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Responses of cassava growth and yield to leaf harvesting frequency and NPK fertilizer in South Kivu, Democratic Republic of Congo

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ABSTRACT

Harvesting young cassava leaves as a vegetable is a common practice in the Democratic Republic of Congo (DR Congo). However, information on its effects on growth and yield of cassava is scarce. Multi-locational trials were conducted on farmers' fields in the province of South Kivu, DR Congo, during two consecutive years to investigate the effects of harvesting frequency of 3 young leaves (no leaf harvesting (NoH); leaf harvesting at 4 week intervals (4-WI) or 2 week intervals (2-WI), starting 4 months after planting) and fertilizer (with or without NPK application) on the growth and yields of cassava, comparable to common practice by farmers in the area, based on a preceding household survey. Overall, harvesting of leaves did not result in significant effects on both height and stem diameter compared with the unharvested treatment. However, collection of leaves at 2-WI significantly ($P < 0.05$) decreased both height and stem diameter, and resulted in significant ($P < 0.1$) reduction of stem yields of 20.9% (4.0 t ha^{-1}) relative to leaf harvesting at 4-WI but only in the second year. Average total biomass and storage root yields in the control treatment were 35.8 and 23.5 t ha^{-1}, respectively and were not significantly affected by leaf harvesting. Application of NPK fertilizer resulted in significant ($P < 0.05$) increases of both height and stem diameter over time, independent of the frequency of leaf harvesting. Mineral fertilizer significantly ($P < 0.05$) increased the overall total, storage root and stem yields by 28.3% (9.5 t ha^{-1}), 19.9% (4.5 t ha^{-1}) and 45.1% (5.0 t ha^{-1}), respectively regardless of the frequency of leaf harvesting. This study indicates that harvesting of young leaves results in small or negligible effects on cassava growth and yields compared to the mineral fertilizers which increase both cassava growth and yields in the conditions of our study.

1. Introduction

Cassava (*Manihot esculenta Crantz*) is a major staple food for over 70% of the population in DR Congo and an important source of income (Lema et al., 2004). The tuberous roots of cassava (El-Sharkawy, 2006) have a high starch content (up to 90% of the dry matter) (Abdullahi et al., 2014; Silvester, 1989) and is a source of calories for millions of Africans (Achidi et al., 2005). Because of its inherent tolerance to various edapho-climatic stresses (El-Sharkawy, 2006), cassava is usually grown on severely depleted soils, often with little or no inputs of fertilizers and pesticides (Howeler, 2002) and hence with very low yields. The average storage root yield in DR Congo, between 2000 and 2014, is 8.9 t ha^{-1} (FAOSTAT, 2016), which is bleak compared to its yield potential of 75–90 t ha^{-1} (Cock et al., 1979; Fermont et al., 2009).

In South Kivu (DR Congo), cassava is generally grown continuously on small plots due to the high population density coupled with land scarcity. This leads to fast depletion of nutrients especially nitrogen (N) and potassium (K) (Agbaje and Akinlosotu, 2004) which are the major nutrients required for optimum growth and storage root yields (Agbaje and Akinlosotu, 2004; Howeler, 1991; Obigbesan and Fayemi, 1976). Furthermore, in many areas farmers harvest all plant parts (roots, stems and leaves) resulting in serious nutrient mining and chemical and physical soil deterioration (Howeler et al., 2000). Therefore, mineral fertilizers, especially N and K may be required in South Kivu to meet the nutrient requirements of cassava. Farmers in this region, however, only

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apply limited amounts of manure or composted crop residues to this crop (Pypers et al., 2011) while mineral fertilizers have never been used for its production in South Kivu (CIALCA, 2010).

While in some cassava-producing countries leaves are not consumed at all, or only eaten during food shortage (Latif and Müller, 2015), in DR Congo, cassava leaves are widely consumed and since they are available throughout the year (Latif and Müller, 2015; Moyo et al., 1998) constitute a major component of the diet. Bokanga (1994) reported that DR Congo may have the highest level of cassava leaf consumption in the world. According to Mahungu et al. (1992) quoted in Achidi et al. (2005), cassava leaves have a share of more than 60% of all vegetables consumed in DR Congo and are an important source of revenue. Several studies (Adewusi and Bradbury, 1993; Bokanga, 1994; Dada and Oworu, 2010; Eggum, 1970; Lancaster and Brooks, 1983; Terra, 1964) have reported the nutritional value of cassava leaves which are a major source of proteins (14–40% on a dry weight basis), vitamins (vitamin B1, B2, B6, C), carotenes and minerals (potassium, iron, calcium, sodium).

Leaf harvesting throughout the growing cycle of cassava is a common practice in South Kivu. Farmers often harvest leaves as needed without accounting for possible adverse effects on storage roots. Surveys conducted in South Kivu, indicated that for home consumption, most farmers (76%) commonly harvest the youngest leaves without petioles when cassava is still young, while later on when the crop is more mature, most farmers (80%) harvest the tender apical leaves and shoots (entire tops). They further reported that they generally cut branches with both edible and nonedible leaves (young and old leaves, respectively) for commercial purposes. The first harvesting of leaves starts as early as 3 months after planting (MAP) and continues then at 2–4 weeks intervals depending on the needs and revenue of the household. Moreover, neighbors within villages are also allowed to collect leaves from the closest fields as long as it is for family consumption. The amount of leaves harvested at each collection depends on the size of the household but also on the season (more leaves in rainy season), but in general, 63% of households reported to collect leaves from 50 to 75% of the plants at each collection event (13% reported a higher proportion), and predominantly (63%) from a single branch per plant.

Several studies have investigated the impact of leaf harvesting on storage root production, but no consistent conclusions can be drawn due to differences in the intensity and frequency of leaf harvesting. However, Dahniya et al. (1981), Lockard et al. (1985) and Phengvichith et al. (2006) tested the effects of leaf harvesting at different frequencies on storage root yields and reported a decrease in storage root yields as the harvesting frequency increases regardless of the variety used (local and/or improved variety). They recommend leaf harvesting at intervals of minimally 2 or 3-months to ensure reasonable yields. Lutaladio and Ezumah (1980), on the contrary recommended a monthly harvesting of leaves as it resulted in large leaf production with little losses in root yields in a study conducted in lowland conditions in DR Congo (Zaire). According to Salisbury and Ross (2004) cited by Dada and Oworu (2010), the effects of defoliation on plants depend on the intensity, frequency and timing of foliage removal.

The typical DR Congo practice of frequent, small amount harvesting of leaves, when only used for household consumption implies that only edible leaves per plant and from random plants within the field (not all plants) are harvested. It is not known whether such a regime (high frequency but low intensity) has a negative impact on yield, and whether there is interaction with the nutritional status of the crop. Nutrient supply by fertilizer is postulated to result in larger leaves, and faster leaf initiation, and may compensate the losses by harvesting of a few leaves. Therefore, the objective of this study was to investigate the effects of the frequency of household harvesting of a small amount of leaves and NPK fertilizer application on the growth and yields of cassava in the South Kivu, DR Congo given the absence of data on these important effects in the highlands of Central Africa.

2. Materials and methods

2.1. Study area

The study was conducted in Kalehe (2.070° – 2.162° S, 28.853° – 28.921° E, 1526–1690 m a.s.l.), a territory of the province of South Kivu in the Eastern part of the Democratic Republic of Congo. Rainfall pattern in Kalehe is bimodal and allows crop cultivation during two seasons. The “A” season lasts from mid-September to mid-January while the “B” season starts in mid-February and ends mid-June, followed by a short dry season referred to as the “C” season. Rainfall averages 1500–1800 mm per year, and the growing period extends to over 325 days per year (Hijmans et al., 2005). Daily rainfall data during the experimental period were obtained from the research center of Lwiro, the closest (distance of 30 km) meteorological station to the field trials. The variability of the rainfall during the two growing cycles was determined using the Shannon index (Bronikowski and Webb, 1996). Soils in Kalehe are classified as Plinthic Ferralsols (Jones et al., 2013) and are of a silty clay texture. Cassava is the main staple crop and an important cash crop grown by all farmers in Kalehe.

2.2. Trial establishment and management

Field experiments were conducted during two consecutive growing cycles of one year each (season 2014 A and 2015 A). In September of each year, seven trials were planted across five sites (a site equals a “locality” or “groupement”) with at least one trial per site. Trials were established in fields presented by participating farmers and repeated in the second year in other fields. Both degraded (unused) land and land on steep slopes were avoided. Prior to trial installation, a composite soil sample from at least 10 random sampling spots per field was collected with an Edelman auger at 0–30 cm topsoil, air-dried, passed through a 2 mm sieve and analyzed for standard physico-chemical properties. Soil texture analysis was done using the LS 13 320 Laser diffraction method, total N and organic carbon using the Dumas combustion method (Dumas, 1931), Available P using the Olsen method (Olsen et al., 1954) while the cobalt-hexamine extraction method (Ciesielski et al., 1997) was used for cation exchange capacity. All analyses were conducted in the laboratories of the Department of Earth and Environmental Sciences at KU Leuven, Belgium.

The experiment was set up following a multi-locational design with two factors. The frequency of harvesting cassava leaves was the main factor with three levels; no harvesting of leaves (NoH), harvesting at 4-week intervals (4-WI) and harvesting at 2-week intervals (2-WI) and fertilizer addition (with or without NPK application) as the other factor. Treatments were not replicated within each field, instead, farmer fields per site and year were considered as replicates. The leaf harvesting regimes were set up to closely reflect the local practice for home consumption. The harvesting of leaves started from 3 to 4 months after planting (MAP) and continued up to 10 MAP. Three youngest fully expanded leaf blades without petioles (4th, 5th and 6th leaf from the top where the 1st opened leaf from the crown was considered as leaf number 1 and the 4th leaf from the top was generally the 1st fully expanded leaf) were collected from a random branch per plant, from 10 randomly selected plants within the effective plot of 16 plants without the border rows. We used ‘Sawasawa’, an improved cassava variety resistant to cassava mosaic disease, which was introduced in DR Congo in 2003 by IITA (INERA, 2008). This variety has on average 2 main stems with 2 primary branches and 3 secondary branches each. This leaf harvesting regime is comparable to the practice used by farmers in the area when the objective of the harvesting is household consumption (not for sale). Collected leaves were mixed, air-dried, and subsequently oven-dried at 60 °C for 72 h for dry matter (DM) determination, and calculation of the harvest index (HI). Fertilizer rates were 100-22–83 kg N-P-K ha^{-1}. N fertilizer was split-applied as urea, half at planting (in the planting hole) and half at 3 MAP, localized around the plant. All P fertilizer was applied in the planting hole as triple superphosphate (TSP) while K fertilizer was split-applied as potassium chloride, half at 1 MAP, and half at 3 MAP.

Plots measured 36 m^2 and fresh cassava cuttings of 25 cm were planted at 1 m by 1 m making a total of 10,000 plants per ha^{-1}. Land preparation was done manually and weeds were regularly controlled using a hand hoe. Farmers performed all field operations but the installation and harvesting of the trials were executed by a team of agronomists together with farmers. Data collection and sampling was done by the agronomist teams. Germination data were collected at 1 MAP. Plant height (distance from the soil surface to the tip of the longest leaf) and stem diameter (at 1 cm above the soil surface) were measured at 3–4, 6, 8, 10 and 12 MAP. Cassava was harvested at 12 MAP. Plants were split into stem (included the useful length or planting material, small and green stems as well as branches) and storage roots. Subsequently, total fresh weight of stem and storage root was recorded and used to determine stem and storage root yields. Thereafter, storage roots were divided in large marketable and small non-marketable storage roots, counted and weighed.

2.3. Economic analysis

A simplified financial analysis was conducted to evaluate the profitability of NPK fertilizer during the two experimental cycles. Additional benefits were calculated relative to the control treatments (i.e. treatment without fertilizer application). The total costs included the purchasing prices of fertilizer, which were obtained from a local agro-dealer in Bukavu (1.3 USD kg^{-1} of urea and 1.4 USD kg^{-1} of TSP and KCl) while the additional net benefits included the revenue from the increased storage root yields due to NPK fertilizer application. The price of storage roots was obtained from local markets in Kalehe, and equaled to 0.40 USD kg^{-1} in both years. An exchange rate of 900 Congolese francs (CDF) to 1 USD was used. The value cost ratio (VCR) was calculated as the additional net benefits over the cost of fertilizer purchase and was considered favourable when exceeding 1.18 USD USD^{-1} (CIMMYT, 1988). Hence VCR is dimensionless and will be used as such in the following.

The VCR were plotted against the storage root yields in the control treatment to determine the critical yield (X_c). Kelly (2006) cited by Fermont et al. (2010), considers a VCR of 2 or more to be an indication that a new production technology creates sufficient economic incentive for adoption by farmers. Therefore, a constant curve was predefined at the VCR of 2 and a linear function was fitted using the dataset from the two experimental years. The coordinates of the intersection point between the two curves constituted the critical control yield (X_c).

2.4. Statistical analysis

Analysis of variance was conducted to determine the effects of (and interaction between) the leaf harvesting frequency and mineral NPK fertilizer application in the two years in Kalehe using a mixed linear model (MIXED procedure, (SAS Institute Inc., 2013)). Exact Wilcoxon two-sample test (NPAR1WAY procedure) was performed to compare the two groups of soils used during the two experimental cycles. The effects of the different factors were compared by computing least square means and standard errors of difference (SED); significance of difference was evaluated at $P \leq 0.1$, $P \leq 0.05$ and $P \leq 0.01$. In the mixed model analysis, leaf harvesting frequency and NPK fertilizer application were considered as 'fixed factors' while farmer's field within site and year were considered as random factors. Linear regression was done using the REG procedure (SAS Institute Inc., 2013).

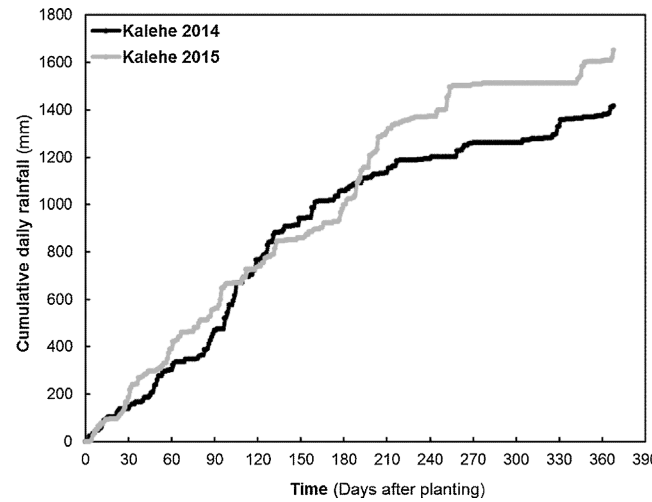

Fig. 1. Cumulative daily rainfall (mm) as recorded at Lwiro station during the two experimental cycles. A cassava cycle indicates a time period from planting to harvesting.

3. Results

3.1. Biophysical characteristics of the study area

Total amount of rainfall in the first growing cycle was less (235 mm difference) than that of the second growing cycle (Fig. 1). However, the rainfall received during the first 6 MAP was comparable in the two cycles of cassava. The Shannon indices (rainfall variability) calculated for the first 8 MAP and at 12 MAP varied between 0.72–0.80 in 2014 while they ranged between 0.78 and 0.83 in 2015.

Soil pH, total nitrogen (N), exchangeable magnesium (Mg) and cation exchange capacity (CEC) were significantly ($P < 0.05$) lower in the sites in 2014 than in those selected in 2015 (Table 1). Soil texture of the experimental fields used in the first year is classified as silty clay loam while in the second year, the texture is silty clay.

3.2. Cassava height and diameter

In the first year, cassava heights were not affected by the frequency of leaf harvesting throughout the growing period, while the application of NPK fertilizer significantly ($P < 0.05$) increased plant height throughout the growing period, regardless of the frequency (at NoH, 4-WI or 2-WI) (Fig. 2). In the second year, however, NPK fertilizer had a significant effect on plant height only when leaves were harvested (at 4-WI or 2-WI) and effects were apparent only starting at 8 MAP. Similar trends were found in the response of stem diameter to the leaf harvesting/fertilizer treatments (data not shown). Fertilizer application generally increased stem diameter throughout the growing period in 2014, while in 2015, increases in stem diameter were only observed when leaves were harvested, and markedly most in the treatment with the highest leaf harvesting frequency (2-WI). Effects of leaf harvesting frequency on crop height and diameter were small or negligible, compared to the effects observed of NPK fertilizer application.

3.3. Cassava storage root yields

Cassava storage root yields were significantly ($P < 0.05$) lower in 2014 than in 2015. The frequency of leaf harvesting did not significantly ($P > 0.1$) affect storage root yield in none of the two growing cycles, without or with NPK fertilizer application. The application of NPK fertilizer resulted in a significant ($P < 0.05$) increase of storage root yield in the two experimental cycles (Table 2). In 2014, the application of NPK fertilizer significantly ($P < 0.05$) increased the overall storage root yields by 19% (4.1 t ha^{-1}) while in 2015, NPK

Table 1
Physico-chemical soil properties of the trial sites in Kalehe.

Property	Unit	Kalehe 2014 (n = 7)		Kalehe 2015 (n = 5)		Significance level
		Mean	Range	Mean	Range	
pH (CaCl2)		4.13	3.86–4.36	4.66	4.12–5.27	**
Organic C	($g\ kg^{-1}$)	35.1	17.2–56.0	40.5	33.3–51.1	ns
Total N	($g\ kg^{-1}$)	2.6	1.5–4.0	3.2	2.8–4.1	**
Olsen-P	($mg\ P\ kg^{-1}$)	10.86	4.38–21.9	26.26	4.93–76.6	ns
Exchangeable K	($cmol_c\ kg^{-1}$)	0.32	0.07–0.69	0.62	0.17–1.39	ns
Exchangeable Mg	($cmol_c\ kg^{-1}$)	0.59	0.08–1.21	1.77	0.36–3.34	*
Exchangeable Ca	($cmol_c\ kg^{-1}$)	1.96	0.19–4.38	4.68	1.17–8.93	ns
Exchangeable Na	($cmol_c\ kg^{-1}$)	0.03	0.02–0.05	0.04	0.02–0.07	ns
Exchangeable acidity	($cmol_c\ kg^{-1}$)	0.38	0.05–0.75	0.27	0.15–0.39	ns
CEC	($cmol_c\ kg^{-1}$)	5.17	3.04–7.81	9.03	5.75–14.2	**
Clay	($g\ kg^{-1}$)	389	159–475	430	339–551	ns
Silt	($g\ kg^{-1}$)	454	354–502	478	425–510	ns
Sand	($g\ kg^{-1}$)	158	46.5–488	92.6	24.0–154	ns

*, **: Significance at $P \leq 0.1$, $P \leq 0.05$, respectively between the two years.

addition resulted in a significant ($P < 0.05$) storage root yield increment of 21% (4.8 t ha^{-1}), irrespective of the frequency of leaf harvesting.

Farmers in Kalehe distinguish tradable and non-tradable storage roots based on their size. Frequency of leaf harvesting significantly ($P < 0.01$) affected weight of tradable storage root per piece only in 2014 and weight of non-tradable storage root per piece in 2015 (Table 2). The application of NPK fertilizer did not have a significant effect neither on the weight of tradable storage root nor on the weight of non-tradable storage root per piece in both experimental years (Table 2).

The number of tradable storage roots per plant was significantly ($P < 0.1$) affected by the frequency of leaf harvesting only in the second year, while the number of non-tradable storage roots per stand was not influenced by the frequency of leaf harvesting in any of the two experimental years (Table 2). The application of NPK fertilizer had significantly ($P < 0.05$) increased both the number of tradable and number of non-tradable storage roots per plant in the two experimental years (Table 2).

3.4. Cassava stem yields

Cassava stem yields were significantly ($P < 0.01$) smaller in 2014 than in 2015. Frequency of leaf harvesting significantly ($P < 0.1$) affected stem yield only in the second year (Table 2). Harvesting of leaves every 2 weeks (2-WI) resulted in significant ($P < 0.1$) loss of stem yield by 21% (4.0 t ha^{-1}) compared with the treatment where leaves were picked every 4 weeks (4-WI). Application of NPK fertilizer significantly ($P < 0.01$) affected stem yields in both 2014 and 2015 (Table 2). In the first year, the application of NPK fertilizer significantly ($P < 0.01$) increased the overall stem yield by 53% (4.8 t ha^{-1}) while in the second year, the addition of NPK fertilizer resulted in significant ($P < 0.01$) stem yield increments of 37% (5.2 t ha^{-1}), regardless of the frequency of leaf harvesting. However, the effect of fertilizer application on stem yield was markedly pronounced with the highest leaf harvesting frequency (2-WI) in the second year.

Also the harvest index (HI), calculated on fresh weight basis, was significantly ($P \leq 0.05$) affected by the frequency of leaf harvesting, but only in 2015 (Table 2). Harvesting of leaves every 2 weeks had significantly ($p < 0.05$) increased the harvest index by 5.0%, independent of fertilizer application, in comparison with the treatment where leaves were harvested every 4 weeks. The application of NPK fertilizer resulted in significant ($P < 0.01$) reduction in the harvest index by 5.6% in 2014 and by 3.4% in 2015, independent of leaf harvesting frequency.

3.5. Leaf dry matter (DM) yield

The average dry weight of leaves collected per plant at different leaf harvesting times and the overall total dry matter yield of leaves harvested per growing cycle were significantly ($P < 0.05$) higher in 2014 than in 2015 (Table 3). The average dry weight of leaves per plant was not significantly ($P > 0.1$) affected by the frequency of leaf harvesting while harvesting of leaves at high frequency (2-WI) roughly doubled ($P < 0.01$) the total dry matter yield per growing cycle relative to leaf harvesting at 4-WI, during the two experimental years. The effect of leaf

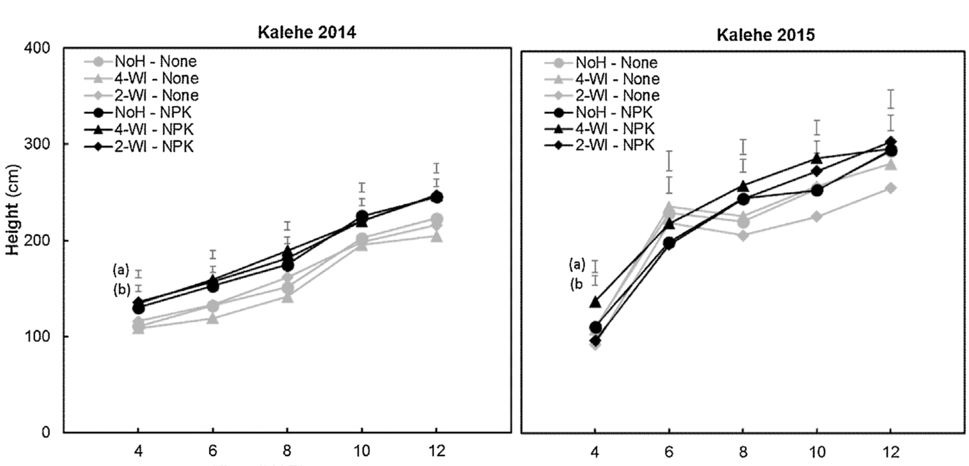

Fig. 2. Cassava heights (cm) at different times (MAP = months after planting) in Kalehe during 2014 and 2015, as affected by leaf harvesting frequency (LHF) and mineral NPK fertilizer. Error bars represent SEDs for LHF (a: upper bars at different times) and SEDs for fertilizer application (b: lower bars at different times). (NoH, 4-WI and 2-WI = treatment without leaf harvesting, harvesting every 4 weeks and 2 weeks and none and NPK = treatment without and with fertilizer application, respectively).

Table 2
Fresh cassava yields and yield components as affected by leaf harvesting frequency (LHF) and NPK fertilizer in Kalehe in 2014 and 2015 seasons.

LHF	Fert.	Total biomass yield (Storage root + Stem)	Storage root yield	Stem yield	Harvest index	FW storage root		Nb storage root	
						Tradable	Non-tradable	Tradable	Non-tradable
		(t ha^{-1})	(t ha^{-1})	(t ha^{-1})	(%)	(g piece^{-1})	(g piece^{-1})	(plant^{-1})	(plant^{-1})
Kalehe 2014									
NoH	None	33.2	23.2	10.0	71.1	409.4	104.1	5.0	3.1
4-WI	None	28.3	20.2	8.1	72.6	361.3	98.7	5.3	3.0
2-WI	None	29.5	20.7	8.9	69.9	320.1	101.4	5.5	2.5
NoH	NPK	41.6	27.0	14.6	65.5	414.9	99.4	6.1	3.6
4-WI	NPK	38.5	24.4	14.0	63.9	357.6	111.9	5.8	3.8
2-WI	NPK	37.5	24.9	12.6	67.4	358.9	97.6	5.9	4.1
SED (LHF)		2.5 ns	1.9 ns	1.1 ns	1.7 ns	21.5***	8.6 ns	0.5 ns	0.4 ns
SED (Fert.)		2.0***	1.5**	0.9***	1.4***	17.4 ns	7.0 ns	0.4*	0.3***
SED (LHFxFert.)		3.6 ns	2.7 ns	1.6 ns	2.5 ns	31.1 ns	12.5 ns	0.7 ns	0.6 ns
Kalehe 2015									
NoH	None	38.3	23.9	14.4	63.5	438.0	123.0	4.3	3.7
4-WI	None	42.2	24.8	17.4	59.1	370.6	117.6	5.3	3.7
2-WI	None	31.7	21.3	10.5	67.9	400.4	158.4	4.2	2.5
NoH	NPK	43.2	26.2	16.7	62.6	367.7	106.8	5.2	5.7
4-WI	NPK	50.2	28.9	21.2	58.2	353.5	106.4	6.8	4.2
2-WI	NPK	49.7	29.4	20.1	59.4	394.0	132.1	5.9	4.3
SED (LHF)		4.0*	2.6 ns	2.1*	2.8*	33.3 ns	13.8***	0.6*	0.6 ns
SED (Fert.)		3.4***	2.2**	1.7***	2.3*	27.7 ns	11.4 ns	0.5**	0.5***
SED (LHFxFert.)		6.1 ns	3.9 ns	3.1 ns	4.4 ns	52.7 ns	21.8 ns	0.9 ns	0.9 ns

*, **, ***: Significance at $P \leq 0.1$, $P \leq 0.05$, $P \leq 0.01$, respectively; ns: not significant; LHF: Leaf harvesting frequency; Fert.: Fertilizer; None and NPK: without and with NPK application, respectively; FW: Fresh weight, Nb: number and NoH, 4-WI and 2-WI: treatment without leaf harvesting, harvesting every 4 weeks and 2 weeks, respectively.

Table 3
Average dry matter (DM) yields of cassava leaves harvested at two different frequencies per hectare and per year in Kalehe.

LHF	Fert.	DM leaves (g plant^{-1} harvest^{-1})	Total DM leaves (kg ha^{-1}yr^{-1})
Kalehe 2014			
4-WI	None	3.3	124.0
2-WI	None	3.3	245.8
4-WI	NPK	3.6	134.2
2-WI	NPK	3.3	249.5
SED (LHF)		0.21ns	11.00***
SED (Fert.)		0.21ns	11.00ns
SED (LHFxFert.)		0.31ns	15.89ns
Kalehe 2015			
4-WI	None	2.7	103.6
2-WI	None	3.1	229.4
4-WI	NPK	3.1	116.3
2-WI	NPK	3.0	223.9
SED (LHF)		0.25ns	12.13***
SED (Fert.)		0.25ns	12.13ns
SED (LHFxFert.)		0.36ns	17.15ns

***: Significance at $P \leq 0.01$; ns: not significant; LHF: Leaf harvesting frequency; Fert.: Fertilizer; 4-WI and 2-WI: treatment with leaf harvesting every 4 weeks and 2 weeks and means 6 harvests and 12 harvests during the growing cycle, respectively; None and NPK: without and with NPK application, respectively; Plant density is 10,000 plants ha^{-1}.

harvesting on total dry matter yield of leaves collected per growing cycle was obvious since 6 harvests were done at 4-WI against 12 harvests at 2-WI. The application of NPK fertilizer did not have a significant ($P > 0.1$) effect on both dry weight of leaves per plant and total dry matter yield of leaves collected per growing cycle in the two years.

3.6. Effects of LHF and fertilizer on storage root versus control yields

To summarize the different effects on the yield difference between those treatments without and with leaf harvesting at different frequencies, the effect of leaf harvesting (i.e. yield difference between the leaf harvesting treatments (4-WI or 2-WI) and the unharvested treatment (NoH)) was plotted against the yield in the unharvested treatment without or with NPK application (Fig. 3a). The relationship obtained by linear regression was not affected by NPK fertilizer application (confirmed using analysis of covariance), and a weak relationship ($R^2 = 0.09$, $P = 0.05$) indicating small reductions in root yield with higher control yields was observed.

Similarly, the effect of fertilizer application (i.e. yield difference between fertilized and none fertilized treatments) was plotted against the yields in the control treatment (treatment without NPK application), and it appeared that the effects of the fertilizer on storage root yields were pronounced and clearly larger when the yields in the control treatment were smaller, irrespective of the frequency of leaf harvesting (Fig. 3b). This relationship was strong ($R^2 = 0.62$) and highly significant ($P < 0.01$).

3.7. Cost-benefit ratio of mineral fertilizer use

In 2014, an average VCR of 2.3 was obtained in the treatment without leaf harvesting while in 2015, this same treatment gave an average VCR of 1.0 USD (USD NPK)$^{-1}$. VCR for storage roots were not significantly ($P < 0.05$) affected by the frequency of leaf harvesting during the two experimental years. In Fig. 3b, the threshold for profitable fertilizer response (VCR > 2) is indicated, showing that VCR values were larger when the storage root yields in the control were smaller, independent of leaf harvesting frequency. Maximal VCR value was 11.7 at a storage root yield of 11.9 t ha^{-1}. The critical control storage root yield (X_c) was 23 t ha^{-1}; at higher yields, the VCR dropped below the critical value of 2.

4. Discussion

4.1. Effect of frequency of harvesting of leaves on cassava yields

Without application of NPK fertilizer, the average storage root yields observed in the treatment without leaf harvesting were similar during the two experimental years. When applying NPK, storage root yields obtained in both 2014 and 2015 were again comparable for the treatments without leaf harvesting. These average storage root yields obtained without or with NPK fertilizer in the two experimental years

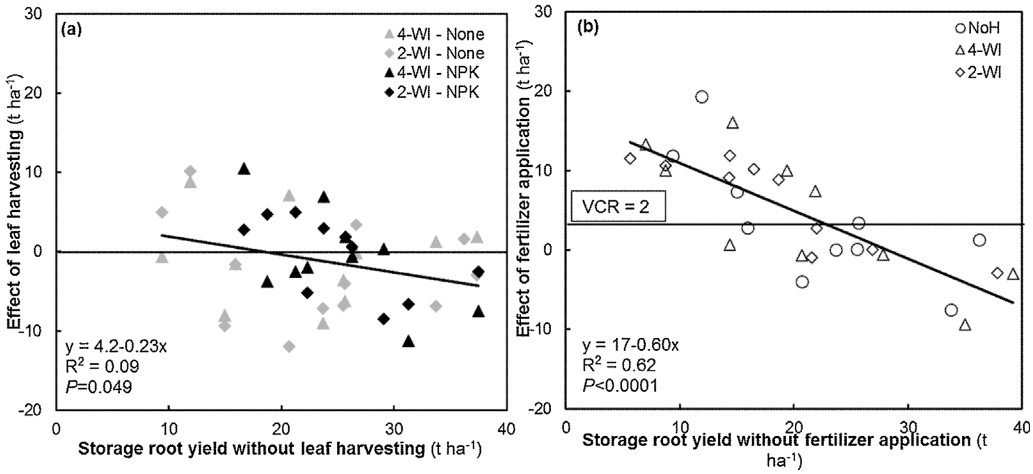

Fig. 3. (a) Relationship between effect of leaf harvesting on storage root yield (storage root yield difference between harvested and unharvested treatments) and storage root yield without leaf harvesting (NoH); (b) Relationship between effect of fertilizer application on storage root yield (storage root yield difference between fertilized treatment and treatment without fertilizer) and storage root yield without fertilizer application. (4-WI – None and 2-WI – None = Effect of leaf harvesting at 4- and 2-week intervals without NPK while 4-WI – NPK and 2-WI – NPK = effect of leaf harvesting at 4- and 2-week intervals with NPK, respectively). A negative value implies a negative effect of leaf harvesting (a) or fertilizer application (b). ANCOVA revealed no significant difference in the relationship between treatment effects (Y) and control yields (X). Regression analysis revealed a significant relationship between the effect of leaf harvesting and control yields and between the effect of fertilizer application and control yields. The horizontal line in Fig. 3b at which VCR = 2: y-intercept = 2 * Fertilizer rate * Fertilizer price/Root price, and indicates that above VCR > 2 and below VCR < 2.

were larger than the average yields reported by FAOSTAT (2016) for DR Congo in 2014 (8.1 t ha^{-1}) and also exceeding the average African storage root yields of 10.9 t ha^{-1} (FAOSTAT, 2014; Legg et al., 2015). This most likely is a result of use of an improved, disease-resistant variety, in combination with optimal crop management, good rainfall conditions and relatively good soil fertility levels.

Harvesting of cassava leaves should in theory reduce the amount of photo-assimilates and the plant will in response partition relatively more of them towards the shoot to compensate for the removal of leaves. A faster development of new leaves is the result and hence a reduced amount of photo-assimilates available for translocation to the roots and a reduction of storage root yields. However, in our study, harvesting of leaves did not result in a significant reduction of storage yields with or without fertilizer application. Storage root yields were indeed not significantly affected by the harvesting of leaves (Table 2), presumably because the quantity of leaves collected in our experiments (Table 3) was probably too small (3 leaves) to induce significant reductions photo-assimilate translocation to the roots, little affecting the final storage root yields. However, the bi-weekly collection of leaves significantly reduced the stem yields relative to the monthly harvesting, and the effect was most marked – while only in the second year – when NPK fertilizer was not applied. Results of our study, carried out in the highland conditions, are different from the findings in lowland conditions by Lutaladio and Ezumah (1980) who reported small losses in storage root yields when leaves were harvested once a month (at 4-week interval). Moreover, more frequent collection of leaves caused even larger reductions of storage root yields (49–66%) relative to the unharvested treatment. Similarly, Lockard et al. (1985) also observed reductions in storage root yields when cassava leaves were harvested at 1-month intervals while no such differences were found between various frequencies in a study carried out in Liberia. Dahniya et al. (1981) quoted in Lockard et al. (1985) also reported losses of storage root yields of 76, 62 and 15% when cassava leaves were harvested at 1, 2 and 3-month intervals, respectively. The lack of effect of leaf harvesting on storage root yields in our study could also be explained by the position and age of leaves collected when compared with previous works. While we only harvested the three youngest fully developed leaf blades without petioles (the 4th, 5th and 6th leaf from the top of a branch without the apical part), in earlier studies, either the terminal five or six leaves from each branch of the plant or all leaves suitable for the market or younger leaves with petioles together with the unlignified upper part of the stem per branch were collected (Lockard et al., 1985; Lutaladio and Ezumah, 1980). Although none of the leaf harvesting treatments had significantly affected the growth or yields of cassava relative to the unharvested treatment, collection of leaves every 2 weeks resulted in a significant reduction of aboveground biomass (stem yield) in comparison with the treatment where leaves were harvested every 4 weeks without NPK application. This suggests that under the conditions prevailing in the highlands of South Kivu, leaves can be harvested at least on a monthly basis, provided the quantity of leaves harvested is small, and that effects of more frequent leaf harvesting (2-weekly) will be minimal. Similar recommendations were made for DR Congo by Lutaladio and Ezumah (1980).

4.2. Effect of NPK fertilizer on cassava yields and value cost ratio (VCR)

Application of NPK fertilizer resulted in significant increases of both cassava storage root and stem yields in the two years of the study. The storage root yield increases due to fertilizer application was a result of significant increase in the number of storage roots (marketable and non-marketable root) per plant (Table 2) rather than the weight of an individual storage root. Similar observations were made by Pypers et al. (2011) and Fermont et al. (2010) in their studies conducted in South Kivu (DR Congo) and in Eastern Africa (Kenya and Uganda), respectively. Similarly, Pellet and El-Sharkawy (1993) and Kasele (1983) also reported an increase in the number of storage roots per plant due to fertilizer application. Results of our study are consistent with the findings by Pypers et al. (2012) who reported also significant responses of cassava to fertilizer in a study carried out in the Bas-Congo province of DR Congo. However, findings by Lema et al. (2004) are opposite to this, as they observed no significant effects of mineral NPK fertilizer neither on the number of storage roots per plant nor on the tuberous root yields in a study conducted in DR Congo with both an improved and a local variety of cassava.

Although the application of fertilizer had significantly increased storage root, stem and total biomass yields in the two experimental years, its effect was more pronounced in the first year than in the second year (Table 2). As a consequence, the average value cost ratio (VCR) figures of fertilizer use were above the critical value of 2 at all frequencies of leaf harvest in the first year while in the second year, the average VCR values were above this critical value only when leaves were harvested. These differences in the response of cassava yields to the NPK fertilizer during the two cycles of cassava were probably due to the different quality of soils of the sites used in the two years. Although only soil pH, total N, exchangeable Mg and CEC were significantly ($P < 0.05$) smaller in 2014 than in 2015, all other measured soil parameters, except the exchangeable acidity were showing smaller values in the first year than in the second year (Table 1). However, their average values were above the critical levels for cassava (Howeler, 2002) in both years. In addition, 43% of the fields used in the first year had soil organic matter, Olsen-P and exchangeable K contents below the critical threshold (3.1% for organic matter, 8 mg P kg^{-1} and 0.18 $cmol_c$ K kg^{-1} (Howeler, 2002)), while in the second year, only 20% of the study sites had organic matter, Olsen-P and K contents below these critical levels. This indicates that the fertility level of the experimental fields in the first year was lower than in the second year and suggests that application of NPK fertilizer in farmers' fields with soil N, available P and K contents below the critical thresholds as defined by Howeler (2002) is likely to result in large responses to mineral fertilizer and consequently in large agronomic use efficiency values of mineral fertilizer and large economic benefits. The variability observed in the response of cassava yields to mineral fertilizer was unlikely due to the amounts of rainfall received during the two cycles of cassava. Although the total amount of rainfall received in the first year was smaller (1415 mm) than in the second year (1650 mm), the amounts received in the first 5 MAP corresponding to the critical period for water-deficit effects in cassava were comparable in the two cycles of cassava (Fig. 1). This period coincides with root initiation and tuberization stages (Alves, 2002). Moreover, the Shannon (D) indices (Bronikowski and Webb, 1996) calculated at 1 MAP, 2 MAP, 3 MAP, 4 MAP, 5 MAP and 12 MAP were also comparable during the two years (D = 0.72, 0.77, 0.80, 0.79, 0.80, 0.76 in 2014 and D = 0.81, 0.83, 0.83, 0.82, 0.81, 0.78 in 2015 at 1, 2, 3, 4, 5 and 12 MAP, respectively), indicating a similar distribution. Fermont et al. (2010) reported that the response of cassava to fertilizer application was reduced when the rainfall from 0 to 3 MAP or total rainfall were below 400 and 1500 mm, respectively. They further reported that water stress before 3–4 MAP reduced the response to fertilizer as it limits the formation of additional sink (storage roots) and source (above-ground biomass) capacity, while no such effect is seen after 3–4 MAP.

5. Conclusion

Our study demonstrates that harvesting of young cassava leaves as vegetables for own household consumption at frequencies in line with farmer's practice (few leaves, from about 2/3 of the plants every 2–4 weeks) does not affect cassava root yields, and has only small effects on cassava growth and stem yield when leaf harvesting is done every two weeks. This has implications beyond the impact on crop production in the study area. Our results also have important implications for the experimental design of studies on nutrient norms involving regular collection of youngest fully developed leaf blades. Provided the leaf harvesting regime does not exceed the frequency and intensity applied in our study, root yield will unlikely be affected and plants subjected to leaf harvesting can still be used in final yield assessment. It may be envisaged to also investigate more aggressive harvesting regimes and finally design proper recommendations for this peculiar practice in order to avoid negative impacts on storage root production. Application of NPK fertilizer resulted in significant increases in both stem and root yield, regardless the frequency of leaf harvesting. Although the application of mineral fertilizer resulted in significant increases of cassava yields, their effects were pronounced and clearly larger when the control yields were smaller independent of the frequency of harvesting of leaves. Therefore, application of NPK fertilizer in farmers' fields with low fertility level is likely to result in large responses to mineral fertilizer and consequently in large economic benefits, and efforts from the extension agents or other relevant actors are needed to enable smallholder farmers to make targeted investments in fertilizer in order to minimize risk and maximize profitability. More information on soil responsiveness to fertilizers is hence crucial and factors determining cost-effective fertilizer use need to be documented.

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