SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 13 No. 2
April 2013
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

TOWARDS SUSTAINABLE HIGHLAND BANANA PRODUCTION IN UGANDA: OPPORTUNITIES AND CHALLENGES

Nyombi K[1]*

Kenneth Nyombi

*Corresponding author email: knyombi@yahoo.co.uk

[1]Makerere University, College of Agricultural and Environmental Sciences
P.O. Box 7062, Kampala, Uganda

ajfand SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 13 No. 2
April 2013
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

ABSTRACT

East Africa highland bananas (*Musa* sp., AAA-EAHB) are an important starchy food and cash crop in Uganda and the Great Lakes region of East Africa. Widespread reports of declining yields in Uganda since the 1930s and the low yields today do raise serious sustainability and food security concerns, especially as food demand increases with a population growth rate of 3.2% per annum. In addition, increasing urbanization continues to increase pressure on the banana systems, with bunches and leaves increasingly transported from rural areas to urban centres, leading to the continued loss of nutrients especially potassium. Actual yields on many smallholder banana farms (5−20 Mg ha^{-1} yr^{-1} FW) in Uganda are far below the estimated potential yield (100 Mg ha^{-1} FW). Farmers cite soil fertility decline, pests (banana weevils and nematodes) and moisture stress as the major factors responsible for yield decline. In response, several organic and mineral fertilization experiments have been carried out at research stations and in farmers' fields in Uganda since the 1950s. Researchers have mostly reported responses to organic fertilizers, no or poor responses to Mg and P fertilization with some responses to K and N fertilization, but with yields that are far below the estimated potential. Although pests are controlled in some trials, researchers have often failed to embrace a systems approach, quite often leaving out factors, such as moisture stress and soil physical conditions that affect the responses to fertilization. The government of Uganda in the National Development Plan 2010/11−2014/15 targets increased agricultural productivity for key staple crops like bananas in alleviating poverty in rural areas and ensuring national food security. In order to set proper banana research priorities to benefit farmers in Uganda, the objectives of this study were: to review past research aimed at reducing banana production constraints, identify opportunities and challenges facing the banana sector and put forward new research perspectives.

Key words: bananas, soil fertility, moisture, Uganda

INTRODUCTION

East Africa highland bananas are an important starchy food and cash crop in Uganda. Communities from central, eastern, western and south-western Uganda have exclusively relied on bananas for over 150 years [1]. Production is mainly by smallholder farmers on fields < 0.5 ha, with medium size farms gaining prominence in southern Uganda [2]. However, reducing productivity and loss of sustainability have been widely reported among farmers, especially in central Uganda [3]. Yields are, for example, reported to have declined from 8.4 Mg ha^{-1} yr^{-1} in 1970 to 5.6 Mg ha^{-1} yr^{-1} in the late 1980s [2]. Irrespective of the accuracy of the figures, it is clear that actual banana yields on smallholder farms (5−20 Mg ha^{-1} yr^{-1} FW) are far from the estimated potential yield (100 Mg ha^{-1} yr^{-1} FW) [4].

Farmers attribute the yield reduction to declining soil fertility, increasing pest pressure (especially the banana weevil - *Cosmopolites sordidus* and nematodes) and moisture stress [2, 5]. Several studies over the years have failed to reverse the downward spiral. They have either focused on fertilizer-mulch interactions [6, 7] or the banana response to mineral fertilizer [4, 8] under rain-fed conditions, with variable responses. In Uganda, the official mineral fertilizer recommendation for highland bananas is a single blanket rate of 100N–30P–100K–25Mg kg ha^{-1} yr^{-1} [7], irrespective of the inherent soil fertility status, variability in soil physical properties and rainfall amounts on banana farms, which affect the banana responses to fertilization.

The government of Uganda in its National Development Plan 2010/11−2014/15 targets increased agricultural production of staple crops to alleviate poverty. In other countries like Costa Rica, it was possible to increase average banana yields from 10−15 Mg ha^{-1} yr^{-1} FW before 1960 to 50−80 Mg ha^{-1} yr^{-1} FW (today) through better horticultural management, cultivar choice and plant protection [9]. This raises a number of questions related to past banana research in terms of its conception, conduction, outputs or policy implications and impact. In this paper, banana production constraints are presented, past banana research reviewed and the major issues leading to the low banana response to fertilization are analyzed (section 2 and 3). Opportunities and challenges facing the banana sector are discussed (section 4) and new research perspectives aimed at increasing banana production towards the potential yield are suggested (section 5). In order to achieve these objectives a literature review was done in order to synthesize and analyze the existing information.

CONSTRAINTS TO HIGHLAND BANANA PRODUCTION IN UGANDA

Soil fertility

Yield reductions due to soil fertility decline were reported as early as 1938 in the Lake shore banana growing areas [5]. The existence of “Lunyu soils” that are highly acidic patches (soil pH < 4) and are low in nutrients (total exchangeable bases < 5 mg kg^{-1}) was first reported in the 1940s [10]. Banana systems are built on mainly Ferralsols and Acrisols [11]. Although they have good physical conditions, inherent fertility is low and nutrient availability largely depends on mineralization of soil

Published by African Scholarly Science Communications Trust
Josem Trust Place, Bunyala Road, Upper Hill, Nairobi
P.O. Box 29086-00625 Tel: +254-20-2351785 Fax: +254-20-4444030, Nairobi, KENYA
Email: oniango@iconnect.co.ke OR info@ajfand.net www.ajfand.net

organic matter. In order to assess the extent of fertility decline, 1700 field trials were conducted at 62 centres covering the entire country in the 1960s [12]. During the Land management study (1999−2002), the same sites were visited and soil samples collected [13]. Analysis indicated that the magnitude of SOM had not significantly changed, but in many cases soil pH, extractable phosphorus (P), calcium (Ca), and potassium (K) were below critical levels. In some cases P, Ca and K levels in the top soil were 20−70% of the levels found in the 1960s. A more recent study of 159 plots in central, south and south-west Uganda found that poor soil fertility is still a constraint especially soil organic matter, total nitrogen and K/(Ca + Mg) [14].

Nonetheless, rapid population growth (3.3% per annum) and increasing urbanization (12% in 2000 and 15% in 2010) continue to increase pressure on the banana systems in Uganda. Bunches and leaves are increasingly exported from rural areas to urban centres leading to the continued loss of nutrients especially potassium. In the urban centres, a small proportion of the banana wastes are collected and sold as livestock feed with the resulting manures mostly benefitting the more affluent farmers close to the urban centres. The soil fertility problem is worsened by limited use of mineral fertilizers by farmers. Less than 5% and less than 1% of the banana farmers in the Lake Victoria basin use mineral fertilizers according to two different studies [3, 15].

Moisture stress

As a rule of thumb, bananas require 25 mm of rainfall per week for satisfactory growth, which corresponds to 1300 mm per annum [16]. However, most of the banana growing regions in Uganda receive between 1000 and 1300 mm per annum. Irrigation is not practiced, implying that moisture stress affects the yields. The high moisture demand in bananas is attributed to both the large plant fresh biomass and the broad leaves. The most important visual signs of stress in bananas is the folding of leaves (the angle between the two lamina indicates the degree of moisture stress), choked bunches after flowering and cessation of growth.

Pests

The banana weevil is the best known banana insect pest in Uganda. It was first reported in 1908 and is a major yield reducing pest at altitudes below 1600 m.a.s.l. [17]. Mature females oviposit in the leaf sheaths and the corm. The feeding larva eats through the rhizome making tunnels, killing suckers and existing roots, thus impeding water and nutrient uptake. Yield losses due to weevils between 14−20% irrespective of cultivar and soil management were reported [18], although weevil populations seemed to be larger in mulched than in non-mulched fields. Consequently, absolute yield losses (Mg ha^{-1} yr^{-1}), were much higher in vigorous management (mulch + manure). Heavy weevil attack has been reported to result in total yield loss in Rakai and Masaka districts, southwestern Uganda [19].

The burrowing nematode *Radopholus similis* (Cobb) Thorne, the root lesion nematode *Pratylenchus goodeyi* (Cobb) Sher & Allen and *Helicotylenchus multicinctus* (Cobb) Golden are a major pest constraint to banana production in Uganda. *R. similis* is the most destructive banana nematode species at altitudes below 1500 m.a.s.l [9]. Root lesion nematodes are a major constraint at altitudes higher than 1500 m.a.s.l. Nematodes attack the roots and rhizomes killing lateral shoots causing necrosis of root tissues and corm. This attack weakens the root system and increases chances of toppling of whole banana plants.

RESEARCH EFFORTS TO REDUCE THE BANANA PRODUCTION CONSTRAINTS

Soil fertility

Organic fertilizers were proposed as the first line remedy to soil fertility decline in Uganda in the 1940s. Research done in the 1940s and 1950s focused on the quantification of organic fertilizers applied and yields data collection on farms. Variable responses to mulch for different cultivars were reported under modest conditions and no efforts to control the weevil [10] (Table 1). Yields for controls ranged 2.5−9.25 Mg ha^{-1} yr^{-1} and yield increases ranged 1.0−7.25 Mg ha^{-1} yr^{-1}. However for this trial, it is hard to determine whether the yield increase was due to soil moisture conservation from mulching and or just fertilization.

From the 1990s, studies focused principally on diagnosing plant nutrition status, the use of mineral fertilizers and the combined application of organic and mineral fertilizers. Highland banana response to mineral fertilization has been variable, location specific and at times disappointing. Yield increases of 103% in the south, 65% in central, 23% in south-west and 28% in Eastern Uganda with a maximum of 37 Mg ha^{-1} yr^{-1} after applying 71N:8P:32K kg ha^{-1} yr^{-1} were reported [14]. Small responses to potassium and magnesium fertilizers in central (Bulingwe 58%; 3.1 to 4.9 Mg ha^{-1} yr^{-1}) in a 40 year old plantation and south-western Uganda (Muyogo 31%; 14.4 to 18.9 Mg ha^{-1} yr^{-1}) in a 14 year old plantation under rain-fed conditions were obtained [20]. Plants at Bulingwe had high levels of peripheral damage due to the banana weevil and moderate levels of internal corm weevil attack, with levels considerably lower than those found at other sites in Luwero district [20]. Weevil damage was very low at Muyogo. This implies that weevil damage may have affected the response [20]. In addition, fertilization with K and Mg fertilizers may offset the Ca:Mg:K ratio in soil and responses to further additions may be hampered by other limiting nutrients such as nitrogen, phosphorus and calcium.

Earlier research by [6] reported a good banana response to mineral fertilizers at Rubale, south-west Uganda, and low response at Kalegebanda and Kabulasoke both in central Uganda, with plantation age ranging 8−50 years. The response (100N+25P+100K) was significant and profitable at only Rubale (maximum yield - 67 Mg ha^{-1} yr^{-1} FW), which was attributed to low pest and disease pressure, the traditional mulching practice and rainfall above long-term averages. Low banana yields at Kalegebanda and Kabulasoke are typical of the Lake Victoria banana zone. Little effect was noted after applying (50N+15P+50K+12.5Mg kg ha^{-1} yr^{-1}) in weevil-infested fields [7].

Yield increase at Ntungamo from 13.7 to 43.2 Mg ha^{-1} yr^{-1} FW with

400N+50P+600K kg ha^{-1} yr^{-1} were reported [4]. The lower response was attributed to soil moisture stress. Low yield increments due to moisture stress from 12 to 16 Mg ha^{-1} yr^{-1} FW were obtained when 100N+50P+100K ha^{-1} yr^{-1} were applied on K-deficient soil in Mbarara [21]. More promising results from central Uganda were reported by [22] for Namwezi cultivar, when different K applications (25–200 kg ha^{-1} yr^{-1}) were combined with a 100 kg N ha^{-1} and P application. After four years, bunch yield in control plots was 12 Mg ha^{-1} yr^{-1} FW and 25–32 Mg ha^{-1} yr^{-1} FW for plots that received NPK fertilizer, with little differences between different K doses, which were not significant.

In summary, banana responses to mineral fertilizers seem site specific and are not guaranteed. This necessitates soil analysis to determine the most limiting nutrients before fertilizer application. In addition, most of the fertilizer response studies have been carried out in fields infested with pests. Therefore, it is imperative to control pests in trials and to minimize soil moisture stress in order to obtain better responses to fertilization.

Moisture stress

Moisture stress has received little attention despite the fact that most of the banana areas receive sub-optimal rainfall. Banana yields in Mbarara reduced by 12% for every 100 mm reduction in rainfall using a base of 1400 mm [23]. Low annual rainfall (678 mm) reduced yields by about 50% at Mbarara, south west Uganda [21]. Extreme moisture stress was noted as a major constraint to banana growth during the dry season in central Uganda [24]. This implies that moisture is a problem in the banana growing areas of Uganda.

Research efforts have mainly focused on the use of organic fertilizers. Higher yields (66%) were reported for plots proximal to the homestead, attributed to improved moisture retention as a result of larger amounts of mulch [25]. Higher yields were also reported in mulched plots than in non-mulched plots, but volumetric moisture contents were lower in the mulched plots due to improved plant growth and higher transpiration rates [26]. Half incorporation and half surface application of coffee husks gave higher yields due to the provision of nutrients and soil moisture retention [22]. However, the use of organics in banana systems is constrained by their availability, with nutrient flows from outfields and grazing areas to the homestead banana fields collapsing due to increased land pressure in Uganda. A study by Wairegi [14] reported that mulch was the most important limiting factor in 20.9% of the banana plots in central Uganda.

Irrigation is uncommon on banana farms in Uganda. With supplemental irrigation to maintain soil moisture content around field capacity (pF 2.0), banana yields of 59 Mg ha^{-1} FW could be obtained at Kabanyolo, central Uganda [27], although the author does not mention the amounts of fertilizers that were used. The profitability of irrigation in year 2 was estimated at UGX. 2.064 million, assuming a farm gate price of UGX. 100 per kg of the bunch. This clearly shows that increasing soil moisture availability if coupled with fertilization can result in increased production.

Pests
Despite studies, the effective control of banana weevils and the nematodes on smallholder banana plantations has eluded scientists up to now. Research efforts have focused on estimating yield losses due to weevil attack, understanding weevil biology and designing weevil control strategies. Field sanitation and better agronomic practices such as spacing, pruning, intercropping, mulching may affect the micro environment and thus favour or discourage weevil egg deposition, tenure time, longevity, fecundity, and or population growth. Changes in cropping patterns have been proposed to alter weevil aggregation patterns and adult longevity. However, the adoption of these practices is hampered by labour availability and farmer perceptions [28]. Biological control research for weevils and nematodes in Uganda is still at its infancy [29]. Chemical control, the use of organophosphates (such as Dursban) and carbamates (such as Carbofuran) though advocated, is not used by farmers due to the costs.

Nematode research has focused on their concentration with respect to distance from the corm, their effect on nutrient uptake and the possibility of increasing fertilizer efficiency through placement. A higher population of nematodes was found within 40 cm radius of the mat. *R. similis* was more concentrated within 10 cm radius, but more *H. multicinctus* was found in the area 30−40 cm from the plant in plantations more than 6 years old [30]. Thus, when fertilizer is applied at a radius of up to 40cm from the banana stool, the uptake efficiency could potentially be diminished if nematodes preferentially reside in roots that are within this radius. Therefore, knowledge of the species distribution in the profile and with respect to distance from the corm could improve management practices and thus increase fertilizer efficacy. However, due to their microscopic size, farmers rarely appreciate the economic importance of nematodes. Systemic pesticides such as Carbofuran are effective against nematodes, but are not used due to the costs.

Interaction of factors
Banana yields are a result of an interaction of a number of factors such as soil moisture level, fertility status, plant factors, environmental factors and the level of pest infestation, but the direction and degree of interaction are sometimes not clear. Little effect was noted after applying chemical fertilizers (N:P:K:Mg; 50 15 50 12.5 kg ha^{-1} yr^{-1}) in weevil infested fields [7]. Similarly, the use of chemical fertilizers was only profitable if nematode and weevil damage are low [6]. Mineral fertilizer alone increased banana yields from 10 to 17 Mg ha^{-1} yr^{-1} in on-farm trials, but when combined with pesticides, yields increased to 23 Mg ha^{-1} yr^{-1}. When pesticides and mulch were combined, yields were 32 Mg ha^{-1} yr^{-1} (Figure 1) [24].

ajfand SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 13 No. 2 April 2013
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

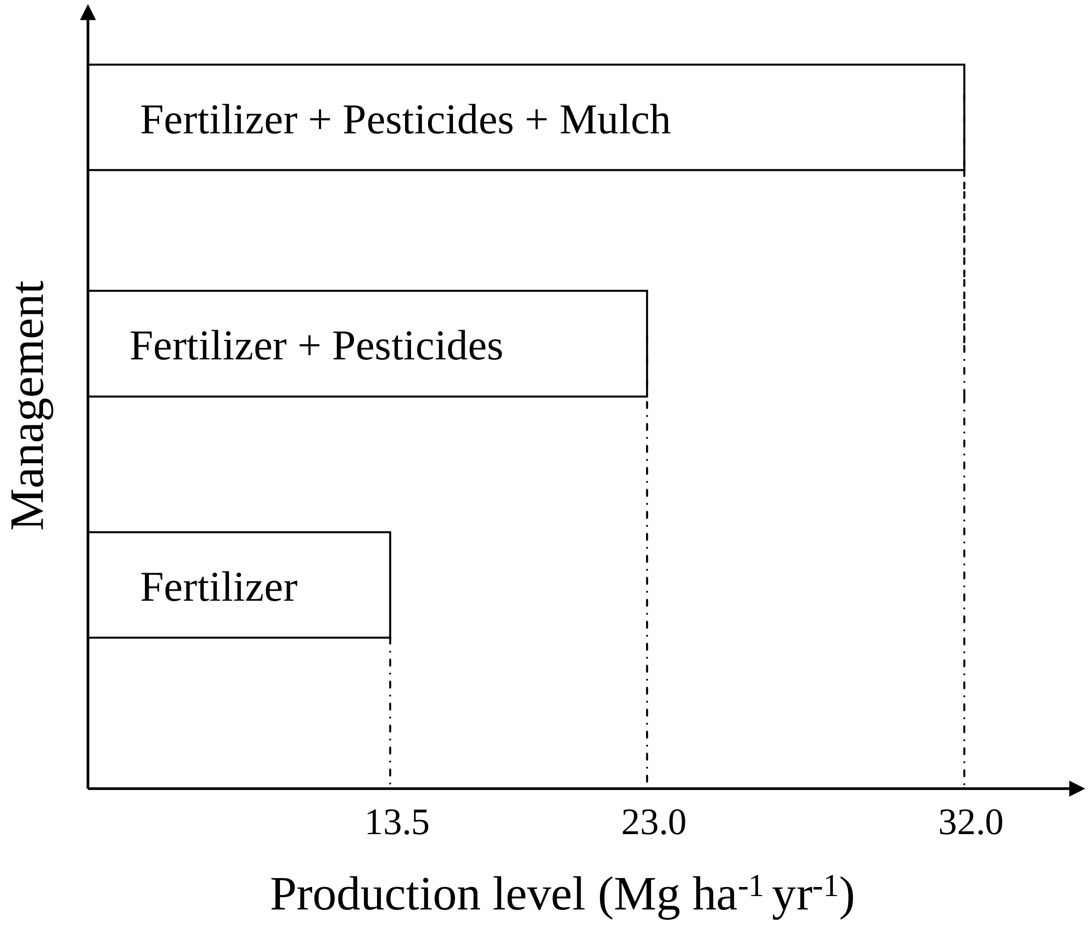

Figure 1: Response of East Africa highland bananas to management. Modified from [24].
Potential yield is 100 Mg ha^{-1} FW [4].

This clearly shows a strong interaction of factors, with mulch (moisture stress) apparently the primary constraint, followed by soil fertility and pests. Therefore, soil fertility management should be combined with pest management, soil moisture conservation or irrigation or rain water harvesting in order to increase the yields.

Interactions between plant nutrient status and pest levels remain largely vague. It has been widely hypothesized that high levels of banana weevil are associated with low soil fertility and nematode infestations [31]. It was hypothesized that weevil attacks in Bukoba, Tanzania were related to nutrient imbalances that affect the plant defense mechanism through reducing pectin and tylose formation, with adequate levels of magnesium linked to low weevil populations [32]. Adequate levels of Mg were associated with low weevil populations. However, work in Ntungamo, south western Uganda found no significant relationship between Mg alone and the weevil population [33]. Magnesium was a limiting factor in Bukoba and K was a limiting factor in Ntungamo. Experimental results from Ntungamo further revealed that weevil population increased as the K/Mg ratio declined from optimum, implying that more

ajfand SCHOLARLY, PEER REVIEWED AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT Volume 13 No. 2 April 2013 PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST ISSN 1684 5374

Mg above the optimum increases weevil populations. These results do contradict results from Bukoba although it is evident that balanced ratios of Mg, K, Ca and other nutrients in the soil are important in determining the intensity of pest attacks. More research is necessary to establish the correct direction of interaction.

OPPORTUNITIES AND CHALLENGES FOR INCREASING BANANA PRODUCTION

The potential yield of highland banana is 100 Mg ha^{-1} $cycle^{-1}$ FW [4]. Reported yields are usually < 50% of the potential. Yield is a result of an interaction of internal factors (tolerance to climatic stresses, photosynthesis rate, assimilate partitioning, chlorophyll contents) and external growth factors (climate – light, temperature, water, wind); edaphic factors (soil organic matter, pH, soil structure, available nutrients); biological (pests, beneficial organisms). In production, the goal is to maximize the growth rate through environmental or agronomic manipulation such as irrigation, fertilization, pest control, plant density and spatial arrangement. However, low quantities of mineral fertilizer imported and high transportation costs from Kenya to Uganda make them unaffordable to small scale farmers. Not surprising, farmers rated constraints to fertilizer adoption with the cost first, availability in nearby shops second, and uncertainty about the quality of fertilizer third [34]. Despite these constraints, profitable on-farm fertilizer responses were obtained under farmer management [14]. Government efforts should target increased access to mineral fertilizers and pesticides at affordable prices.

The profitability of fertilizer use in bananas is strongly related to the distance to the urban market [34, 35]. In addition, the banana chain is fragmented with farmers receiving about 44% of the market price [36]. This hinders the adoption of mineral fertilizers, because farmers will have less money to spend on inputs. Banana areas in central Uganda have a comparative advantage in marketing highland bananas due to proximity to the urban markets; however, production has reduced due to land pressure, labour shortage and pests and diseases [2]. Nonetheless, as the economy develops, population urbanizes, incomes increase, market infrastructure expands, and agriculture operates on a more commercial basis. The current level of urbanization has already created markets for banana, due to their traditional preference. However, this demand has not been translated into improved crop management, probably due to low banana farm-gate prices, which have to be increased. This can be through formation marketing cooperatives, that can help bargain for better prices.
.
Within the banana cultivars, susceptibility to pests differs. Reported weevil damage scores two to three times higher were reported in Kisansa and Nassaba (both belonging to Musakala clone set) than in Mbwazirume and Nakyetengu (both belonging to Nakitembe clone set), while the extent of weevil penetration into the central cylinder was highest for Nakitembe, Namwezi (Nfuuka clone set) and Musakala (Musakala clone set) [37]. These results may partly explain the risk aversion strategies of banana farmers through planting several cultivars. However, this information coupled with moisture stress tolerance may serve as a basis for

Published by African Scholarly Science Communications Trust
Josem Trust Place, Bunyala Road, Upper Hill, Nairobi
P.O. Box 29086-00625 Tel: +254-20-2351785 Fax: +254-20-4444030, Nairobi, KENYA
Email: oniango@iconnect.co.ke OR info@ajfand.net www.ajfand.net

selecting the best cultivars.

Soil moisture stress, especially in the early stages and at critical stages such as flower initiation, has been reported to severely affect bunch size [4]. Since irrigation is not practiced on banana farms, farmers should be encouraged to harvest rain water and utilise water from streams in order to irrigate bananas during dry spells. This could result in price advantages due to off-season production.

NEW RESEARCH PERSPECTIVES

Most of the research on highland bananas has focused on pests and their influence on the response to fertilization. However, farmers currently recognise that declining soil fertility and moisture stress are the most important production constraints. In most of the previous studies, yields in the pest infected plots were compared with a control where the pest pressure was absent. However, in such control plots, the assumption was that water, radiation and nutrient constraints were absent, but this is often false. It is clear that yields obtained on smallholder farms or on research stations are a result of interaction of a number of factors across altitude and rainfall gradients. There is a need to adopt a systems approach in order to understand the factors and their interactions in determining banana yield, rather than applying fertilizers to plots infested with weevils and where moisture stress is bound to reduce the response to fertilization further.

From the trials, nutrients limiting banana production have been identified. However, the importance of the deficiencies especially phosphorus (role in root development) and potassium (role in stomata opening and closure) is likely to increase with climate change. In addition, the deficiencies show strong spatial and temporal variability in banana systems [14]. This necessitates research on mineral fertilizer recommendations for the major banana producing areas, because rainfall amounts vary widely. With irrigation not practiced on banana farms, the combined application of organic and mineral fertilizers is probably a better option for increasing yields due to the synergetic effects. Strong synergy between the soil organic matter content (mulch and manure application) and mineral fertilizers was reported by Smithson [6] in an established banana plantation at Rubale, southwest Uganda. Banana yield was 67 Mg ha^{-1} yr^{-1} at a density of 700 mats ha^{-1}, with a fertilizer application of 100N−25P−100K kg ha^{-1} yr^{-1}. The addition of organic materials leads to improved water infiltration, a better soil structure [26], and increased faunal activity [38]. This improves the recovery efficiency of mineral fertilizers. Research and extension efforts should target increased production of grasses, for example, on farm boundaries such as elephant grass.

Soil moisture is a crucial constraint, necessitating the use of soil and water conservation measures like mulching and the construction of trenches. However, availability of organic materials and labor are key constraints. Considering the annual variations in rainfall, it is important to provide additional water especially during the dry spells. More research on simple water harvesting techniques and gravity flow schemes is required. The benefit-cost ratios of irrigation in order to maintain soil moisture pF < 2.5 need to be determined by researchers. Profitability of this intervention may largely depend on the proximity to the urban market (low transportation costs) because of the increased production costs.

CONCLUSIONS

From this study, the following conclusions can be made:

1- Declining soil fertility, increasing pest pressure and moisture stress are the key production constraints cited by farmers.

2- Increasing banana prices, urbanisation and infrastructure development are likely to increase demand for bananas and reduce the transportation costs. For banana farmers to be able to increase their incomes, support from government and other agricultural organizations is crucial. This can be in form of farmer education through on-farm demonstrations on research plots of new or improved technologies.

3- In order to reduce the production constraints, banana research should embrace a systems approach (complete understanding of how plant-soil-environmental factors interact to determine banana yield). Research should be done on mineral fertilizer recommendations for the major banana producing areas. With irrigation not practiced on banana farms, the combined application of organic and mineral fertilizers is probably a better option for increasing yields due to the synergetic effects. However, research should also focus on simple rainwater harvesting techniques and the benefit-cost ratios of irrigation.

ajfand SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 13 No. 2
April 2013
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

Table 1: Response of East Africa highland bananas to organic and mineral fertilizers at different sites in Uganda

Source / Topic	Location/s	Description / Growth conditions / applications (kg $ha^{-1}yr^{-1}$)	Cultivar	Yield control (Mg ha^{-1} yr^{-1})	Yield treatments (Mg ha^{-1} yr^{-1})
Agricultural record investigations (1950−1952)[1]	Kawanda Agricultural Research Institute	Rain-fed conditions, Weevils and nematodes not controlled	Nakabululu	9.25	12.5
			Nandigobe	7.25	9.5
			Namwezi	5.50	10.75
			Lwewunzika	6.00	7
			Siira	2.75	10
			Mbwazirume	2.75	9.5
			Muvubo	4.75	5.25
			Nakitembe	2.50	4.25
Nitrogen and potassium fertilizer response under variable pest pressure[2]	Kabulasoke (central Uganda)	Rainfed, on-farm (under farmer management)	Nabusa (dominant)	4.1 (25 kg P $ha^{-1}yr^{-1}$ applied)	
		25P+100K			3.7
		25P+100N			5.0
		25P+100K+100N			7.1
		25P+200K+100N			8.0
	Kalegebanda (central Uganda)	Rainfed, on-farm (under farmer management)	Kisansa (dominant)	4.9 (25 kg P $ha^{-1}yr^{-1}$ applied)	
		25P+100K			7.2
		25P+100N			11.8
		25P+100K+100N			8.5
		25P+200K+100N			9.6
	Rubale (southwest Uganda)	Rainfed, on-farm (under farmer management)	Nyanshenyi (dominant)	45.6 (25 kg P $ha^{-1}yr^{-1}$ applied)	
		25P+100K			43.2
		25P+100N			53.4
		25P+100K+100N			67.3
		25P+200K+100N			44.8

ajfand SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 13 No. 2
April 2013
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

Table 1: continued

Effect of potassium and magnesium fertilizers on banana[3]	Bulingwe (central Uganda)	Rainfed, on-farm (under farmer management)	Mixed	3.1	
		100K−0Mg			4.9
		100K−25Mg			3.5
		100K−50Mg			3.2
	Muyogo (southwest Uganda)	Rainfed, on-farm (under farmer management)	Mixed	14.4	
		100K−0Mg			18.9
		100K−25Mg			17.9
		100K−50Mg			18.2
Effect of potassium deficiency, drought and weevils[4]	Mbarara, southwest Uganda (NARO-IITA research farm)	Rainfed	Enyeru		
		100N−50P−100K (1998)		6.8	8.5
		100N−50P−100K (1999)		9.8	14.2
		100N−50P−100K (2000)		15.6	24.1
		100N−50P−100K (2001)		15.1	23.3
Management practices for highland banana[5]	Region	Rainfed, farmer management	Mixed		
	Central Uganda	71N−8P−32K		12.4	20.4
	South Uganda	71N−8P−32K		9.7	19.7
	Eastern Uganda	71N−8P−32K		25.5	32.6
	South-west Uganda	71N−8P−32K		20.0	24.8
Understanding banana growth[6]	Kawanda (central Uganda)	Rainfed, weevils controlled	Kisansa	18.2	
		0N–50P–600K			25.4
		150N–50P–600K			19.2
		400N–0P–600K			23.7
		400N–50P–0K			19.7
		400N–50P–250K			22.9
		400N–50P–600K			22.1
	Ntungamo (southwest Uganda)	Rainfed, weevils controlled	Kisansa	13.7	
		0N–50P–600K			33.8

ajfand SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 13 No. 2
April 2013
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

	150N–50P–600K	39.6
	400N–0P–600K	27.9
	400N–50P–0K	13.0
	400N–50P–250K	36.4
	400N–50P–600K	43.2

Adapted from various sources:

[1]Jameson Department of Agriculture record of investigations Printed at Entebbe, Uganda, 1950−1952, 1951.

[2]Smithson PC, McIntyre BD, Gold CS, Ssali H and IN Kashaija Nitrogen and potassium fertilizer versus nematode and weevil effects on yield and foliar nutrient status of banana in Uganda, *Nutr. Cycl. Agroecosyst.* 2001; 59: 239-250.

[3]Smithson PC, McIntyre BD, Gold CS, Ssali H, Night G and S Okech Potassium and magnesium fertilizers on banana in Uganda: yields, weevil damage, foliar nutrient status and DRIS analysis. *Nutr. Cycl. Agroecosyst.* 2004; 69: 43-49.

[4]Okech SH, van Asten PJA, Gold CS and H Ssali Effects of potassium deficiency, drought and weevils on banana yield and economic performance in Mbarara, Uganda. *J. Agric. Sci.* 2004; 9: 511-519.

[5]Wairegi LWI Management practices and opportunities in East African highland banana (Musa spp. AAA-EA) production in Uganda, PhD thesis, Wageningen University, Netherlands, 2010.

[6]Nyombi K Understanding growth of East Africa highland bananas: experiments and simulation, PhD thesis, Wageningen University, Netherlands, 2010.

REFERENCES

1. **Allan W** The African Husbandman. Barnes and Noble, New York, USA, 1965.

2. **Gold CS, Karamura EB, Kiggundu A, Bagamba F and AMK Abera** Monograph on geographic shifts in highland cooking banana (Musa, group AAA-EA) production in Uganda, *Afr. Crop Sci. J.* 1999; **7**: 223-298.

3. **Bekunda M and PL Woomer** Organic resource management in banana based cropping systems of the Lake Victoria basin, Uganda, *Agric Ecosyst. Environ.* 1996; **59**: 171-180.

4. **Nyombi K** Understanding growth of East Africa highland bananas: experiments and simulation, PhD thesis, Wageningen University, Netherlands, 2010.

5. **Davies G** Banana and Plantains in East African highlands. In: Banana and Plantains. Gowen S (ed) Chapman and Hall publishers, 1995.

6. **Smithson PC, McIntyre BD, Gold CS, Ssali H and IN Kashaija** Nitrogen and potassium fertilizer versus nematode and weevil effects on yield and foliar nutrient status of banana in Uganda, *Nutr. Cycl. Agroecosyst.* 2001; **59**: 239-250.

7. **Ssali H, McIntyre BD, Gold CS, Kashaija IN and F Kizito** Effects of mulch and mineral fertilizer on crop, weevil and soil quality parameters in highland banana, *Nutr. Cycl. Agroecosyst.* 2003; **65**: 141-150.

8. **Wairegi LWI, van Asten PJA, Kiwanuka C, Tenywa M and M Bekunda** Assessment of soil management practices in East African highland cooking banana (*Musa* spp. AAA-EA) systems in Uganda, paper presented at AFNET workshop, Arusha, Tanzania, 2007.

9. **Stover RH and NW Simmonds** Bananas. 3rd edition. Harlow Essex, UK. Longman Scientific and Technical, 1987.

10. **Department of Agriculture record of investigations** Printed at Entebbe, Uganda, 1948−1954 and 1st April 1950-31st March 1952.

11. **Zake JYK, Nkwiine C, Okwakol M, Sessanga S, Bwamiki DP and JK Tumuhairwe** Soil management for sustainable banana productivity in Uganda. In: Diagnostic survey on key constraints of banana production in Uganda. Working document, UNBRP, IITA, NRI, UK. Manuscript, 1994.

12. **Foster HL** The basic factors which determine inherent soil fertility in Uganda. *J Soil Sci* 1981; **32**: 149–160.

13. **Ssali H** Soil organic matter and its relationship to soil fertility changes in Uganda. In: Policies for Improved Land Management in Uganda: second national workshop. EPTD workshop summary paper no. 12 pp 99−107. Nkonya, E., Sserunkuuma, D., Pender J. (eds). International Food Policy Research Institute (IFPRI), Kampala, Uganda, 2002.

14. **Wairegi LWI** Management practices and opportunities in East African highland banana (Musa spp. AAA-EA) production in Uganda, PhD thesis, Wageningen University, Netherlands, 2010.

15. **Sseguya H, Semana AR and MA Bekunda** Soil fertility management in the banana-based agriculture of central Uganda: farmer’s constraints and opinions. *Afr. Crop Sci. J.* 1999; **7**: 559-567.

16. **Purseglove JW** Tropical crops: Monocotyledons. London, Longman, 1988.

17. **Hargreaves H** Insect pests of bananas. In: Tothill JD (ed.). Agriculture in Uganda. Oxford, UK, Oxford University Press, 1940.

18. **Rukazambuga NDTM, Gold CS and SR Gowen** The influence of crop management on banana weevil, Cosmoplites sordidus (Coleoptera: Curculionidae) populations and yield of highland banana (cv. Atwalira) in Uganda. *Bull. Entom. Res.* 2002; **92**: 413-421.

19. **Sengooba T** Survey of the banana pest problem complex in Rakai and Masaka districts: Preliminary trip report. Uganda Ministry of Agriculture, Kawanda research station, Uganda, 1986.

20. **Smithson PC, McIntyre BD, Gold CS, Ssali H, Night G and S Okech** Potassium and magnesium fertilizers on banana in Uganda: yields, weevil damage, foliar nutrient status and DRIS analysis. *Nutr. Cycl. Agroecosyst.* 2004; **69**: 43-49.

21. **Okech SH, van Asten PJA, Gold CS and H Ssali** Effects of potassium deficiency, drought and weevils on banana yield and economic performance in Mbarara, Uganda. *J. Agric. Sci.* 2004; **9**: 511-519.

22. **Zake JYK, Bwamiki DP and C Nkwiine** Soil management requirements for banana production on the heavy soils around Lake Victoria in Uganda. *Acta Hort.* 2000; **540**: 285-289.

23. **Taulya G, van Asten PJA, Okech SHO and CS Gold** Effect of drought on the yields of an East African highland banana (cv. Kisansa) in Uganda. Paper presented at the Soil Science Society of East Africa Conference, Masaka, Uganda, 2006.

24. **Rubaihayo PR, Odongo OJB and JA Bananuka** Some highland banana production constraints in Masaka district of Central Uganda. *In:* African Crop Science Conference Proceedings 1994; 1: 188-192.

25. **Bananuka JA and PR Rubaihayo** Banana management practices and performance in Uganda. African crop science conference proceedings 1994; **1**: 177-182. Adipala E, Bekunda MA, Tenywa, JS, Ogenga-Latigo MW and JO Mugah (eds).

26. **McIntyre BD, Speijer PR, Riha SJ and F Kizito** Effects of mulching on biomass, nutrients and soil water in banana inoculated with nematodes. *Agron. J*. 2000; **92**: 1081-1085.

27. **Bananuka JA** The Effect of Drought Stress and Cultivar on Growth and Yield of Bananas. PhD thesis, Makerere University, Kampala, Uganda, 2001.

28. **Gold CS** Biology and integrated management of banana weevil, Cosmoplites sordidus (Germar). In: Molina AB, Roa VN and MAG Maghuyop (eds), Advancing banana and plantain R and D in Asia and the Pacific, INIBAP-ASPNET. pp 28-33, 2000.

29. **Ochieno DW** Endophytic control of *Cosmopolites sordidus* and *Radopholus similis* using Fusarium oxysporum V5w2 in tissue culture banana. PhD thesis, Wageningen University, 2010.

30. **Kashaija IN, McIntyre BD, Ssali H and F Kizito** Spatial distribution of roots, nematode populations and root necrosis in highland banana in Uganda. *Nem.* 2004; **6**: 7-12.

31. **Speijer PR, Budenberg B and RA Sikora** Relationships between nematodes, weevils, banana and plantain cultivars and damage. *Ann. App. Boil.* 1993; **123**: 517-525.

32. **Bosch C, Lorkeers A, Ndile MR and E Sentozi** Diagnostic survey: constraints to banana productivity in Bukoba and Muleba districts, Kagera region, Tanzania. Working paper no. 8. Tanzania/Netherlands Farming Systems Research Project, Lake Zone. Ari Maruku, Bukoba, Tanzania, 1995.

33. **Okech SHO, Gold CS, Speijer P, Ssali H and E Karamura** Relationships between soil fertility, banana weevil and nematodes in the East Africa highland cooking banana in Ntungamo, south western Uganda. In: Proceedings of the first international conference on banana and plantain for Africa. Craenen K, Ortiz R, Karamura EB, and DR Vuylsteke (eds). *ACTA Horticulturae* 2000; **540**: 505-511.

34. **van Asten PJA, Lorenzen J, Wairegi L, Mukasa D, Batte M, Muchunguzi P and M Pillay** Increasing Profitability of Bananas in Uganda through Improved Agronomic Management; identifying opportunities and constraints for improvement of banana coffee intercropping systems; and enhancing banana productivity in Uganda by disseminating new hybrids to farmers. International Institute of Tropical Agriculture (IITA) / Agricultural Productivity Enhancement Programme (APEP) – Technical report. pp 12-34. Kampala, Uganda, 2008.

35. **Bagamba F** Market Access and Agricultural Production. The Case of Banana Production in Uganda. PhD thesis, Wageningen University, the Netherlands, 2007.

36. **PIBID** Banana marketing and microfinancing in Uganda. Presidential Initiative on Banana Industrial development. Kampala, Uganda, 2009.

37. **Gold CS, Okech SH and R Ssendege** Banana weevil population densities and related damage in Ntungamo and Mbarara districts, Uganda. In: Africa crop science conference proceedings. Makerere University, Kampala, Uganda pp 1207-1219. Adipala E, Tenywa JS and MW Ogenga-Latigo (eds), 1997.

38. **Okwakol MJN and HN Kagole** Interactive effects of mulches and soil macrofauna on banana production at Kabanyolo, Uganda. Mimeo. pp 67, 1993.