Xanthomonas wilt of banana drives changes in land-use and ecosystem services across infected landscapes

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Abstract: Changes in land-use have been observed in banana-based systems in the African Great Lakes region affected by Xanthomonas wilt disease (XW) of banana. Through participatory focus group discussions (FGDs) and the 4-cell method, changes in land-use were retrospectively assessed in 13 XW-affected landscapes/villages along a 230 km transect from Masisi (XW arrived in 2001) to Bukavu (XW arrived around 2014) in eastern Democratic Republic of Congo during 2015. The four-cell chart ranked land-use by mapping the area under production and the number of households involved in production. Farmers' perceptions on the sustainability of new land-uses were also documented. Soil nutrient content and erosion levels were measured for five major land-use options/ trajectories on 147 fields across 55 farms in three landscapes along the transect. From being ranked the most important crop (92% of landscapes i.e. produced on large areas of land and by many households) before XW outbreaks, its importance had declined with most households in 36% of the landscapes growing it on smaller farms while in 64% of cases by few households on smaller pots. Farmers uprooted entire banana mats or fields, expanding land under other crops, mainly beans, taro, sweet potato, cassava, maize, coffee and eucalyptus. Species richness did not change at landscape level, though 21 crops were introduced at farm level. Land-use for banana is however still perceived to be more sustainable due to its multi-functional roles. Soils under banana plots were found in general to be better in their chemical attributes while high erosion levels (Mg ha^{-1} year^{-1}) were observed under cassava (1.7-148.9) compared with banana (0.3-10.7) and trees (0.3-5.9). The current shift away from banana could thus have profound effects on supply of key services and sustainability of the production systems. This study offers a good basis/entry point for interventions in the XW-affected landscapes.

Keywords: communities; disease; multi-functional; perceptions; soil erosion; uprooting.

1. Introduction

Musa spp. (banana and plantain, hereafter banana) is an important food and income fruit crop the world over [1]. The crop ranks sixth in production, with an annual world production of about 144.6 million Mg [2]. The East and Central African Great Lakes region contributes one third of the world production, with production estimates of 5.2, 1.8, 1.4 and 1.4 million Mg ha^{-1} year^{-1} reported for Uganda, Rwanda, Burundi and the Democratic Republic of Congo, respectively [2]. In this region, banana provides 30 - 60% of food energy needs of over 70 million people [3-4] and is also important for income generation through market sales [5-6]. The region is a secondary centre of diversity for the East African Highland bananas (AAA genome) and plantains (AAB genome) [7-8]. Banana in the region, is mainly grown as a perennial crop/permanent vegetation and plantations that are 30 to 50 years old are very common [9-10].

The crop is grown across a wide range of agroecological zones either as sole crop or in association with various annual or perennial crops, offering a broad range of ecosystem services in addition to food, feed and fibre [11]. The thick year-round canopy offered by its broad leaves, the mulch cover provided by dead leaves, leaf sheaths and harvested plant parts and an extended superficial root system help reduce soil erosion [12-14], hence contributing to the resilience of the agroecosystems. The banana crop could thus be considered as a foundation species in this part of the word. A foundation species is a common/ abundant species whose attributes (structural or functional) define an ecological community or ecosystem [15]. Tampering with a foundation species can potentially affect the socio-cultural, economic and ecological resilience of a landscape. Modest to dramatic decline has been observed over the past two decades in the lifespan and productivity of banana plantations, and food and income security of banana dependent households has been severely affected by pests (weevils and nematodes) and diseases (mainly Xanthomonas wilt, banana bunchy top disease and Fusarium wilt).

The banana Xanthomonas wilt disease (XW), the most recent constraint, has been particularly devastating to banana production in this period in the region. First observed in Ethiopia in 1939 [16], XW was reported in Uganda and eastern DR Congo in 2001 [17-18] and has since spread to the entire East and Central Africa region, compromising plantations, and food and income security at local, national and regional levels [19]. The disease causes death of affected plants and makes infected bunches inedible. As a control measure, or out of frustration, there has been widespread cutting and uprooting of diseased mats or fields. In response to the disease, farmers have also been reported to have diversified into other crop species and off-farm activities [20]. Thus, in addition to XW effects on food and income security, the disease has been postulated to be accompanied by changes in land-use and species composition at farm and landscape level, with potential positive or negative effects on the food systems and other ecosystem services. These changes have not been systematically documented as a basis for evaluating the repercussions to livelihood outcomes and ecosystem services in the affected landscapes.

This study retrospectively analysed the i) trajectories of change in land-use patterns in response to XW in the XW-affected landscapes, ii) changes in production, consumption and marketing of banana and other key crop species in the landscape, iii) soil nutrient content and amount of soil erosion for major land use types and iv) farmers' perceptions on the sustainability of the new land-uses. Objectives (i) and (ii) were achieved through recall studies in landscapes exposed to XW disease for time periods varying between 1 to 14 years. Objectives (iii) and (iv) were attained through field measurements and interviews across farms.

2. Materials and Methods

2.1   Study area

This study was conducted in the eastern part of the Democratic Republic of Congo (DR Congo) that comprises two provinces, North Kivu and South Kivu. The province of North Kivu covers an area of 59,631 km² and has 4.9 million inhabitants. It is located between 0° 58' latitude North to 02° 03' latitude South and 27° 14'-29° 58' longitude East [21], mean annual rainfall ranges between 1268 mm and 1556 mm and an altitude range of 909 - 1803 meters above sea level (m) [22]. South Kivu is located between 1° 36' - 5° latitude South and 26° 47' - 29° 20' longitude East and has an area of 69,130 km², a population of 3.9 million people [21]. Annual rainfall in South Kivu varies between 1,437 mm and 1,661 mm and an altitude range varying between 950 to 2019 m [22]. In this predominantly highland region, agriculture is the main basis of livelihoods of the rural and peri-urban population, with most of them farming at a subsistence level. Banana and plantain are important staple and cash crops contributing to the food and income security of over five million people [23]. For example, banana/plantain and their products (e.g. beer) were reported to provide about 80 percent of incomes in South Kivu [24].

2.2   Land-use trajectories and food systems

The study was conducted along a 230 km-long axis from Masisi in North Kivu province to Bukavu in South Kivu province (Fig. 1) in 2015. This transect was selected as a case study because it starts at a disease front and comprises sites with various timespans of high disease presence/pressure.

The data for this study was collected using a total of 13 village-level focus group discussions (FGDs). Eleven of the 13 FGDs were conducted at approximately 20 km interval along the 230-km axis starting from Kahanga-Kabingu village in Masisi territory to Kashusha village in Bukavu, while the other two FGDs were conducted on Idjwi Island (i.e., Idjwi North and Idjwi South) located in Lake Kivu, South-Kivu province (Fig. 1, Table 1). XW was first reported at Masisi in the year 2001 while it arrived at Bukavu, the last FGD location, in 2014 (Fig. 1, Table 1).

The snowball sampling technique was used for the identification of parishes affected by XW along the study transect. With the snowball sampling technique [25], the existing study objects inform the recruitment of the subsequent subjects based on their acquaintance. Within the parishes, villages affected by XW were purposively sampled for the FGDs through interaction with community leaders, key informants and extension agents in the study area (Table 1).
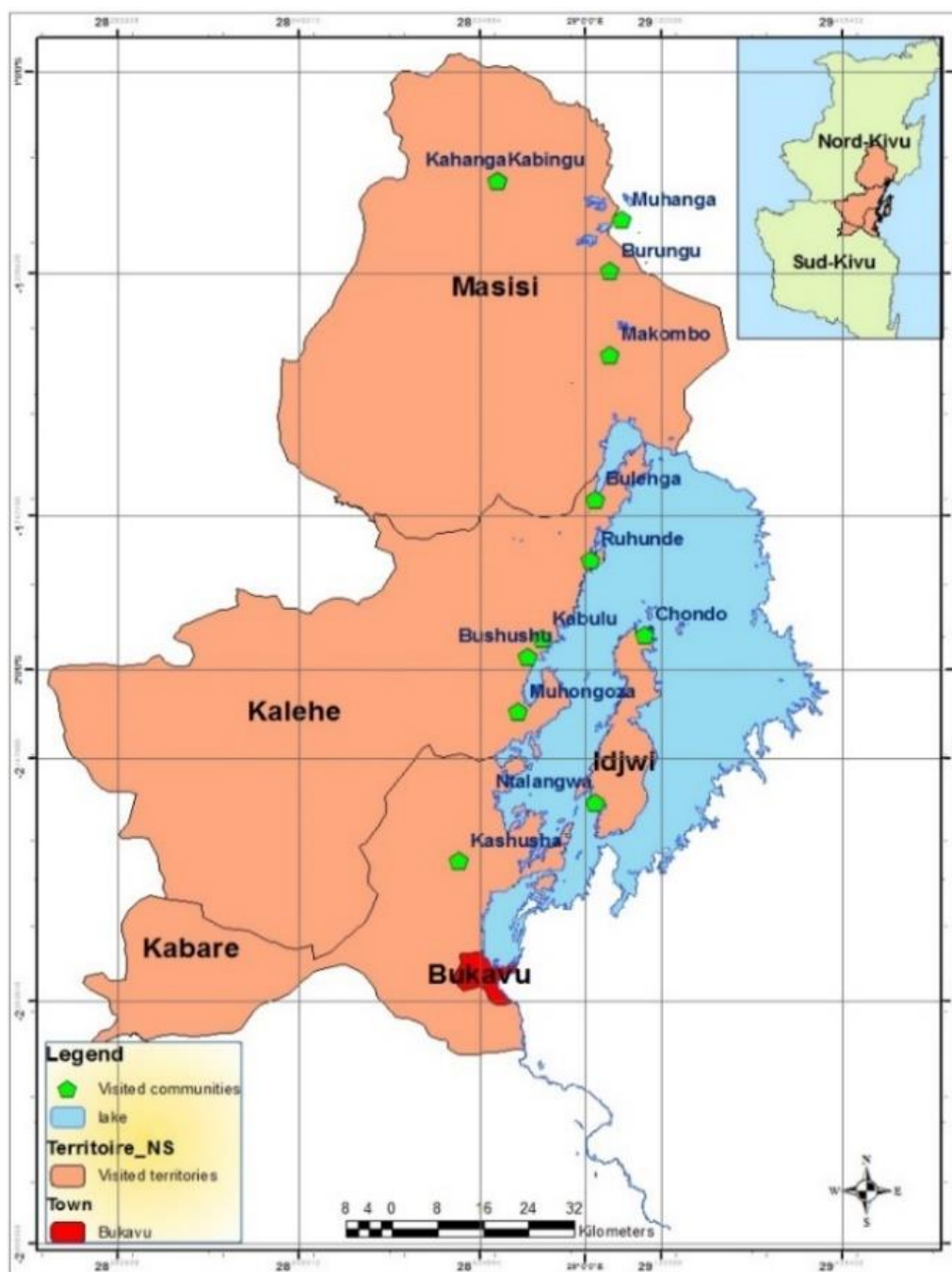
Figure 1. Map showing the locations of the communities/landscapes that participated in the Focus Group Discussions conducted in North and South Kivu provinces in eastern DR Congo.

A total of 10 farmers in a sex ratio 1:1, each at least 30 years of age participated in FGDs. Precaution was taken to select only farmers that had been fully active in the study sites for a period of over 10 years. It was postulated that this category of farmers had a better understanding/experience with the impact of the biotic stresses, especially XW, and understanding of the changes and trajectories in the crop diversification and food systems at these sites. The distribution of the FGDs in the study area is detailed in the Table 1 below.

Table 1. The positioning of the sampled villages and focus group discussions along the 230 km study axis.

Province	Territory	Village	Year of XW outbreak	Longitude	Latitude	Altitude	Distance from Masisi
North-Kivu	Masisi	Kahanga- Kabingu	2004	-	-	-	0
		Muhanga	2001	S01.24778	E029.05931	1701	20
		Burungu	2004	-	-	-	40
		Makombo	2008	S01.47358	E029.04045	2010	60
South-Kivu	Kalehe	Bulenga	2005	S01.71581	E29.01702	1525	80
		Ruhunde	2005	S01.81677	E029.00951	1520	100
		Kabulu	2005	S01.94952	E028.93301	1757	120
		Bushushu	2009	S01.97875	E28.90992	1486	140
		Muhongoza	2004	S02.07115	E28.89534	1585	160
	Kabare	Kahanga	2009	S01.18282	E028.8617	1488	180
		Kashusha	2012	S02.32044	E28.80240	1713	210
	Idjwi	Chondo	2002	S01.94219	E029.09471	1550	-
		Ntalangwa	2008	S02.22220	E029.01602	1492	-

The FGDs were guided using a structured questionnaire. The facilitator used a checklist to elicit information from the participants and probed for triangulation of the responses whenever necessary. Care was also taken to ensure full participation of all the FGD participants. A four-cell chart [26-27] was used to retrospectively rank the trajectories and changes in crop species and cultivar diversification and importance in landscapes affected by XW. The four-cell is a participatory rapid rural appraisal technique created to assess agrobiodiversity and local food system flows [28, 27}. It allows for a quick identification and assessment of changes in food security and diet diversity [27]. The four-cell chart ranks species abundance and distribution by looking at area under production and the number of households involved in production. This results into four cells or groupings i.e. a species being grown on: i) a large acreage and being produced by many households; ii) large acreage but by few households; iii) small acreage but by many households and iv) small acreage and few households (Fig. 2).
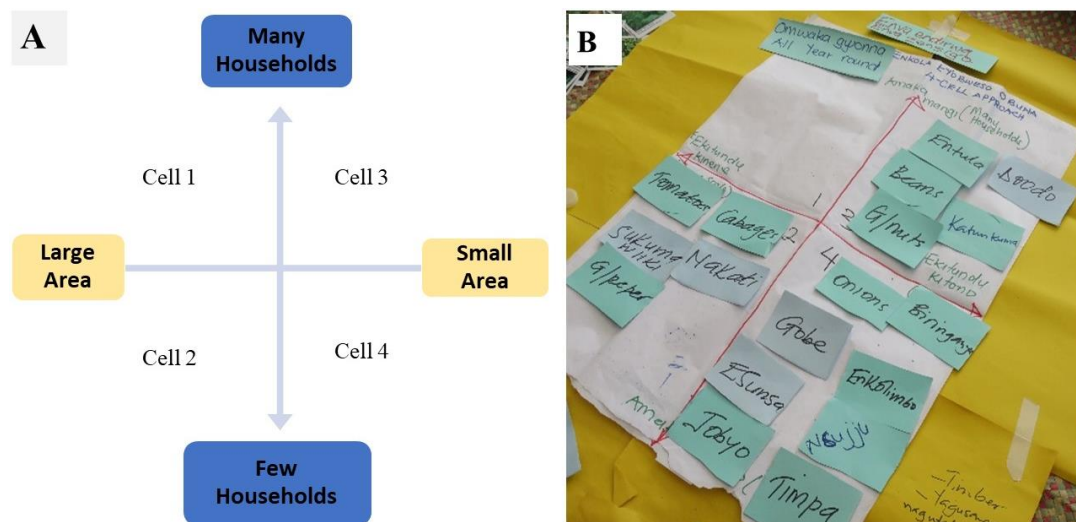
Figure 2. A four-cell chart (A) and an example of farmers posting of different crop species on a four-cell chart within a landscape and a point in time (B). The four-cell analysis were conducted across 13 landscapes in South/North Kivu provinces, eastern DR Congo.

Data were coded and analysed using both quantitative and qualitative methods. Descriptive statistics were carried out using STATA and GenStat v. 12 software [29]. MS Excel was used for developing figures. The qualitative information was either used to explain and interpret the quantitative information provided by the respondents during the group discussions or compiled and sorted through a coding process to generate descriptive tables and figures.

2.3 Effect of XW driven land use trajectories of change on selected supporting and regulatory ecosystem services

To determine the potential effect of land use changes and trajectories on selected supporting and regulatory services (objective iv), 147 fields spread across 55 farms on three sites along the transect, namely Idjwi North (Northern part), Katana (midway) and Mushinga (southern part) were examined. All the three sites are in South Kivu province. Soil related agroecosystem services such as pest and disease regulation, nutrient flows, soil formation and structure are provided by several interrelated processes that govern decomposition, soil formation, soil structure, erosion control, soil moisture and aeration, and cycling of mineral nutrients and carbon [30]. These soil variables are thus a good measure of the effect of farm management on soil health and a good proxy for soil ecosystem services [30-32]. To infer the potential effect of the land-use trajectories of change due to XW on ecosystem services, soil chemical properties and soil erosion rates were determined. Soil chemical properties served as a proxy for nutrient recycling, an import supporting ecosystem function, while soil erosion rates served as proxy for erosion control, an important regulatory service in the landscape.

2.3.1 Soil carbon and nutrients

The content of soil organic matter (SOM), total nitrogen (N), available phosphorus and exchangeable bases (K and Ca) were measured as indicators for soil quality and were used to compare different land-use options and to infer the potential impact of the land-use trajectories. Composite samples of five soil cores (2 cm in diameter and 15 cm deep; using a soil auger) were collected diagonally in fields under different land uses (crops or plant species) in the middle of the main

growing season (i.e. October 2016). Each sample was air dried, sieved to pass through a 2-mm mesh and analysed for soil pH and nutrient composition at the National Agricultural Research Laboratories, Kawanda, in central Uganda. The exchangeable cations and available phosphorus were extracted using Mehlich 3 extraction method at a pH of 2.5 [33] then determined using an atomic absorption spectrophotometer. Soil organic carbon content was determined colorimetrically at 600 nm after digestion with potassium dichromate and sulphuric acid (Walkley-Black). Nitrogen was extracted using sulphuric/selenium digestion mixture, at 330ºC and later quantified colorimetrically using salicylate method. pH was read from a 1:2.5 soil:water extract. Soil texture was determined using the Bouyoucos hydrometer method [34].

Mean levels of SOM, N, available phosphorus and exchangeable bases across the different land use options were analysed through Analysis of Variance, with means separation using LSD at 5%. The GenStat statistical package v.12 [29] was used for the analysis.

2.3.2   Soil erosion losses

Erosion rates for different land uses were determined using the revised universal soil loss equation (RUSLE) [35-37]. RUSLE estimates the annual erosion rate on a field based on field slope, rainfall intensity, soil type, crop characteristics and management practices. It is expressed as [35]:

$$A = R*K*LS*C*P \qquad (1)$$

Where: A = estimated average soil loss (Mg ha^{-1} year^{-1}); R = rainfall-runoff erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}); K = soil erodibility factor (Mg h MJ^{-1} mm^{-1}); L = slope length factor; S = slope steepness factor; C = cover-management factor; and P = support practice factor.

Rainfall-runoff erosivity (R) is a measure of erosion potential of a rainfall event and is influenced by duration and intensity of the event; and R for the study site were in the order of 3,750 MJ mm ha^{-1} h^{-1} year^{-1}, as calculated by Vrieling et al. [38]. Soil erodibility factor K is a measure of susceptibility of soil particles to detachment and transport by rainfall and water runoff. K was determined using the method developed by Kassam et al. [39] for Kenyan soils. Using this approach, soil texture results for each land-use unit/ field (see Section 2.3.1) and soil units for the study areas were used as input for determining the K classes and the associated K values. The soil units for Mushinga, Katana and Idjwi were respectively, haplic Acrisols, humic Cambisols and haplic Ferralsols [40-41]. On farm data for input in the RUSLE included the slope length (L) and steepness (S) of fields, main crop species grown on fields, tillage practices and supportive field management practices. The lengths for each field or segment, was measured using a 100 m length tape measure whereas the % slope was computed using the equation:

$$S = \text{Rise of slope/ Run of slope} *100\% \qquad (2)$$

The rise (m) was obtained from the difference between the elevations of the upper and lower parts of the field along the length of the slope measured using global positioning unit (GPS, **Garmin -**

GPSMAP 64s; www.garmin.com) whereas run of slope was obtained using the Pythagoras theorem (i.e. Run of slope^2 = L^2 – Rise of slope^2).

LS, which is the proportion of soil loss under a given condition compared to that of a site with a standard slope steepness of 9% and length 22.13 m was determined as described by Stone and Hilborn [37] using:

$$LS = [0.065 + 0.0456 \, (S) + 0.006541 \, (S)^2] \, (L \div \text{constant})^N \qquad (3).$$

Where: S = slope steepness in %; L = length of slope (m); constant = 22.13 m; and N= N values of 0.2, 0.3, 0.4 and 0.5, respectively, correspond to S values of <1, 1≤ slope< 3, 3 ≤ slope < 5, and ≥ 5.

The crop management and tillage factor (C) determines the relative effectiveness of crop and soil management in prevention of soil erosion and was computed as the product of the crop type factor (score of 0 to 1) and the tillage method (score of 0 to 1) [37]. The plant/crop canopy cover factor (ranging between 0 and 1) was estimated using Equation (4) [41, 35]:

$$\text{Crop type factor} = 1 – Fc * \exp(-0.1 * H) \qquad (4)$$

Where Fc is the proportion of the ground covered by the canopy, H (ft) is the distance the raindrops fall after hitting the canopy. Fc and H were captured through visual assessments and estimations on farm. For the assessment of canopy height (H) in intercropped fields, one species was considered if dominant, otherwise an average was considered where two or more species had a more or less equal share of the land cover. Thus, the crop type factor was influenced by the level of species diversity and the attributes of the species complex. The tillage method factor was scored between '0' and '1' ('0' denoting good practice while '1' a bad practice) as described by Stone and Hilborn [37]. The supportive practice factor P is the ratio of soil loss through a supportive practice to that through farming up and down the slope and varies between a scale of '0' (good practice) to '1' (bad practice) [41, 37].

The tillage method factors, crop type/cover factor, the support practices and the soil erosion rates were compared across the dominant land-use options using Analysis of Variance (ANOVA) and the means separated as described in the Section 2.3.1 above. Due to an unequal distribution of land use options across the sites and the lack of interaction between the sites and land use options, ANOVA was only computed for the land use options.

2.4   Farmers' perceptions on the future role of banana crop and the sustainability of the key land-use trajectories in XW affected landscapes

Farmers perceptions on future role of banana and the ability of the major land use trajectories to fill the gap left by the banana crop obtained through structured interviews in the FGDs in 2.2 above and on farms.

3. Results and discussion

3.1 On-farm coping strategies against Xanthomonas wilt disease

Communities affected by XW disease reported several coping strategies (Fig. 3). The most prevalent practices across communities/ landscapes included uprooting of diseased mats, cutting of sick plants and removal of male floral buds to prevent insect-mediated infections (Fig. 3). These practices form the basic cultural control practices being promoted for managing XW disease [43]. Other practices being promoted such as farm tool sterilization and formation of community task forces to enforce disease control occurred in only 45% and 27% of the landscapes, respectively. Ochola et al. [44] reported some of these practices as the prevalent agroecological practices on farms affected by XW disease.
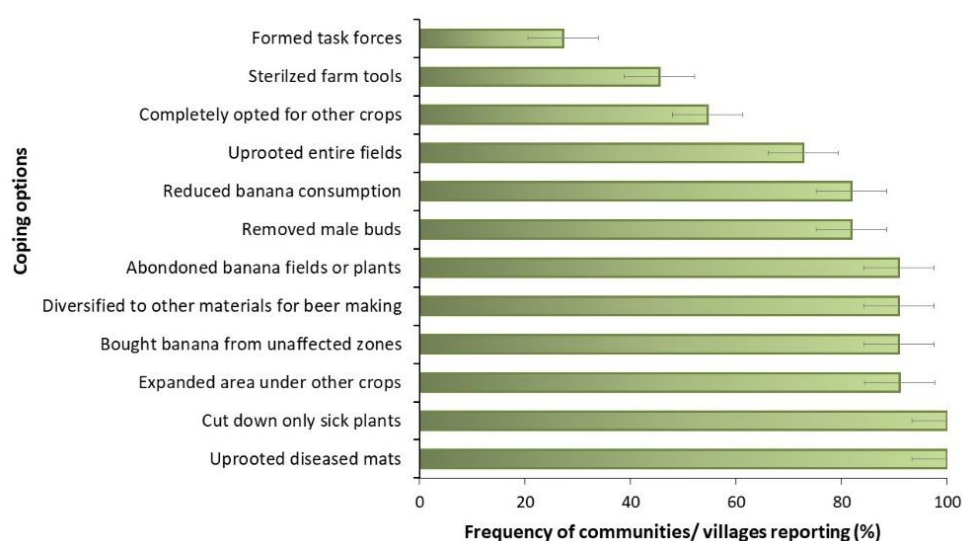

Figure 3. Responses and/ or coping strategies in reaction to Xanthomonas wilt across different banana growing communities/ landscapes in eastern DR Congo. Error bars represent standard errors.

Uprooting of entire banana fields was also prevalent across 73% of the communities. In 55% and 91% of the cases, landscapes reported the complete abandoning of the banana crop and expansion of the area under other crops, respectively (Fig. 3). This was mainly due to frustration due to severe yield losses and persistence of infections on farms. The consumption of banana also declined across 82% of the landscapes in eastern DR Congo while in 90% of the cases, households had diversified to other crops for beer making. Nkuba et al. [45] reported changes in diets, with an increased consumption of maize and root and tuber crops (36% of households) and a reduction in number and size of meals (52%) as coping strategies within households affected by XW in Rwanda and Tanzania.

3.2 Crop diversification trajectories due to Xanthomonas wilt disease

Prior to the outbreak of XW, farmers ranked banana as the most important crop on farms across the studied landscapes, followed by beans and cassava. However, following XW outbreak, crop rankings changed, with banana dropping to the fourth in importance, relative to the other crops, across the study landscapes (Fig. 4A). Food crops, mainly cassava, maize, sweet potato and soybean

gained in importance (Fig. 4A). Cassava currently ranks as the most important crop across the XW affected landscapes in eastern DR Congo. A big shift in ranking also occurred for soybean (13th to the 8th). The ranking of beans in the food system remained unchanged while coffee and taro dropped in importance.

A shift was observed towards increasing the area under a large number of crop species by many households (i.e. to cell 1), mainly from being grown on small areas by many households (i.e. cell 3) (Fig. 4B).
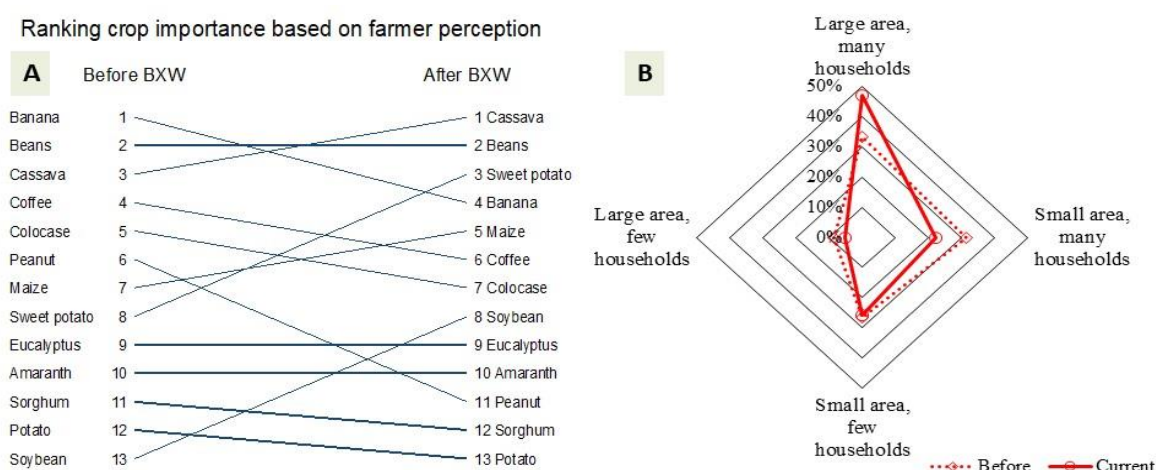

Figure 4. Farmers' perceptions on the rankings in importance of different crop species (**A**) and trends in crop species richness (%) on along the quadrants of a 4-cell chart (**B**) following the outbreak of XW in 13 landscapes in eastern Democratic Republic of Congo. Cells 1, 2, 3 and 4, respectively stand for a species being grown on i) a large acreage and by many households; ii) large acreage but by few households; iii) small acreage but by many households and iv) small acreage and by few households. Data was captured in the period 2015/16.

The four-cell chart predominantly grouped the banana crop into cell 1 before the outbreak of XW disease across the 13 XW-affected landscapes (Fig. 5). Banana was ranked first in 92% of the villages, produced on large land areas and by many households across the villages. Cassava (85%) and beans (46%) were also more likely to be grouped in cell 1 across the surveyed landscapes before the outbreak of the disease (Fig. 5; Chi^2 = 92.1, P <0.0001). At the time of this study (after or at the peak of XW epidemics), only a single village ranked banana first among the crop species. Farmers reported uprooting entire banana mats and/or fields while expanding land under other crop species and/ or introducing new crop varieties (Figures 3, 5). Banana no longer fell into cell 1 of the four-cell chart. In 36% of the villages banana was produced by many households but on small areas (cell 3), while in 64% of cases it was produced by few households on small areas (cell 4) (Fig. 5; Chi2 = 61.1, P <0.0001). Species richness did not change at landscape level, though 21 crop species were introduced at farm level across the villages. Pronounced changes in importance were mainly observed for 14 food crops and tree species, mainly beans, taro, sweet potato, cassava, maize, coffee, eucalyptus and soybeans in terms of area under production and the number of households producing them (Figures 5 and 6).
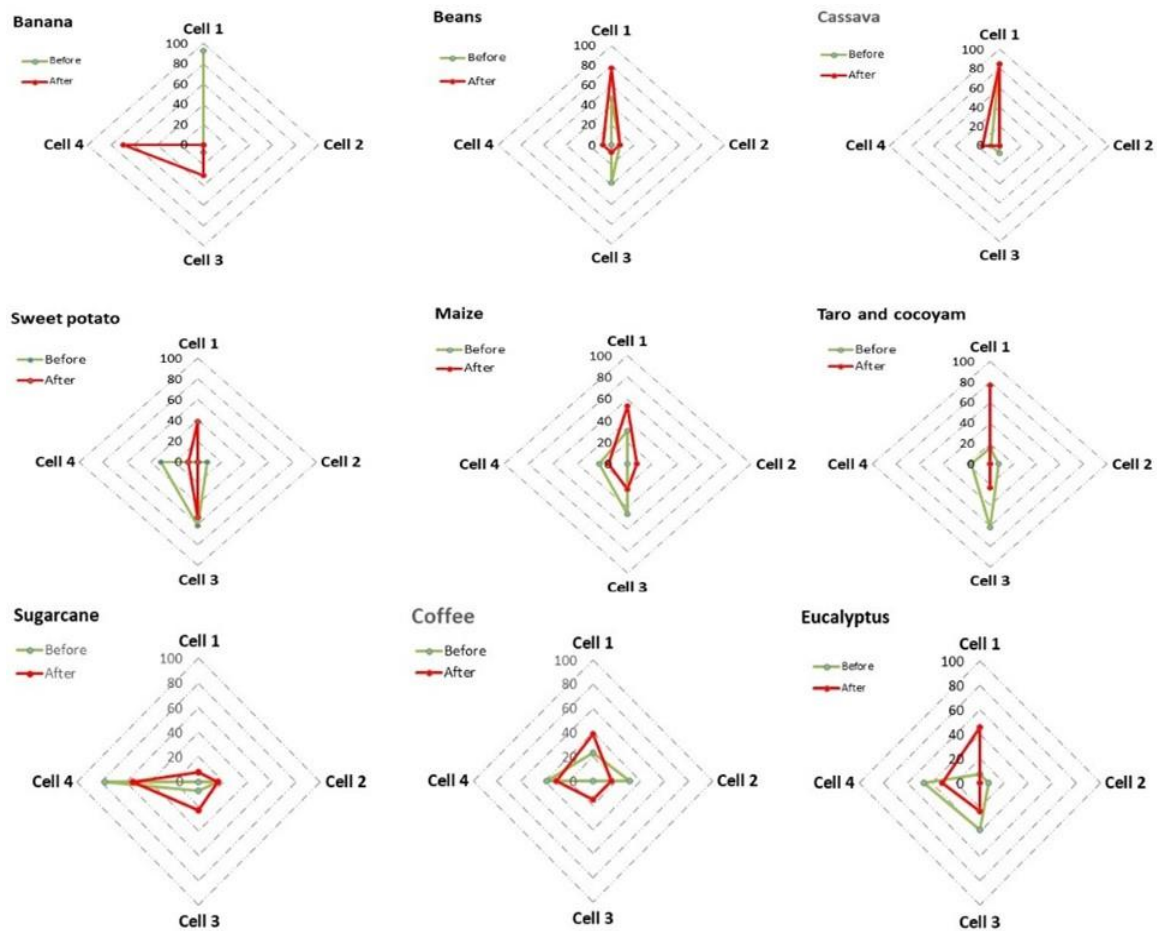
Figure 5. Spider plots showing the shifts in diversity (abundance) of selected key crop species before and after the outbreak of Xanthomonas wilt disease of banana across 13 landscapes in eastern Democratic Republic of Congo. Cells 1, 2, 3 and 4, respectively stand for a species being grown on i) a large acreage and by many households; ii) large acreage but by few households; iii) small acreage but by many households and iv) small acreage and by few households.

Increase in the importance and production of the 14 crops was reported to target the filling of the food security and income gap that arose from the loss of the banana crop to XW disease. Nkuba et al. [45] similarly reported increases in the area under maize, root and tuber crops on XW affected farms in Tanzania and Rwanda. Replacement of banana with sweet potatoes and cassava after devastation by XW has also been reported in Uganda [46]. The high ranking of cassava can be attributed to its complementary role to banana as a food and income crop in these XW affected landscapes. The increments in the area and the number of households growing coffee and taro (Figures 5 and 6) is not in tandem with the drop in the rankings of these crops (Fig. 4). The slight drop in the rankings for coffee and taro (cf. Fig. 4) could be attributed to the urgent need to bridge the food and income gap, with quick maturing annual crops taking the priority. This is supported by the fact that the number of households and area under coffee, taro and cocoyam relative to the period before XW outbreak had increased (Fig. 5). The leap in the rank of soybean was attributed to ongoing promotion of soybean as a biological nitrogen fixation agent and source of income by international projects in the region.
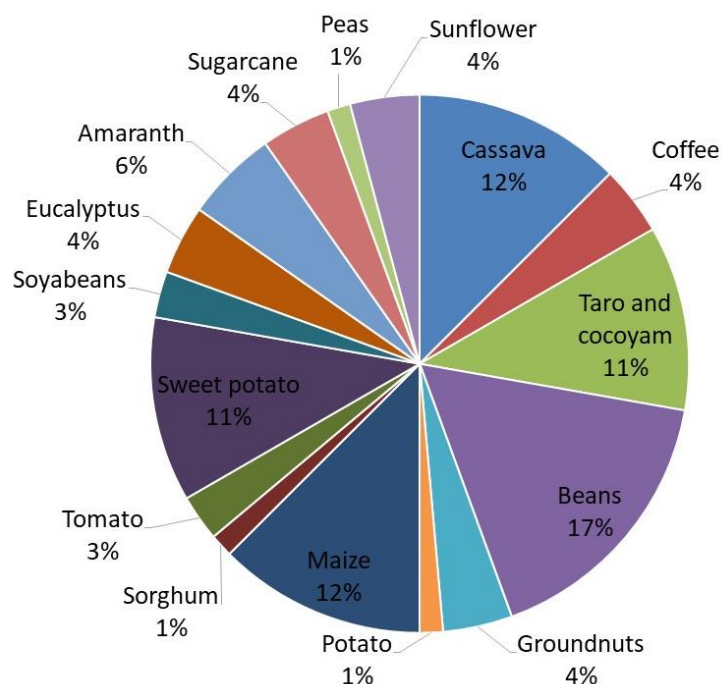
Figure 6. The crop species used to replace uprooted banana fields in landscapes affected by Xanthomonas wilt disease of banana in the eastern DR Congo.

Farmers' choices of replacement crops for banana in XW affected landscapes mainly comprised of the urgent need to bridge the income gap i.e. market value and improve food and nutrition security. The potential environmental benefits or effects on e.g. soil erosion, nutrient recycling received the least attention from farmers when considering crops to replace banana. This could be due to farmers' limited knowledge on or perceived less importance of such services, in addition to these services often being intangible [11].

3.3   Perceived changes in the food systems due to XW stress

XW disease induced changes in the value chains of major staple crops from production to consumption within the affected areas. Declines in the production and consumption of banana occurred across all (100%) XW-affected landscapes, while the sale by households and purchase by households from other markets of banana only increased in 23% and 38% of the affected landscapes, respectively, relative to the time before the outbreak of XW (Fig. 7). The decline in banana production and consumption within households was predominantly attributed to XW disease. Delayed management of XW disease is reported to result in up to 100% yield losses. Increases in household sales of banana in some of the landscapes despite the decline in production and consumption can be attributed to the attractive higher market prices resulting from a low supply of bunches in the market. Nkuba et al. [45] also reported a 35% decline in banana sales by farmers and a doubling of banana bunch prices in Tanzania and Rwanda due to XW disease. The slight increment in household expenditure on banana bunches, is because some households were able to buy bunches from the local or urban markets to meet the household demand for banana-based food and banana beer beverage that also had an attractive price in the market. Increases in production was observed for all the major food and tree crops in most of the XW-affected landscapes (Fig. 7). These increases were due to increased land allocation (cf. Fig. 5) to meet the food and income needs of the households. For example, increases in consumption were reported for sweet potato, beans, taro, maize and cassava while relative sales of beans, coffee, cassava and eucalyptus increased. The increased production of beans was also attributed to an increased productivity of the crop in abandoned or destroyed banana

fields that had a higher soil fertility. An increase in coffee purchase was also reported, possibly due to farmers and middlemen buying locally, and bulking for future sales or for transportation to outside markets (e.g. in neighbouring Rwanda) with higher prices. Pronounced increases in production and trade sugarcane were also observed (Fig. 7).
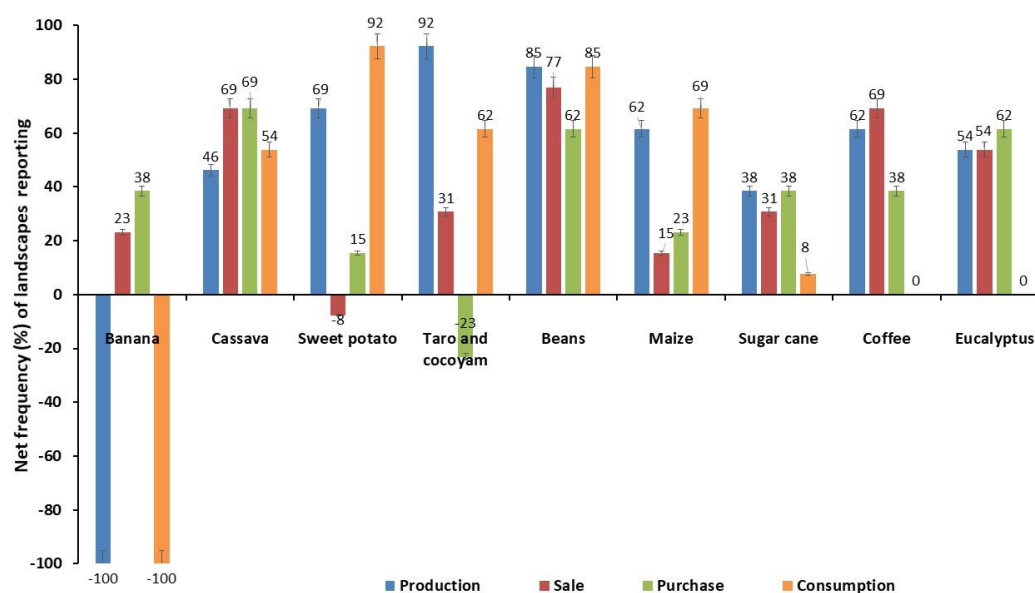

Figure 7. Net frequency (%) of landscapes reporting changes production, sale, purchase and consumption of key food and tree crops across 13 landscapes affected by Xanthomonas wilt disease of banana in eastern Democratic Republic of Congo.

3.4   Farmers' perceptions on the future role of banana and the sustainability of the key land-use trajectories in XW affected landscapes

Despite banana being severely affected by XW, it still occupies a unique position in the farming system, due to its multi-functional benefits and roles in the production system. The most important benefits reported by farmers included, its regular and all year-round production (100% of landscapes), household preference to consume banana fruits (100%), its high profitability (92.3%) and its ranking as the major contributor to household income (92.3%) (Fig. 8). Farmers described the crop to be their "local bank", stemming from the ease of its conversion into cash. This is in line with the findings of Vandamme [47] who reported the banana crop to play an important economic role as a farmers' `bank account' for unexpected or major expenses and thus its importance in the agriculture sector in eastern DR Congo. Banana was also important for beer making, a use that was reported to enhance social cohesion (70%). Study groups reported the loss of banana to have exposed youth to more potent alcoholic beverages, increasing health and social problems within their landscapes, thus the need to restore banana production and the banana local beer industry. The crop is also an important source for livestock feed, materials for construction of temporary shelters. Farmers were therefore still eager to manage the disease or re-introduce the crop on their farms. Approximately half (54%) of the landscapes visited in the study area were either still producing or had resumed banana cultivation despite the presence of the XW, while the other percentage had not. No association ($R^2 = 0.01$) was observed between the time of exposure to the disease, and the continuation and resumption of a landscape to produce banana. The continuation or resumption of a landscape to produce banana was also influenced by farmers' access to clean planting materials, the differential importance of banana for food and income, and the variability in incidence and severity of the

infection XW across the landscape. For example, clean planting materials were not accessible in the study region while in one out of the 13 sites, banana was not highly ranked and grown on large scale, as such XW disease was not a major concern. The key replacement crops were also reported to have failed to bridge the food security and income gap left by the banana crop. Due to the perennial nature of the banana crop, farmers reported a lower cost of production e.g. in labour and inputs whereas the other crops demanded major cultivation annually and investments in inputs annually.

Not surprisingly, only farmers in about 10% of the landscapes recognized the role of banana in reducing soil erosion in the landscape. This was because it is less tangible and lacked immediately visible benefits to most farmers.
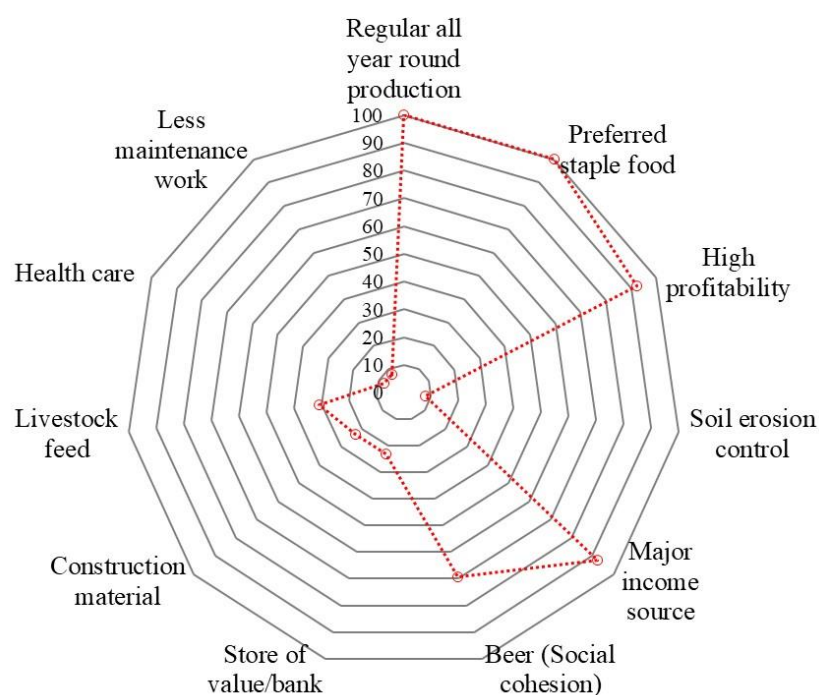

Figure 8. Farmers perceived comparative benefits offered by the banana crop across 13 landscapes in eastern Democratic Republic of Congo. Numbers denote percentage of villages reporting.

3.5   Soil quality

The soil chemical properties significantly differed ($P<0.05$) between the land-use options and sites, whereas no significant interactions ($P>0.05$) were observed between the land-use options and sites (Table 2). No use of chemical fertilizers was reported by farmers across the study sites for the analysed land-use options. Soil organic matter (SOM) and nitrogen (N), potassium (K) and phosphorus (P) were consistently higher in fields planted with trees and banana (Table 2). The banana crop also scored high for exchangeable bases calcium (Ca) and magnesium (Mg). Banana extracts large amounts of soil N and P [48] and as such, a higher depletion of these nutrients in soils with banana would have been expected.

Table 2. Variation of soil chemical properties for six major land-use options (i.e. banana, cassava, coffee grass, annual crops and trees) in XW affected across three landscapes (Idjwi (I), Katana (K) and Mushinga (M)) in eastern Democratic Republic of Congo.

Soil chemical property	Site	Main plant cover					LSD	P	P value	Cv%
		Banana	Cassava	Grass	Annual crops	Trees		values	(Sites)	

Soil Organic Matter	I	3.96bcd	3.58def	3.84cde	4.16bc	5.03a				
	K	3.49ef	3.52ef	*	3.48efg	3.36fg	0.43	0.20	0.01	21
	M	4.37bf	3.68cdef	3.98bcd	3.048g	4.22b				
	Mean	**4.04v**	**3.61w**	*	**3.54w**	**4.33v**	**0.30**	**0.02**		
Nitrogen (%)	I	0.30bcd	0.27de	0.28cde	0.30bcd	0.36a				
	K	0.26e	0.27de	*	0.26e	0.26e	0.03	0.27	0.02	18
	M	0.32b	0.28cde	0.30bcd	0.22f	0.31bc				
	Mean	**0.30v**	**0.27w**	*	**0.26w**	**0.32v**	**0.02**	**0.03**		
Phosphorus (ppm)	I	36.19abc	14.81d	3.81d	20.78bcd	48.26a				
	K	23.93bcd	8.85d	*	21.27bcd	16.07d	21.34	0.99	0.08	194
	M	13.11d	3.37d	4.45d	12.73d	17.06d				
	Mean	**24.58v**	**9.08w**	*	**17.81v**	**29.03v**	**14.4**	**0.10**		
Potassium (cmol(+)/kg soil)	I	0.21e	0.19f	0.14f	0.13f	0.19f				
	K	0.46ab	0.31cde	*	0.36bc	0.50a	0.10	0.07	<.001	65
	M	0.44ab	0.15f	0.16f	0.15f	0.23def				
	Mean	**0.36v**	**0.20wx**	*	**0.19x**	**0.27w**	**0.07**	**<.001**		
Calcium (cmol(+)/kg soil)	I	9.02c	7.22cd	4.51e	8.67c	5.04de				
	K	15.85b	15.97b	*	16.15b	21.46a	2.49	0.32	<.001	49.8
	M	9.18c	4.73de	4.17e	8.94c	3.50e				
	Mean	**10.52v**	**8.00w**	*	**10.35v**	**7.83w**	**1.71**	**0.02**		
Magnesium (cmol(+)/kg soil)	I	4.68de	4.48de	2.69g	5.12d	2.74g				
	K	8.80a	6.99bc	*	8.67a	7.98ab	1.25	0.08	<.001	43
	M	6.57c	2.97fg	3.74efg	4.03def	3.51efg				
	Mean	**6.35v**	**4.38x**	*	**5.42w**	**4.17x**	**0.86**	**<.001**		

Means followed by the same letter 'a' to 'g' and 'v' to 'x' within rows and a row for a given soil chemical property, respectively are not significantly different. '*'= missing data.

The observed higher availability of these and other nutrients in banana fields could be linked to the location of most banana plots close to homesteads, which allows for easy application of household wastes. The banana crop, due to its large size and wide spacing, and in contrast to other crops, is more compatible with the deposition of most household wastes in between plants. It was also common to see banana plots with some mulch and/ or heavy crop litter. The permanent nature of banana fields, high recycling of banana wastes, the application of external mulch and kitchen wastes under banana fields have been reported to improve nutrient availability and recycling in banana fields [11]. Bekunda and Woomer [49] also reported farmers to preferentially apply available organic resources on plots close to the homestead. Mulch and crop residues also intercept, slow and reduce runoff through retaining a fraction of rainfall/runoff, increasing hydraulic roughness, ponding and infiltration, obstructing and diverting runoff [50], potentially reducing nutrient loss through erosion. In contrast, fields under cassava and other annual crops generally received no external inputs. Stems of cassava and some annual crops e.g. maize and sorghum were often exported out of fields and used as fuel wood while some annual crop residues were burnt on farm, practices that lead to nutrient depletion.

Fields under grass where generally low in soil P, K and Ca content, possibly due to constant extraction of nutrients through livestock grazing (Table 2). Such fields also predominantly consisted of fields previously found to be less productive for food crops.

3.6   Soil erosion control

The mean values of the variables for estimating soil erosion levels or its variables with exception of slope length were significantly different across the land use options (P <0.001) and the three study sites (P<0.05) (Tables 3). Significant interactions between land cover options and sites occurred for soil erodibility (K), the crop management factor (C), and the support practice (P).

The crop cover factors that influences the crop management factor C were highest for land cropped with cassava (0.41-0.47) and annual crops (0.47-0.54) while least for fields covered by grass (0.01-0.02) (Table 3). Of the food crops, the banana crop (0.09-0.12) had the least crop cover factor. The cover factors in this study (Table 3) for the various crop/plant categories are comparable to those reported in literature (e.g. [36-37, 51-54]). The tillage factor values for fields under grass and trees were low due to no tillage. Tillage practice values under coffee and banana (often minimum or zero tillage) were lower and more supportive in controlling soil erosion than those under cassava and annual crops (Table 3). Fields planted with annual crops and cassava were subjected to routine cultivation, exposing the soil to run-offs. In line with the low crop cover type factors and tillage method factors, fields under grass, trees and banana had lower C values (0.002-0.06) compared with 0.21-0.33 for cassava and 0.27-0.43 for the annual crop fields across the sites (Table 3).

In general, most farmers did not adhere to support practices (P) that help minimize soil erosion. For example, most farmers cultivate down the slope (instead of along contour bands), a practice that encourages soil erosion. Cassava and annual crops ranked worst with regards to these practices while coffee and banana fields were moderate due to minimum/zero tillage practiced on some farms (Table 3).

The mean slope factor (LS) was mainly influenced by the slope gradient. LS and slope respectively, varied from 0.45-16.3 and 4-39% and were in general highest for fields planted with trees and least for fields planted with the annual crops. The ground surface of fields planted with trees were often covered by grass and/ or thick layers of leaf litter. Growing trees with deep root systems on steep slopes and annual crops on relatively flatter areas could be a farmer strategy for minimizing soil loss and/or put such lands to fruitful use. Banana crops (% slope of 4-16%) relative to cassava (4-20%) were cultivated on relatively flat areas (Table 3), probably due to most banana farms being located close to homesteads which were more often located on flatter portions of the available land. The farms at Katana were on more gentle slopes (4-5%) compared to Idjwi (10-28%) and Mushinga (6-39%).

Soil erodibility factor, K varied between 0.0053 and 0.0268 Mg h MJ^{-1}mm^{-1} and was lower at Katana compared with Idjwi and Mushinga. These K values are comparable to 0.009-0.021 Mg h MJ^{-1}mm^{-1} reported for the Tangata catchment in Rwanda [55], 0.016 Mg h MJ^{-1}mm^{-1} for the Kainjuki highlands in Kenya [52] and 0-0.24 Mg h MJ^{-1}mm^{-1} for the whole of Rwanda [56].

Table 3. The scores for the RUSLE covariates for different crop/plant covers on farms across landscapes affected by Xanthomonas wilt disease in eastern DR Congo.

Site	Main plant cover	Soil erodibility factor (K)	Crop cover	Tillage method factor	C factor	Slope length (L)	% slope (S)	LS	P	Amount of eroded soil (A)	#A for standardised mean slope
Idjwi	Banana	0.02684	0.12	0.43	0.048	61.1	15.6	4.61	0.43	10.7	12.74
	Cassava	0.02642	0.47	0.61	0.284	48.0	19.5	5.94	0.87	148.9	141.87
	Grass	0.02371	0.01	0.25	0.002	47.5	20.8	5.80	0.63	0.4	0.36
	Annual crops	0.02502	0.47	0.57	0.271	42.3	9.5	1.52	0.83	28.3	55.35
	Trees	0.02700	0.04	0.31	0.013	30.5	27.5	8.76	0.47	5.9	3.99
Katana	Banana	0.00527	0.09	0.51	0.047	43.0	4.0	0.46	0.70	0.3	0.33
	Cassava	0.00527	0.41	0.53	0.213	47.4	3.9	0.45	0.92	1.7	1.93
	Grass	*	*	*	*	*	*	*	*	*	*
	Annual crops	0.00527	0.47	0.55	0.265	34.8	4.6	0.52	0.63	1.4	1.35
	Trees	0.00527	0.04	0.50	0.018	44.6	5.2	0.69	1.00	0.3	0.26
Mushinga	Banana	0.01449	0.12	0.50	0.058	48.0	10.7	2.12	0.77	5.0	8.07
	Cassava	0.01479	0.47	0.69	0.329	55.0	17.0	5.29	0.98	98.8	100.31
	Grass	0.01449	0.02	0.25	0.005	57.9	14.0	3.47	0.25	0.4	0.49
	Annual crops	0.01449	0.54	0.80	0.434	69.7	5.8	0.97	1.00	22.8	67.85
	Trees	0.00527	0.02	0.29	0.006	36.8	38.8	16.31	0.28	0.4	0.18
LSD		0.00210	0.03	0.06	0.026	15.9	6	3.24	0.15	46.5	-
F pr (Main plant spp.)		<.001	<.001	<.001	<.001	0.396	<.001	<.001	<.001	<.001	-
F pr (Site)		<.001	0.005	0.004	<.001	0.345	<.001	0.01	0.026	0.026	-
Fpr (interaction)		0.009	0.53	0.009	<.001	0.71	0.197	0.202	0.003	0.21	-
Cv%		23	19	21	30	57	73	135	37	198	-

A = estimated average soil loss (Mg ha^{-1} year^{-1}); R = rainfall-runoff erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}); K = soil erodibility factor (Mg h MJ^{-1}mm^{-1}); C **factor**= cover-management factor; and P = support practice factor and LS = proportion of soil loss under a given condition to that of a site with a standard slope steepness of 9% and length 22.13 m. #A= estimated soil loss per land-use for the same slope (%), standardised using mean slope for each site. "-" = not computed.

The mean soil erosion levels (A) computed using the RUSLE equation were in general lower for the fields under grass (0.4 Mg ha^{-1} year^{-1} of soil loss per annum), trees (0.5-5.9) and banana (0.3-10.7) compared with 29.5% Mg ha^{-1} year^{-1} for coffee, 1.4-28.3 for the annual crops and 1.7-148.9 Mg ha^{-1} year^{-1} for cassava fields (Table 3). The high erosion levels for cassava fields can be attributed to allocation of cassava to the less fertile steep slopes and the less protective tillage and support practices under cassava (Table 3). The soil erosion levels were generally lower at Katana (0.3-1.7 Mg ha^{-1} year^{-1}) that had less soil erodibility and more gentle slopes compared with 0.4-98.8 Mg ha^{-1} year^{-1} at Mushinga and 0.4-148.9 Mg ha^{-1} year^{-1} at Idjwi. Several farms at the Mushinga and Idjwi site were on steep slopes, coupled to their higher soil erodibility rates (Table 3). The trend in erosion levels for landscapes under banana, coffee and annual crops as reported by [14] for the Lake Victoria basin catchment are similar though higher compared with those of the land uses in this study. Lufafa et al.

[14] reported soil loss levels of 32-47 Mg ha^{-1} year^{-1} for banana and coffee systems and 93 Mg ha^{-1} year^{-1} for the annual crops. In the Kianjuki catchment area in central Kenya, Angima et al. [52] reported higher soil losses between 30-666 Mg ha^{-1} year^{-1} for annual rotations, banana and coffee-based systems. However, despite a comparable LS factor (1-29), the Kianjuki site had twice higher rainfall erosivity of 8,527 MJ mm ha^{-1} h^{-1} year^{-1} compared with 3750 MJ mm ha^{-1} h^{-1} year^{-1} in the current study sites. Apart from land use under grasses, trees and banana, and the Katana site, erosion levels for cassava, coffee and annual crops were above the tolerable soil loss rates of 2.2-10 Mg ha^{-1} year^{-1} reported for the Kainjuki catchment in Kenya [52] and 15 Mg ha^{-1} year^{-1} used for the Tangata catchment in Rwanda [55].

Given the current trajectory of farmers in these XW affected landscapes to shift to cassava, beans and other annual crops, the unsuitable location of several farms on steep slopes (6-28%) coupled with the poor tillage and support practices under the alternative land uses, erosion levels are likely to rise on XW affected farms and landscapes. Strategies for supporting farmers alternative land uses to mimic banana production system and land uses such as land under trees and grasses needs to be explored and promoted. Potential practices could include the integration of contour hedges, grass bands, mulching and the use of cover crops to reduce runoff in erosion prone land use options.

4. Conclusion

Xanthomonas wilt disease of banana leads to death of affected plants and decay of infected bunches. All the study sites reported XW to severely distress their production systems. Uprooting of entire banana fields, expanding area under other crop species and totally abandoning banana for other crops was common across the landscapes. No changes in crop species richness at landscape level were observed though changes were eminent at farm level, with some farms introducing individual crop species. The overall trend across the sites was to increase the production of crops such as cassava, sweet potato, maize, sugarcane and eucalyptus with the objective of filling the short-term food security and income gaps arising from the loss or low productivity of bananas due to XW disease. Cassava and coffee especially, have already been important food and/or income crops in the region, with better developed market value chains, offering a better option in the short and long term to bridge the food and income gaps left by the banana crop. However, the observed trends in crop diversification in XW affected landscapes needs to be supported through deliberate efforts to improve extension services, seed systems, post-harvest handling and market value chains. Banana is still perceived as the preferred crop due to its multi-functionality in providing food, fodder, fiber, incomes and other ecosystem services in the landscape. The current trajectory in land-use will potentially increase soil loss and negatively affect the productivity and resilience of the soils. Strategies to manage XW and rapidly restore banana production in affected landscapes are necessary. In parallel, efforts are needed to support other land-uses, especially land under cassava so as to mimic the natural ecosystems in the supply of services such as erosion control and nutrient recycling e.g. through planting hedges and grass bands along contours. This study stresses the importance of a holistic approach focused on the entire banana-based agroecosystem in addressing the XW problem and is a good basis/ entry point for interventions to sustainably improve production systems, incomes and food security in XW-affected landscapes.

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