of the MTRR soils were higher than that of the CT and MTRV soils. Throughout the five year trial period MTRR at least maintained the extractable P and exchangeable K contents, while with MTRV the contents of both these nutrients decreased steadily. The decline in extractable P and exchangeable K with prolonged MTRV are indicative of soil fertility degradation. Hence, soil fertility can be

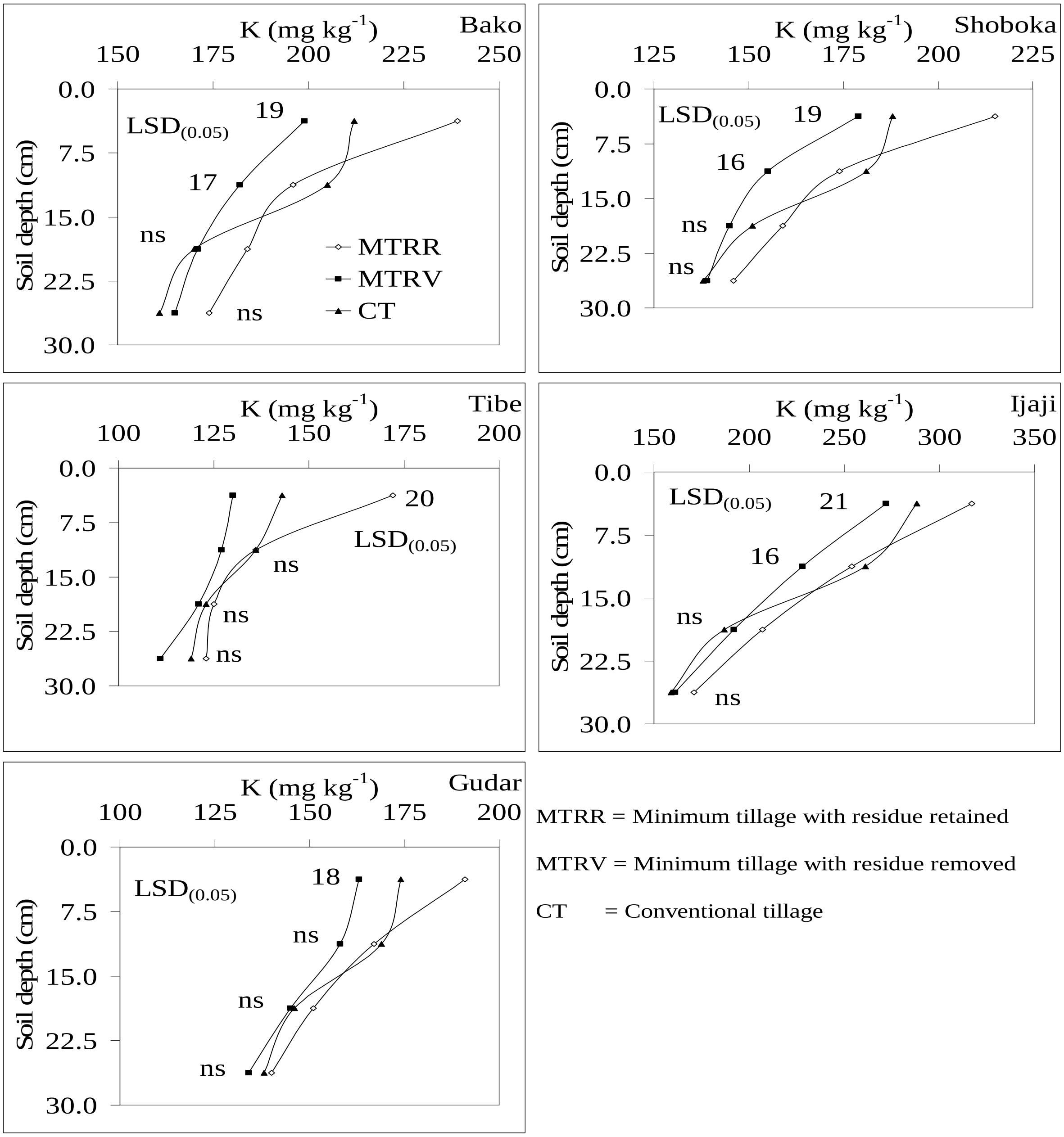

Figure 7. Effect of tillage system on exchangeable K measured after harvesting in the 0-7.5 cm, 7.5-15 cm, 15-22.5 cm and 22.5-30 cm layers of Nitisols at the five experimental sites in 2004.

maintained or restored for sustainable crop production in Western Ethiopia with MTRR if care is taken of the acidification that coincide with this tillage system. This study's findings could be extrapolated to the remaining highland regions of Ethiopia as well as those of other African countries where cropping is practiced on Nitisols.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

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Hydrogel polymer in emergency and early growth of citrus rootstocks

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The development of techniques for rapid and uniform emergence of seeds is the alternative to the diversification of citrus rootstocks that were little used due to low vigor compared to 'Rangpur' lime, the main rootstock used in Brazil, but it has shown susceptible to serious disease problems, such as the citrus sudden death (CSD). The addition of the hydrogel polymer to the substrate can increase the uniformity of seed emergence and reduce the time for the production of rootstocks due to the increase in water availability. Thus, the study was done to evaluate the formulation of the substrate with the hydrogel polymer on the uniformity of emergence and early growth of citrus rootstocks. The factorial scheme 3 × 2 × 2 was used, with the factors: Three rootstocks ['Rangpur' lime (*Citrus limonia* Osbeck), *Poncirus trifoliata* (L.) and 'Sunki' mandarin (*Citrus sunki* Hort. ex Tanaka); two formulations of substrate (with and without 0.4 g per container of Hidroplan-EB/HyB-M® polymer and two environments (greenhouse with an average maximum temperature of 36.6°C and minimum of 17.2°C and growth chamber programmed with temperature to 25°C and a photoperiod of 12 h, distributed in a completely randomized design with four replications and 35 seeds per plot. The emergency velocity index (EVI), the percentage of emergence and early growth of rootstocks were evaluated. Data were subjected to analysis of variance and the means were compared by Tukey test at 5% of probability. The addition of the polymer to the substrate favored the percentage of emergence and EVI of 'Rangpur' lime and of mandarin 'Sunki' seeds in the growth chamber. The 'Rangpur' lime was the rootstock which presented the highest percentage of emergence and uniformity in both environments. The addition of the hydrogel polymer to substrate favored initial growth of citrus rootstocks.

Key words: 'Rangpur' lime, *Citrus limonia* Osbeck, *Poncirus trifoliata* (L.), 'Sunki' mandarin, *Citrus sunki* Hort. ex Tanaka, substrate.

INTRODUCTION

In the formation of citrus nursery trees, the seeds are used for the production of rootstocks (Siqueira et al., 2002). The main rootstock used in Brazil in recent years, 'Rangpur' lime (*Citrus limonia* Osbeck), has proved susceptible to serious disease problems (Moreira et al., 2010), such as the citrus sudden death (CSD), disease associated with a virus (Maccheroni et al., 2005). Therefore, the need to diversify the use of rootstocks has

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been identified.

The alternatives of tolerant rootstocks to the CSD are *Poncirus trifoliata* (L.); 'Swingle' citrumelo [*Citrus paradisi* Macfad. cv. Duncan × *P. trifoliata* (L.) Raf.]; 'Cleopatra' mandarin (*Citrus reshni* Hort. ex Tanaka) and 'Sunki' mandarin (*Citrus sunki* Hort. ex Tanaka) (Girardi et al., 2007; Pompeu Junior et al., 2008). However, they are rarely used by nurserymen due to low vigor compared to 'Rangpur' lime.

One difficulty for the increased use of these mandarins, *P. trifoliata* (L.) and 'Swingle' citrumelo is the low drought tolerance. Another is at the nursery stage; the seed germination can be a limiting factor because the number of days to germination occurs, resulting in irregularity between seedlings and slowing the formation phase of the rootstocks. Among the stages of citrus nursery tree production, the production of rootstock is responsible for about 60% of the requested time. This delay is due to the period of germination, which can reach 60 days or more (Sousa et al., 2002).

The time of citrus nursery tree production can be from 10 to 15 months after sowing, with the appropriateness of the growth environment in several countries, including Brazil (Carvalho et al., 2005). For this it is necessary for the germination to be uniform and occurs as soon as possible. To promote germination, water availability is a major factor to guarantee ideal conditions for seed imbibition, and initial rapid growth of rootstocks are characteristics that contribute to advance the appropriate time of grafting point.

In order to improve the availability of water in the substrate, the addition of hydrogel polymer to the soil favors seed germination, root development, plant growth, and contribute to improving aeration and soil drainage, minimize nutrient losses by leaching (Azevedo et al., 2002). The polymers are arrangements of organic molecules (Fonteno and Bilderback, 1993) that exhibit granular when in dry form. When hydrated, these are transformed into a soft elastic gel (Prevedello and Loyola, 2007), capable of absorbing about a hundred or more times its weight in water.

Furthermore, the containers used for the production of rootstocks comprise small volume of substrate, which limits the availability of water to plants making necessary frequent irrigation, resulting in significant loss of some nutrients (Cruz et al., 2008). Thus, the use of the hydrogel polymer on substrate is an alternative to improve the process of production of citrus rootstocks, because it keeps the substrate humid, minimizes nutrient leaching and increases growth of plants.

The addition of hydrogel polymer to substrate showed satisfactory results for the rootstock 'Cleopatra' mandarin (Cruz et al., 2008) and propagation by cuttings of sweet passion fruit (Hafle et al., 2008). Also, it favored the highest percentage of survival, length of roots and shoots of blackberry cv. 'Brazos' (*Rubus* sp.) (Moreira et al., 2012) and in reducing the frequency of irrigation for the production of passion fruit seedlings (Carvalho et al., 2013).

Based on the above, the study was done to evaluate the formulation of the substrate with the hydrogel polymer on the uniformity of emergence and early growth of citrus rootstocks.

MATERIALS AND METHODS

The experiment was conducted at the division of fruit crops of Federal University of Jequitinhonha and Mucuri Valleys (UFVJM) in Diamantina, Minas Gerais, Brazil, located at 18° 14 '56 "S and 43° 36' 0" W, from December 2012 to March 2013.

For the evaluation of the seed emergency was used factorial scheme 3 × 2 × 2, with the factors: three rootstocks ['Rangpur' lime (*C. limonia* Osbeck), *P. trifoliata* (L.) and 'Sunki' mandarin (*C. sunki* Hort. ex Tanaka); two formulations of substrate (with and without 0.4 g per container of Hidroplan-EB/HyB-M® polymer and two environments (greenhouse with an average maximum temperature of 36.6°C and minimum of 17.2°C and growth chamber, programmed with temperature to 25°C and a photoperiod of 12 h, distributed in a completely randomized design with four replications and 35 seeds per plot. To monitor the temperature variations during the experiment, a digital termohygrometer (Model MT 240 MINIPA) inside the greenhouse was installed (Figure 1).

The hydrogel polymer was incorporated to the substrate Bioplant®, by the homogenization of the mixture before filling the containers. The Hidroplan-EB/HyB-M® is a mixed product of a copolymer of acrylamide and potassium acrylate used to absorb and retain large quantities of water.

The seeds of rootstocks were sowed in containers of 50 ml (one seed per container). During the emergency the frequency of irrigation was used to keep the humid substrate and to ensure uniform seed emergence. For this, in the growth chamber the irrigation was performed every 2 days and in the greenhouse daily.

At 25 days after sowing the emergence started, using as criteria for emergence the radicle protrusion of 1 mm. To evaluate the emergency velocity index (EVI), it was counted the number of seedlings that emerged every 2 days until the 66th day, and it was calculated using the formula suggested by Maguire (1962): [$EVI = (G1 / N1 + G2/N2 + ... + Gn / Nn)$]; G = number of seeds emerged and N = number of days that have evaluated the emergence.

After the end, the emergence period was done in the thinning of rootstocks, because of polyembryony, leaving only one seedling per container. From this time the nitrogen fertilization of rootstocks was done, applying 10 ml of a solution (1% of N) per container weekly. At 60 days after emergence the germination percentage, the shoot length (cm), the stem diameter (mm), the number of leaves per plant, the leaf area (cm^2), the root length (cm), the number of lateral roots, the dry shoot mass (g) and the dry root mass (g) of each rootstock was evaluated.

The shoots and the roots were washed in water running and placed to dry in an oven with forced air circulation at 65°C, until constant mass to determine dry mass, on electronic scale accurate to 0.001 g.

Leaf area was determined using the methodology of Benincasa (2003), which the leaf discs were obtained with a puncher of known area. These disks and the leaves were placed to dry in an oven with forced air circulation at 65°C in paper bags to determine its mass. Leaf area was calculated according to the equation: [LA = (dry mass of leaf × disc area / dry mass of the disks)].

In order to compare, the growth was adopted the 3×2 factorial scheme, with three rootstocks: 'Rangpur' lime; *P. trifoliata* and 'Sunki' mandarin and two substrate formulations: with and without hydrogel polymer, this is because after emergence all plants in

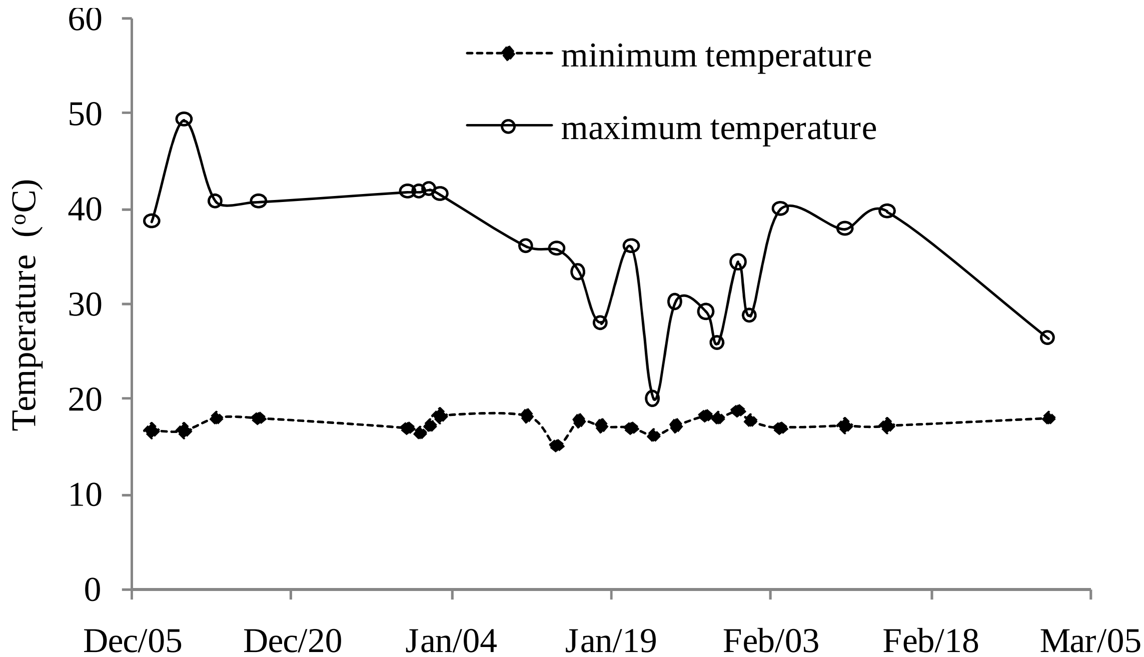

Figure 1. Average of minimum and maximum temperatures recorded in the greenhouse during the emergence and growth of rootstocks, Diamantina, Minas Gerais, Brazil.

Table 1. Rootstocks versus environment interaction of emergence velocity index (EVI) and percentage of emergence of citrus rootstocks grown on substrate with and without hydrogel polymer in greenhouse and growth chamber growth chamber.

Rootstocks	EVI		Emergence (%)	
	With polymer	Without polymer	With polymer	Without polymer
	Growth chamber			
'Sunki' mandarin	4.0^{Ba}	3.7^{Bb}	36.5^{Ba}	35.7^{Ba}
'Rangpur' lime	10.0^{Aa}	9.2^{Ab}	89.0^{Aa}	82.7^{Ab}
Poncirus trifoliata	0.5^{Ca}	0.5^{Ca}	7.2^{Ca}	11.5^{Ca}
	Greenhouse			
'Sunki' mandarin	2.75^{Ba}	2.75^{Ba}	31.0^{Ba}	27.2^{Ba}
'Rangpur' lime	5.01^{Ab}	8.75^{Aa}	55.0^{Ab}	87.0^{Aa}
P. trifoliata	0.25^{Ca}	1.01^{Ca}	7.2^{Ca}	13.2^{Ca}
CV (%)	18.5		10.2	

Means followed by different small letters in the line differ by F test and the capital letters in column differ by Tukey test at 5% probability of error.

growth chamber were taken to the greenhouse.

Data were subjected to analysis of variance and the means were compared by Tukey test at 5% of probability.

RESULTS AND DISCUSSION

Interaction among rootstocks, the addition of the polymer and the environment for the EVI and the percentage of emergence were observed (Tables 1 and 2).

It was observed that the 'Rangpur' lime was the rootstock with greater EVI in the two environments. The addition of the polymer favored emergence uniformity of 'Rangpur' lime and 'Sunki' mandarin seeds when they were sowed in the growth chamber. The behavior of 'Rangpur' lime was similar regarding the percentage of emergence, achieving the best results in both environments. 89.01 and 82.75% of emergence with and without the addition of polymer in the growth chamber,

Table 2. Environment versus polymer interaction of emergency velocity index (EVI) and percentage of emergence of citrus rootstocks grown on substrate with and without hydrogel polymer in greenhouse and growth chamber, inside each species.

Environment	EVI		Emergence (%)	
	With polymer	Without polymer	With polymer	Without polymer
		'Sunki' mandarin		
Growth chamber	4.0^{A}	3.7^{A}	36.5^{A}	35.7^{A}
Greenhouse	2.7^{B}	2.7^{A}	31.0^{A}	27.2^{A}
		'Rangpur' lime		
Growth chamber	10.0^{A}	9.25^{A}	89.0^{A}	82.7^{A}
Greenhouse	5.0^{B}	8.75^{A}	55.0^{B}	87.0^{A}
		Poncirus trifoliata		
Growth chamber	0.5^{A}	0.5^{B}	7.2^{A}	11.5^{A}
Greenhouse	0.2^{B}	1.0^{A}	7.2^{A}	13.2^{A}
CV (%)	18.5		10.2	

Means followed by different capital letters in the column, different by F-test at 5% probability of error.

respectively, and 87.00% without the use of hydrogel polymer in the greenhouse (Table 1).

The differences in the percentage of emergence and uniformity can be related to the seed coat, because the seed coat of *P. trifoliata* is more leathery than the other citrus rootstocks, favoring the rottenness of seeds during germination (Rouse, 1997). The integument is considered the main limiting factor for seed germination of these rootstocks, which possibly have low germination due to low water absorption, or loss of seeds caused by the long period that they remain in contact with the substrate. Significant increase in seed emergence of hybrid rootstock from *P. trifoliata* has been achieved with the removal of the seed coat by Moreira et al. (2010).

Comparing the environments, it was observed under the conditions of growth chamber that the addition of the hydrogel polymer favored the higher emergence uniformity for all rootstocks. However, without polymer, *P. trifoliata* showed greater emergence uniformity in greenhouse, possibly because in this environment the irrigation was performed daily (Table 2).

For the percentage of emergency, 'Rangpur' lime showed the highest values with 89% of seed germination with the use of the polymer on the substrate in growth chamber (Table 2), possibly because the greenhouse with the addition of the polymer provided excessive humidity in substrate, damaging its aeration and consequently the emergency, which did not occur in the growth chamber by irrigation have been held every 2 days. This behavior suggests that the irrigation should be performed less frequently with the use of polymer. Carvalho et al. (2013) observed that it is possible to irrigate the substrate in a greenhouse with an interval of 1 day with the use of hydrogel polymer on the substrate.

In general, it was observed that the addition of the hydrogel polymer promotes uniformity emergency when environmental conditions are not favorable. On the other hand, it is not enough to increase seed emergence, probably because even in the presence of humidity, low germination results from the presence of the seed coat. To increase germination the use of techniques for removal of the seed coat is necessary, because it makes possible to achieve more than 90% of emergence, while with seed coat the emergence does not reach 30%. This behavior was observed in 'Flying Dragon' (*P. trifoliata* var. *monstrosa)* and hybrids of *P. trifoliata,* both used as citrus rootstocks (Moreira et al., 2010).

The difficulty of obtaining high percentages of emergence in the nursery has been reported by many researchers, mainly because the number of days for seed emergence to occur, results in disuniformity among the seedlings, slowing the formation phase of rootstocks (Sousa et al., 2002).

In the initial growth of rootstocks, there was an interaction between application of the polymer substrate and rootstocks for all evaluated characteristics.

The incorporation of the polymer to the substrate favored the initial growth of rootstocks (Table 3). The plants of *P. trifoliata* showed greater growth in height, stem diameter, root number, leaf area, dry mass of shoot and root system with the addition of the polymer to the substrate.

For 'Rangpur' lime, the behavior was similar with better results in relation to the stem diameter, number of leaves, dry mass of shoot and root in the presence of the polymer (Table 3).

The development of stem diameter is important to anticipate the production of rootstocks because the

Table 3. Height, stem diameter, number of leaves, number of roots, root length, leaf area, dry mass of shoot and dry mass of root of citrus rootstocks grown on substrate with and without the addition of polymer hydrogel in greenhouse at 60 days after emergence.

Rootstocks	Height (cm)		Stem diameter (cm)	
	With polymer	Without polymer	With polymer	Without polymer
'Sunki' mandarin	6.5^{Ba}	5.9^{Ba}	1.2^{Ba}	1.2^{Ba}
'Rangpur' lime	7.6^{ABa}	6.8^{Ba}	1.7^{Aa}	1.4^{Bb}
Poncirus trifoliata	9.8^{Aa}	7.1^{Ab}	2.0^{Aa}	1.8^{Ab}
CV (%)	13.9		8.1	
	Number of leaves		Number of roots	
'Sunki' mandarin	9.4^{Aa}	8.5^{Aa}	21.8^{Ba}	23.5^{Ba}
'Rangpur' lime	8.3^{Aa}	6.8^{Bb}	35.1^{Aa}	32.7^{Aa}
P. trifoliata	7.9^{Aa}	7.2^{ABa}	30.2^{Aa}	27.2^{ABb}
CV (%)	10.6		15.2	
	Root length (cm)		Leaf area (cm²)	
'Sunki' mandarin	10.1^{Ab}	11.5^{Aa}	3.1^{Ba}	3.9^{Aa}
'Rangpur' lime	10.7^{Ab}	12.1^{Aa}	4.5^{Aa}	4.2^{Aa}
P. trifoliata	11.1^{Ab}	12.9^{Aa}	3.7^{Ba}	2.4^{Bb}
CV (%)	7.7		15.5	
	Dry mass of shoot (g)		Dry mass of root (g)	
'Sunki' mandarin	1.27^{Ba}	1.18^{Aa}	0.99^{Ba}	1.30^{Aa}
'Rangpur' lime	1.64^{Aa}	1.36^{Ab}	1.70^{Aa}	1.20^{Ab}
P. trifoliata	1.59^{Aa}	0.92^{Bb}	1.50^{Aa}	0.90^{Bb}
CV (%)	8.4		14.9	

Means followed by different small letters in the line differ by F-test and capital letters in column differ by Tukey test at 5% probability of error.

greater development in diameter can anticipate the time of grafting (Schäfer et al., 2006).

On the other hand, 'Sunki' mandarin did not differ from those grown without the incorporation of the polymer, except for the length of the root system that was longer in the absence of polymer, the same behavior was observed in other rootstocks (Table 3). This can be attributed to greater availability of water in the substrate, because the root system tends to become deeper when humidity conditions are scarce in the exploration zone of the root, leading the growth of the root system to increase efficiency in absorbing water.

The difference in the growth of rootstocks with the polymer can be attributed to the improved hydraulic properties of substrate, increasing the availability of water (Azevedo et al., 2002; Saad et al., 2009).

This improvement is important for the production of citrus nursery trees, because the conventional method of nursery trees production in controlled environments used small containers, which limits the availability of water (Cruz et al., 2008). For these reasons, the addition of hydrogel polymer to substrate is possible in order to reduce the frequency of irrigation, providing water and fertilizer saving.

Comparing growth among rootstocks, larger height and larger stem diameter for *P. trifoliata* was observed with and without the use of polymer. The stem diameter is directly related to plant height (Bernardi et al., 2000), and is the morphological characteristic of the rootstock which defines the possibility of grafting (Bernardi et al., 2008). This behavior may occur due to intrinsic differences of species, by the genetic characteristics to each rootstock. Another important aspect was noticed that the use of the polymer, the growth in relation to the number of leaves, number of roots, dry mass of shoot and root system of *P. trifoliata* was similar to 'Rangpur' lime, whereas in the absence of the polymer, 'Rangpur' lime showed higher growth (Table 3). This can be attributed to *P. trifoliata* to be a rootstock that has low drought tolerance, so with the greater availability of water it can be similar to 'Rangpur' lime which is a rootstock well accepted by nurserymen for its excellent vigor.

The difference of development is common to be found among the rootstocks, which may occur due to different genetic characteristics, which affect the light and CO_2 use, influencing the uptake, transport and interaction of nutrients in the plant (Fochesato et al., 2006). However, each species can develop mechanisms to grow under adverse conditions, such as the reduced availability of water, which is one advantage of ‘Rangpur’ lime compared to other rootstocks that without addition of the polymer, it showed a higher number of roots (Table 3).

The results of this study show that the addition of the hydrogel polymer to substrate for the production of rootstocks is presented as alternative to reduce the time in the nursery, because of better emergence uniformity and growth of plants. However, the use of appropriate techniques is necessary to optimize the percentage of emergence of species with potential for citrus rootstocks, which have the integument as a limiting factor.

Conclusions

The addition of the hydrogel polymer to the substrate favored the percentage of emergence and EVI of ‘Rangpur’ lime and of ‘Sunki’ mandarin seeds in the growth chamber.

The ‘Rangpur’ lime was the rootstock which presented the highest percentage of emergence and uniformity in both environments.

The addition of the hydrogel polymer to substrate favored early growth of citrus rootstocks. The hydrogel polymer can be added to substrate in order to reduce the irrigation frequency.

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Banana irrigation management and optimization: A comparative study of researcher-managed and farmer-managed irrigated banana production in Shire Valley, Malawi

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Banana yield and quality in Malawi is low due to drought, low fertility and poor management practices. Therefore, a comparative researcher-managed and farmer-managed irriagated banana study was initiated in 2004/2005 to develop guidelines and promote banana irrigation optimisation for small-scale farmers. Specifically, the research aimed to determine and compare researcher-managed and farmer-managed optimum irrigation in respect to banana yield, quality, income and gross margins, and facilitate transfer of banana irrigation technology to farmers. Irrigation treatments ranged from 0, 50 and 100% evapotranspiration (ET) of estimated banana ET, laid out in a randomized complete block design (RCBD) with four replicates. Irrigation was scheduled using the soil moisture balance system. The results of banana production and gross margin analysis for both researcher-managed and farmer-managed experiments showed that average yield and quality increased linearly with increasing irrigation. Highly significant differences (P < 0.001) were observed between amounts of applied water in average bunch weight, average hand weight and average finger weight per hectare both under researcher-managed and farmer-managed fields, respectively. The gross margin analysis showed negative gross margin under non-irrigated banana enterprise and positive gross margin at 100% ET for both researcher-and farmer-managed fields, respectively. Irrigation raised farmer earnings from -4 to 27 US$/day (non-irrigated to irrigated banana) and it was optimal to produce banana under 100% ET. The findings showed that banana enterprise has a commercial orientation that can reduce poverty for smallholder farmers. It is recommendable that Malawi and other countries should advocate banana irrigation agribusiness because it can facilitate the attainment of food security and poverty reduction.

Key words: Irrigation scheduling, evapotranspiration, gross margin, banana.

INTRODUCTION

Banana (*Mussa* spp) is both a staple food and cash crop in Malawi. The main production districts are Karonga and Chitipa where banana is a staple food (Chizala, 1995). Thyolo, Mulanje and Nkhatabay districts, among others, grow banana as a cash crop at small-scale level (Figure 1). IITA (2004) survey conducted in Nkhata-Bay and

Mulanje found that 50% of the income to farmers in Nkhata-Bay comes from banana, while in Mulanje banana contributes 43% of the farmers' income. The survey also found that banana was the second most important crop in Nkhata-Bay after cassava, while in Mulanje banana was the third most important crop after maize and cassava. But banana yields and quality have been low and poor to effectively influence poverty and hunger eradication due to drought, poor soil fertility, pests and diseases, low yield varieties (Banda and Mwenbanda, 1992) and lack of information on recommendable management practices. Giant (Williams) and Dwarf Cavendish are some of the high yielding varieties (Banda and Mwenbanda, 1992) among desert bananas that are highly promoted in Malawi. The Ministry of Agriculture and Food Security has been promoting banana farming through production of health planting materials and training farmers on proper husbandry practices in Shire Valley since 1997. Other Cavendish promoted includes Grand nain, Gros Michel and Chinese Cavendish.

Banana is such a promising miracle (Wambugu, 2004) crop with a potential to eradicate hunger and poverty in Africa in general since it is not a seasonal crop; it is very nutritious (potassium, vitamin A) and has multiple dietary uses such as desert, beer brewing, and fruit juice as well as medicinal use. Its low resistance to drought and rapid physiological response to soil water deficit (Robinson, 1995) make it sensitive to even slight variation in soil water content (Robinson and Alberts, 1987). This is because of its poor ability to draw water from dry soil due to shallow spreading root distribution (Champion, 1968). Goenaga and Irizarry (2000) reported a banana decrease from 47 to 9% or visa vice due to imposed drought stress. Banana as tropical crops requires 1200 to 2690 mm of water depending on the prevailing climate (Simmonds as cited by Robinson and Alberts, 1986; Doreenbos and Kassam, 1986). Such amount is not attained in Shire Valley with annual rainfall less than 600 mm (Fandika et al., 2007). Apart from drought, the exact nature of banana root system makes irrigation a critical solution to drought stress. Giant Cavendish is one banana variety that has shown strong (Fandika et al., 2006) and positive linear relationship between yield and applied water (Young et al., 1985). The average bunch weight yield is reported to have increased from 5 to 20 kg when water application increased from 0 to 120% evapotranspiration (ET) in Malawi (Chizala, 1995; Fandika et al., 2006). Robinson and Alberts (1986) reported bunch weight increase from 31.7 to 44.6 kg with water increase from 25 to 75% of ET and annual yields increase from 55.1 to 83.4 kg. This strong response to the applied water indicated that irrigation is essential in banana production to reduce critical drought stress, probably the most limiting non-biological factor in banana production (Robinson, 1995). High yield of 60 t ha^{-1} year^{-1} (Fandika et al., 2006) has been reported in Shire Valley, Malawi when irrigated at 100% ET. Despite promising banana yields from previous conversional irrigation research, yields and quality among farmers were still low and poor. Majority of farmers are still growing banana under unimproved techniques because were not involved in previous conversional irrigation research. Conversional research lack farmer's participation in technology development and such approach reduces dissemination and adoption rate by small-scale farmers (Donovan, 1994; Pretty, 1995).

In the Shire Valley of Southern Malawi, banana production is mainly practiced under rainfed conditions. In this semi-arid zone, high solar radiation (>17.0 MJm^{-2}d^{-1}), warm temperatures (24.1 to 36.5°C), and low relative humidity (61 to 77.5%) make continuous banana harvesting over the whole year impossible (Fandika et al., 2006). Adequate water requirements can only be met by irrigation as consequences of low and erratic rainfall (400 to 600 mm) falling in a season that range from October to March. Nevertheless, useful information about banana irrigation and optimization, obtained from Kasinthula Research Station (Fandika et al., 2006), International Research Institution (Goenaga and Irizarry, 2000) and other fruit crop growing areas (Banda and Mwenebanda, 1992) was not fully adopted by small-scale farmers in Shire Valley region. Goenaga and Irizarry (1998) recommended 1.0 pan factor (100% ET) as the adequate water consumption for banana optimum production (Doreenbos and Kassam, 1986). Hence, the comparative case study of researcher-managed and farmer-managed banana experimentation on banana irrigation management was initiated for comparison of conversional research findings with lead farmer's findings so that farmers' capacity to improved technologies is assessed. The purpose of the study was to develop guidelines and promote banana irrigation optimization for small-scale farmer poverty and hunger eradication.

Specifically, the study aimed at determining and comparing researcher-managed and farmer-managed optimum irrigation in respect to banana yield, quality, income and gross margins, and faciliate transfer of effective irrigation treatments to small-scale farmers through lead farmers in Malawi.

MATERIALS AND METHODS

Location

The comparative researcher-managed and farmer-managed banana irrigation optimization study was conducted at Kasinthula Research Station in Chikwawa, Malawi. It is located at a latitude of

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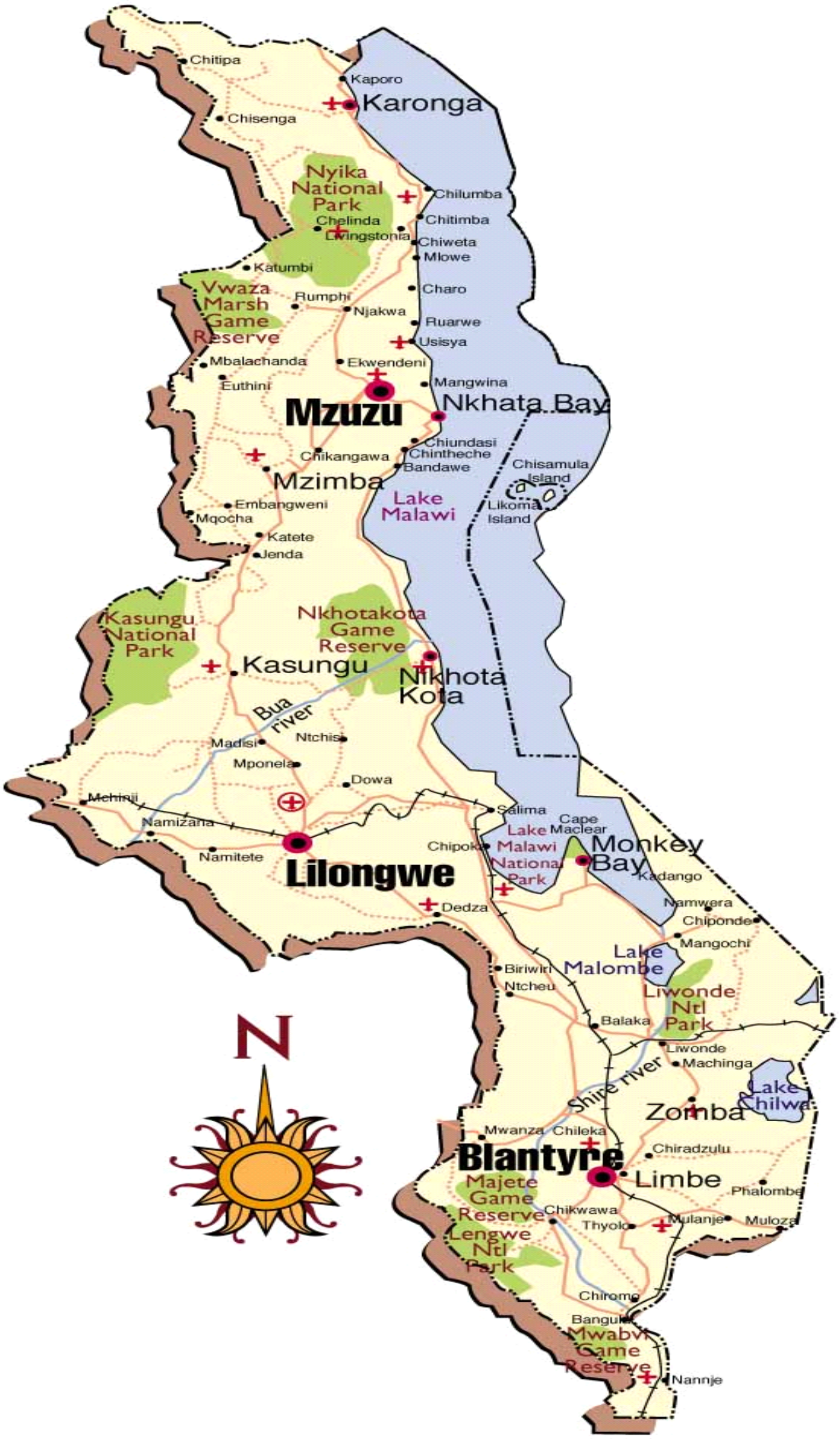

Figure 1. Map of Malawi showing the towns and Districts.

16° S and longitude 34°5' E. The altitude is 70 m above sea level whose long-term annual average minimum and maximum temperature, annual precipitation, relative humidity, wind speed and evaporation are 18.6°C, 35.6°C, 520 mm, 70%, 4.7 km day^{-1} and

8.6 mm day^{-1}, respectively. Scientific experimentation and unit farming system approaches (Chambers et al., 1989) were concurrently used to easily compare researcher-managed and farmer-managed banana yields, quality and gross margins in 2004/2005 growing seasons.

Unit farming research system

Unit farming research system is a technology transfer initiative (Chambers et al., 1989; Donovan, 1994) for communities around the research station. In this case, new irrigation technologies developed by the Department of Agricultural Research Services at Kasinthula Research Station in Chikwawa were utilized by farming communities including farmers who reside around the research station thus Technology Transfer Initiatives around Kasinthula Research Station. The station embarked on this Technology Transfer Initiative in August, 2002 as a response to the concern of low adoption of irrigation management and optimization technologies by communities surrounding the research station. The Technology Transfer Initiative at Kasinthula Research Station was different from other research stations in the sense that, the lead farmers were selected from their homes to practice new farming technologies on station, while at other research stations, lead farmers were left at their original farms to practice new developed technologies. The selected lead farmers were called unit farmers and the system is called unit farming system and was used to acquaint farmers with modern irrigation system before the technology is fully transferred to local farmer's fields.

Three farmers were participatory selected (by research scientists/extension officers) from a sample of more than 3000 farm families of Chikwawa District Agriculture Office within Shire Valley Agricultural Development Division (SVADD). Research scientists from Kasinthula Research Station linked with the District Agricultural Development Officer (DADO) to come up with farmers who could practice new technology under research-farmer management. The three lead farmers (namely Christopher Makhaza, Eliya Zeti and Yohane Tembo) were selected from Mitole Extension Planning Area (EPA). Each farmer had a different crop of his choice, Mr. Christopher Makhaza selected banana, Mr. Eliya Zeti selected cotton and Mr. Yohane Tembo selected maize to be grown under well scheduled furrow irrigation. Field days were being conducted (from 2003 to 2005) on farmer's fields during vegetative and maturity stage of each crop to facility technology transfer to the community. This paper only discusses banana researcher-managed and banana unit farmer-managed for Mr. Christopher Makhaza.

Experimental design

Both researcher-managed and farmer-managed approaches used three irrigation treatments of 0, 50 and 100% ET. The amount of applied water was determined from the calculated banana ET. The calculated ET (100% ET) from weather data was treated as a base amount. Then the other amounts were calculated as percentages of the base amount in the order of 0 and 50%. The treatments were laid out in a randomized completely block design (RCBD) with four replicates. The plot sizes were 10 × 10 m with 4 mats spaced 2.5 × 2.5 m totaling to 16 mats per plot which is equivalent to 1600 mats per hectare. The same irrigation regimes were deliberately tested at two fields to convince the farmers that they can deal with the effects of drought stress on banana production. The study was comparing yields, quality and gross margin at lead farmer level with those from research-managed field to show other farmers that it is possible for them to adopt such technology and achieve high yields and gross margins.

Agronomic practices

The land was ploughed by tractor and 10 × 10 m basins were hand made. Banana suckers (variety Giant Williams) were planted on 3rd February, 2004 in pits at a spacing of 2.5 × 2.5 m equivalent to 1600 suckers per hectare. Cattle manure was first applied at 10 kg per planting hole. Irrigation water was applied uniformly until the plants were fully established. Irrigation water was applied in 10 × 10 m basins using a gated 15 cm diameter Poly(Vinyl Chloride) (PVC) pipe. Each gate was set at a flow of 30 L/min. The flow rate out of each gate was determined using a bucket method. The PVC was laid at the beginning of the furrows and was connected to a concrete lined canal in which the water level was maintained at a constant head above the centre of the PVC pipe inlet. Irrigation scheduling under both fields (Researcher-managed and farmer-managed fields) was carried out by maintaining a soil moisture balance sheet. The soil moisture storage was estimated from the available water holding capacity of 100 mm m^{-1} and the crop root zone. 200 kg N ha^{-1} and 200 kg K ha^{-1} fertilizer was applied to both fields. The cost of farm inputs and labour was recorded for gross margin analysis.

Field day, farmers training and data collection

Field days and farm visits were being conducted for farming communities to learn technologies being implemented by the unit farmer and appreciate how improved technologies can eradicate hunger and poverty at household and national level in Malawi. The Department of Research trained the unit farmer in all the banana production techniques which he was explaining to other farmers during field days, open days and visits by other farmers. The lead farmer was explaining on how he implemented the research program, yield and profits being realised from the project. The unit farmer finally graduated to his own farm after government loaned him a 20 horse power pump to establish his own field outside the research station.

During harvest of the banana, research personnel collected data on yield and other desirable yield components which were analyzed accordingly using analysis of variance (ANOVA) to determine the yield and profit variability between researcher-managed and farmer-managed fields. Regression analysis was used to determine the relationship between yield and water application. It was envisaged that through data collection, one can know why and how science and technology benefit or fail to benefit the resource-poor Malawian farmers.

RESULTS AND DISCUSSION

The results showed that average yields (hand weight, bunch weight and average yield per hactare) and gross margin increased linearly with increasing amounts of applied water (Tables 1 to 4) both under researcher-managed and farmer-managed banana fields. Highly significant differences ($P < 0.001$) were observed between amounts of applied water in average bunch weight, average hand weight and average banana yield per hectare (Table 1). Highest bunch weight of 20.5 and 18.86 kg for researcher-and farmer-managed fields, respectively was obtained at 100% ET of applied water, while the 0% irrigation treatment had the lowest bunch weight of 5 and 3.46 kg for researcher-and farmer-managed fields, respectively (Tables 1 to 2). Hand weight

Table 1. Banana variable response to different amount of applied water under researcher- managed fields.

ET (%)	Applied water	Days to flowering	Days to harvest	Number of hands per bunch	Number of fingers per hand	Hand weight (kg)	Average bunch weight (kg)	Banana yield (t ha^{-1})
0	609	342	478	7	14	0.59	5.0	3.45
50	980	316	412	8	15	2.09	17.3	21.31
100	1722	307	409	9	15	2.39	20.5	25.84
Mean		322	433	8	15	1.69	14.3	16.87
SE±		14.60	16.92	0.42	0.49	0.16	1.56	2.67
CV%		10.33	8.97	11.86	7.7	21.18	25.01	29.40
Significance		NS	*	NS	NS	***	***	***

Note: P < 0.05 = *; 0.01 = **; 0.001 = ***.

Table 2. Banana variable response to different amount of applied water under farmer-managed conditions.

ET (%)	Applied water	Days to flowering	Days to harvest	Number of hands per bunch	Number of fingers per hand	Hand weight (kg)	Average bunch weight (kg)	Banana yield finger weight (t ha^{-1})
0	609	345	470	4.8	10.0	0.51	3.5	1.20
50	980	310	412	7.6	14.0	2.32	16.3	20.31
100	1722	306	410	7.6	14.2	2.37	18.9	21.40
Mean		320	431	6.7	12.7	1.73	12.9	14.30
SE±		14.60	16.92	0.42	0.49	0.16	1.56	2.67
CV%		10.33	8.97	11.86	7.7	29.55	27.99	36.48
Significance		NS	*	NS	NS	***	***	***

Note: P < 0.05 = *; 0.01 = **; 0.001 = ***.

Table 3. Banana gross margin analysis under researcher-managed field conditions.

ET (%)	Irrigation (mm)	Yield (tha^{-1})	Banana Suckers	Banana price (U$/kg)	Sucker price (U$/seed)	Income (U$)	Irrigation cost (U$50/interval)	Farm input costs (U$)	Total costs (U$)	Gross margin (U$)
0	0	3.15	1000	0.32	1.07	2,078.00	0	3528.5	3528.50	-1,450.50
50	980	21.31	6500	0.32	1.07	13,774.2	1960	3528.5	5488.50	8,285.70
100	1722	25.84	8200	0.32	1.07	17,042.8	3444	3528.5	6972.50	10,070.3
Mean	1554	16,77	5233	0.20	1.07	10,965.0	2702	3528.5	5329.83	8,452.60

followed similar trend as bunch weight, and it was resulted into significant differences in both bunch hand weight per bunch significant differences that and total banana yield.

Similarly, highest average banana yield of 25.84 and 21.4 t ha^{-1} for research and farmer, respectively,

Table 4. Banana gross margin analysis under farmer managed field conditions.

Et (%)	Irrigation (mm)	Yield (t h-1)	Banana Suckers	Banana price (U$/kg)	Suckers price (U$/seed)	Income (U$)	Irrigation cost (50U$/int.)	Farm inputs costs	Total costs (U$)	Gross margin (U$)
0	0	1.20	890	0.32	1.07	1336.30	0	3528.5	3528.5	-2192.20
50	980	20.31	7600	0.32	1.07	14,631.2	1960	3528.5	5488.5	9,142.70
100	1722	21.40	9400	0.32	1.07	16,906.0	3444	3528.5	6972.5	9,933.50
Mean	1554	16,77	5233	0.20	1.07	10,957.8	2702	3528.5	5329.83	7089.46

were obtained at 100% ET of applied water. The 0% irrigation treatment produced the lowest average banana yield of 3.45 and 1.20 t ha^{-1} (Tables 1 to 2) under researcher-managed and farmer-managed fields, respectively. The yields under researcher-managed was higher than under farmer-managed banana though not significantly different ($P > 0.05$). These results agrees with other findings (Robinson and Alberts, 1986; Manica et al., 1976) who found that increasing water application from 25 to 75% ET increases bunch weight and annual yields and Geonaga and Irizarry (1998) who stated that water for banana is applied sufficiently at a pan factor of 1.0 which is equivalent to 100% ET in is study. However, the total amount of water the banana used including rainfall ranged from 609 to 1722 mm which is within the range documented by Doreenbos and Kassam (1986).

The banana yield results between researcher-managed and farmer-managed fields were not significantly different showing that small-scale farmers can adopt scientific standards if properly trained or oriented. Furthermore, these yields trends showed other farmers that banana requires ample and frequent supply of water (Fandika et al., 2006) and that because water deficits in the vegetative period affect leaf development which in turn can influence the reproductive phase in the number of flowers, hands and bunches produced (Wahad, 2000). However, it was interesting to note that average number of hands per bunch and average number of fingers per hand (Tables 1 to 2) did not significantly differ with increasing amounts of applied water entailing that these factors are not influenced by soil water content but are perhaps genetically determined. But day to harvesting was different because day to flowering was reduced by water deficit while reducing yield.

During open days, farmers observed and learnt that water deficits in the yield formation period reduce fruit size, quality and suckers production. They also noted that reduced leaf area reduces the rate of fruit filling resulting in small fruit diameters in low water application treatments. Lead farmers also observed significant differences between plant characteristics such as neck length, average plant height, days to harvest, average bunch diameter and average pseudo-stem showing that water is very essential for a healthy banana plant and that water constitutes a major portion of a banana plant to as high as 90% (Chizala, 1995). The greatest lesson to farmers was that regular water supply under irrigation, produces taller plants with greater leaf area which results in earlier shooting, higher yields as well as high profits. Both researcher-managed and farmer-managed banana fruits were sold at U$0.32 per kg at supermarkets while seed was sold at U$1.07 to Non-Governmental Organizations (NGOs), government institutions and other individual farmers.

Irrigated banana is of high quality and offers an agricultural enterprise to small-scale farmer which is market-orientated as it fetched high gross margin than non-irrigated banana. Robinson and Alberts, (1987) reported increased quality and premium market prices on irrigated banana. As of now, the number of farmers that has adopted banana irrigation management and optimization on commercial basis in their fields has increased from one to more than twenty in communities around Kasinthula Research Station. In addition, NGOs have influenced the adoption in their impact areas. As a result more than 100,000 banana suckers (seed) from Kasinthula were sold to other regions of the country.

The gross margin analysis showed negative gross margin under non-irrigated banana enterprise (-U$1450.50 and - U$2192.2) and positive gross margin (U$10,070.30, and U$9,933.50) at 100% ET for researcher-managed and farmer-managed fields, respectively. Irrigation raised farmer earnings from -U$4 to U$27 per day (non-irrigated to irrigated banana) and it was optimal to produce banana under supplementary irrigation (100% ET) other than non-irrigated and full irrigation (Tables 3 to 4). The findings showed that banana enterprise has a commercial orientation that can reduce poverty for smallholder farmers in Malawi. Agricultural sectors can use such a miracle promising crop and technology to further carry a market oriented agribusiness study for banana to enhance attainment of Millennium Development Goals (MDGs) in the sub-Saharan Africa.

The scientists and extension workers can properly guide farmers in crop diversification and on how to reduce risk and uncertainties in times of market fluctuation and yield drop. It is believed that banana is one such crop in the sub-Saharan Africa that will facilitate the achievement of food security and poverty reduction. The main reasons why banana can help to achieve MDGs are that banana has multiple dietary uses and is not a seasonal crop which is thus harvested all year long (Wambugu, 2004). If properly managed, therefore, farmers will have food and income all year long. Sub-Saharan Africa should take it as its miracle crop for poverty and hunger eradication.

CONCLUSIONS AND RECOMMENDATIONS

Irrigation, technology dissemination and farmer participatory research improved banana yield and quality. The farming research system facilitated development of banana production guidelines in Malawi. The yield and gross margin analysis is under non-irrigated banana (-U$1450.50 and - U$2192.2) and positive (U$10,070.30, and U$9,933.50) at 100% ET irrigation for researcher-managed and farmer-managed fields, respectively. Irrigation raised farmer earnings from -U$4 to U$27 per day (non-irrigated to irrigated banana). It is optimal and proofitable to produce banana under supplementary irrigation (100% ET) other than non-irrigated. Unit farming research system increased tranfering of this technology to a wide range of farmers. It can therefore be concluded that banana production among small-scale farmers can be optimized for food security and income at household level through farmer's particiaption. If optimal banana production at small-scale irrigation farms promoted in Malawi, food security and income per capital will rise. The findings showed that banana enterprise has a commercial orientation that can reduce poverty for smallholder farmers. It is, therefore, recommendable that nations should advocate banana irrigation agribusiness.

Conflict of Interests

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

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Full Length Research Paper

Modelling approaches for addressing complexity in plant health management

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Harmful organisms affect the quality and quantity of food production. In a world of increasing changes in climatic, economic and social conditions, the design of effective measures against these organisms requires more accurate information. Mathematical models provide a scientific and quantitative language to describe the complex relationships that causes pest outbreaks. With the goal of analysing options to deal with this complexity, we discuss different mathematical approaches to modelling. The best model to support plant protection decisions will vary with each situation. Mathematical models range from very simple correlations between events to complex comprehensive systems of differential equations used to represent the dynamics of processes. Large-scale scenarios at the national or continental level can be supported adequately with simple, static and general models. Analytical or descriptive dynamic models are the best options to support pest management in well-defined regions or locations with little variation in external factors. Explanatory dynamic models are needed when great variations in pest behaviour are expected as a result of higher-order interactions with the host and the environment. If necessary, a quantitative analysis can be performed using mathematical modelling. In practice, the feasibility of such a quantitative analysis will depend on the time available for decision-making and data collection concerning the problem.

Key words: Mathematical models, plant health, predictive models.

INTRODUCTION

Plant health is one of the main concerns of nations worldwide. Attention is given not only to the economic

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implications of reductions in food production but also to the environmental impact that phytosanitary measure generate. Furthermore, the impacts on food security caused by inappropriate plant health practices account for almost 40% of annual crop losses (Flood, 2010). The complexity of this situation has stimulated the formation of interdisciplinary teams of scientists and technicians searching for a better understanding of the processes of introduction, dispersal and establishment of new pests in agricultural zones. Moreover, the teams have investigated the impacts of new pests on food production and biodiversity as well as the alternatives for management or eradication of these organisms on a sustainable basis (Jacobsen, 1997; Schrader, 2004; Banito et al., 2007).

Current reviews of these objectives (Rafoss, 2003; Corrado and Quaglia, 2004; Baker et al., 2009) suggest that the analysis of the phytosanitary situations must change in several senses: (a) from qualitative to quantitative methods of assessing risk (b) from considering pest outbreaks as isolated events to the visualisation of the processes that originated the outbreaks and (c) from considering these situations as black-box processes, where only outputs are considered, to an explanatory approach where the focus is set on the understanding of the interactions that determine the behaviour of the processes. To support these changes, the parallel development of at least three items is required (Bouma, 2007):

(1) Education and training for everyone involved with plant protection, including but not limited to decision makers, researchers, technicians and producers.
(2) A framework with scientific descriptions of the responses of organisms to the environment, in particular weather and climate.
(3) An infrastructure of weather and climate monitoring.

Mathematical models play a very important role in enhancing the capability to perform quantitative analysis of phytosanitary problems. They provide a very powerful language to understand and represent the interactions among weather, crop and pest variables (Allman and Rhodes, 2004). Mathematical models can help to assess the probabilities of the introduction, reproduction and dispersal of pests and the magnitude of pests' effects on crop yields and quality. Mathematical models are of particular interest for agricultural and ecological research because the construction and implementation of decision support systems require precision in analysis and conclusions. According to Thornley and France (2007), mathematics allows theory to be connected with experimentation and supports the progress of science from qualitative to quantitative methods of analysis.

In this review, several mathematical approaches used to model the processes of plant health maintenance are compared. The review will emphasise data requirements and practical benefits.

Models as tools to understand predict and control systems

A model can be defined as a simplified representation of a particular domain of reality (Bossel, 1994). In terms of systems theory, a model is a representation of a system, where a system is defined as a portion of reality constructed by elements in interactions that show specific attributes or properties (Forrester, 1994). A general description of systems and their properties has been given by Bossel (1994) as follows: systems fulfil certain functions associated with purposes recognisable by an observer; systems have characteristic arrangements of their elements and a structure that determines their function, purpose and identity; and systems are not divisible, that is, if one or several elements are removed, the system's purpose cannot be realised.

Haefner (2005) distinguishes four kinds of models according to their level of precision and complexity, including the conceptual or verbal model, which is composed of descriptions in natural language; diagrammatic models, which are graphical representations of objects and relations; physical models, which are physical mock-ups of a real system or object; and the formal model, which represents the mathematical approach. Models using algebraic or differential equations are scientific models because they provide numerical descriptions of systems. Biological systems are hierarchically organised, and in nature all elements are connected. Therefore, a key aspect of model creation is the definition of the boundaries of the system (Haefner, 2005).

Boundaries support the critical distinction between elements that are part of the system and elements that are external influences. Suppose that Figure 1 represents the approaches taken by two analysts to the same phytosanitary problem. Analyst 'A' sets system boundaries centred on the life cycle and behaviour of the pest and uses factors within these boundaries to look for alternatives to reduce its population. Analyst 'B' draws system boundaries centred on crop growth variables and will find completely different alternatives to protect production because the system boundaries include a much wider set of factors.

A model is thus a description of a problem in terms of systems, but there can be many different models of the same problem according to the limits assigned to the system. Descriptions of a system can refer to its different properties (Forrester, 1994). There are many classifications of mathematical models, and all of them are useful according to the criteria used to separate or classify models. In the scheme of Figure 2, a distinction is made between Mathematical and Non-Mathematical Models according to a classification provided by Haefner (2005). Specifically, a model is said to be mathematical if it contains in its structure a numerically expressed hypothesis about the system's behaviour that can be tested through comparison with observed data.

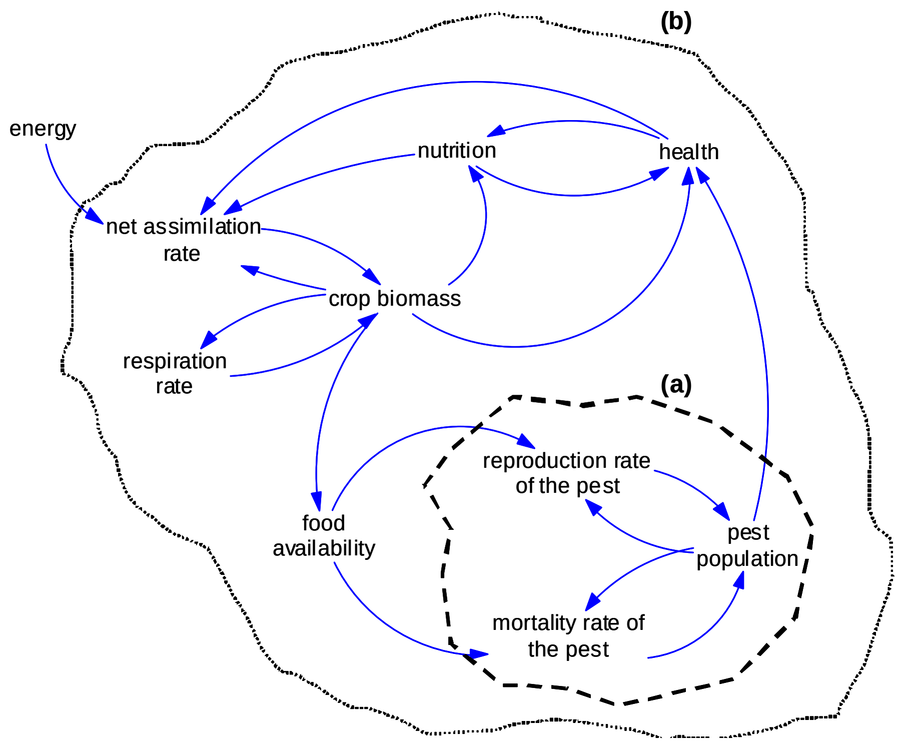

Figure 1. System boundaries definition of a phytosanitary problem by two different observers.

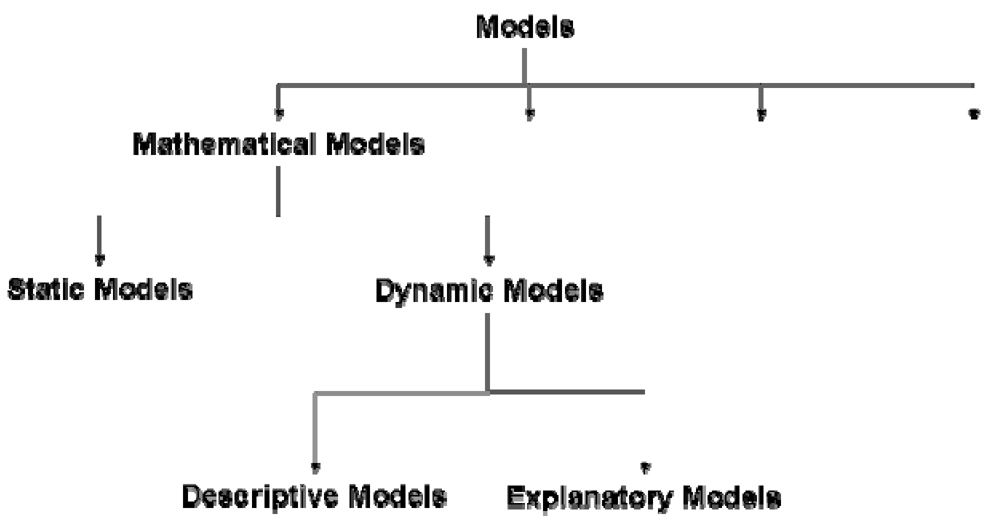

Figure 2. Models classification derived from Haefner (2005).

Mathematical models may be static or dynamic. Some of the properties of a system may change over time in response to the system's own structure or to the influence of an external variable. Some other properties can be considered constants in time. Models referring to properties that do not change with time are classified as static models. Models considering the variations over time of some characteristics are classified as dynamic models (Kepés, 2007). Dynamic models can also be classified according to the ways in which they describe the changes in a system over time. Models describing only the outputs of a system are considered to be descriptive models, whereas models that explicitly describe the interactions of elements that generate system changes are classified as explanatory or ecological models (Haefner, 2005; Lima et al., 2009).

Static models, the first step towards a quantitative approach

Static models are characterised by the absence of a time variable from their structure (France and Thornley, 2007). These models are mathematical equations, e.g., linear regression equations that establish a relationship of proportionality among one or more variables considered to be “dependent” and a series of other variables classified as “independent” (Haefner, 2005). Bayesian networks that represent the statistical dependencies among a set of random variables (e.g., diseases and symptoms) are also static models (Kepés, 2007). Static models are useful for characterising the state of a system at a given moment. An implicit assumption made when a static model is used to represent the state of a system is that this state will not change during a certain period (Kepés, 2007).

The entire world is experiencing a transformative period marked by the most accelerated changes in history. The globalisation process has spread not only products and technologies but also pests associated with some commodities (Lima and Berryman, 2006). Climate change is perceived mainly through the increased frequency and intensity of extreme meteorological events: drought, floods, warming, and other events that affect the natural distribution of many organisms (Rosenzweig et al., 2001; Ladányi and Horváth, 2010). As new conditions continue to appear, the lack of requisite knowledge is the main factor that limits the rational and effective management of phytosanitary problems. Under these circumstances, qualitative considerations, based on expert knowledge, represent the best option for supporting decisions about the risk that a specific pest represents and the identification of management alternatives.

Pest Risk Analysis is a good example of this situation. When a new exotic pest appears as a threat, there is little time and often very little information about the organism. In the original method established as the standard by the International Plant Protection Convention, IPPC (Food and Agriculture Organization, 2007a; b), the risk represented by a pest is categorised by using an ordinal classification of “High”, “Medium” and “Low” levels. The criteria used for this purpose reflect a series of qualitative considerations about the likelihood of introduction and the estimated magnitude of the impact. A significant improvement to this methodology is the application of static models to derive quantitative estimates of the probability of entry, establishment or spread of the pest. The advent of such static models has led several authors to apply a correlative approach to assess the risk. These modelling techniques, called “comfort indexes”, relate the potential distribution of a pest to climatological or meteorological variables. Pest risk maps, representing the risk levels of a region, are created to obtain a preliminary strategy in the process of planning the preventive measures to be used against exotic or quarantine pests (Magarey et al., 2007). These models are used to calculate probabilities for a specific criteria defined by model outputs; this criteria can be based on the number of favourable days for a given organism (Magarey et al., 2007; Moschini et al., 2010).

The most common static models fall into two general classes and yield estimates of two different kinds of variables. Infection models for plant pathogens are based on temperature-moisture response functions, whereas degree-days models are used to calculate the number of phenological stages and the number of generations for arthropods or other organisms.

The structure of a general simple regression model is:

$$Y = a + bX,$$

where: Y = dependent variable, generally associated with the infection intensity or probability.

a and b are constant and X coefficient, respectively.

X is an independent variable, usually representing the effect of weather.

Kang et al. (2010) have estimated the percentage of appressorium formation of the fungus *Colletotrichum acutatum*, the causal agent of anthracnose of chili pepper, using a multiple linear regression model as follows:

$$P = -13.3 + 0.612T + 0.928W$$

where: P = percentage of appressorium formation; T = level of temperature (°C); W = period of wetness (h).

The authors used this model in comparison with nonlinear models to forecast the time at which weather conditions are favourable to plant infections by the fungi. According to the possible relationships that define a phytosanitary problem presented in Figure 1, this approach only considers one pest-related variable: the reproduction rate, represented as a percentage. This variable is indirectly estimated as a function of the environmental influences represented by the temperature and the wetness period.

Computer systems based on static models have been developed to estimate the potential distributions of species. Some of these systems are used to create pest risk maps. The following systems are among the most extensively used. NAPPFAST (North Carolina State University APHIS Plant Pest Forecasting System) (Magarey et al., 2007), is an Internet-based system for developing plant pest risk maps. The system has a climate database using daily time intervals and has a biological template to create simple static models. CLIMEX (Climatic Index) (Sutherst et al., 1999) is a

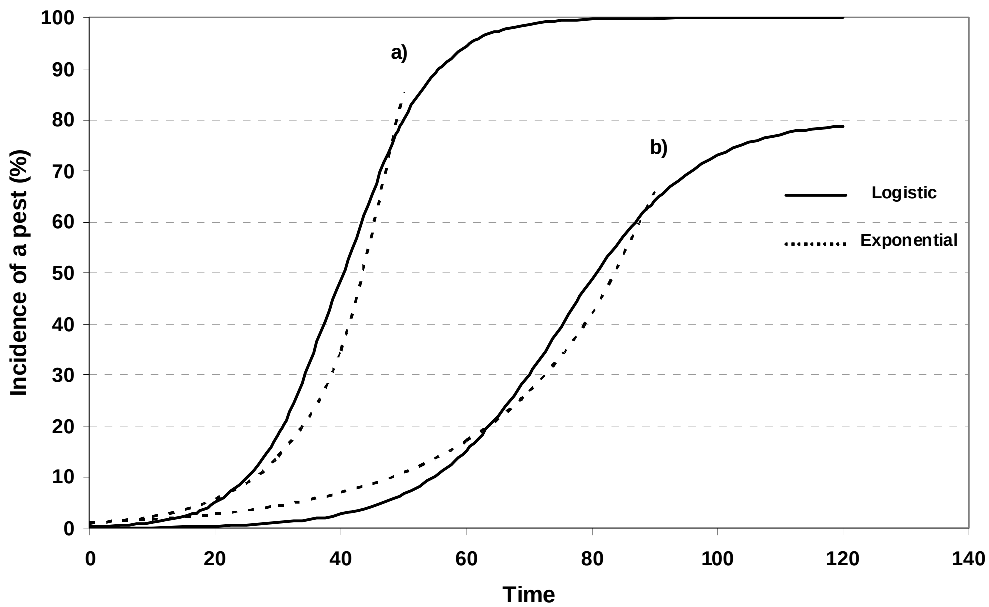

Figure 3. Examples of descriptive dynamic models fitted to two different locations.

computer system that estimates the climatic regions that a species could potentially occupy in the absence of other physical or biological limiting factors. The system relates field and experimental data on the occurrence of a pest to a series of climatic indexes calculated on a weekly basis (Beddow et al., 2010; Sutherst et al., 2004). BIOCLIM (Bioclimatic Analysis and Prediction System) developed by Busby (1991) and MAXENT (Maximum Entropy Method) created by Phillips et al. (2006) are systems that estimate the geographic distribution of species by using observed data on species' occurrence and associated climatic indexes. These systems have been used to assess the potential distribution of plant pests.

Static models are very important for supporting plant protection decisions on the scale of countries or continents if site-specific data to characterise pest growth or development are not available or if the time for the decision is limited. Caution must be exercised if predictions are made using static models because correlations are usually valid only under very specific conditions (Faherty, 2008; Jackson, 2008).

Descriptive dynamic models: Changing the view from events to behaviour

Dynamic models allow scientists to connect events over time to describe the behaviour of a system (Thornley and France, 2007). Models that do not have an explicit representation of the mechanistic process that determine the behaviour of a system are classified as Descriptive or Phenomenological models (Haefner, 2005). In these models, the system is treated as a black box with a single input or stimulus and a single output or response (Bossel, 1994; Vázquez-Cruz et al., 2010). The development of Descriptive models utilises the analytic mathematical approach. These models have a high theoretical value, and the general mathematical structure that they embody can be applied to represent the evolution of many different processes. Biological, economic, social, and other kinds of applications are possible using Descriptive models.

Descriptive dynamic models must be fitted to suitable data and require large data sets based on time series observations. Therefore, they are valid only under the particular conditions for which the model parameters were estimated (Bossel, 1994; Haefner, 2005; Parry et al., 2005; Thornley and France, 2007). Consider the hypothetical conditions of Figure 3, representing the growth of a disease in two locations designated (a) and (b). The fitted models are the Exponential (dashed line) and the Logistic (solid line). Although the model structure in each case is the same, the fitting parameters are very different from one location to the other because of the effects of physical and biological factors related to local conditions. The variables that can be included in these models are Pest population, its Rate of reproduction and Time. These equations are generally focussed on the pest subsystem of a phytosanitary problem and can be used to forecast the time course of pest infestations and the progress of diseases (Arneson, 2006; Forbes et al., 2008). Frequently, they are also used to perform comparisons between patterns of disease progress for different cultivars and management strategies (Arneson, 2006; Madden et al., 2000).

In this study, progress curves of incidence and severity are created by plotting a given variable (Y axis) as a function of time (X axis). Some frequently used descriptive growth curves are the Exponential, the Monomolecular, the Logistic, the Gompertz and the Weibull model. Descriptive dynamic equations are derived by assuming some characteristic relationships among the initial disease intensity, the initial inoculum availability and the absolute rate of change of disease intensity. This rate simultaneously represents the susceptibility of the host and the suitability of the environment (Haynes and Weingartner, 2003). If the rate of disease increase (*dY/dt*) is assumed to be proportional to disease intensity (*Y*), the curve follows the Exponential model (Thornley and France, 2007). The differential equation for this curve is:

$$dY/dt = cY$$

where *c* is a parameter known as the specific or relative growth rate. Integrating this equation:

$$Y = Y_O e^{ct}.$$

If the rate of change in disease level depends on diseased (Y) and healthy tissue *(1-Y)*, the resulting curve is the well-known Logistic Model (Arneson, 2006; Tornley and France, 2007; Sparks et al., 2008). Its differential equation is:

$$dY/dt = cY(1-(Y/K))$$

where *K* represents the total plant tissue. Integrating this equation:

$$Y = K/(1 + e^{c(t-t_0)}).$$

Descriptive dynamic models have been extensively used as a method for evaluating genetic resistance to several important crop diseases. The area under the Disease Progress Curve calculated from these models is considered to represent a direct measure of the resistance of a genotype (Haynes and Weingartner, 2003; Contreras et al., 2009).

The most important application of these models is the forecasting of disease progress for use in the planning of certain plant health management strategies (Cooke et al., 2006). For this purpose, a sufficient amount of experimental data must be available to ensure that the model parameters are accurately estimated (Bossel, 1994; Haefner, 2005). Descriptive models can be used to develop phytosanitary alert systems or to calculate the potential adaptation of a pest (Andersen, 2005). It is important to consider that these models generally fail to represent processes' behaviour if the weather conditions differ significantly from those prevailing when the fitting parameters were estimated (Bossel, 1994).

Explanatory dynamic models: An ecological approach

Explanatory or Ecological models are intended to identify and understand those processes that are decisive for systems' behaviour. In these types of models, structure and function are described in terms of differential equations directly related to the real system (Bossel, 1994). The equation's coefficients correspond to real characteristics of the process that can be measured, that is, they are not obtained indirectly, as in descriptive models (Bossel, 1994; Haefner, 2005).

To model the process, many characteristics of the systems must be known: their elements, connections and mutual influences. The differential equations formulated in explanatory systems must be solved using numerical methods (Thornley and France, 2007). The numerical solution facilitates the inclusion of as many variables as necessary to represent the behaviour of a process (Peart and Curry, 1998; Thornley and France, 2007). More than a single equation, an Ecological model is a system of equations. Influence or flow diagrams provide an overview of the model components and interactions.

In plant health management, ecological models are a useful tool to examine the interactions among plants, pests and the environment (Tixier et al., 2006; Ellner et al., 2002; Ladányi and Horváth, 2010). The elements or variables of the system are defined as quantities that change with time. Depending on the role that the variables play in the model, they are categorised as state or rate variables. State variables define the state of the system at a given moment in time. Examples of state variables are insect population and disease incidence. Rate variables define the rate or speed at which the state variables change. These variables have dimensions "per unit time" (Thornley and France, 2007).

A phenomenon termed "feedback" occurs if a state variable affects one or more of its rate variables and produces nonlinear behaviour. If the rate changes in direct proportion to the state, a positive feedback loop occurs and promotes an exponential growth or decay of the process. If the rate is inversely proportional to the state, negative feedback is present. The process behaves asymptotically (Haefner, 2005). The diagram of Figure 4 represents a model of a root pest, the Mexican rootworm, *Diabrotica virgifera zeae* (Quijano et al., 2010). The model includes soil water variables (*SW, WC1, WC2, and SH*) that influence larval hatching (*H*) and the plant's capacity to satisfy the evaporative demand of the environment (*PCD*). The root growth (*RGR*) process is also included to estimate the food availability (*RB*) for the larvae and the effect of root consumption (*CR*) on the plant's capacity to absorb water. The life cycle of the insect reflects the effect of temperature through the influence of the Degree-Days variable (*DD*) on the developmental rate. The names and descriptions of these variables are given in Table 1. The equations of state are

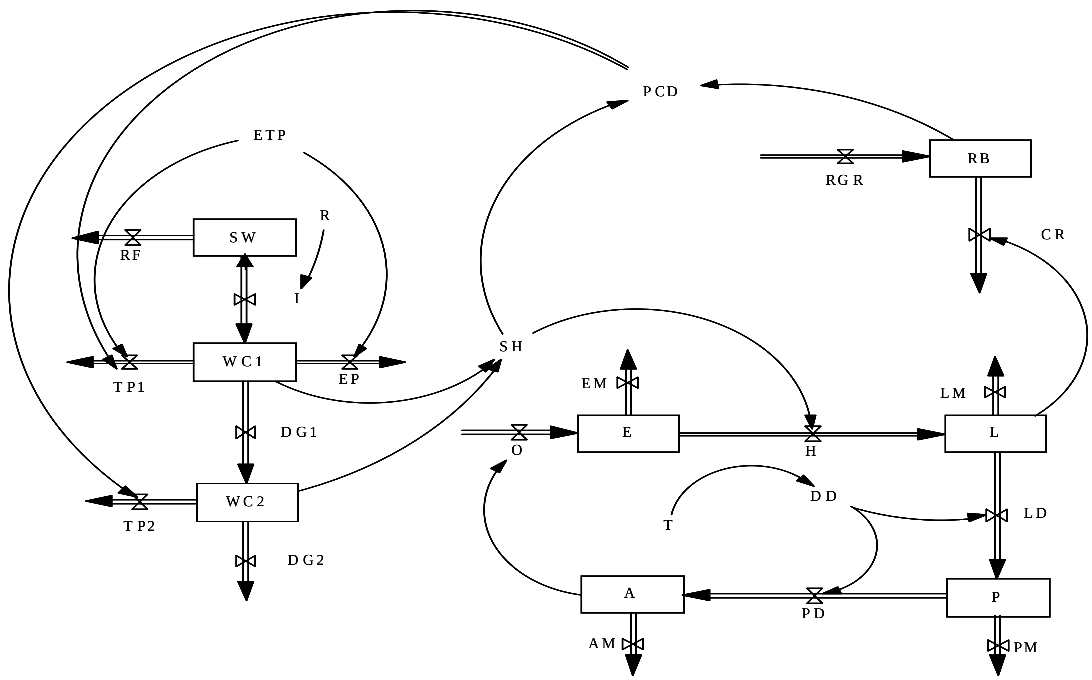

Figure 4. Flow diagram of a root pest – host – environment model. Adapted from Quijano et al. (2010).

numerically integrated over a time period (dt) of one day. Descriptive and static models can be used to calculate the values of the rate of variables.

The Ecological Modelling approach is very helpful when a strong interaction exists among the host, the pest and the environment. It facilitates the inclusion of as many variables as are necessary to represent the entire system. Two types of ecological models are of interest in plant-protection applications: models of population dynamics to represent the life cycle of arthropods, insects, mites, nematodes, etc., and epidemiological models to represent diseases caused by fungi or bacteria.

Wang and Shipp (2001) developed a population dynamics model of *Frankliniella occidentalis* (Pergande) to determine the economic thresholds for this pest on greenhouse cucumber. A model to simulate phenology, growth, and plant-parasitic nematode/banana interactions (SIMBA) has been created by Tixier et al. (2006) to predict *Radopholus similis* and *Pratylenchus coffeae* population dynamics. The model considered the interspecific competition between these organisms and was used to optimise the nematicide applications. Tixier et al. (2008) used this model to evaluate the response of new banana hybrids to plant-parasitic nematodes in Martinique. By taking into account the pest-host-environment interactions, the authors could find alternatives to reduce the use of pesticides.

Reji and Chander (2008) have created a mechanistic model of the population dynamics of the rice bug (*Leptocorisa acuta*, Thunb.) in India. The model was used to determine the population peaks of the rice bug to support the programming of control measures. One of the models used most widely for diseases is the Potato Late Blight prediction model, used to target fungicide application to times of the greatest need to reduce the use of chemicals. This model has been modified recently by Henshall et al. (2006). The model calculates infection periods as a function of hourly temperature, relative humidity and surface wetness.

A more complex model involving coconut palms (the host plant), the pathogenic microorganism -*Phytomonas staheli* McGhee & McGhee, and the insect vector - *Lincus lobuliger* Bred. (Hemiptera: Pentatomidae) has been developed by Sgrillo et al. (2005) to simulate the dynamics of the disease caused by the pathogen. The population dynamics of healthy and infected insect vectors were included as a subsystem. The results from the model help to support the conclusions that control techniques for the vector only delay the spread of the disease and that it would be more convenient not to apply control techniques for *Lincus sp*. in areas where the disease is absent.

Miranda et al. (2008) proposed a theoretical model of the interaction of the Asian citrus psyllid (*Diaphorina citri* Kuwayama) with its natural enemies. The model has not yet been validated, but it was used in a preliminary investigation to calculate an ecological balance between the number of females of the natural enemy *Tamarixia radiata* and the quantity of healthy buds present in the tree. This model will be of great value for estimating the actual psyllid densities. A characteristic common to all of

Table 1. Description of the variables in the Mexican rootworm, *Diabrotica virgifera zeae* K. and S. model (Quijano et al., 2010).

Variable	Equation	Description
State variables		
SW	*SW(t+dt) = SWt + dt(I – RF)*	Superficial water
WC1	*WC1(t+dt) = WC1t + dt(I – EP – TP1 –DG1)*	Water content at a depth of 0 – 10 cm
WC2	*WC2(t+dt) = WC2t + dt(DG1 – TP2 – DG2)*	Water content at a depth of 10 – 20 cm
RB	*RB(t+dt) = RBt + dt (RGR – CR)*	Root biomass
E	*E(t+dt) = Et + dt(O – EM – H)*	Egg population
L	*L(t+dt) = Lt + dt(H – LM – LD)*	Larval population
P	*P(t+dt) = Pt + dt(LD – PM – PD)*	Pupal population
A	*A(t+dt) = At + dt(PD – AM)*	Adult population
Rate variables		
I	*f(R, SP)*	Infiltration
RF	*f(R, SW, I)*	Runoff
EP	*f(ETP, WC1)*	Soil evaporation
TP1	*f(ETP, WC1, PCD)*	Transpiration at a depth of 0 – 10 cm
DG1	*f(WC1, WC2)*	Drainage at a depth of 0 – 10 cm
TP2	*f(ETP, WC2, PCD)*	Transpiration at a depth of 0 – 10 cm
DG2	*f(WC2)*	Drainage at a depth of 10 – 20 cm
O	*f(A, SW)*	Oviposition
EM	*f(E, SW, T)*	Egg mortality
H	*f(E, DD)*	Hatching
LM	*f(L, T)*	Larval mortality
LD	*f(L, DD)*	Larval development
PM	*f(P, SW, T)*	Pupal mortality
PD	*f(P, DD)*	Pupal development
AM	*f(A, T)*	Adult mortality
CR	*f(RB, L)*	Root consumed
Auxiliary variables and constants		
ETP		Potential evapotranspiration
R		Rain
PCD		Plant capacity to satisfy evaporative demand
T		Temperature
DD		Degree-Days

these models is that they need scientific descriptions of organisms' response to the environment and accurate input data to correctly represent the dynamic nature of the biological processes involved in pest-host-environment interactions.

Final considerations

Mathematical models provide a powerful language to represent and understand the complexity of the biological processes involved in plant health management. Understanding the system and describing the structural relationships that govern the behaviour of the system in mathematical terms is the more effective and rational way to acquire the capacity to predict and control system outputs. Quantitative modelling gives a more detailed description of processes but requires many observations to minimise uncertainty (Thakar et al., 2010). Complexity increases with the number of components included in the model and with its temporal resolution. According to Javier and DiStefano (2009), a major new direction in systems biology modelling is the creation of multiscale models that combine different levels of detail as a function of the available data. Comprehensive models are of proven importance as a reference to identify gaps and to organise the available knowledge. In many cases, experimental data and mathematical descriptions are not available or are very difficult to obtain, so a simpler approach must be adopted. In some cases, a basic model yields sufficient detail, and comprehensive approaches are not required.

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Conflict of Interest

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

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Study on winter bud dormancy in Red Bayberry (*Myrica rubra)* a forest, horticulture and ornamental tree

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A study to prevent or brake bud dormancy in 3 to 4 years old *Myrica rubra* cv. 'Biji' plants under controlled green house and field conditions, was conducted using GA_3 and WPM nutrient media as fertigation and drainage. Two batches of the plant were shifted in different growth stages "dormant" and "non-dormant". Plants shifted in the month of October were in the late autumn growth stage (non-dormant), while plants shifted in the month of December were in a complete bud dormancy stage. Plants of the first batch were prevented to enter bud dormancy while in the second batch bud dormancy was broken by providing warm temperature ranging 25±3°C in the green house. Green house plants took 2-4 weeks to initiate the growth flushes as compared to 17 to 18 weeks taken for the field plants. Buds break and leafs shed in the green house were observed earlier in the plants drained with nutrients media followed by fertigation, while spraying of GA_3 delayed leaf shed and increased shoot length both in the green house and in the field. GA_3 treated plants sprouted few days earlier than that of control. Significant differences were observed in initial sprouts among the treatments of GA_3, nutrient fertigation and nutrient drainage as compared to the control plants. Similarity in days to initial sprout was observed in both the nutrient fertigation and drainage methods with a slight variation of one or two day's differences. Nutrients used as drainage showed outstanding results than fertigation.

Key words: Bud dormancy, gibberellic acid, GA_3, *Myrica rubra*, warm temperature.

INTRODUCTION

Myrica rubra with a common name of red bayberry is an important member of *Myricaceae* family used for horticultural, forestry, ornamental and medicinal purposes. This is one of the endemic species of Far East Asia grown under warm and humid climates. It is grown in China, Japan, India, Thailand, Burma and Vietnam as fruit or forest tree while in America and Europe as an ornamental tree (Wu, 1995; Chen et al., 2004). It is also a rich source of tannin, flavonoids, polyphenols and perfumery compounds (Yang et al. 2003). Due to long lifespan, great economic value, low production costs and nitrogen fixing activity, the red bayberry is considered a good economic source for the growers (He et al., 2002; Li, 2002).

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Red bayberry is also an ideal selection for soil conservation and forest ranges. China National Forestry Bureau has selected red bayberry as one of the forest trees for soil conservation and barren land reclamation (He et al., 2004). Annual vegetative growth in *Myrica rubra* has three distinct flushes spring, summer and autumn. Spring shoots starts from late March to late June, developing from the last year spring or summer twigs. Summer flush starts from late June and ends in August, while autumn flush starts from August and ends in late October or early November depending upon the climatic condition of the region. Summer vegetative growth is the heaviest flush followed by spring and autumn.

Alternate bearing may develop if the total vegetative shoots constitute more than 60% of flowering shoots (Chen et al., 2004). The old leave abscise at the beginning of May and reach at its peak when the spring shoots stops growing; however, leaf abscission is influenced by both the growing environment and the cultivar (Chen et al., 2004).

Winter bud dormancy occurs in many fruit trees and woody perennials, and they are characterized on the basis of dormancy periods (Oukabli and Mahhou, 2007). In the dormancy period, visible growth becomes suspended but developmental changes can still occur (Saure, 1985). Some of these changes are promoted by cool temperatures and are required for breaking the dormancy. This has a great effect on the time period, amount of buds break and flowering (McPherson et al., 1997). Dormancy can be controlled by preventing plants from entering true dormancy or by hastening bud break from plants that have already entered true dormancy (Saure, 1985). The hastening bud break can be achieved by low temperature or by Gibberellic acid treatments (Criley, 1985).

Dormancy regulation in vegetative buds is necessary for plant survival, development and architecture of plants. In many cases, breaking of dormancy results in increased cell division and changes in the developmental process (David et al., 2003; Lang et al., 1987). Vegetative bud dormancy is controlled by plant hormones and the environmental signals control the production and perception of these hormones (David et al., 2003). In these, temperature plays main role in controlling bud dormancy release and subsequent growth of buds (Marc et al., 1999).

The objectives of this study was to determine whether *Myrica rubra* plants could be prevented from entering the true winter bud dormancy in the controlled green house temperature and/ or hasten the dormancy using GA_3 and nutrients media. This study will help to understand the phenomenon of dormancy in Bayberry plants which will regulate vegetative shoots throughout the year and turning the vegetative buds into floral buds. This will help to overcome the alternate bearing and could advance fruit maturation period in the plants.

MATERIALS AND METHODS

Plant material

Potted plants of *Myrica rubra* cv. 'Biji' were obtained from the Nurseries of the Horticulture Department, Zhejiang University, Hangzhou, China. These plants were approximately 65-75 cm tall and 3-4 years old. Pots were filled in with garden soil, farmyard manure, perlite and sand at 1:1:1:1 ratio by volume. Two experiments were conducted in the green house controlled temperature and relative humidity with the aim to prevent the plants from entering true bud dormancy during the chilling months and/or hasten dormancy in comparison with the plants growing under normal environmental conditions in the field. The temperature of the green house was 25±3 °C. On shifting plants to the green house, a light uniform pruning was done to remove the two-third part of the current year shoots for clear observations. All the agronomical operations were carried out as required both in the green house and in the field.

One batch of the plants was shifted to the green house in the last week of October when autumn growth flushed in *Myrica* before the onset of chill. The other batch was shifted in the first of week of December when the plants completely entered true winter bud dormancy. Average temperature and relative humidity for the months of November, December, January, February, March and April in growth chamber in comparison with the outside temperature is given in Figure 1. The weather data was recorded by a computerized meteorological observatory specially made for controlling green house environments by Priva® Intégro. The system was adjusted to record both inside and outside temperatures and relative humidity of the green house chamber after every five minutes. Plants were drenched with WPM medium diluted, 5 times once in two months and the plants were irrigated 2 days after the drenching of the nutrients. Medium pH was adjusted to 5.8. All the agronomical operations were carried out thoroughly.

One batch was shifted to the green house in the last week of November when the plants were in full dormant stage. Three treatments were applied to hasten winter bud dormancy and are given below:

(1) Spraying of different concentrations of GA_3. Plants were sprayed with GA_3 100, 200, 300 and 400 ppm.
(2) Spraying of different strength of WPM media (McCown and Lloyd, 1981) also called fertigation, which entails: (a) WPM medium diluted to ¼ strength, (b) Medium diluted to ½ strength, (c) Medium diluted to ¾ strength and (d) Full concentration of WPM medium. Medium was sprayed on the plants to wet the plants from top to bottom.
(3) Different concentrations of WPM media in the form of drainage called nutrient drainage was carried out: (a) WPM medium diluted to ¼ strength (b) Medium diluted to ½ strength (c) Medium diluted to ¾ strength and (d) Full concentration of WPM medium.
(4) None of the above method was applied to the control plants.

There were two plants in each treatment, replicated three times. Data on days to initial sprout, leaf shedding (days counted from the day when the swollen buds were opened), number of leaves per shoots and shoot length was recorded. Analysis was done by using General Linear Model Procedure (by SAS Inc., Software package) and means were separated for significant differences using LSD test at $P < 0.05$.

RESULTS

Dormancy in green house versus field plants using GA_3 and nutrient media

Plants in the green house conditions did not enter the

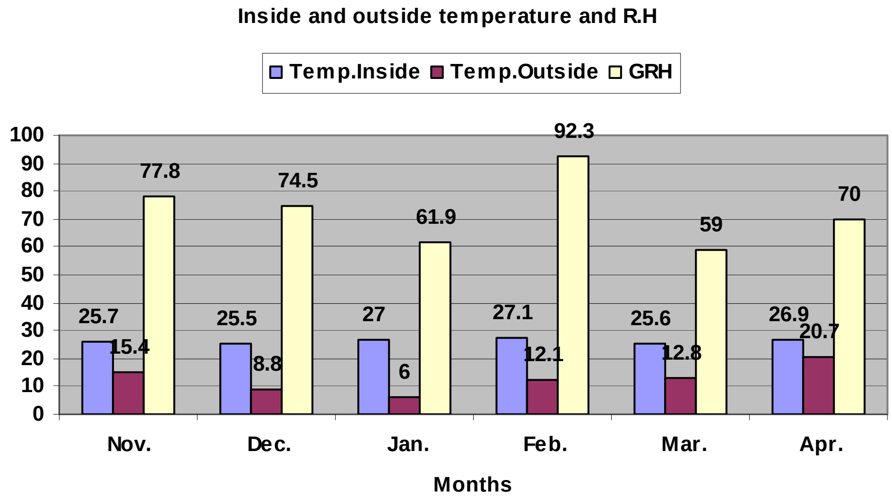

Figure 1. Temperature and relative humidity difference between inside and outside of green house.

Table 1. Effects of GA_3, nutrient fertigation and drainage on the bud dormancy of *Myrica rubra* in the green house conditions.

Treatment	Initial sprout (Days)	Leaf Shed (days)	No. of leaves	Shoot length (cm)
Control	28.67±0.577[a]	6.33±0.578e	12.67±1.15[b]	13.30±0.889e
GA_3				
100	21.00±1.000[b]	10.66±0.577d	14.00±1.00[b]	21.37±0.611d
200	21.33±0.577[b]	12.33±0.577[c]	15.66±0.577[a]	27.63±0.472[c]
300	20.00±1.000[bc]	14.33±0.578[b]	15.66±0.578[a]	30.77±1.550[b]
400	18.66±0.577[c]	17.67±0.577[a]	16.00±1.000[a]	34.33±1.464[a]
Nutrient Fertigation				
¼	17.33±0.577[a]	7.66±0.577[a]	17.00±1.000[ab]	19.20±0.916[c]
½	17.33±0.577[a]	7.00±1.000[a]	18.00±1.000[a]	20.56±0.602[cb]
¾	17.00±1.000[a]	7.33±0.578[a]	16.33±0.577[b]	21.86±0.378[b]
Full conc.	15.66±0.577[b]	7.33±1.154[a]	17.30±0.577[ab]	24.20±0.900[a]
Nutrient Drainage				
¼	15.66±0.577[a]	8.33±0.577[a]	16.33±0.577[c]	19.60±0.360[b]
½	16.33±0.577[a]	7.34±0.578[ab]	16.66±1.527[c]	20.20±1.900[b]
¾	16.33±0.577[a]	6.67±1.154[b]	20.00±1.000[b]	22.80±0.700[a]
Full conc.	15.66±0.577[a]	7.66±0.576[ab]	22.330±0.578[a]	23.93±0.305[a]

Values are means ± standard deviation. Values within a column followed by the same letter are not significantly different at 5% level of probability using LSD test.

winter bud dormancy, Table 1. Plants neither treated with GA_3 nor fertilized though exhibited delay in the emergence of new sprouts, did not undergo the dormancy phase. Nutrients supplied in form of drainage and fertigation advanced the initial sprout followed by GA_3 treatments. Initial sprout in plants drained with all four treatments of nutrient concentrations was found non-significant; however they sprouted 13 days earlier than control plants. Significant differences in initial sprout were observed among the treatments of GA_3. Maximum numbers of days (21.33±0.577) were taken to initial bud sprout by 200 ppm of GA_3 as compared to the minimum (18.66± 0.577) of 400ppm. Leaf shed days were counted after the first bud sprout. A significant difference was found among differences in days taken to leaf shed. Minimum days (6.33) to leaf shed were taken by control.

Comparing the three methods, plants treated with nutrient drainage shed the leaves earlier in all the treatments followed by nutrient fertigation and GA_3 respectively. Maximum days (17. 67) to leaf shed in the

Table 2. Effects of GA_3, nutrient fertigation and drainage on the release of bud dormancy of *Myrica rubra* in the field conditions.

Treatment	Initial sprout (Days)	Leaf Shed (days)	No. of leaves	Shoot length (cm)
Control	127.00±1.000[a]	12.67±1.154d	19.33±1.154[c]	16.77±0.251e
GA3				
100	118.67±0.0578[b]	14.00±1.000[c]d	22.67±0.578[ab]	22.94±0.513d
200	116.33±0.577[c]	15.76±0.578[c]	22.00±1.000[b]	25.70±0.360[c]
300	116.34±0.578[c]	28.67±1.527[b]	23.67±0.577[a]	30.78±1.569[b]
400	115.33±0.577[c]	33.34±1.527[a]	23.00±1.000[ab]	34.40±1.200[a]
Nutrient Fertigation				
¼	125.33±0.578[a]	11.00±1.000[b]	20.00±1.000[b]	21.37±0.814d
½	124.00±1.000[a]	12.00±1.000[ab]	21.34±1.154[b]	24.80±0.200[c]
¾	124.27±0.577[a]	12.67±1.527[ab]	23.67±0.577[a]	27.06±0.378[b]
Full Conc.	123.34±0.573[a]	14.00±1.000[a]	24.33±0.578[a]	29.67±0.321[a]
Nutrient Drainage				
¼	125.34±0.577[a]	11.3±41.527[a]	23.67±1.527[b]	24.90±0.900[a]
½	123.00±1.000[b]	11.67±1.527[a]	24.34±1.527[ab]	27.56±0.802[b]
¾	123.00±1.730[b]	11.67±2.081[a]	25.67±1.154[ab]	27.90±0.964[b]
Full Conc.	123.00±1.000[b]	13.00±1.000[a]	26.33±0.577[a]	30.27±0.737[c]

Values are means ± standard deviation. Values within a column followed by the same letter are not significantly different at 5% level of probability using LSD test.

green house conditions were taken by 400 ppm treatment. Data on number of leaves were recorded after two months. Maximum numbers of leaves were found when plants were drained with full concentration of nutrients followed by ¾ nutrient drainage as compared to the maximum (12.67) in control. Shoot length as observed had maximum of 34.33 cm in the plants treated with GA_3 400 ppm followed by 30.77 and 27. 63 cm in 300 and 200 ppm of GA_3 respectively as compared to the minimum (13.30) of control.

In the field conditions, all plants that were either treated or untreated entered the true winter bud dormancy due to the unfavorable environmental conditions. Different methods to break dormancy did not advance the process of dormancy. However, GA_3 treated plants in general sprouted few days earlier than that of control. Significant differences in initial sprout were observed among the treatments of GA_3, nutrient fertigation and nutrient drainage as compared to the control plants (Table 2). Maximum numbers of days (118.67±0.0578) were taken to initial bud sprout by 100 ppm of GA_3 as compared to the minimum (115.33±0.577) of 400 ppm. Similarity in days taken to initial sprout was observed in both the nutrient fertigation and drainage methods with a slight variation of one day difference.

Days to leaf shed were counted after the first bud sprout. A significant difference was found among the differences in days taken to leaf shed. Maximum days (33.34±1.527) to leaf shed were taken by the plants treated with 400 ppm of GA_3 as compared to12.67± 1.154 in the untreated plants. Only with a difference of one or two days, all plants treated with nutrient fertigation and drainage took the same time to leaf shed. Maximum days (17. 67) to leaf shed in the green house conditions were taken by 400 ppm GA_3 treatment. Data on number of leaves were recorded after two months.

On the annual shoot flush least number of leaves (19.33±1.154) were observed in control plants as compared to the maximum (26.33±0.577) in plants drained with full strength of the nutrient media. Shoot length was accelerated by the GA_3 treatments. Maximum shoot length (34.40±1.200 cm) was noted for the plants sprayed with 400 ppm of GA_3 in comparison with (16.77±0.251) of control plants.

Breaking and/or hastening dormancy

Plants shifted in the last week of October, were at the last stages of the autumn growth flushes before entering the true winter bud dormancy while those shifted in the first week of December were completely dormant. A Batch of plants shifted on October 25 did not undergo the true bud dormancy as the normal growth flushes continued even in the dormant periods by the plants in the normal field conditions. Dormancy in the plants shifted in the first week of December was broken in the green house conditions. The green house temperature played a vital role in breaking the bud dormancy. A slight difference in data on different parameters was observed as shown in Table. 3. Both the dormant and non-dormant plants showed similar trends of growth in the controlled green

Table. 3. Response of *Myrica rubra* plants to the green house conditions shifted on different dates to prevent the plants to enter or accelerate winter bud dormancy.

Plant shifted on	Initial sprout (Days)	Leaf Shed (days)	No. of leaves	Shoot length (cm)
October 25, 2003	28.66± 0.577	6.33± 0.577	13.30± 0.888	12.67± 1.154
December 1, 2003	29.66± 2.51	6.67± 1.527	14.66± 1.527	14.40± 0.953

Values are means ± standard deviation. Data was collected after two months in the controlled green house conditions with an average monthly temperature of 25±3°C.

house conditions, however, improvement in the growth was observed in the parameters of the dormant plants.

DISCUSSION

It was observed that all plants in the field conditions either treated or untreated entered the true winter bud dormancy due to the unfavorable environmental conditions. On the contrary, plants either treated or untreated in the warm temperature of green house were prevented to enter bud dormancy. Green house plants took 2-4 weeks to initiate the growth flushes as compared to 17-18 weeks for the field plants. It means that due to the harsh weather conditions especially temperature the plant buds were put in to ecodormancy to temporarily terminate the growth. As the outside unfavorable conditions prevails for longer periods, *Myrica rubra* plants entered into endodormancy where signals are being transmitted to the plants to put the buds in the state of endodormancy to protect the vegetative buds by ensuring that meristems will not resume growth until the stable return of permissive conditions.

Warm temperature of the green house (25±3 °C) played a significant role in either breaking or preventing the plants from entering bud dormancy. Olavi et al. (2003) reported that exposing Betulla species to different temperature regimes and light conditions, the warm temperature of 21 °C significantly delayed the induction of dormancy. Temperature appears to be the main factor controlling the changes in the intrinsic growth capacity of both, floral and vegetative endodormant buds (Leite et al., 2004). Temperature plays a significant role in the induction and breaking of endodormancy (David et al., 2003). Mowat (1995) maintained the plant shoots of persimmon in the constant temperature of 23 °C, the optimum root temperature for both dormancy release and the proportion of budburst was 13°C.

The results of this study showed that plants neither treated with GA_3 nor fertilized though exhibited delay in the emergence of new sprouts, did not undergo the dormancy phase. In contrast to the field experiment, GA_3 and nutrient media application was not effective to break or hasten dormancy. Similar results where GA_3 did not retard the time of initiation of the shoots in the field conditions were reported by Roberto and Thomas (1998).

With the application of nutrient media, earlier and vigorous growth was observed in both the field and green house conditions. This may be due to the accumulation/or absorption of nutrients by plants during winter and their subsequent use in the bud break period. Accumulations of nutrients in perennial plants occur when resources supply exceeds demand (nutrient used by the plant functions), thus incurring no cost to growth. Richard et al. (1998) reported that Pistachio plants adequately fertilized, accumulated storage substances as reserve nutrients. These nutrients were allocated to reproductive and vegetative growth on resumption of the plant growth after dormant state.

Conflict of Interests

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

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An overview of current agronomic practices of smallholder farmers in semi-arid Central and Western Zimbabwe

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Smallholder farmer productivity in developing countries is limited by diverse biophysical, political and socio-economic factors. The objective of this study was to establish current agronomic practices of smallholder farmers in semi-arid Lower Gweru and Lupane areas of Zimbabwe and to identify possible research and extension interventions that may improve crop productivity of these farmers. Focus group discussions, interviews and desktop study were used to collect data. Horticultural production is the main livelihood in Lower Gweru, while field crop and livestock production are livelihoods in both areas. Conventional tillage is the predominant tillage system. Important crops include maize (*Zea mays* L.), pearl millet (*Pennisetum glaucum* (L) R.Br.), sorghum (*Sorghum bicolor* L.) and groundnuts (*Arachis hypogea* L.). Farmers grow both hybrid and open-pollinated maize varieties (OPVs) with more farmers in Lupane than in Lower Gweru, growing these OPVs. The number of farmers growing improved varieties of small-grain crops has increased, since mid 1990s. The method and frequency of weeding depends on tillage system used and availability of equipment as well as draft power. Adoption rates for technologies such as water conservation and use of adequate soil ameliorants as well as effective crop rotations are low due to limited resources. The study identified some research and extension interventions that may be employed to improve crop productivity in semi-arid areas of Central and Western Zimbabwe.

Key words: Smallholder farmers, agronomic practices, semi-arid areas, research and extension interventions.

INTRODUCTION

The majority of the rural population in Zimbabwe are smallholder farmers located in Natural Regions (NRs) III, IV and V of the country. These regions are generally characterized by low and erratic rainfall resulting in low agricultural potential. Inherently low fertility status of the soils also contributes to low agricultural potential of these demonstrated significant year to year variability in maize yields due to seasonal rainfall variability, for these semi-

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arid areas. Despite the marginal conditions in these areas, most smallholder farmers continue to rely on rain-fed agriculture, cropping in particular, for their livelihoods.

In Zimbabwe, the term “smallholder farmers” refers to farmers working on fields in the communal and resettlement areas as well as co-operative farmers. In this study, the opinions and needs of communal area farmers are addressed. Smallholder farmers are generally characterized by a limited resource base. Waddington et al*.* (2004) characterize smallholder productivity as “low input – low output” farming, while Rockstrom (1999) describes small-scale farmers in semi-arid regions as being “generally risk minimizers rather than yield maximizers.” Ellis-Jones and Mudhara (1995) point out that smallholder farmers in semi-arid Zimbabwe face great challenges as they are required to respond to a wide range of environmental and economic variables. Notable agricultural research and extension efforts have been made to improve the livelihoods of smallholder farmers in Zimbabwe. However, expected benefits from these efforts, for example through development and dissemination of new technology are not always realized. This is due to among other reasons, inadequate knowledge of farmers’ circumstances, leading to development of inappropriate technologies, from the farmer’s point of view. Several authors including Avila (1985) and Hardaker et al. (1984) highlight the need for stakeholders to study and understand the farming system for effective adoption of technologies recommended to farmers. This study which was carried out partly to fill in some gaps in the baseline survey for the IDRC climate change project on capacity building, in Zambia and Zimbabwe, reviews agronomic practices of smallholder farmers in Lower Gweru and Lupane communal areas of Zimbabwe. These areas represent marginal areas where approximately 70% of the population resides and where crop production is practised by all smallholder farmers. The data and information collected are useful in directing crop research and extension efforts. The current status quo of the farming systems may also provide indicators of possible farmers responses to environmental changes such as climate change and increased climate variability.

MATERIALS AND METHODS

The study area comprises Lower Gweru and Lupane communal areas. Most of Lower Gweru lies in Natural Region III while Lupane is in region IV. Natural Region III is a semi -intensive farming region receiving annual rainfall of 550-700 mm while Region IV is semi-extensive and receives annual rainfall of 450-600mm (Vincent and Thomas, 1962). Both regions are subject to mid-season dry spells with region IV experiencing more severe spells as well as periodic seasonal droughts. Temperatures are generally high, with annual mean maximum temperatures ranging from 24-28°C, for Region III and 32-35°C for Region IV. The high temperatures render rainfall received less effective due to high evaporative losses. Soils in both regions range from vertisols to sands (Thompson and Purves, 1978) and most areas in these regions consist of shallow, coarse grained sands, which have a low production potential (Thompson and Purves, 1978; Grant, 1981; Mashiringwani, 1983). A considerable area of deep, fine grained sands is also found in the west of the country (which includes Lupane) (Thompson and Purves, 1978). These soils are relatively infertile and subject to severe wind erosion particularly if they are cropped.

Data and information were collected on current agronomic practices employed by the farmers in the study area. Methods used to collect data include secondary data (Bless and Higson-Smith, 2000), semi-structured interviews (Flick, 2006; Gill et al., 2008) with agricultural extension personnel, structured interviews (Punch, 2005; Gill et al., 2008) and Focus Group Discussions (FGDs) (Gill et al., 2008; Harrell and Bradley, 2009) with heads of households. Two wards were selected from each communal area and these were Mdubiwa and Nyama Wards for Lower Gweru and Daluka and Menyezwa Wards for Lupane. In each ward, three villages were selected. A total of 48 farmers were selected using random systematic sampling from a household list that had been compiled for the International Development Research Centre-Climate Change Adaptation in Africa (IDRC-CCAA) project baseline survey carried out in the four wards listed above, during 2008. The household survey was a case study, carried out to fill in information gaps that had been identified in the main IDRC baseline survey. FGDs were also held with farmers from the same wards and villages with five (5) farmers randomly selected from each village, bringing the total number per discussion group to 15. A questionnaire was developed and tested for the household survey while checklists were prepared for the FGDs and semi-structured interviews. In FGDs farmers were grouped by ward and gender. Methods of data collection in FGDs included brainstorming, time charts, matrix scoring and ranking (Chambers, 1994; Sutherland, 1998). The FGDs and household interviews were conducted and solicited data on agronomic systems and practices.

RESULTS AND DISCUSSION

Tillage systems

The predominant tillage system in both Lower Gweru and Lupane communal areas is conventional tillage where the ox and / or donkey-drawn plough, is the most commonly used tillage implement. In Lupane, more than half the farmers also use “*gatshompo*” (the use of planting basins) on some of their fields, while in Lower Gweru approximately 29% of farmers practice zero tillage (digging ahole on unploughed land in which to place the seed) on some or all of their fields. About 10% of farmers in Lower Gweru also practise ““*chibhakera*” (hand digging of the whole field and then planting) (Figure 1). Thus some of the farmers use more than one tillage systems for land preparation and planting, depending on soil type and labour availability. Most farmers plough just prior to planting while about 30% of the farmers in these areas also do winter ploughing. Planting basins are more suitable for farmers with inadequate draft power and implements which is the case in Lower Gweru and Lupane. In addition, the use of basins spreads labour for land preparation over the dry seasons, promotes timely planting and reduces the risk of crop failure, even under drought conditions, due to the concentration of water and available fertilizer in the basins (Twomlow et al., 2008). The use of mulch (if available) on the basins also enhances moisture retention and improves crop

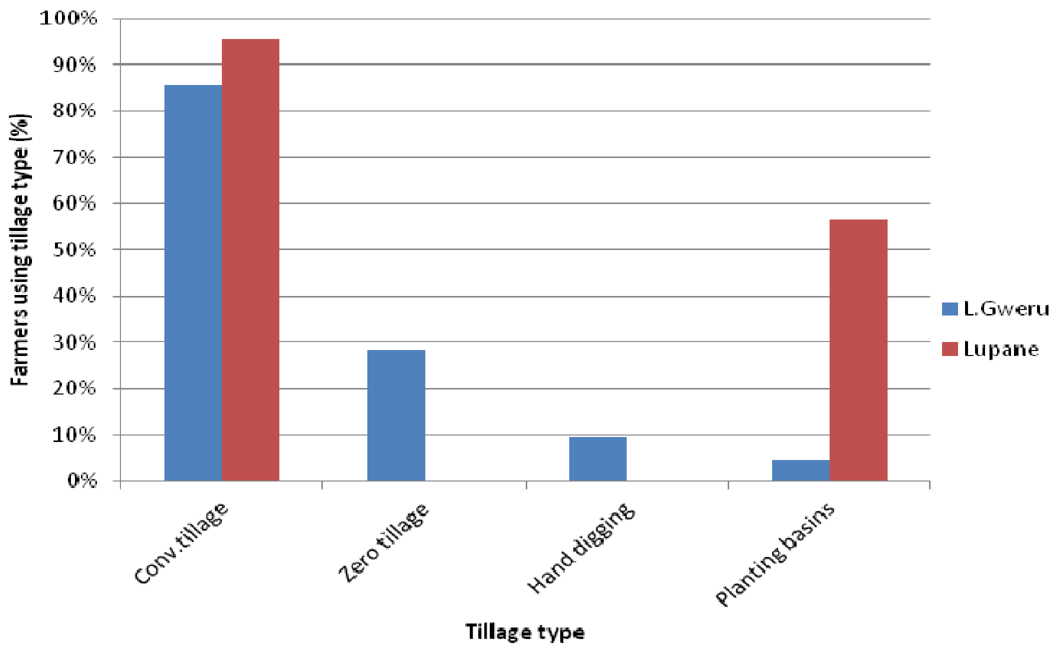

Figure 1. Tillage systems used by farmers in Lower Gweru and Lupane communal areas during the 2008/09 cropping season

enhances moisture retention and improves crop productivity. Twomlow et al. (2008) established that crop yields increased, on average, by 15 to 300% across 13 pilot districts in Zimbabwe over three seasons (2004/05 to 2006/07) of using planting basins, depending on rainfall pattern and amount, soil type and fertility. The adoption rate for use of planting basins is higher in Lupane than Lower Gweru, presumably due to more intense extension effort in Lupane where rainfall inadequacy and unreliability are more critical.

Crops grown

Farmers in Lower Gweru and Lupane grow a wide range of field crops (Figure 2) and these include maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), groundnuts (*Arachis hypogea* L.), cowpeas (*Vigna unguiculata* (L.) Walp), bambara nuts (*Vigna subterranean* (L.) Verdc), melons (*Citrullus lanatus* (L.) Thunb), pumpkins (*Curcubita maxima* L.), sugar beans (*Phaseolus vulgaris*), pearl millet (*Pennisetum glaucum* (L) R.Br.), rapoko (*Eleusine coracana* L.) and sweet potatoes (*Ipomea batatas*.L). Farmers ranked crops they consider important according to contribution to food security, improved livelihoods and income generation as well as according to the number of farmers growing the crop and the uses to which the crop can be put. In Lower Gweru, the most important cereal crop is maize while finger millet and sorghum are grown to a lesser extent. In Lupane, the main cereal crops are maize, pearl millet and sorghum and in Daluka ward, these were ranked 1 to 3 respectively. In Menyezwa ward, pearl millet is the most important cereal, followed by sorghum and then maize. "*Amajodo*" (sour melon), a type of melon that is cooked and consumed on its own or boiled and consumed together with maize grain, was ranked first and second by men and women in Menyezwa ward respectively. Groundnut is the main legume crop in Lower Gweru, while in Lupane it is cowpea. In Lower Gweru sweet potatoes are grown for both consumption and sale, while in Lupane production of this crop is limited. Individual farmer interviews and discussions with local extension officers did not indicate that the sour melon was the number one (1) crop in Menyezwa ward as revealed in FGDs. The crop however, yields quite well in relatively dry years as compared to wet years, implying its high abundance in dry years. The most probable explanation for the highest ranking of the sour melon by the Menyezwa group of farmers is that, during the 2008/2009 season, when the FGDs were conducted, farmers in this ward depended on the crop for survival as other crops had failed. Farmer interviews did not reflect the high priority that was given to sugar beans by Mdubiwa farmers in FDGs. This is probably because not all farmers that were interviewed own irrigation plots in one of the two irrigation schemes that are in this ward.

Varieties of main cereal and legume crops grown

Farmers indicated that their choice of variety is normally

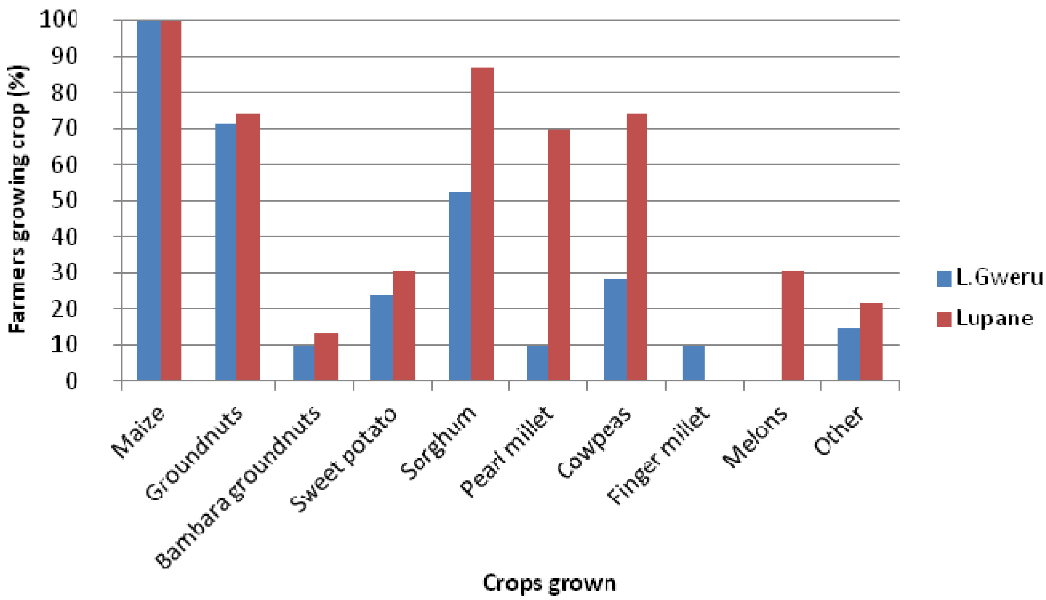

Figure 2. Percentage of farmers growing different crops in Lower Gweru and Lupane communal areas during the 2008/09 growing season.

governed by factors such as earliness to maturity, tolerance to drought, yield potential, ease of management and good storability. Short statured varieties, for example, are generally preferred to tall varieties for easy harvesting while the "red cob" an OPV of maize is preferred over other varieties, for its good resistance to weevil attack. However, in recent years, farmers have had little varietal choice and what they grow is mainly dictated by what is available, provided it suits their rainfall regimes. Farmers in the study areas use more than one crop variety in a season as a way of spreading risk of complete crop failure in these water stress environments.

In both communal areas, maize hybrids as well as OPVs are used. In Lupane the hybrids and traditional OPVs are used to about the same extent (about 75% of farmers use each of these categories of varieties), while in Lower Gweru about 90% of farmers use hybrid maize seed; traditional OPVs are used by 40% of the farmers. Improved OPVs, which generally yield higher than traditional OPVs, are used to a lesser extent compared to unimproved OPVs, being about 20 and 10% of the farmers in Lupane and Lower Gweru, respectively. Very early (110-120 d) to early maturing (120-130d) hybrids are grown in Lupane while in Lower Gweru the range stretches to medium (130-140d) maturity hybrids. Although hybrids generally have a higher yield potential than OPVs, for varieties in the same maturity group (Chiduza et al., 1994; Pixley and Bänziger, 2001), farmers in the study areas continue to choose to grow OPVs as they are relatively cheap to grow and planting seed is readily available When maize is grown from hybrid seed retained from previous harvests, there is non-uniformity of the crop in the field as well as reduction in yield due to segregation of characteristics of the individual parental plants. In contrast, OPV seed can be retained for several years without incurring significant yield reductions (Chiduza et al., 1994; Pixley and Bänziger 2001; Tinsley, 2009a). Use of seed retained from previous harvests has cushioned farmers in the study area against shortages of planting seed on the market during certain seasons, including the 2008/09 season when this study was carried out.

The use of improved varieties of small grain crops, sorghum and pearl millet by communal farmers in western Zimbabwe, including Lupane was reported to be low (Ahmed et al*.,* 1997). The study has established that about 60% of the farmers in Lupane use improved varieties of either crop, with Pearl Millet Variety 3 (PMV3) being the main pearl millet variety and Macia (white), the main sorghum variety. The most commonly grown traditional "unimproved" pearl millet variety is "*Harare*" while for sorghum it was unclear what the main traditional variety was, since some farmers were not sure of the names of traditional varieties they were growing. There is an indication that the use of improved small grain varieties has increased. This trend is most likely due to earliness of these varieties to reach maturity, a favourable trait in low and erratic rainfall areas, as well as promotion of the varieties, particularly in Lupane, by NGOs and Government extension agencies.

Groundnut seed is often in short supply and farmers normally grow any varieties made available to them. About 30% of farmers grow Natal Common variety; 20%, Valencia Red and 5%, Valencia White. A substantial number of the farmers were not sure of the names of varieties they were growing. Most farmers have been

Table 2. Inter-row spacing and plant densities achieved when planting behind the plough with animals harnessed to a cultivator yoke and with the plough width adjusted to 30 cm, for major cereal and legume crops (Source: Lower Gweru and Lupane farmer interviews, 2009).

Crop	Number of furrows skipped before next planting row	Inter-row spacing achieved (cm)	Intra-row spacing used (cm)	Plant population (plants/ha)
Maize	2	90 *(90)*	25-30 *(30)*	37 000-44 000 *(37 000)*
Sorghum	1	60 *(90)*	10-25 (after thinning) *(7-10 after thinning)*	66 000-167 000 *(111 000-160 000)*
Pearl millet	1-2	60-90 *(50-75)*	10-25 (after thinning) *(20-30 after thinning)*	~44 400-167 000 *(53 300-100 000)*
Groundnuts	0-1*	30-45 *(50-75)*	7-10 *(5-7.5)*	~ 222 200-476 000 *(178 000-400 000)*
Cowpeas (upright varieties)	0-1*	30-45 *(45)*	10-15 *(15)*	~150 000-333 300 *(~150 000)*

Figures in brackets and italics are recommended spacing and populations from the Ministry of Agriculture.
* When a row is skipped the plough width is maintained at standard width of 20 cm

growing these varieties for a long time and their continued use contributes to the general decline in groundnut yields in the smallholder farming sector of Zimbabwe (Shumba, 1983). Improved varieties such as Nyanda and Falcon, released in the 1980s and 1990s, have been in short supply since their release and it was unclear whether farmers in Lupane and Lower Gweru grow them or not.

Both the spreading and upright varieties of cowpeas are grown by the farmers. However, most farmers prefer the upright variety IT18, popularly known as "*mupedzanhamo*" (poverty terminator) as it matures quite early (about 90 days), providing food, before most crops are ready for consumption. The variety is also high yielding.

Planting methods and times

The majority of farmers who use conventional ploughing either plant behind the plough or open up planting furrows in ploughed fields. With the former method, variable row spacings are achieved, depending on the type (size) of yoke to which the animals are harnessed and the number of furrows skipped before the planting furrow. As an example, when draft animals are harnessed to a cultivator yoke, skipping one furrow before the planting row gives a row spacing of 60 cm whereas when two rows are skipped, the resultant inter-row spacing is 90cm (Table 1). Thus a higher plant population is achieved where less furrows are skipped, if the same intra-row spacing is maintained (Table 1). In contrast, harnessing animals to a plough yoke, which is shorter than the cultivator yoke, gives narrower inter-row spacings. A plant population of about 37 000 ha^{-1} is recommended for maize in medium to low agricultural potential areas such as Lower Gweru and Lupane. By using an inter-row spacing of 90 cm and an intra-row spacing of 25-30 cm farmers achieve a population range whose lower limit is equal to and upper limit about 20% higher than the recommended population (Table 1). Farmers should adopt the recommended intra-row spacing of 30 cm for upland maize production, while an intra-row spacing of 25 cm may be used by farmers such as those in Nyama Ward, who grow maize in wetlands where soil water is less limiting.

Sorghum and pearl millet are drilled in 60 and 60-90 cm rows respectively and plants are then thinned to about 10-25 cm within the row. For both pearl millet and sorghum, the population range that farmers use falls outside the recommended range (Table 1), with much discrepancy in the upper and lower range values for pearl millet and sorghum, respectively. Recommendations from the Ministry of Agriculture stipulate that sorghum plant populations below 90 000 plants ha-1 should be avoided (Ministry of Agriculture, Mechanization and irrigation Development in Zimbabwe, 2011). On the contrary, Ismail and Ali (1996) in their study on effects of plant population on sorghum yield in dry-land farming systems suggest that populations less than 90 000 plants ha^{-1} could still give reasonable grain yields in low cropping potential areas such as Lower Gweru and Lupane. The variations in plant populations between farmer and recommended practices (varying from seemingly small e.g. for maize to large e.g. for pearl millet), may require on-farm field experiments to verify whether there are significant grain yield differences due to the different plant populations and to establish the associated economic implications (e.g. higher unnecessary input costs). Winter ploughing followed by opening up planting furrows on the onset of rains or a few weeks before onset of rains (dry planting), is also commonly practised by farmers in the study area. They open the furrows using a plough drawn by animals harnessed to the cultivator yoke or plough yoke depending on the intended inter-row spacing. With this method of planting it is relatively easy to achieve the desired inter-row spacing as there is no requirement for adjusting the plough width. Farmers should be encouraged to plough their fields in winter as this practice conserves moisture from the previous season, promotes early crop establishment and reduces weeds (Sibanda, 2005; Mpatane et al., 2012). Over and above recommendations from the Ministry of Agriculture, farmers are also guided by the method of weed control they use, in their choice of inter-row spacing, e.g. if the animal-drawn cultivator is used, a wider spacing is required than when the hand hoe is used. Other planting methods used by farmers include planting in basins and marking out planting lines using wires, followed by hoe planting. Both methods are suitable for relatively small fields. Planting basins which are most commonly used for maize, are spaced either 75 cm x 75 cm or 90 cm x 60 cm and the recommendation is to plant three seeds per station. Thinning may then be done after emergence to remain with two plants per station, giving a target population of about 37 000 plants per ha. This practice may be considered wasteful by farmers particularly for hybrid seed which is relatively expensive and sometimes not readily available. To reduce the loss, extension officers encourage farmers to thin out extra plants when the soil is wet and transplant them onto another piece of land (Musasanuri and Pawadyira, 2013) - personal communication).

Farmers indicated that planting dates were dependent on a number of factors including availability of soil water, seed and draft power. Farmers are aware of the importance of early planting, given their water stress environments. They thus, aim to plant most of the crops with the first rains or dry plant before the rains. In Lower Gweru maize, groundnuts and rapoko are sown first, while in Lupane it is maize and pearl millet that have first priority. Shumba (1989) shows that delaying planting of maize by up to 21 days after first effective rains reduces yield by about 30%. Due to late planting, the crop is unable to intercept full sunlight radiative load available since, by 22 December when the sun is overhead, the crop will not have developed full canopy. Other disadvantages of delayed planting are reduced soil and water conservation due to delayed crop cover (Norton, 1995). Dry planting which is also meant to reduce labour demand for planting at the start of the rainy season, is mostly done in October. In Lupane, almost all of the pearl millet is dry planted. Farmers in this area argue that dry planting of this crop results in early establishment of the crop and allows it to mature at the same time as wild grasses, a factor that reduces crop damage/loss from bird attack as the birds will not only be feeding at that time, on the crop, but on wild grasses as well. Staggering of planting dates is a characteristic feature of the planting process for most farmers. Cropping calendars drawn up by the farmers showed that planting stretches from as early as late October (mostly dry planting) to as late as the first dekad of January in both study areas, depending on rainfall pattern. In general most of the planting is done during the period from the second dekad of November until the second dekad of December.

Weeding

Crop competition with weeds is always a major constraint as weeds use water, nutrient and solar radiation resources and yet they do not contribute to production, but rather reduce crop yield. Hand hoeing is carried out by all the farmers in the study areas; this is consistent with the findings of Chatizwa and Nazare (2000) that all farmers in the different farming sectors of Zimbabwe use hand weeding. Farmers with draft animals and equipment also use cultivators to remove weeds in-between plant rows and in both Lower Gweru and Lupane communal areas, about 50% of the farmers use these cultivators. However, for farmers who use planting basins, the weeding method is predominantly hand hoeing.

Approximately 70% of farmers in the study areas weed twice while less than 10% weed once or thrice, under the conventional tillage system. The practice of weeding twice is in agreement with the Zimbabwe Ministry of Agriculture recommendation to combine fertilizer application with weed free management through three tillage operations per crop (Snapp et al., 2003). The three operations being ploughing and planting plus two weeding operations. Mudhara (1995) also established that most farmers in semi-arid Chivi communal area in Southern Zimbabwe weed twice. A survey conducted during the 2009/10 and 2010/11 seasons in 15 districts across different Natural Regions of Zimbabwe also showed that under the conventional tillage system, most smallholder farmers weed their fields twice, irrespective of Natural Region (Nyamangara et al., 2013). Field experiments, for example by Kumwenda and Kabambe (1995) in Malawi and Mabasa and Nyahunzi (1995) in both low and high rainfall areas of Zimbabwe suggest that weeding twice has yield benefits. However, from field experiments conducted during the 1995/96 to 1998/99 at the University of Zimbabwe farm located in northern Zimbabwe under Natural Region II, Mashingaidze (2004) established that there was no grain yield benefit from increasing the frequency of hand hoe weeding from once to twice or thrice during the 1998/99 season and no significant difference in grain yield between a maize crop weeded once and one weeded twice during the 1997/1998. Results from simulation modeling also show that, in risky environments such as Lupane, only the first weeding is critical and that a second weeding does not have detectable benefits (Dimes et al., 2002). As suggested by Mashingaidze (2004) and IIRR and ACT

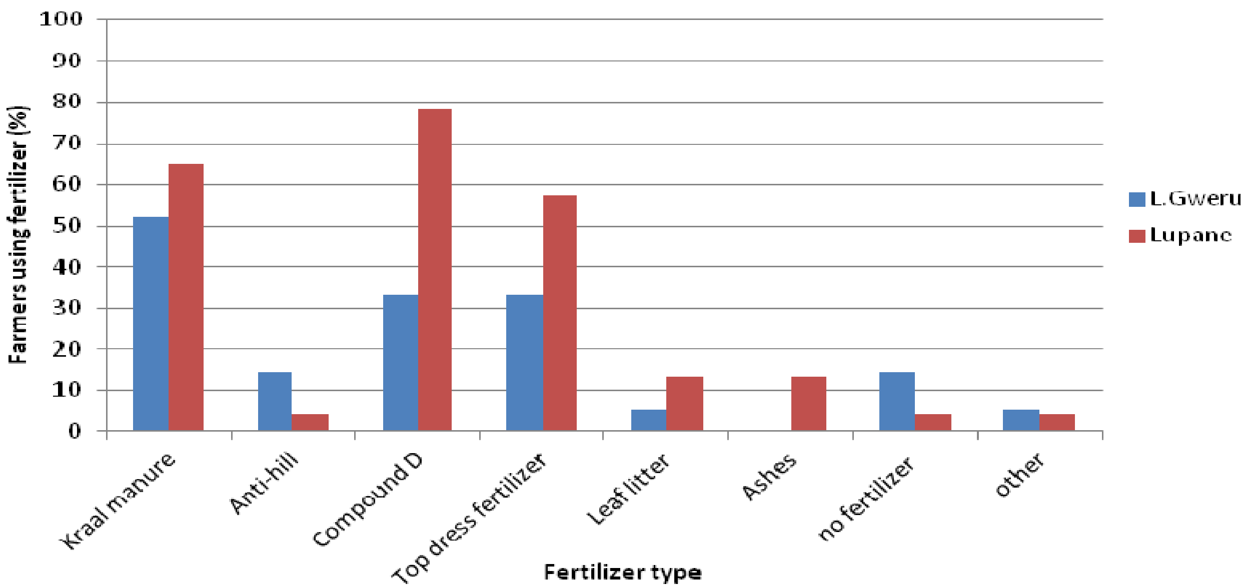

Figure 3. Fertilizer types used by farmers in Lower Gweru and Lupane communal areas during 2008/09 cropping season.

(2005), smallholder farmers, particularly those who entirely hand hoeing to control weeds, can reduce the need to weed more frequently by embarking on cultural practices such as intercropping with good cover crops, reducing inter-row spacing and early planting to control weeds. It was apparent that, in the majority of cases, farmers who use planting basins, also have fields where they practise conventional tillage. They weed three times on the basin plots, but only twice and rarely once on conventionally tilled fields. The high frequency in weeding on planting basins is consistent with Nyamangara et al. (2013)'s findings that farmers in different Natural Regions of Zimbabwe, who use planting basins, weed at least three times. Thus, the frequency of weeding varies according to tillage practice used. The method and frequency of weeding also depends on the availability of equipment and draft power. Weeding three times on planting basin plots is consistent with the observation that weed infestations tend to be high under minimum tillage (Mabasa et al. 1999; Twomlow et al., 2008). Thus, farmers who use planting basins need more labour during the season as well as during land preparation. However, with planting basins, weed pressure gets less in subsequent years (Twomlow et al., 2008).

Fertilizer use

Farmers in the study areas apply little fertilizer to their fields mostly because the fertilizers are expensive and / or unavailable. They also use less fertilizer because of limitations in soil water in these areas. The main soil ameliorants used are cattle manure and inorganic fertilizers (compound D, with N:P:K =7:14:8 and Ammonium nitrate, N =34.5% or urea, N = 46%), while leaf litter, anti-hill and ash are used to a lesser extent (Figure 3).

Although about 15 and 60% of the farmers in Lower Gweru and Lupane respectively, own donkeys, they do not use donkey manure and their reason is that, this manure burns crops, due to high nutrient content presumably high N. Manure and inorganic fertilizer rates used are quite diverse and most farmers use amounts that are below the recommended rates. The majority of farmers who use inorganic fertilizers regularly use 100 kg ha^{-1} of compound D and a top dress of 50-100 kg ha^{-1} of Ammonium Nitrate or 50 kg ha^{-1} of urea on maize in both natural regions III and IV. Blanket fertilizer recommendations given by extension officers are 200-300 and 150-200 kg ha^{-1} compound D (basal) for natural region III and IV respectively, while corresponding top dressing fertilizer rates are 150-200 and 100-150 kg ha^{-1} Ammonium Nitrate respectively. The general recommendation for cattle manure is 20-30 t ha^{-1}, but due to limited supplies farmers often apply limited amounts. The use of planting basins allows precision application of the limited fertilizers and as a result of this and other benefits associated with use of these basins, it was found that more farmers in Lower Gweru and Lupane are adopting the practice.

Farmers and agricultural extension officers pointed out that some farmers use inorganic fertilizers only when they get them from government or NGO drought relief programmes. This is in agreement with Ahmed et al. (1997), who drew the same conclusion regarding some farmers in South-western Zimbabwe, including Lupane district. Ellis-Jones and Mudhara (1995) establish that nearly all communal area farmers in Zimbabwe used fertilizers over the period 1992-1994 when fertilizer was provided at no costs, under the government drought relief and recovery programmes. Agricultural extension staff in the study areas confirmed that there was a decline in fertilizer use in these areas from the late1990s to the early 2000s, following the phasing out of drought relief programmes. With the launch of new government input schemes such as "*Maguta*", "Champion Farmer" and the SADC input scheme (Mare, 2010, personal communication), inorganic fertilizer use is likely to increase, but probably only temporarily, in the targeted communal areas which include both Lupane and Lower Gweru. Some farmers in Lupane are sceptical about using inorganic fertilizers as they believe that these fertilizers "kill" the soil. This observation is consistent with Ahmed et al. (1997)'s findings regarding perceptions of some farmers in Western Zimbabwe, on fertilizer use. Of the commonly used inorganic fertilizers, compound D and Ammonium Nitrate, it is the former that they believe to be more detrimental to the soil especially when one does not use it continuously (every season) in a particular field - "the problem is worse if one does not apply the fertilizer every season". A similar perception by some smallholder farmers in Western Kenya is highlighted by Misiko et al. (2009) where the farmers believe that fertilizers "spoil" the soil in that "the soil gets addicted to the fertilizer" so much that if it (the soil) is not fertilized, crop (maize) yields drop drastically. The perception that fertilizer "kills" the soil probably arises as a result of increased soil acidity due to use of inorganic fertilizers, particularly nitrogenous fertilizers which leads to reduced or non-availability of nutrient elements to the crop.

Cropping systems and patterns

The "true" rotations that farmers practise are basically cereal - legume rotations and these are practised by about a third of the farmers in each of the communal areas. Maize-groundnut-maize rotation is the most common rotation in Lower Gweru while in Lupane maize, sorghum or pearl millet is rotated with cowpeas. In Lower Gweru, maize-bambara nut rotation is popular with women. Other crop sequences include maize-pearl millet-maize, maize-sorghum-maize, sorghum-groundnuts-sorghum and fallow-bambara nuts (that is, bambara nuts grown on a newly opened field). Some farmers in the study areas, allocate certain fields / soils to particular crops, for example, in Lupane some farmers plant maize, continuously on the more fertile and high soil water holding capacity "*isidaka"* soils. This practice is a limitation to the implementation of rotations. In Lupane, farmers believe that pearl millet revives the soil because of its high tillering ability (more roots are developed) and for this reason, they alternate it with maize, so that maize benefits from the improved organic matter content of the soil.

Although most farmers are aware of the benefits of a good crop rotation, they do not practise effective rotations and the rotations they use do not have a consistent pattern. These findings are consistent with Mudhara (1995), who concludes that in the third year, farmers in Chivi communal area (southern Zimbabwe) rotate only 40% of the area planted to maize in the previous year with other crops such as pearl millet, finger millet, groundnuts and sunflower. Chuma et al. (2001) also highlight the point that smallholder farmers in Zimbabwe do not practise effective rotations. One reason for ineffective and / or inconsistent rotations is their decision to allocate more land to grain cereals in an attempt to achieve household food security each year. This is in line with Ahmed et al. (1997)'s findings that most smallholder farmers in south-western Zimbabwe allocate most of their cropping area to cereals, namely maize, pearl millet and sorghum. So, where cropping land is limited, priority is given to these staple crops. Seed shortages and labour constraints lead to a reduction in area planted to grain legumes, groundnuts in particular, and this contributes to ineffective and inconsistent crop rotations in these communal areas. Shumba (1983) highlights the shortage of groundnut seed as a major constraint to groundnut production in communal areas of Zimbabwe while labour shortage is another important constraint, especially for the resource poor farmers (Shumba, 1983; Waddington and Karigwindi, 2001; Zingore et al*.,* 2009).

Farmers in Lower Gweru and Lupane predominantly practise sole cropping, although pumpkins, sweet reeds and melons are often sparsely intercropped with the main cereal crops. A few farmers grow or strip intercrop groundnuts, cowpeas or bambara with cereal grain crops, especially maize. In Lupane, some farmers are forced to intercrop due to shortage of planting seed, since they will not have adequate seed of one crop to plant all the intended cropping area. Others intercrop sorghum with maize due to shortage of land, but they do not intercrop pearl millet with maize as they believe that the two crops are "not compatible". In fact, the farmers ascertain that maize dies when intercropped with pearl millet. Extension officers in Lupane verified that the common practice was to mix sorghum and maize and not pearl-millet and maize, but they were not sure why this was the case. Although pearl millet has been found to have allelopathic effects on germination and growth of certain weeds, for example as was established by Narwal et al. (1998), in weed suppression experiments, the possibility of direct allelopathic effects of pearl millet on maize germination and growth may be ruled out in this case since farmers who practise sole cropping indicated that they usually grow maize after pearl-millet and get a good maize crop. The ability of pearl millet to regenerate growth following drought conditions and to tiller heavily under fertile and adequately wet soil conditions probably makes the crop a better competitor than maize, under these conditions. This may explain farmers' views on the performance of maize and pearl millet when the two are grown together.

Water management practices

Inadequate soil water is a limiting factor to crop productivity in both Lower Gweru and Lupane, although flooding and waterlogging are occasionally experienced. Water management, particularly as it relates to soil water conservation and water harvesting goes a long way in improving water availability in these water stress environments.

Less than 50% of farmers use any form of water conservation measures in either communal area. However, more farmers in Lupane than in Lower Gweru use some of the techniques. This scenario is expected since rain water is more scarce in Lupane than in Lower Gweru. Contour ridges followed by winter ploughing are the main conservation techniques used by farmers in both areas. About 48% of farmers in Lupane and 24% in Lower Gweru use contour ridges while winter ploughing is practised by 16 and 35% of farmers in Lupane and Lower Gweru respectively. It was pleasing to note that most of the farmers who used contour ridges had moved away from the traditional graded contour ridges to the zero gradient contour ridges which are more suitable for retaining water in the field. Use of planting basins, conserves soil water as the water is concentrated in the basins. Farmers who use this method also apply mulch to the basins when it is available, hence the use of mulch by 30% of farmers in Lupane where basins are more commonly used. Pot-holing and tied ridging are used by a few farmers (less than 10%), while ridging is practised by about 13% of farmers in Lupane. Low adoption rates for water conservation techniques such as use of tied ridges, is not unique to Lower Gweru and Lupane, as the adoption of these technologies by smallholder farmers elsewhere in Zimbabwe and Africa are also slow and low (Chuma et al*.,* 2001; Mutetwa and Kusangaya, 2006; Chiputwa et al., 2011; Marongwe et al., 2012; Nyamadzawo et al., 2013). Reasons for low adoption rates include shortage of draft power and labour, lack of suitable implements, inadequate institutional support and lack of capital to purchase inputs (Chuma et al*.,* 2001; ; Mazvimavi and Twomlow, 2009; Nyagumbo et al., 2009; Nyamadzawo et al., 2013). Nyamadzawo et al. (2013) also attribute low adoption rates for soil and water conservation technologies to blanket recommendations and yet according to Nyagumbo et al., 2009 and Places and Deewes, cited in Chiputwa et al., 2011, biophysical requirements for effective implementation of the different technologies are known. Although some technologies conserve water during low rainfall seasons, they result in waterlogging during high rainfall seasons and this discourages farmers from adopting them (Mutekwa and Kusangaya, 2006).

CONCLUSION AND RECOMMENDATIONS

The study established cropping systems and practices of smallhoder farmers in Lower Gweru and Lupane areas of Zimbabwe It was established that the majority of smallholder farmers in the study area use conventional tillage systems. Farmers should be encouraged to practise minimum tillage rather than conventional tillage since minimum tillage promotes sustainable agriculture as there is minimum disturbance of the soil. Minimum tillage also uses less energy and is ideal for resource poor farmers who do not have enough draft animals and implements. The minimum tillage technologies, that a few farmers in the study area are using, e.g. planting basins are rather labour intensive. Use of appropriate equipment rather than use of hand hoes to make basins may improve adoption of this technology. Tillage practices such as ripping and direct seeding equipment such as the jab planters can also be introduced to the farmers to ease and promote minimum tillage. A wide variety of crops are grown by the farmers. This study confirmed that maize is the main cereal crop in Lower Gweru, while pearl millet is the major cereal crop in Lupane. Groundnut is the major dryland legume crop in Lower Gweru, while in Lupane it is cowpeas.

It was noted that both hybrid varieties and OPVs of maize are grown by the farmers, with more farmers in Lupane using OPVs than those in Lower Gweru. It was disappointing to find that in both areas improved OPVs are used by fewer farmers than the traditional/local OPVs. Due to the biophysical and political-economic constraints faced by smallholder farmers in Lower Gweru and Lupane and Zimbabwe's semi-arid areas at large, OPVs have a place in these areas. It is encouraging to report that it appears more farmers are currently using improved varieties of small grain crops than in the past. However, the current political situation has resulted in a general seed shortage for most crops and farmers have coped by using seed retained and selected from previous harvests and the use of OPVs of maize has gone a long way in alleviating the maize hybrid seed shortage.

The study has shown that in most cases, farmers have reasons for what they do or do not do and it is important for researchers and extension agents to understand the underlying reasons, before they can propose any interventions. Although farmers are aware of the benefits of certain crop husbandry practices such as soil and water conservation and crop rotations, adoption of these practices is low and slow because of the biophysical and economic constraints that the farmers encounter.

It is apparent that research work is needed to understand some observations made by farmers, for example the detrimental effects that donkey manure has on crop growth and development. Suggestions could then be made on how the manure can be treated to render it useful to farmers. The negative interactions between maize and pearl millet that farmers have observed may also need investigation. Legume crop breeders should avail improved varieties as farmers are still growing the traditional low yielding varieties. Seed multiplication agencies should supply adequate seed of improved small grain crops, open pollinated maize varieties and sunflower.

There is room for improving smallholder productivity through recommendation of practices such as use of appropriate plant spacings for small grain crops as some of the farmers in the study area are using variable spacing which is at variance with the recommended spacing. Use of improved OPVs should be encouraged in these areas as they yield better than traditional OPVs. Due to farmers' sceptism about fertilizer use, fertilizer use may remain insignificant in areas such as Lupane. It is essential to educate farmers on how fertilizers work under different soil, crop and management conditions. Fertilizer use efficiency could be improved by employing techniques such as precision agriculture and micro-dosing, technologies which have been tested elsewhere in the country. Other sustainable technologies of improving soil fertility, for example, inclusion of nitrogen fixing species in cropping systems should be encouraged since inorganic fertilizers are expensive and organic sources often inadequate and of poor quality.

Given the marginal nature of their cropping environment and labour constraints, smallholder farmers in the study area (particularly those in Lupane) who use conventional tillage systems may not have to weed more than once. They can use cultural practices such as intercropping with good cover crops and early planting to minimize the frequency of weeding. Effective implementation of the agronomic improvements suggested in this paper can be achieved through collaborative on-farm demonstration trials, where farmers, extension agents and researchers from both the public and private sectors participate.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Social and environmental aspects of family farming at Cacoal City, Rondônia State, Brazil

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This study aimed to evaluate social and environmental aspects of family farming at Cacoal City, Rondonia State, in Brazil. This is applied in non-experimental (descriptive) research. Questionnaire was designed as the main tool of the study. Eleven (11) semi-structured interviews were conducted with family farmers from eleven cooperative associations. Quantitative and qualitative approaches were employed in the scientific research, using a questionnaire consisting of twenty four questions that sought to evaluate environmental aspects of the sample of family farmers. It was concluded that agriculture continues to be basis of the local development and rurality model found in the Western Amazon Brazil.

Key words: Social and environmental, family farming, Western Amazon.

INTRODUCTION

In developing countries, more than half of the population lives in rural areas, often in situation of extreme poverty. According to CEPAL (2012), in 2010 there were 180 million poor in the region, receiving less than two U.S. dollars per day, of which more than 71 million lived in extreme poverty, earning less than one U.S. dollar per day. The total rural population of the region reached 141 million people, 20 million more than in 1999, of which 75 million were poor and almost 40 million lived in extreme poverty.

Rural development is defined as a localized process of social change and sustainable economic growth, which aims at the constant improvement of the rural community and of each individual integrated in it (Anguita and Azcona, 2007). The territorial organization is an essential tool to delineate rural development. Liberalism, spontaneous evolution driven by the laws of the market and by economic interest groups can hardly ensure the implementation of sustainability criteria that should be required of the rural territory.

According to Márquez (2001), rural development is the process of economic development and structural change to improve the living conditions of the local population inhabiting a given space. The author identifies three dimensions to rural development: the economic, the socio-cultural and the political administrative. Through this process, it seeks to improve the conditions of life and work that enables the creation of employment and income that is compatible with the preservation of the environment and the sustainable use of natural resources.

According to these authors, in Latin America and

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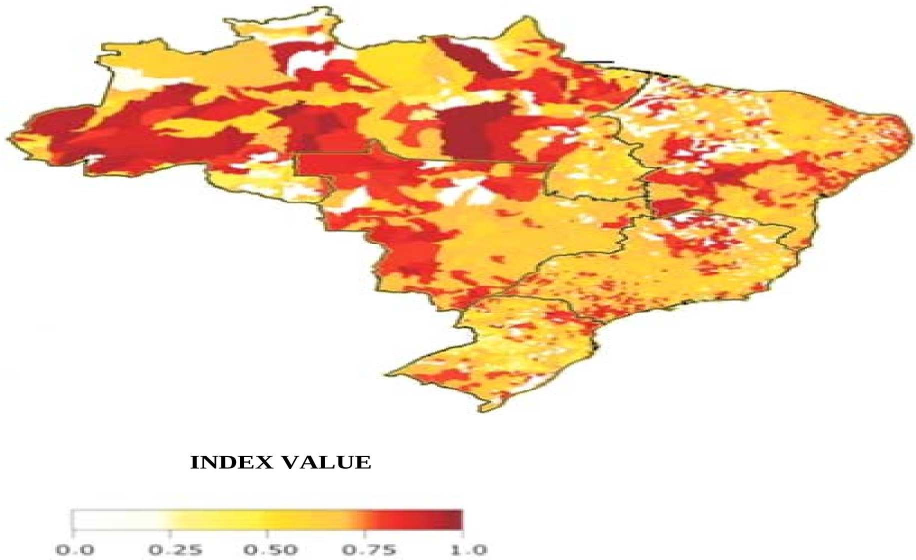

Figure 1. Gini-land index in Brazil. Source: Barreto and Sparovek (2005).

Caribbean this rural population is characterized as one who cultivates marginal lands mostly dry, which lacks of sufficient knowledge to be able to read and write, whose families are numerous and suffer from high rates of mortality. This segment of the population is composed of smallholders dependent on rainfall, landless workers, indigenous peoples and tribes. This situation of rural poverty causes massive degradation of local natural resources.

According to Guanziroli et al. (2009), the peculiarities of agricultural production shorten the economies of scale, superiority occurrence in massive industrial company, in analogy to the small and medium enterprise. The benefits from production on a large-scale are abbreviated by adopting cooperative forms of production and trade. The farmers have advantages in the management of working efficiency, pronounced in intensive production that requires careful cultivation, which cannot be compensated by the firm employer. Even paying higher wages, it is difficult to get the waged proletarian the productivity achieved by a family who works for themselves.

According to Hoffman and Ney (2010), there is a contrast in the high concentration of land ownership in Brazil, which has updated Gini-land index average of 0.86. The Gini-land index has theoretical foundation in the Lorenz curve, as the quotient between the area of inequality *(α)* and the value of this limit: Gini-land = $\alpha / 0.5 = 2\alpha$. This curve characterizes the inequality of a distribution. The Gini-land index can vary from 0 to 1. At 0, there is no inequality (land ownership is equally distributed to all individuals). At 1, the inequality is at a maximum (only one individual has possession of all the land available) (Waquil and Mattos, 2002).

In order to meet the demand of the Ministry of Agrarian Development, the Agricultural Census (IBGE, 2006) adopted the concept of family agriculture, according to Law number 11,326, from 24 July, 2006 (BRAZIL, 2006) which establishes guidelines for the formulation of the National Policy for Family Agriculture and Rural Family Enterprises.

In Law number 11,326, family farming was defined as follows: Article 3 - For the purposes of this Act, family farmer and rural family entrepreneur is one who practices activities in rural areas, serving both the following requirements:

1) Does not hold, in any capacity, greater than four (4) fiscal modules area.
2) Use predominantly labor of your own family in the economic activities of your establishment or enterprise.
3) Has predominantly household income originated from economic activities linked to the establishment itself or enterprise.
4) Drive your establishment or enterprise with your family.

In Brazil, family farmers, who use at least 50% of labor from their own families, operate about 85.2% of agricultural establishments. Family farming occupies 30.5% of agricultural lands, but accounts for 37.9% of Brazilian agricultural production. Family farming, commonly associated with outdated forms and production for subsistence, is in the essence of the modern Brazilian agribusiness, accounting for 31.6% of soybean production, 39.9% of poultry production and 48.6% of corn production (Guanziroli et al., 2009). The Gini-land index for Cacoal is currently ranging from 0.25 to 0.50 (Figure 1).

Conforms to Buainain et al. (2003), in Brazil, 39.8% of family farms have less than 5 ha, 30% are between 5 and

20 ha and 17% are in the range of 20 and 50 ha. Family farmers with an area greater than 100 ha and less than the maximum regional area represents only 5.9% of establishments which occupy 44.7% of the entire area of the Brazilian family farming.

The aim of this study was to evaluate social and environmental aspects of family farming in Cacoal City, Rondonia State. The research problem arose from the question: What are the environmental characteristics of the family farming at Cacoal City, Rondonia State, Brazil?

MATERIALS AND METHODS

Cacoal is Brazilian municipality located in the Rondonia State, distant 479 km from the capital Porto Velho, located in the central region. It is located at latitude 11°26'19" south and longitude 61°26'50" west, with an altitude of 200 m. Its estimated population in IBGE (2010) was around 78,958 inhabitants. It has an area of 13,792.638 km^2. The climate is hot and humid, with annual average temperature of 34°C. The annual average precipitation ranges from 1,750 to 2,750 mm annually.

This is applied in non-experimental (descriptive) research. The methodology of research is survey because the main purpose of the researcher is identifying the social and environmental aspects of family farming in Cacoal City, Rondônia State, in Brazil. Questionnaire was designed as the main tool of the study. All questions except the personal characteristics of family farmers were written as five-point Likert scale. In addition to questionnaires, observations and interviews were also used.

The case study was conducted in a sample of family farmers from eleven cooperative associations of Cacoal, central Rondonia, in Brazil. Semi-structured interviews were conducted, consisting of theoretical presuppositions descriptions of the qualitative and quantitative approach. We sought to observe, expose, analyze and correlate facts or phenomena. A questionnaire consisting of 24 questions that sought to evaluate socio-demographic and environmental aspects in the sample was used. Socio-demographic and socio-environmental variables evaluated age group, degree of literacy, agricultural activities of the farmers, family size, among others. All responses were analyzed statistically with support of the Statistical Package for the Social Sciences in its version 19.0 (Statistics, 2011). Data was analyzed using correlation coefficient of Spearman.

RESULTS

Spearman correlation coefficient was used to evaluate the relations between the family members of the family farming who worked in their property, agricultural technology by family farming consulted and trading of agricultural produce of family farmers with the age of family farmers.

The results obtained show that there is a statistically significant, negative relationship between the family members of the family farming who worked in their property ($r = -0.809$, p (two-tailed < 0.01) agricultural technology by family farming consulted ($r = -0.795$, p (two-tailed < 0.01) and trading of agricultural produce of family farming ($r = -0.684$, p (two-tailed ≤ 0.02) with the age of family farmers.

Two farmers (18.2% of the sample) said that the monthly turnover of the property is a maximum of one minimum wage of R$ 724,00 (U$ 324,00). Five farmers (45.5%) said that the monthly revenue ranges from 2 to 3 minimum wages. One farmer (9.1%) said that the monthly revenue ranges from 3.1 to 4 minimum wages, a farmer (9.1%) said that the monthly revenue ranges from 4.1 to 5 minimum wages and two farmers (18.2%) said that the monthly revenue of the property is greater than 5.1 minimum wages (Table 1).

One farmer (9.1%) said that the biggest challenge for the family farm is conquering the consumer market, two (18.2%) said that the biggest challenge is getting rural credit, two (18.2%) said keep the family on the farm, and six (54.5%) said that the low financial return is the greatest challenge of family farming (Table 2).

Two farmers (18.2%) said that the difficulties faced while selling the products are consumer requirements, one (9.1%) said it is to get quality products and eight (72.8%) said that value of the products is low (Table 3).

Five farmers (45.5%) said that environmental technology most used on the farm is plowing the soil, two (18.2%) said pasture rotation, two (18.2%) said irrigation and two (18 2%) said production control (Table 4).

Eight farmers (72.7%) said they contribute to the environment by preserving the legal reserves of the property, one (9.1%) said by making crop rotation on the property, one (9.1%) by maintaining the quality of water and one (9.1%) said to contribute by practicing adequate soil management on the property (Table 5).

The data analysis of federal, state and local government programs offered to farmers showed that two producers (18.2%) of the sample (n = 11) used the family grant, seven (63.6%) used the National Program for Strengthening Family Agriculture (PRONAF) and two (18.2%) producers said they did not use any government program (Table 6).

In Cacoal City, there is 5,924 family farmers, 82 families settled at program Agrarian reform in Brazil, five (5) fishermen and (1) an indigenous land (Table 7).

In the City, 69.86% of the properties have between 0.5 and 50 ha, and 6.07% over 200 ha. However, the mean areas of these major producers rotate around 917 ha (Table 8).

Due to the work of the National Institute of Colonization and Agrarian Reform in Brazil (INCRA), in the agrarian structure system of Rondônia State and Cacoal City, the State and this City currently have, on average, 25% of its land designated for small rural workers, 6% for public competition, 34% are areas of land regularization and 35% indigenous areas and conservation units.

DISCUSSION

In a research conducted by DIEESE (2011), about the distribution of the employed people in agriculture for

Table 1. Monthly income of family farmers at Cacoal City, in 2011.

Monthly income (minimum wage)	Number of farmers	Percentage (%)
1	2	18.2
2 - 3	5	45.5
3.1 - 4	1	9.1
4.1 - 5	1	9.1
More than 5.1	2	18.2

Source: Survey data using SPSS 19.0 software.

Table 2. Challenges of family farm according to producers from Cacoal, in 2011.

Challenge	Number of producers	Percentage (%)
Conquering the consumer market	1	9.1
Getting rural credit	2	18.2
Family on the farm	2	18.2
Low financial return	6	54.5

Source: Survey data using SPSS 19.0 software.

Table 3. Difficulties faced while selling the products, Cacoal, in 2011.

Difficulties while selling	Number of producers	Percentage (%)
Qonsumer requirements	2	18.2
Quality of the products	1	9.1
Low price	8	72.8

Source: Survey data using SPSS 19.0 software.

Table 4. Environmental technology most used on the farm, Cacoal, in 2011.

Environmental technology	Number of producers	Percentage (%)
Plowing the soil	5	45.5
Pasture rotation	2	18.2
Irrigation	2	18.2
Production control	2	18.2

Source: Survey data using SPSS 19.0 software.

Table 5. Contributions to improve the environment in the property, Cacoal, in 2011.

Environment contribution	Number of producers	Percentage (%)
Preserving the legal reserves	8	72.7
Crop rotation	1	9.1
Quality of the water	1	9.1
Soil management	1	9.1

Source: Survey data using SPSS 19.0 software.

income, by gender, it was found that 20.2% of men and 9.7% of women had average monthly income of half (0.5) minimum wage, 25.2% of men and 6.8% of women had average monthly income ranging from 0.5 to 1 minimum

Table 6. Government programs used by family farmers in Cacoal City, in 2011

Govern problem	Number of producers	Percentage (%)
Family Grant	2	18.2
Pronaf	7	63.6
No government program	2	18.2

Source: Survey data using SPSS 19.0 software.

Table 7. Social demand in Cacoal City.

City	Family farmers	Settled family	Fishermen	Indigenous lands
Cacoal	5,924	82	5	1

Source: IBGE (2006).

Table 8. Agrarian structure of Cacoal City in 2011.

City	Area group	Up to 2.0 ha	2.1 to 5.0 ha	5.1 to 10.0 ha	10.1 to 20.0 ha	20.1 to 50.0 ha	50.1 to 100.0 ha	100.1 to 200.0 ha	More than 200.0 ha
Cacoal	%	2.75	23.10	11.40	11.65	20.96	16.84	7.24	6.07
	Mean area	1.2	3.7	7.5	14.6	32.7	67.5	123.1	917.0

Source: IBGE (2006).

wage, 7.8% of men and 1.1% of women had average monthly income of 2 to 5 minimum wages, 1.5% of men and 0.3% of women had average monthly income of 5 to 10 minimum wages.

These results may be related to the fact that, as DIEESE (2011), the average monthly income for 53.6% of the rural workers in Brazil was R$ 795.00. According to the author, the average monthly income per household in rural areas was R$ 380.00.

These results may be related to the fact that land access to a wide range of family producers in different production systems, there is a lack of professional training and specialized technical assistance (Camargo and Oliveira, 2012). According to DIEESE (2011), the average monthly income for 53.6% of the rural workers in Brazil was R$ 795.00.

The results from Tables 4 and 5 are similar to those obtained by Borges et al. (2013). These researchers found that 100.0% of the fish farmers who practiced family farming in Western Brazilian Amazon said meet legal obligations of the rural property and 60% reported to contribute to the conservation of protected environmental areas, in order to consider the welfare and social and environmental development of the rural property (health, recreation and education).

Conclusion

Based on the information gathered, it was possible to understand the perception of farmers regarding the social and environmental aspects in which they are inserted through the analysis of fundamentals that support the development of socio-environmental education plan, so that the rural population be sensitized and know the problems related to the conservation of flora and fauna.

Models that account for the low-paid work on family farms not fully elucidate the situation found in Brazil. The entrance to the land, in the past and in the present, constitutes the expectation of independence for a population that brought their social design conditioned to the large property or, also in essence, from analogies of work that combined compadrio, consanguinity and companionship.

Agriculture continues to be the foundation of the local development and of the rurality model found. This rurality can join or move away from a peasant model, while the profile of social and with nature similarities, suitable to provoke a cultural and environmental landscape interesting to those who live in the countryside. Only in this way, the family farm can fill multiple roles to ensure its action in a rural sense of transforming a variety of subjects.

Conflict of Interests

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

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Interactive effects of fertilizer and inoculum concentration on subsequent development of xanthomonas wilt in banana

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Soil nutrient depletion and Xanthomonas wilt (*Xanthomonas campestris* pv. *musacearum*) are major causes of declining productivity in smallholder banana systems in East and Central Africa. This study examined the interactive effect of fertilizer and inoculum concentration on development of Xanthomonas wilt. Fertilization significantly (*p*<0.01) increased the plant height, plant girth and leaf area in banana compared to control without fertilizer. Despite this, between 9 and 21 days post inoculation (dpi) all inoculated plants had exhibited typical disease symptoms (that is, chlorosis, necrosis and wilting of leaves). No significant reduction (*p*>0.05) in disease incidence, wilt severity index or mortality could be associated with increasing fertilizer amounts. Interestingly, there was a highly significant (*p*<0.01) overriding effect of inoculum concentration on the ability of fertilizer to reduce wilt severity index and mortality in banana. Plants inoculated with 10^6 to 10^{12} cfu mL^{-1} developed twice as much disease compared to 10^4 cfu mL^{-1} inoculations. Average mortality of 9.2% for 10^4 cfu mL^{-1} inoculated plants provides evidence of the potential to cause latent infections. Low bacterial loads are implicated in recent field resurgence of Xanthomonas wilt in banana orchards where disease had been successfully contained.

Key words: Banana, fertilizer, inoculum concentration and Xanthomonas wilt.

INTRODUCTION

Banana (*Musa spp.*) supports the livelihood of millions of smallholder farmers in Uganda, contributing directly to household food security as a major staple food crop and to incomes through sales of raw and ripened fruit or other value-added products (Karamura et al., 1991). With an estimated annual production of 10 million tonnes from 1.5 million hectares, Uganda is the second largest world producer of bananas after India (Nowakunda and Tushemereirwe, 2004). Nevertheless, banana productivity over the past 40 years has been declining across majority of traditional banana areas due to numerous pests and diseases and worsening soil nutrient depletion (van Asten et al., 2004; Gallez et al., 2004). As a result, an unprecedented geographic shift in production occurred towards non-traditional areas in southwestern Uganda (Gold et al., 2000; Bagamba et al., 2010).

Majority of highland bananas in Uganda are cultivated on continuous basis on ferralsols and acrisols having low

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inherent soil fertility (Sanchez et al., 1997). Despite a high annual demand for nitrogen and potash,smallholders hardly invest in fertilizers due to lack of access to inputs and high prices (van Asten et al., 2010;Ochola et al., 2013). Moreover, researchers have shown that low soil fertility generally reduces host plant vigour and leads to increased susceptibility to pests and diseases (Patriquin et al., 1995; Spann and Schumann, 2010). Improved plant nutrition influences the physiology and biochemistry of the plant host, which ultimately affects the microclimate and reduces infection by pathogens (Agrios, 2005). Most vigorously growing plants often offset the most damaging effects of some diseases, since a balanced nutrient supply optimal for plant growth is usually optimal for plant resistance as well (Agrios, 2005; Dordas, 2008). Averting nutrient deficiencies using fertilizers is one way of controlling some of the most important plant diseases in an integrated pest management system (Atkinson and McKinlay, 1997; Oborn et al., 2003). Nevertheless, debate continues about the effects of fertilizers on plant growth and disease development. Notably, a particular nutrient may decrease the severity of one disease but have a completely opposite effect on another disease (Büschbell and Hoffmann, 1992; Hoffland et al., 2000). In addition, certain nutrients bear a more direct and greater impact on plant pathogens (Huber and Graham, 1999; Graham and Webb, 1991).

Despite its emergent status, Xanthomonas wilt caused by the bacterium *Xanthomonas campestris* pv. *musacearum* (Xcm) is now a disease of high economic threat to banana-dependent livelihoods in the Great Lakes region (Tushemereirwe et al., 2003; Karamura et al., 2008; Tinzaara et al., 2009b). The disease indiscriminately attacks all cultivated banana genotypes, with infections often resulting in total yield loss mainly from rotting of edible and marketable fruit and subsequent death of the plant (Tushemereirwe et al., 2006; Biruma et al., 2007; Smith et al., 2008). Most vascular wilt diseases affect the physiology of host plants by increasing resistance to water flow and nutrient uptake (Goodman et al., 1986; Tyree and Sperry, 1989). The impairment of nutrient translocation and utilization due to occlusion of xylem vessels by masses of bacterial exopolysaccharides induces water and nutrient deficiency at infected sites, which ultimately leads to wilting and death of leaves and stems (Hopkins, 1989; Thoquet et al., 1996b; Da Silva et al., 2001). The Xcm bacterium was first isolated forty years ago on enset (*Ensete ventricosum*) - a close relative of banana that is native to the Ethiopian highlands (Yirgou and Bradbury, 1968), but was only reported in Uganda in 2001 on East African highland bananas (Tushemereirwe et al., 2003). Thereafter, its presence was confirmed in eastern Democratic Republic of Congo (Ndungo et al., 2006), Tanzania (Mgenzi et al., 2006), Rwanda (Reeder et al., 2007) and Burundi (Carter et al., 2010).

Due to lack of meaningful host plant resistance against Xanthomonas wilt, cultural practices including destruction and disposal of infected plants, disinfection of contaminated farm tools, use of disease-free planting materials and timely removal of male buds with forked stick are widely recommended to farmers to reduce the disease incidence to acceptable levels (Eden-Green, 2004; Tinzaara et al., 2006; 2013). More recently, literature has emerged that exogenous application of potassium, calcium and nitrogen reduces susceptibility to Xanthomonas wilt in banana (Atim et al., 2013). Notwithstanding, these findings have a number of limitations: (1) first of all, manipulation of nutrient concentrations achieved under *in vitro* conditions though appealing are often elusive under actual field conditions, and (2) inoculating plants with Xcm concentration of 10^8 cfu mL^{-1} does not account for the phenomena of latency due to low bacterial loads. Nevertheless, a dearth of systematic research confounds our understanding of the natural mechanisms through which fertilizers interact with plants to affect the dynamics of pathogens. Few studies have shown inoculum concentration as an important variable determinant of disease expression (Reddy et al., 1979; Nishijima et al., 1987). Therefore, this study provides an opportunity to advance our knowledge of the interactive effects of fertilizer and inoculum concentration on the subsequent development of Xanthomonas wilt. It is thus hypothesised that the concentration of inoculum at infection has an overriding effect on the ability of fertilizers to prevent or reduce development of Xanthomonas wilt under natural conditions.

MATERIALS AND METHODS

Experimental site

The study was conducted in Mukono District, a hotspot of banana Xanthomonas wilt in Uganda. The experimental site was located in Kifu Forest Reserve (00°28'N and 32°44'E elevation 1250 m above sea level) the only location designated for controlled BXW epidemiological studies in Uganda. Generally, the thick forest provides perfect seclusion from neighbouring farmers' fields, which minimizes any long-distance vector transmission. Climate at Kifu is warm-humid with average temperature of 25°C and precipitation of 1560 mm per annum distributed in two seasons (March – June and August – November). The experimental site is located on a crystalline basement characterized by metamorphosed granites and soils originating from quaternary alluvial and lacustrine deposits Soils at the Kifu are mainly Ferralsols with Gleysols in the swamps (Okorio, 2000).

Plant materials and experimental design

Disease-free tissue culture plantlets of cultivar "Mbwazirume" (EA-AAA genome) were obtained from a private local supplier, Agro-Genetic Technologies Limited. Plants were established in 12 inch-diameter pots containing a mixture of two parts natural forest soil and one part lake sand (2:1) which had been steam-treated for 2 h at 90°C in an indirectly fired cylindrical metallic drum. No further amendment of the medium with dolomitic limestone was done. A total of 504 pots were arranged in a split-plot design with three replications (168 pots each). The composite fertilizer NPK (17:17:17) was used to ensure that all these three essential nutrients

Table 1. Effect of fertilizers on banana growth a day prior to inoculation.

Treatment[+]	Plant height (cm)	Pseudostem girth (cm)	Leaf area (cm^2)
0 NPK	89.9	13.4	953
125 NPK	122.3	15.9	1589
250 NPK	137.3	17.4	1722
Mean	116.5	15.5	1421
LSD (p<0.05)	**	**	**

[+]Fertilizer treatments: 0 NPK (0 kg ha^{-1}), 125 NPK (125 kg ha^{-1}) and 250 NPK (250 kg ha^{-1}). **Significant at $p<0.01$.

were applied in equal amounts. Three fertilizer treatments (0, 125 and 250 Kg ha^{-1}) formed the main plots while four Xcm concentrations (10^4, 10^6, 10^8 and 10^{12} cfu mL^{-1}) comprised the sub-plots. Each fertilizer treatment (56 pots) was randomly assigned per replication. Fertilizer was applied monthly by direct placement of 2.3 and 4.6 g pot^{-1} in correspondence with the fertilizer treatments 125 and 250 Kg ha^{-1}, respectively. After three months, 14 pots were randomly allocated per NPK treatment to be inoculated with the four different Xcm concentrations.

Xcm inoculum and inoculation

Bacteria were obtained from fresh bacterial ooze from a symptomatic plant from the study site. The ooze was then cultured and grown at 24°C for 72 h, on a semi-selective growth media, cellobiose cephalexin agar (CCA) (Mwebaze et al., 2006) containing yeast extract (1 gL^{-1}), glucose (1 gL^{-1}), peptone (1 gL^{-1}), NH_4Cl (1 gL^{-1}), $MgSO_4.7H_2O$ (1 gL^{-1}), K_2HPO_4 (3 gL^{-1}), agar (14 gL^{-1}), beef extract, (1 gL^{-1}), cellobiose, (10 gL^{-1}), cephalexin (40 mg L^{-1}), 5-fluorouracil (10 mg L^{-1}) and cycloheximide (120 mg L^{-1}). Bacterial cells were then harvested into sterile water, the optical density adjusted to 0.5 (c. 10^8 cfu mL^{-1}) with sterile water at 600 nm wavelengths on a spectrophotometer (Biomate-3, Thermo Electron Corporation, USA). Ten-fold serial dilution was used to obtain the desired lower concentrations (c. 10^4 and 10^6 cfu mL^{-1}). Thereafter, highest concentration (c. 10^{12} cfu mL^{-1}) was obtained by gradual addition of bacterial cells to 10^8 cfu mL^{-1} until the optical density was raised from 0.5 to 0.8. Six-month-old plants were inoculated by injecting 1 mL of the Xcm cell suspension into the leaf petiole of the youngest leaf using an insulin syringe (Micro-Fine Plus, 0.33 x 12.7 mm, Beckton Dickinson, USA).

Xanthomonas wilt development

Effect of fertilization on plant growth (plant height, plant girth and total leaf area) was determined a day prior to inoculation. Plant height was measured as the pseudostem height from ground level to the tip of the second youngest leaf while plant girth was the circumference of the pseudostem at 15cm above ground level. The estimated total leaf area was calculated based on information of biometric measurements of the third leaf taken from each plant using the formula $TLA = L \times B \times 0.8 \times N \times 0.662$ (Kumar et al., 2002) whereby: TLA is the total leaf area of the plant, L and B are the length and breadth of third leaf, N is the number of leaves on the plant, 0.80 is the proportionality factor proposed by Murray (1960) and 0.662 is a coefficient.

Data on incubation period (the time between inoculation and symptom development) and subsequent disease development was collected twice a week, beginning from 3 days post inoculation (dpi). Xanthomonas wilt severity was rated visually using the following scale: 0 = no wilt symptoms; 1 = 1 leaf wilted; 2 = 2 - 3 leaves wilted; 3 = 4 leaves wilted; 4 = all leaves wilted; and 5 = plant dead (Winstead and Kelman, 1952). Complete or partially wilted plants were tagged to avoid double counting in subsequent assessments and also to avoid the possibility of missing out those plants that died early during the experiment.

Disease development for each treatment was presented using a wilt severity index (%) calculated according to the formula $[(0 \times a + 1 \times b + 2 \times c + 3 \times d + 4 \times e + 5 \times f)/(n \times 5)] \times 100$ where: n denotes total number of plants per treatment, 0,1…5 is disease severity scale, and a, b…f denotes respective number of plants in each severity scale (Ssekiwoko et al., 2006). Incidence was determined as the proportion (%) of inoculated plants that subsequently became symptomatic while latency was the proportion (%) of inoculated plants that were asymptomatic (did not display typical Xanthomonas wilt symptoms).

Data analysis

The analysis of variance (ANOVA) was conducted using GenStat 11th Edition (VSN International, UK) and means were separated using the least significant difference ($p<0.05$).

RESULTS

Fertilizer and growth of banana plants

Fertilizers treatments were commenced three months prior to inoculation with varying X cm inoculum concentrations. Results show that fertilization contributed significantly ($p<0.01$) to increased plant height, plant girth and leaf area compared to controls without fertilizer (Table 1). Banana plants to which 250 kg ha^{-1} fertilizer was applied had the highest means for all growth parameters meanwhile those with 0 kg ha^{-1} showed the least means (Table 1).

Xanthomonas wilt incidence

Xanthomonas wilt symptoms, that is, chlorosis and necrosis were observed from 9 to 21 days post inoculation (dpi) for across all treatments in this study (Figure 1). Data of Xanthomonas wilt incidence for inoculum concentration showed that 10^4, 10^6 and 10^8 cfu mL^{-1} resulted in over 90% incidence in all fertilizer treatments, while at 10^{12} cfu mL^{-1} only the 250 kg ha^{-1} resulted in 85.7% incidence (Table 2a). On average, 94% incidence was observed across all fertilizer treatments. However, increasing fertilizer amounts resulted in no

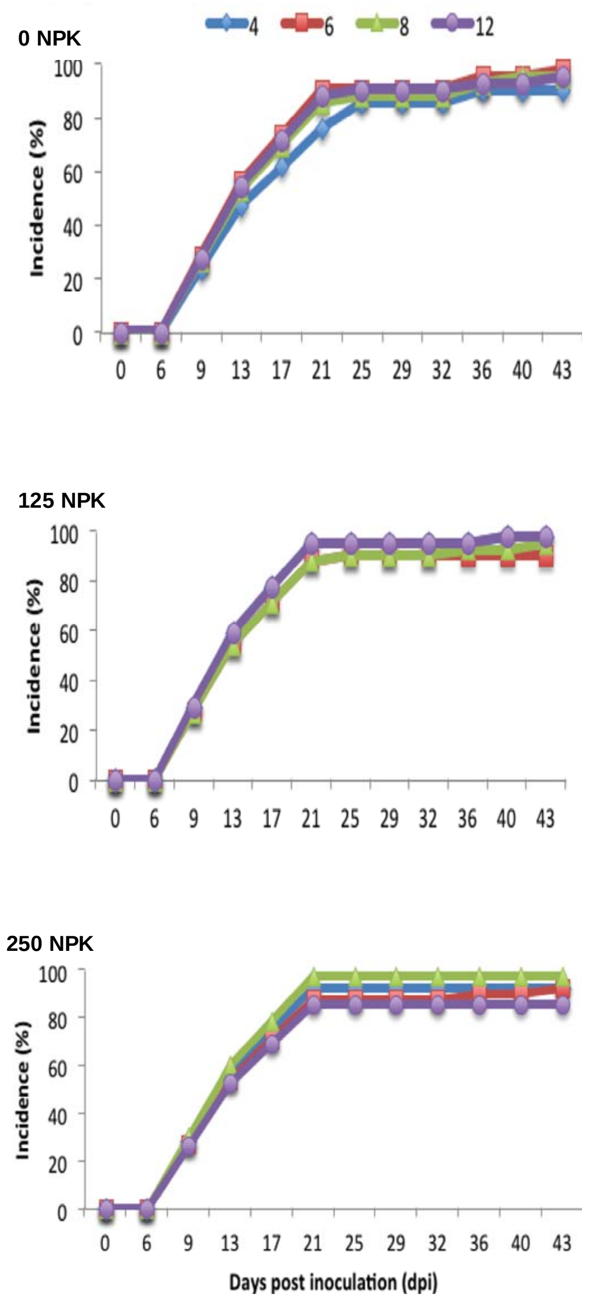

Figure 1. Effect of fertilizer treatment and inoculum concentration on the progress of incidence (% symptomatic plants) of Xanthomonas wilt in banana. Fertilizer treatments: 0 NPK (0 $kgha^{-1}$), 125 NPK (125 $kgha^{-1}$) and 250 NPK (250 $kgha^{-1}$). Inoculum concentrations of *Xanthomonas campestris* pv. *musacearum*: 10^4 (4), 10^6 (6), 10^8 (8) and 10^{12} (12) cfu mL^{-1}.

significant (p>0.05) level of suppressiveness to development of Xanthomonas wilt (Table 2a). Although, plants inoculated with 10^8 cfu mL^{-1} experienced the highest mean incidence (96%), the magnitude of difference was not significant (p>0.05) from other inoculum concentrations (Table 2).

Xanthomonas wilt severity index

From the data in Figure 2, it is apparent that the wilt severity index between 0 and 21 dpi was not statistically significant (p>0.05) for the inoculum concentrations at the different fertilizer levels in this experiment. However, later (after 21 dpi) highly significant (p<0.01) wilt severity indices were detected for the inoculum treatments 10^6, 10^8 and 10^{12} cfu mL^{-1} (Figure 2). The results shown in Table 3 indicate that average wilt severity index at higher inoculum concentrations was about twice that of 10^4 cfu mL^{-1} plants. There is strong evidence of primary inoculum overriding the effect of fertilizer. From data, it is clear that mean wilt severity index increased with increasing inoculum concentration (Table 3). Contrary to findings by Atim et al. (2013), fertilizer applications appeared to exacerbate wilt severity index of 10^8 cfu mL^{-1} inoculated plants. As anticipated, plants inoculated with the lowest bacterial load also exhibited the least (33.7%) wilt severity index, irrespective of fertilizer application (Table 3). Linear regression analysis (r^2 = 0.999) indicated that wilt severity index (y) could be predicted from inoculum concentrations (x) based on the equation $y = 2.21x + 16.6$. In general, no clear benefit of fertilizer in the prevention of Xanthomonas wilt could be identified in this experiment.

Mortality and latency

Table 4 shows the experimental data on percent mortality collected at 89 dpi. As can be noted, 10^6 to 10^{12} cfu mL^{-1} inoculated plants experienced significantly (p<0.01) higher mortality compared to 10^4 cfu mL^{-1} inoculations (Table 4). Apparently, none of the differences between 10^6, 10^8 and 10^{12} cfu mL^{-1} were statistically significant. It is apparent from the data in Table 4 that 10^4 cfu mL^{-1} is the minimum bacterial population required to elicit infection in banana. On average, 9.2% mortality of 10^4 cfu mL^{-1} inoculated plants suggests a great potential of causing latent infections in banana (Figure 3). There was no significant difference (p>0.05) in mortality between non-fertilized and fertilized conditions, although the 125 kg ha^{-1} fertilizer treatment was found to reduce mortality by 22.1 and 26.3% on 10^6 and 10^{12} cfu mL^{-1} inoculated plants respectively (Table 4). Both 125 and 250 kg ha^{-1} fertilizer treatments were not effective at reducing mortality in 10^8 cfu mL^{-1} inoculated plants but instead seemed to exacerbate it (Table 4). Data contained in Table 4 is consistent with wilt severity index data in Table 3, which shows that inoculum concentration has an overriding effect on the extent to which fertilizers can effectively reduce susceptibility and eventual mortality due to Xanthomonas wilt. In summary, this study reveals a transient interaction between fertilizer and inoculum concentration that is unlikely to limit further development of Xanthomonas wilt especially in situations were inoculum concentration exceed 10^6 cfu mL^{-1}.

Table 2. Interaction of fertilizer treatment and inoculum concentration on the progress of Xanthomonas wilt incidence (%) in banana.

Fertilizer treatment^{+}	Inoculum concentrations (Log_{10} cfu mL^{-1})*				Mean^{y}
	4	6	8	12	
0 NPK	90.5^{ab}	97.6^{b}	95.3	95.3	94.6^{ab}
125 NPK	97.6^{b}	90.5^{ab}	95.3	97.6^{b}	95.3
250 NPK	92.9^{ab}	92.9^{ab}	97.6^{b}	85.7^{a}	92.3^{ab}
Mean^{x}	93.7^{ab}	93.7^{ab}	96^{b}	92.9^{ab}	94.0^{z}

$^{+}$ Fertilizer treatments: 0 NPK (0 kg ha^{-1}), 125 NPK (125 kg ha^{-1}) and 250 NPK (250 kg ha^{-1}); * Inoculum concentration: 4 (10^{4} cfu mL^{-1}), 6 (10^{6} cfu mL^{-1}), 8 (10^{8} cfu mL^{-1}) and 12 (10^{12} cfu mL^{-1}); ^{x} Column means for inoculum concentration; ^{y} Row means for fertilizer treatments; ^{z} Grand mean; Values in the same column or rows followed by the same superscript letter are not significant (*p*>0.05).

Table 3. Interaction of fertilizer treatment and inoculum concentration on the progress of Xanthomonas wilt severity index (%) in banana.

Fertilizer treatment^{+}	Inoculum concentrations (Log_{10} cfu mL^{-1})*				Mean^{y}
	4	6	8	12	
0 NPK	33.5^{a}	62.3^{h}	59.8^{gh}	64.7^{i}	**55.1^{ef}**
125 NPK	35.9^{a}	57.5^{fg}	64.0^{hi}	63.3^{hi}	**55.2^{ef}**
250 NPK	31.8^{a}	58.2^{fg}	65.1^{i}	57.5^{fg}	**53.2^{e}**
Mean^{x}	33.7^{a}	59.3^{g}	63.0^{hi}	61.8^{h}	54.5^{z}

$^{+}$ Fertilizer treatments: 0 NPK (0 kg ha^{-1}), 125 NPK (125 kg ha^{-1}) and 250 NPK (250 kg ha^{-1}); * Inoculum concentration: 4 (10^{4} cfu mL^{-1}), 6 (10^{6} cfu mL^{-1}), 8 (10^{8} cfu mL^{-1}) and 12 (10^{12} cfu mL^{-1}); ^{x} Column means for inoculum concentration; ^{y} Row means for fertilizer treatments; ^{z} Grand mean; Values in the same column or rows followed by the same superscript letter are not significant (*p*>0.05).

Table 4. Percent mortality$^{\#}$ of banana plants due to the interaction of fertilizer treatment and inoculum concentration.

Fertilizer treatment^{+}	Inoculum concentrations (Log_{10} cfu mL^{-1})*				Mean^{y}
	4	6	8	12	
0 NPK	15^{ab}	82.4^{de}	65.4^{d}	85.5^{de}	**62.1^{d}**
125 NPK	7.5^{a}	60.3^{cd}	80.8^{de}	59.3^{cd}	**52.0^{cd}**
250 NPK	5.1^{a}	72.7^{d}	79.5^{de}	67.9^{d}	**56.3^{cd}**
Mean^{x}	9.2	71.8^{d}	75.2^{de}	70.9^{d}	56.4^{z}

$^{\#}$ Final mortality data was collected at 89 dpi prior to termination of the experiment. $^{+}$ Fertilizer treatments: 0 NPK (0 kg ha^{-1}), 125 NPK (125 kg ha^{-1}) and 250 NPK (250 kg ha^{-1}). * Inoculum concentration: 4 (10^{4} cfu mL^{-1}), 6 (10^{6} cfu mL^{-1}), 8 (10^{8} cfu mL^{-1}) and 12 (10^{12} cfu mL^{-1}). ^{x} Column means for inoculum concentration. ^{y} Row means for fertilizer treatments. ^{z} Grand mean; Values in the same column or rows followed by the same superscript letter are not significant (*p*>0.05).

DISCUSSION

Xanthomonas wilt is a serious and intractable banana production constraint responsible for losses worth US$ 500 million in the Great Lakes region of East and Central Africa (Tushemereirwe et al., 2004; Smith et al., 2008). This study provides experimental evidence on the effects of fertilizer-inoculum concentration interaction on subsequent development of Xanthomonas wilt in banana.

The application of fertilizer significantly increased growth of banana plants (that is, height, pseudostem girth and leaf area). These results agree with the findings of several studies, in which nutrients are reported to boost physiology of crop plants (Patriquin et al., 1995; Dordas, 2008; Spann and Schumann, 2010). In addition, some authors have maintained that nutritional status can modulate a plant's predisposition to facultative parasites including Xanthomonas, Alternaria and Fusarium (Chase,

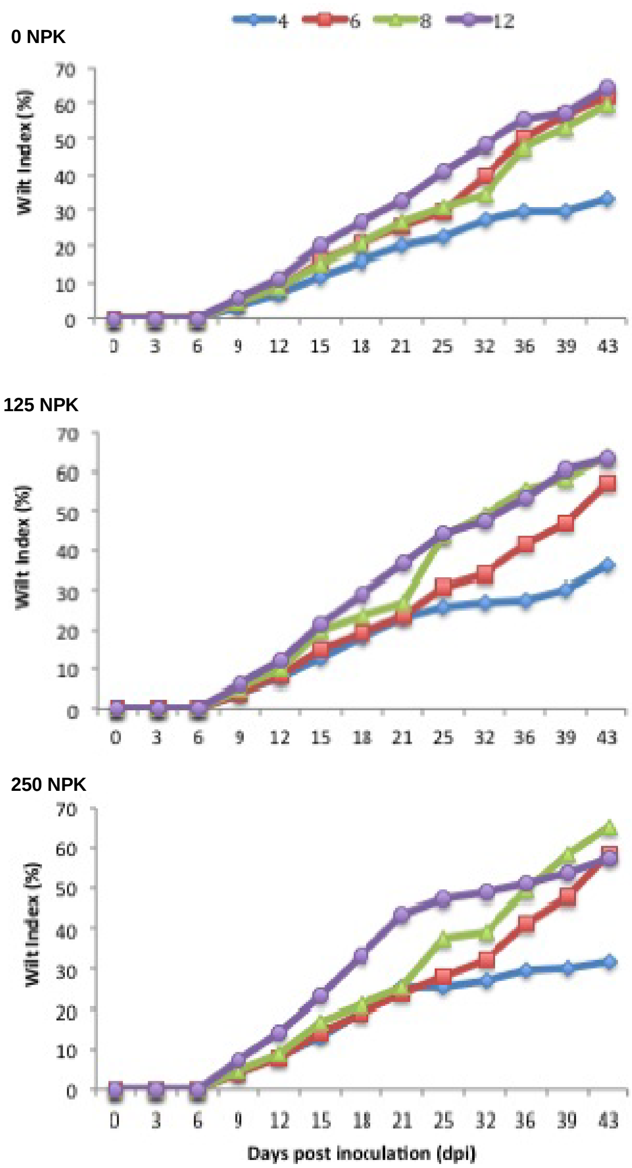

Figure 2. Effect of fertilizer treatment and inoculum concentration on the progress of wilt index (%) of Xanthomonas wilt in banana. Fertilizer treatments: 0 NPK (0 $kgha^{-1}$), 125 NPK (125 $kgha^{-1}$) and 250 NPK (250 $kgha^{-1}$). Inoculum concentrations of *Xanthomonas campestris* pv. *musacearum* are: 10^4 (4), 10^6 (6), 10^8 (8) and 10^{12} (12) cfu mL^{-1}.

1989; Blachinski et al., 1996; Woltz and Engelhar, 1973). Contrary to earlier findings by Atim et al. (2013), this study provides no evidence of significant fertilizer-induced resistance against Xanthomonas wilt in banana. Though it is difficult to explain this result, it is most likely that crop nutritional status only augments the inherent potential for defence. Unfortunately, exploiting this potential using fertilizer is already confounded by the lack of meaningful resistance in most cultivated bananas (Ssekiwoko et al., 2006).

From the disease triangle, it is evident that provision of suitable crop environment (that is, through fertilization) is unlikely to eliminate the development of Xanthomonas wilt, especially when other conditions such as host susceptibility and pathogen virulence are conducive for infection (Agrios, 2005). Some authors have suggested that effectiveness of fertilizer for disease management depends essentially on the attacking pathogen (Büschbell and Hoffmann, 1992; Carballo et al., 1994). Our study produced evidence of the overriding effect of inoculum concentration on the effectiveness of fertilizers for Xanthomonas wilt control. This is most likely due to a multiplicity of pathogenicity factors that function to redirect host metabolism for microbial nutrition and growth. Most bacteria belonging to the genera *Pseudomonas*, *Xanthomonas* and *Ralstonia* are known to secrete type three effector proteins (TTEs) for colonizing and parasitizing susceptible plant hosts (Salanoubat et al., 2002; Agrios, 2005; Bretz and Hutcheson, 2004). In many cases, TTEs are reported to interfere with host defence mechanisms by enhancing nutrient uptake by the pathogen and adaptation to host plant environment (Cornelis and Van Gijsegem, 2000; Innes, 2001; Abramovitch et al., 2003; Chisholm et al., 2006). Studholme et al. (2010) found Xcm strains to have the YopJ-like C55 cysteine proteases in its TTE apparatus that is responsible for suppression of innate defences in banana.

Another important finding was that direct inoculation of fertilizer treatments with different concentrations of Xcm significantly increases the wilt severity index and mortality. Dickinson (2003) noted that as bacterial population increases in the xylem, a quorum sensing mechanism induces expression of the Lys-R type global regulator, resulting in the copious secretion of extracellular polysaccharides (EPS). Unfortunately, this study provides no direct evidence implicating the copious production of EPS with the rapid wilting and high mortality of banana plants inoculated with greater than 10^4 cfu mL^{-1} concentrations. Nevertheless, there is agreement with Vidaver and Lambrecht (2004) who found 10^6 cfu mL^{-1} to be the inoculum threshold required for expression of most infectious bacterial diseases. It is therefore likely that the slow build-up of Xanthomonas wilt noticeable for 10^4 cfu mL^{-1} plant inoculations is reminiscent of latent infections. Ocimati et al. (2013) found that Xcm bacteria can survive latently without induction of disease in banana mats for a period of up to 2 years. This prolonged duration of latency presents a major concern among researchers, especially in the light of recent resurgence of Xanthomonas wilt in growing areas wherein it had been contained (Tinzaara et al., 2013; Ocimati et al., 2014).

A paradox emerging from this study relates specifically to the bacterial load overriding the effect of fertilizer in reducing Xanthomonas wilt. This contradicts the findings of Atim et al. (2013) whereby exogenous applications of potassium, calcium and nitrogen reduced susceptibility to Xanthomonas wilt. The muted effect of fertilizer suggests

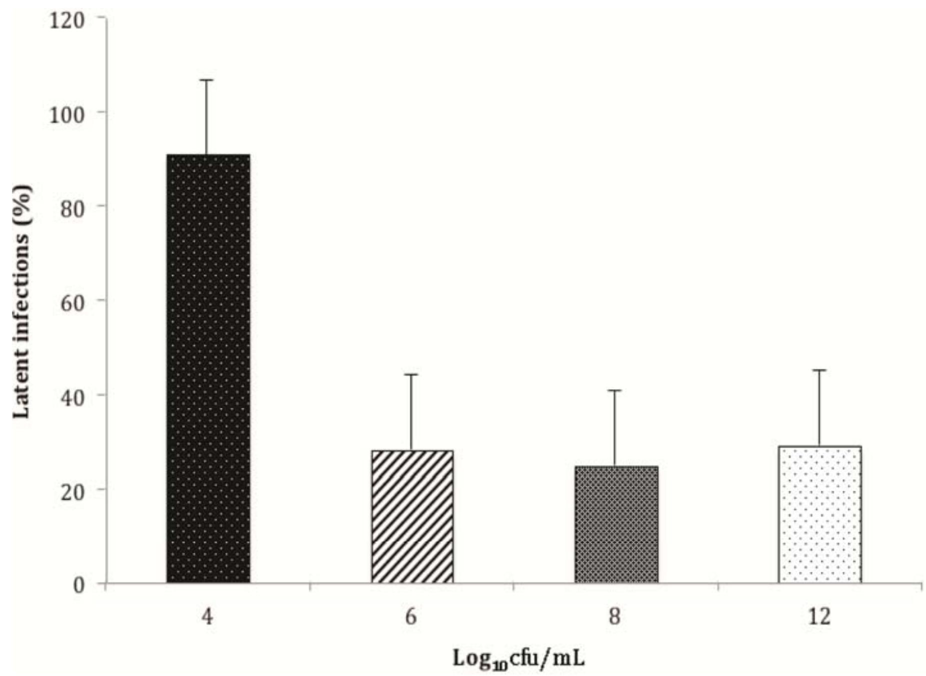

Figure 3. Xanthomonas wilt latent infections (%). Inoculum concentrations of *Xanthomonas campestris* pv. *musacearum* are: 10^4 (4), 10^6 (6), 10^8 (8) and 10^{12} (12) cfu mL^{-1}.

that a weak link may exist in its interaction with inoculum concentration. This combination of findings has important implications for integrated disease management in smallholder banana systems. Nevertheless, they should be interpreted with caution prior to endorsements against the utility of fertilizers for Xanthomonas wilt control. Epidemiological studies reveal that the greatest degree of Xanthomonas wilt control is achieved when risk of transmission is reduced by the prompt elimination of primary inoculum sources (Eden-Green, 2004; Biruma et al., 2007). Hence, disease eradication requires a strict adherence by smallholders to the timely removal of male inflorescence, disinfection of cutting tools, destruction of infected materials and monitoring of movement of plant materials within and from suspect areas.

Conflict of interest

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

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