Analysis of soil and plant nutrients in the spread of Banana Bunchy Top Disease in Rusizi District

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Abstract

Banana in Rwanda is an important crop; however it has many production constraints which limits its potential such as banana bunchy top disease (BBTD). This study was conducted to asses the role of soil and plant nutrients in the spread of banana bunchy top disease in Rusizi district specifically in Bugarama, Muganza and Nzahaha Sectors. Soil and plant samples were collected from selected farmers' fields having banana bunchy top incidence and managed differently. The samples were analyzed in laboratory for nutrients content. We sampled 12 fields plots in Bugarama plain (Bugarama, Muganza and low part of Nzahaha sector) where banana bunchy top disease was dominant and from 8 farm plots in the area surrounding Bugarama area (the remaining part of Nzahaha sector). The result showed that the parameters measured varies accordingly to BBTD incidence and banana plantation management. Additionally, it has been seen that, the reason limiting the spread of BBTD in the areas surrounding Bugarama plain was caused by many factors: Potassium, Calcium, Total Nitrogen and Phosphorus based on their existence at high level in the area with BBTD than in the area without BBTD. Altitude had an influence on the spread of BBTD; as altitude increased BBTD incidence decreases. Persistence of BBTD in Bugarama may be attributed to the low altitude of 963m

Key words: **Key words**: BBTD, Soil Nutrients, Plant Nutrients, Altitude, Spread

Introduction

Banana (Musa spp.) is the fourth most important food crop in the world after rice, maize and wheat. It is a staple food crop for about 70 millions of people in Africa including Burundi, Democratic Republic of Congo (DR Congo) and Rwanda (Frison and Sharrock 1999; INIBAP 2000). In Rwanda, banana is one of the major commodities in agricultural sector used as cash and food crop contributing 60-80% of household income. Bananas are grown on 213 000 ha and occupy 23% of arable land, considered as welfare sign. Community attaches considerable value to the banana crop beyond economic gain. Bananas became a social symbol of Rwandan culture, an obligatory element of every ceremony and essential agricultural landscape (Mpyisi et al. 2000). It is cultivated around the house, and is regarded as a symbol of prosperity and wellbeing (Lassoudière and Al, 1989). Unfortunately, banana yields are low due to constraints such as the banana bunchy top disease (BBTD) which is one of the most devastating viral diseases in many banana producing regions of Africa, Asia, and the South Pacific (Dale 1987; Su et al.2003). The occurrence of BBTD represents a serious threat to food security in the regions where banana is one of the main staple crops for small-scale growers.

BBTD is caused by the *banana bunchy top virus* (BBTV), a complex circular single-stranded DNA virus with multiple genomic components, belonging to the genus *Babuvirus* in the *Nanoviridae* family (Karan *et al*. 1994; Dale *et al*. 2000; Wanitchakorn *et al*. 2000; Horser *et al*. 2001; Su *et al*. 2003; Vishnoi *et al*. 2009). BBTV genetic diversity has been revealed, using pathological and molecular patterns, with the existence of two distinct groups of BBTV isolates (Karan *et al*. 1994; Wanitchakorn *et al*. 2000; Su *et al*. 2003). These two groups were designated as Asian and South Pacific groups. The Asian group comprises of isolates from Asian region such as the Philippines, Taiwan and Vietnam, while the South Pacific group contains isolates from different regions of the South pacific region of Australia and Fiji as well as isolates from regions located outside this South Pacific region such as Burundi, Rwanda, Egypt and India (Karan *et al*. 1994; Wanitchakorn *et al*. 2000; Horser *et al*. 2001).

The virus is transmitted in a persistent manner by the banana aphid, *Pentalonia nigronervosa* (Magee, 1927) as cited by Hooks et al. (2008). BBTV is also spread through infected plant suckers and other plant tissues used in banana propagation. Plants infected at cooler stage do not bear fruit, and fruits on the late infected plants are typically stunted and unmarketable (Hooks et al., 2008). Additionally, the virus spreads to suckers through the rhizome and thus the entire banana mat eventually becomes infected (Dale & Harding, 1998). Hooks et al. (2008) reported that the first symptom of the disease was indicated by the appearance of dark-green streaks on the undersurface of the leaf, and as the disease progresses, infected leaves become progressively stunted and malformed and have a more upright bearing than usual, eventually resulting in a bunchy display. The disease was reported in 1987 in the Rusizi valley encompassing parts of Rwanda and Burundi (Sebasigari and Stover 1987). From that period it persisted in Bugarama valley without spreading in surrounding areas of Rusizi District in western province of Rwanda.

Despite viral disease presenting the major threat of banana production in the region, no specific in-depth investigations have been undertaken to generate sufficient information of limiting factors of the spread of BBTD. This study was undertaken to investigate the role of soil and plant nutrients in spreading Banana Bunchy Top Disease in areas surrounding Bugarama Valley. Therefore, this study was conducted in three sectors Bugarama, Muganza and Nzahaha in Rusizi district, western province of Rwanda. The study aimed at assessing the role of soil and plant nutrients in the spread of BBTD. Soil and plant nutrients status in Bugarama plain where BBTD is dominant and in its surrounding areas where there is no BBTD and relationship between altitude and BBTD were also studied.

MATERIALS AND METHODS

Study area

The study was conducted in Rusizi district specifically in Bugarama, Muganza and Nzahaha sectors, in the western-province of Rwanda; bordering Burundi in the south, DRC in the west, Gashonga and Rwimbogo sectors in North and Gikundamvura sector in East (Figure 1). The site was purposively selected basing on the fact that there is dominance of Banana Bunchy Top Disease in Bugarama plain for a long time without spreading to other sectors of Rusizi district around. (Nsabimana *et al*. (2008).The area is located in imbo agroecological zone at 980 meters above sea level. The climate is tropical continental and humid with average temperature of 25^{o}C. The area has a bimodal rainfall regime with the short rain season from November to January and the long rain season from February to May. The altitude ranges from 900 to 1400m. The rainfall varies from 1050 to 1500mm, and soils (Figure 2) are of alluvial types (Verdoodt and Van Ranst, 2003).

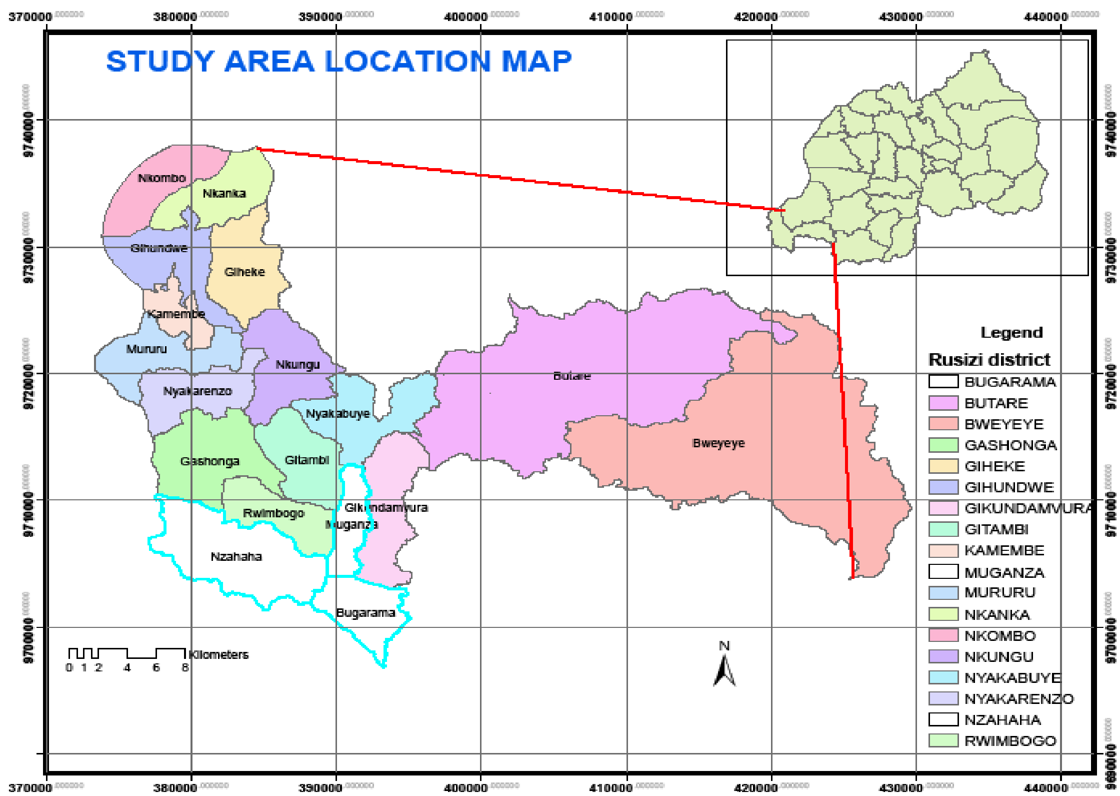

Figure 1: Administrative map of Rusizi district.

Methods

We used Focus Group Discussions (FGDs) in order to have an overall image of the BBTD and preliminary information. FGDs were held with farmers from different landscape locations, and from different socio-economical categories. The discussion was articulating principally about the history of BBTD, their evolution and the disease management. On the other hand, the identification of the disease was done by determining the incidence and severity. For each field, altitude was taken using GPS.

After identifying farms with different incidences, Bugarama, Muganza and low part of Nzahaha sector was considered as blocs which represent the areas dominated by Banana bunchy top disease. The above part of Nzahaha sector was taken as bloc without Banana bunchy top disease because there were no symptoms of disease. In order to see if there is any link between banana management used by farmers and BBTD, different fields with different managements was chosen. Four management practices, the most dominant in banana farming systems of Bugarama plain were taken as treatments: (T1) mulched banana; (T2) unmulched banana; (T3) intercropped banana and (T4) Abandoned banana. After identifying treatments, soil and plant samples was collected for further laboratory analysis.

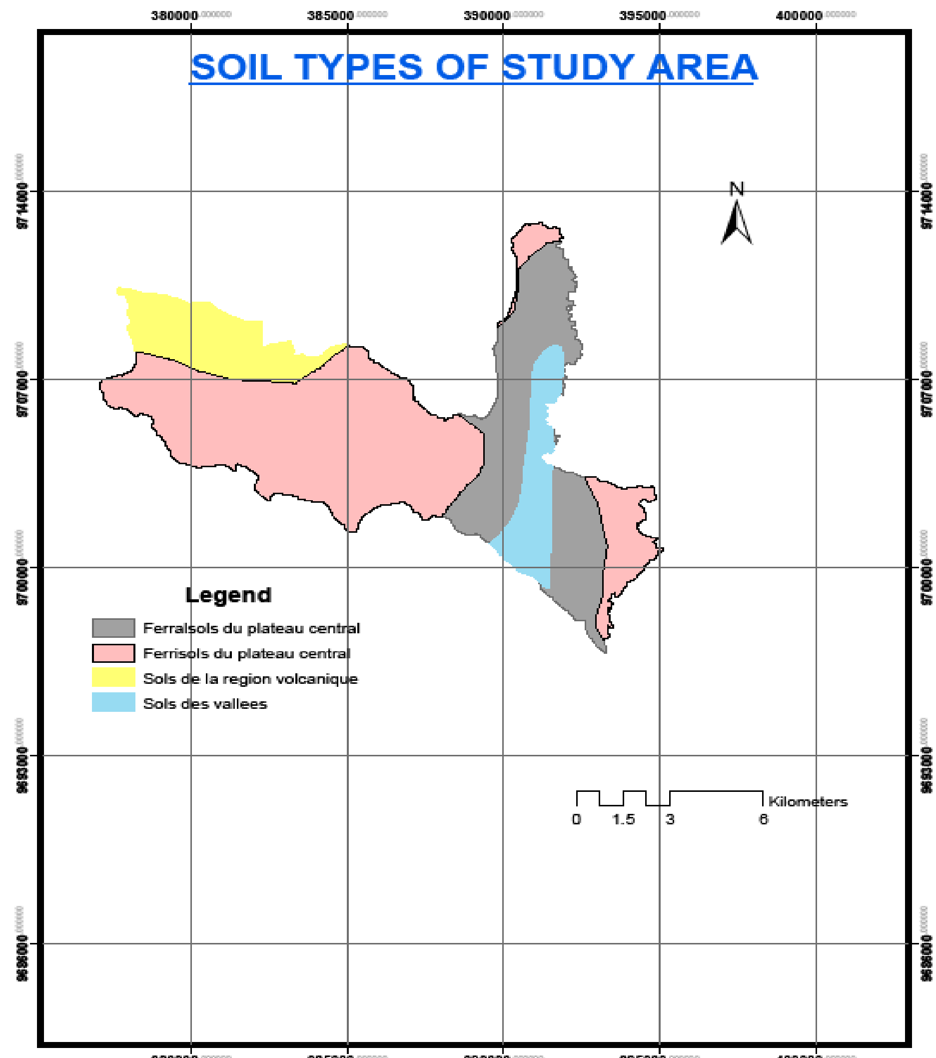

Figure 2: Soil types of studied area (Bugarama, Muganza and Nzahaha sectors)

EXPERIMENTAL DESIGN.

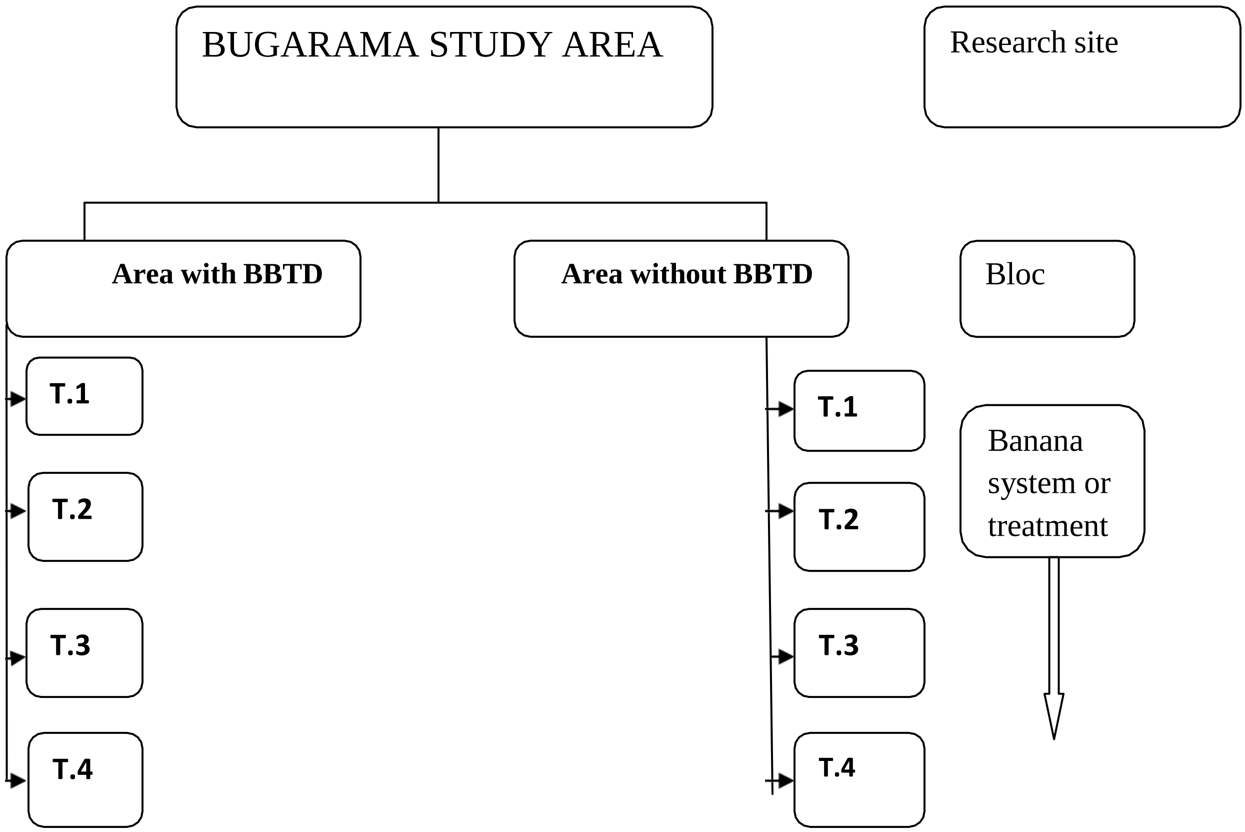

***Figure** 5: Experimental design*

T.1: Mulched Banana

T.2: Unmulched banana

T.3: Intercropped banana

T.4: Abandoned banana

Two – factor Randomized Complete Bloc Design (RCBD) was adopted as the experimental layout. To assess the effects of management practices on soil and plant nutrients accordingly to the presence of BBTD, experimental fields were selected using the following criteria.

a. Two (2) blocs, presence of banana bunchy top disease and absence of banana bunchy top disease.

b. Four management practices, the most dominant in banana farming systems of Bugarama plain were used as treatments: (T1) mulched banana; (T2) unmulched banana; (T3) intercropped banana and (T4) Abandoned banana.

Soil sampling techniques was a zone system where field was divided into almost homogeneous zone and sampling was done in place between banana rows at regular distance in each zone avoiding field border. Since the main proportion of the root system develops between 20 to 40 cm of the upper soil layer, therefore, physical, chemical and biological properties of the top soil are more crucial to banana plants than those of the deeper subsoil. An appropriate soil auger was used to collect soil samples from the two considered layers (20 and 40cm). For each layer, 700 to 1000 g of composite soil samples was packaged. The auger was cleaned by water and dried when moving from one layer to another and from one location to the next, in order to avoid cross contamination. After soil collection on each position, samples were carefully sealed in strong polyethylene bags and taken to laboratory where they were air dried then, conventional analytical methods were employed following procedures described in Okalebo et al., (2002). Banana leaves were taken following the recommendations of the Banana Foliar Analysis Standardization (Piqué *et al.*, 1996). A composite sample of ten banana leaves in each field of the area with BBTD and another composite sample for each field in the area without BBTD were taken. A composite leaf-lamina sample was taken from the third uppermost open leaf. This helped to determine the nutrients at leaf level of the plant.

The determination of the number of affected plants from each banana plantation was done by choosing randomly 30mats met on two diagonals traced by joining the four corners of the field and on which I evaluated 15 mats in a random way on each diagonal. The determination of the number of affected plants from that sample was used to express the proportion of affected plants as a percentage of total number in initial sample (Incidence): **Incidence**=Number of affected plants x 100/ Number of examined plant (Barnett, 1986; Nutter, 1991).

Laboratory Analysis

After collecting samples from the field, it has been brought to the Laboratory of department of soil and Environmental Management, Faculty of Agriculture, National University of Rwanda for routine chemical analysis. The soil samples were first air-dried, lightly ground and screened through a 2mm and 0.5mm sieve. Then conventional analytical methods that follow procedures described in Okalebo et al. (2002) was employed. pH water and pH KCl was determined using a pH meter in a 1:2.5 soil: water or KCl ratio, soil organic carbon by the Walkey-Black oxidation method, total N by Kjeldahl digestion, distillation and titration method, available P by the Olsen extraction method and exchangeable bases by the ammonium acetate extraction method, and from extracts concentrations of Ca was determined and Mg by atomic absorption spectrophotometry, K and Na by flame emission. Then ECEC was determined by summation of exchangeable bases and acidity. Plant samples were dried, after which they were ground to powder. To determine N by the Kjeldahl method. K, Ca, Mg, P and Fe were determined by atomic absorption spectrophotometry.

Data analysis

Microsoft Excel was used for data entry and management. ANOVA was performed using Genstat software for window 3rd edition (VSN-International Ltd., UK) to test the difference between soil nutrients partitioning into banana managements and plant nutrients partitioning into banana aboveground botanical biomass as affected by treatments. Mean comparison was based on least significant differences (*LSD*) at $P \leq 0.05$ and tested using F probability. The correlation between soil nutrients, altitude and BBTD were analyzed using SPSS software.

RESULTS

Soil parameters

Soil status analysis was limited to six parameters which are the main indicators of soil fertility. Those parameters are soil pH, Total nitrogen, available phosphorus, available basic cations and cation exchange capacity.

Soil pH

Table 1: *The mean-values of soil pH in different treatments*

Treatment	**Bugarama**	**Muganza**	**Nzahaha**	
	with BBTD			without BBTD
T1 (Incidence: 18%)	7.150	7.161	7.140	7.070
T2 (Incidence : 66%)	7.130	7.120	7.140	6.445
T3 (Incidence: 33%)	7.005	6.995	7.015	6.415
T4 (Incidence: 58%)	7.120	7.130	7.110	6.415
Probability	0.870	0.860	0.880	0.002
LSD	0.6123	0.6023	0.6223	0.2261

L.S.D. = Least Significant Differences of means,

The pH varies according to the farms managements which has different incidence values. The pH was significantly higher according to the interpretation norms (Mutwewingabo et al., 1989) in banana with incidence of 18% under mulched farms. This was based on the existence of undecomposed plant materials to that treatment which ameliorate soil acidity by making a complex with Al^{3+} (Wong and Swift (2003). This area is suitable for growing banana due to the pH which is included in the range of 5.5 and 7.7 (Simmonds 1985).

2. The mean-values of Total Nitrogen (%) in studied areas

Treatment	Bugarama	Muganza	Nzahaha	
	With BBTD			without BBTD
T1 (Incidence: 18%)	0.145	0.135	0.155	0.2450
T2 (Incidence : 66%)	0.100	0.08	0.11	0.2250
T3 (Incidence: 33%)	0.105	0.115	0.125	0.2950
T4 (Incidence: 58%)	0.150	0.140	0.130	0.1850
Probability	0.011	0.001	0.021	0.003
LSD	0.008	0.018	0.028	0.0259

There was a variation among banana management types. It was much higher in mulched banana with 18% of incidence compared to other treatments or managements. Similar findings were also reported in previous studies by Brady et al.,(2002), and showed that changes in soil management practices like mulching affect the content of total nitrogen, depending on the type and rate of mineralization of the mulching materials. Based on the standard interpretation norms by lassoudiere (2007) for the soils of Rwanda, the total nitrogen content is classified as low to moderate.

3.

The mean-values of Phosphorus (%) in studied areas

Treatment	Bugarama	Muganza	Nzahaha	
	With BBTD			without BBTD
T1 (Incidence : 18%)	20.87	19.37	22.37	21.67
T2 (Incidence : 66%)	7.46	10.46	8.96	13.96
T3 (Incidence: 33%)	10.15	11.65	8.65	11.84
T4 (Incidence: 58%)	17.86	19.36	20.86	19.21
Probability	0.032	0.022	0.042	<.001
LSD	0.007	0.008	0.009	0.980

L.S.D = Least Significant Differences of means

Available P was increased in soils under mulched banana. This was attributed to the effect of soil pH and organic matter content on the availability of P. The low pH in unmulched banana increased P-adsorption largely from the precipitation as $AlPO_4$ and $FePO_4$ oxides. As pH increases with mulching, the activity of Fe and Al decreases, this results in higher P concentration in solution. The effect of organic compounds on P availability is attributed by either the coating of Fe and Al particles by humus to form a protective cover or complexing Fe and Al by organic anions produced from the decomposition of organic matter (Brady et al., 2002), thus preventing their reaction with H_2PO_4. This hypothesis is supported by the work from Rashid, (2005) who found that increasing soil pH and organic matter were the main factors in P availability in banana soils.

EXCHANGEABLE BASES

1. The mean-values of Calcium (Cmol/kg)

Treatment	Bugarama	Muganza	Nzahaha	
	With BBTD			without BBTD
T1 (Incidence : 18%)	22.40	26.80	19.40	20.90
T2 (Incidence : 66%)	18.15	26.65	19.65	16.65
T3 (Incidence: 33%)	22.60	19.05	17.55	16.05
T4 (Incidence: 58%)	21.10	19.60	23.61	18.10
Probability	0.010	0.0125	0.011	0.009
LSD	1.240	1.260	1.250	1.555

2. The mean-values of Magnesium (Cmol/kg).

T1 (Incidence : 18%)	4.645	6.145	4.260	3.145
T2 (Incidence : 66%)	3.360	3.35	3.825	3.37
T3 (Incidence: 33%)	3.420	4.260	3.43	3.410
T4 (Incidence: 58%)	3.510	4.155	5.655	2.655
Probability	0.019	0.029	0.039	0.006
LSD	0.737	0.757	0.747	0.258

3. The mean-values of Potassium (Cmol/kg).

T1 (Incidence : 18%)	1.485	1.660	1.475	1.465
T2 (Incidence : 66%)	1.120	1.110	1.235	1.10
T3 (Incidence: 33%)	1.32	1.590	1.310	1.30
T4 (Incidence: 58%)	1.01	1.230	1.000	0.99
Probability	0.006	0.005	0.007	0.012
LSD	0.336	0.316	0.326	0.1999

4. The mean-values of Cation Exchange Capacity (CEC).

T1 (Incidence : 18%)	27.05	32.81	28.55	25.55
T2 (Incidence : 66%)	23.84	31.82	22.34	20.84
T3 (Incidence: 33%)	28.23	21.71	23.21	20.21
T4 (Incidence: 58%)	29.47	26.32	24.82	23.32
Probability	0.012	0.002	0.022	0.013
LSD	2.17	2.16	2.18	
1.910				

L.S.D = Least Significant Differences of means

The results of the exchangeable bases showed differences according to the types of banana management grouped as treatments. The low soil chemical fertility observed in abandoned banana implies nutrient mining by trees but also by nutrients exportation in mulches to banana plantations. Similar findings were reported by Woldeamlak et al., (2003). The high nutrients status observed in mulched banana than in abandoned was also reported by Gousseland (2003). Among the reasons the small leaching losses under perennial crops than annual crops was cited.

The accumulations of Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} in mulched banana are probably the results of decreasing nutrient losses by runoff related with low slope in Bugarama plain where BBTD is dominant. In the area without BBTD this accumulation can be attributed to soil conservation measures which dominate the area. In general, the soil nutrients status or the soil fertility level is classified as high to very high, and need additional mineral and organic inputs to improve the productivity and crop production. The studied soils show a good level of major exchangeable cations. Normally, perennial crops like banana are more resistant to Na^+ deficiency (Schroth and Sinclair, 2003).

Plant parameters

The mean-values of Total nitrogen (%).

Treatment	**Bugarama**	**Muganza**	**Nzahaha**	
	With BBTD			without BBTD
T1 (Incidence : 18%)	1.710	1.700	1.720	1.665
T2 (Incidence : 66%)	2.085	2.135	2.075	2.065
T3 (Incidence: 33%)	2.56	2.570	2.580	1.405
T4 (Incidence: 58%)	2.180	2.17	2.19	1.650
Probability	0.007	0.006	0.008	0.005
LSD	0.242	0.262	0.252	0.2024

The mean-values of Phosphorus (%).

T1 (Incidence : 18%)	22.98	23.015	31.950	23.00
T2 (Incidence : 66%)	26.235	26.25	26.950	26.265
T3 (Incidence: 33%)	31.05	31.03	31.06	24.555
T4 (Incidence: 58%)	21.93	21.96	29.500	21.95
Probability	0.024	0.014	0.034	<.001
LSD	465.0	463.5	466.5	22.53

The mean-values of Potassium (Cmol/kg).

T1 (Incidence : 18%)	38.890	37.890	51.789	39.890
T2 (Incidence : 66%)	35.858	43.135	36.858	37.858
T3 (Incidence: 33%)	24.162	43.520	22.162	23.162
T4 (Incidence: 58%)	25.069	44.366	27.069	26.069
Probability	0.002	0.003	0.001	<.001
LSD	1.4	1.39	1.41	1805.8

L.S.D = Least Significant Differences of means

The distribution pattern of the nutrients into different aboveground botanical parts of banana plants was also found by Kelling et al., (2000) where he found that the nutrients is highly accumulated in the leaves than in any other banana botanical parts. Based on the standard interpretation norms by Reuter and Robison (1986) reviewed in Okalebo *et al., (2002)*, the obtained results on nitrogen leaf content fall in deficient range for both banana growths in area with and without BBTD. Nitrogen is a major constituent of photosynthesis apparatus and that nitrogen is highly needed for the increase in number of leaves for banana plant (Charrier et al., 1997).

According to interpretation norms set by Reuter and Robison (1986), reviewed in Okalebo et al., (2002), the obtained results on leaf phosphorus content of banana plants are high. The partitioning into banana aboveground biomasses followed by phosphorus in banana leaves can be attributed to high pH in soil. This was also found by Charrier et al., (1997) where they found also that leaves constitute major uptake sites for Phosphorus. According to Brady and Weil (2002), this is due to the fact that phosphorus plays a major role in photosynthesis processes which explains its high leaf content when compared to other part. The fact that Potassium is highly accumulated in leaves was also found by Martin (2007) in Papua New Guinea, where they found that K is highly needed in banana nutrition during the flowering and fruiting. Due to high K accumulated in the fruit and plant tissue, K is considered the most important plant nutrient in banana production. It is the most abundant cation in the cells of the banana plant (Lahav, E. 1995).

Relationship between Altitude and BBTD

Figure 3 present the influence of altitude on Banana Bunchy Top Disease. This figure shows that, as altitude increases, BBTD decreases also.

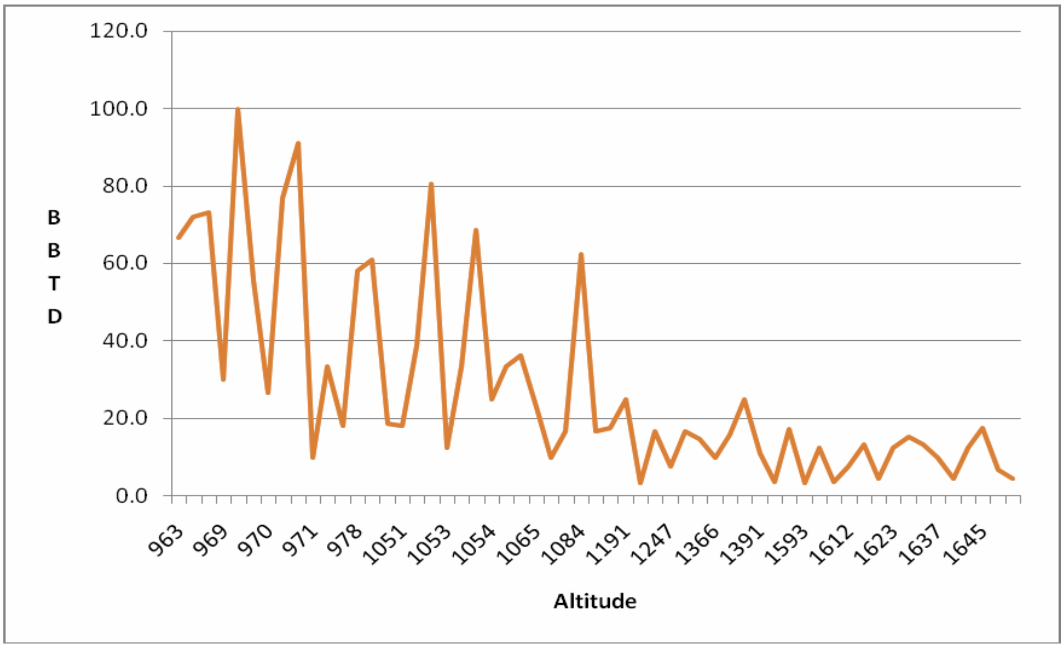

Figure 2: Influence of altitude on banana bunchy top disease

Altitude which goes with temperature showed an influence on BBTD spreading. Temperature can be seen as another factor limiting the spread of BBTD. Temperature which is high in the area with BBTD it means in Bugarama plain compared to the area without BBTD. In other words as the temperature decreases, BBTD decreases. These findings are in agreement with Antoine *et al*. (1989) who reported that transmission rate is 55 and 100% when BBTD acquisition temperature is 20 and 27^{0}C, respectively and although aphid activity at 16 and 20^{0}C is very low.

Conclusion

Despite the role of Banana in Rwandan economy, it has many production constraints which limit its potential such as soil fertility declining, poor management, pests and diseases. BBTD present the major threat of banana production in Bugarama plain since 1987 but no specific in-depth investigations have been undertaken to generate sufficient information of limiting factors of the spread of the disease. This study aimed at assessing the role of soil and plant nutrients in the spread of BBTD. Soil and plant nutrients status in Bugarama plain where BBTD is dominant and in its surrounding areas where there is no BBTD and relationship between altitude and BBTD were also studied. Soil and plant samples have been collected according to the incidence of the disease and Banana management techniques.

Results of this study revealed the soil and plant nutrients status in Bugarama plain where BBTD is dominant and in surrounding areas of Bugarama where there is no BBTD. It showed that soil nutrients like Potassium, Calcium, Phosphorus and Total Nitrogen can be seen as responsible for not spreading of Banana bunchy top disease based on their more presence in the area without BBTD than in the area without BBTD. As far as factors like banana management, landscape position was studied; results showed that different mulch materials applied in banana fields by banana growers have different efficiencies on soil nutrients and on nutrients uptake into banana above ground biomasses. This confirmed the influence of nutrients on the spread of Banana bunchy top disease. In addition, results showed that parameters like temperature and altitude had an influence on BBTD spreading. From this study, some preliminary recommendations can be made:

- The banana growers should enhance the use of mulch which only provides enough nutrients after their decomposition but also prevents against erosion.
- The development of banana production in western part of Rwanda can only be achieved through the control of banana bunchy top disease and the adoption of good management practices. Policy makers should help banana farmers to implement soil conservation measures, and should help farmers to restore the productivity of their soil as soil erosion is, among others, the cause of soil fertility degradation in the study area.

References

Brady N.C. and Weil R. R., 2002.*The nature and properties of soils, thirteen edition, Pearson Education*, Inc., Upper Saddle River, New Jersey 07458

Charrier, A., Jaquot, M., Nicolas, D., 1997. Amélioration des plantes tropicales. Cirad et Orstom, France.

Dale, J. L. 1987. Banana bunchy top: an economically important tropical plant virus disease. Adv. Virus Res. 33:301–325.

Dale J.L., Harding R.M. (1998) Banana bunchy top disease: current and future stratified for control. In Plant Virus Disease Control, pp. 659–669. Eds A. Hadidi, R.K. Khetarpal and H. Koganezawa. St. Paul, MN, USA: APS Press.

Delveaux, B., 1995. Soils in banana and plantain by Gower S. Champman et Hall, Landon. Pp 230-257.

Delepierre Go. (1974). Les régions agricoles du Rwanda. Note technique n°13, ISAR RUBONA, Butare, Rwanda 24p.

Eastwood, H.W. (1946). A successful campain. Bunchy top disease of bananas. Controlled by co-operative effort. *Agricultural Gazette* Nov, Dec, 1946, and Jan, 1947.

Frison, E. and Sharrock, S. 1999. The economic, social and nutritional importance of banana in the world. In: *Proceedings of International symposium on bananas and food security* held in Cameroon, Douala, 10-14 November 1998.

Gaidashova, S.V., Okech, S., Van den Berg, E., Marais, M., Gatarayiha, C.M. and Ragama, P.E. 2004. Plant parasitic nematodes in banana based farming systems in Rwanda: species profile, distribution and abundance. *African Plant Protection* 10:27-33.

Gaidashova, S. V., Karemera, F. and Karamura, E. B. 2008. Agronomic performance of introduced banana varieties in lowlands of Rwanda: *African Crop Science Society*. 16: 13-16

Gousseland J. 1983. Etude de l'enracinement et de l'émission racinaire du bananier 'Giant Cavendish' dans les andosols de la Guadeloupe. Fruits 38:611-623.

Hooks C.R.R., Manandhar R., Pereze. P., Wang k.H., and Almeida R.P.P., 2008. Comparative Susceptibility of Two Banana Cultivars to Banana Bunchy Top Virus under Laboratory and Field Environments. *Entomological Society of America*. 102: 897 – 904

INIBAP (International Network for the improvement of Banana and Plantain) (2000) Banana: Food for the poor. INIPAB, Montpellier, France

Kelling, K.A., S.M. Combs and J.B. Peters, 2000. Plant Analysis as a diagnostic tool.

Lassoudière A.,2007.,Le bananier et sa culture,edition Quac,ISBN:978-2-7592-0046-

Lahav E (1995). Banana nutrition. In: Gowen S (Ed.), Bananas and Plantains. Chapman & Hall, London pp: 258-316.

Martin–Prevel, P., 2007. Aspects dynamiques des éléments minéraux dans la production végétale: travaux sur bananier. Potassium Symposium. 9: 295–316. *In:* Lopez, A. and J. Espinosa, (eds.) *Manual on the Nutrition and Fertilization of Banana*. p. 54. Potash and Phosphate Institute of Canada.

Mpyisi, E., Nyarwaya, J. B. and Shyiringiro, E., 2000. Statistiques Agricoles: production agricole, élevage, superficie et utilization des terres. Annee agricole 2000. MINAGRI-FSRPUSAID.

Magee C.J.P. 1927. Investigation on the bunchy top disease of the banana. Council for Scientific and Industrial Research, Bulletin, 30, 1–64.

Magee, C.J.P. (1967). Report to the government of Western Samoa: the control of banana bunchy top. *South pacific commission, Technical paper* No 150

Mutwewingabo et Rutunga (1989). Les aspects de la fertilisation de sols acide dans les régions de hautes et moyenne altitudes du Rwanda en relation avec leurs propriétés physico-chimiques in premier séminaire sur la fertilité des sols du Rwanda. 265p.

Nsabimana A, Gaidashova SV, Antale GN, Karamura D, Van Staden J (2008) Banana cultivar distribution in Rwanda. *African Crop Science Journal* 16 (1), 1-8

Okalebo, J.R., Gathua K.W., and Woomer P.L.. 2002. *Laboratory Methods of Soil and Plant Analysis*: A working manual. Second edition, TSBF-CIAT and SACRED, Africa, Nairobi, Kenya.

Simmonds, N.W., 1985. Classification et amélioration génétique de la banane. Dans IRAZ-CRDI (1985) production et recherche sur la banane en Afrique de l'est et Afrique centrale. Acte de colloque régional tenu à Bujumbura, Burundi, du 14 au 17 décembre 1983. Pp 77-86.

Schroth, G. and Sinclair F.L., 2003. *Trees, Crops and Soil fertility: Concept and research Methods*. CABI Publishing. Cromwell Press. Trowbridge. Uk

Rashid, A., 2005. Soils: Basic concepts and principles. *In: Soil Science*. Memon, K.S. and A. Rashid, (eds.). National Book Foundation, Islamabad.

Robinson J.C. 1985. Root depth in bananas. Citrus Subtropical Fruit Research Institute Information Bulletin 155:6-8.

Woldeamlak, B. And Stroosnijder, L. 2003. Effects of agro-ecological land use succession on soil properties in the chemoga watershed, Blue Nile basin, Ethiopia. *Geoderma* 111: 85-98

Verdoodt A., Van Ranst E, (2003). *Land evaluation for agricultural production in the tropics. A large-scale land suitability classification for Rwanda*. Ghent University, Laboratory of Soil Science. Gent, Belgium. 258 p