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Nitrogen, phosphorus, and potassium fertilizer effects on cassava tuber yield in the coastal district of Dondo, Mozambique

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Meeting an increasing demand for cassava (*Manihot esculenta* Crantz) by industrial and commercial food sectors requires basic agronomic information on fertilizer requirements and appropriate fertilizer recommendations for high tuber yield and quality. A no-till study involving twenty fertilizer treatments consisting of different combinations of nitrogen (N), phosphorus (P), and potassium (K) fertilizer rates was initiated in 2013 at Milha-14, in the coastal district of Dondo, Sofala province, Mozambique. The objective of the study was to assess cassava yield performance under different soil fertility and smallholder farm conditions. Applying only 60 kg/ha N (fertilizer combination: 60-0-0 kg/ha N-P_2O_5-K_2O) yielded less (8.5 tons/ha) compared to the unfertilized control treatment (14.7 tons/ ha). Applying 60 kg/ha N combined with 60 kg/ha P_2O_5 (60-60-0 N-P_2O_5-K_2O kg/ha) yielded the highest (27.7 tons/ha; $p < 0.05$). No response to K was observed, but K additions are recommended to avoid K mining.

Key words: Cassava, tuber yield, fertilizer.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a perennial, multi-use, subsistence crop domesticated in Brazil (Hillocks et al., 2002a) and grown throughout the tropics (Food and Agricultural Organization of the United Nations (FAO, 2013). Cassava provides edible leaves and tubers (Boansi, 2017; Li et al., 2010) and is produced almost

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exclusively by small-scale, resource-poor farmers (El-Sharkawy, 2004) on nutrient-depleted soils (Mariscal, 1984), in mono- or poly-culture (El-Sharkawy, 2004). Due to the ability of cassava to produce reasonable yields in areas with poor soil fertility (Boansi, 2017) where other crops would not thrive (Fermont, 2009), most farmers in Africa under-fertilize or do not fertilize cassava (El-Sharkawy, 2004). Cassava is rarely grown as a main crop, but instead fills the important niche of being a "hunger" crop or the crop of last resort.

Mozambique produces surplus cassava despite falling into the category of countries that use little or no fertilizer in cassava production (FAO, 2011). Cassava alone contributes to approximately 6% of the country's gross domestic product (GDP) (FAO-Mozambique, 2010) and about 628 kcal per person per day. The latter contribution places Mozambique among the top three countries globally that rely on cassava for caloric intake (El-Sharkawy, 2004). In the 1960s, cassava was more than 45% of the diet, but by 2006 its share decreased more than 40% due to the increased market share of other products such as maize (*Zea mays*). Even with its decreased market share, cassava remains one of the main food products in Mozambique. Maize, which had a high diet share in the early 2000s, has decreased from 25 to 20% in food intake share. This decrease was attributed to lower yields and increased imports of other commodities such as wheat and rice (Promar Consulting, 2011).

In Mozambique, about 75% of the economically active population is engaged in agriculture (Gwarizimba, 2009). The majority of the population are small-scale resource-poor farmers who farm on 1.78 ha average. Cassava is produced extensively throughout the country (Promar Consulting, 2011), almost entirely for household consumption (Gwarizimba, 2009). The cassava cropping season is variable because the cropping season and harvest date is dependent upon the type of cassava grown (Promar Consulting, 2011) and household consumption needs. Cassava is an excellent niche crop for subsistence households because it can be harvested almost continuously over several months and up to a couple years (Donovan and Tostão, 2010). Cassava is typically planted in November and harvested between July and October. For many varieties, maximum cassava yields occur after 10 to 12 months.

Cassava Brown Streak Disease (CBSD) and African Cassava Mosaic Disease (ACMD) impact cassava production (Boansi, 2017; Hillocks et al., 2002b). It is estimated that the CBSD disease alone has affected more than 50% of the cassava production with more aggravation in the Northern provinces of Nampula and Zambezia. To address this issue, the government of Mozambique has taken steps to identify and promote disease-free and disease-resistant varieties (Promar Consulting, 2011). Presently, Mozambique is the fifth largest producer of cassava in Africa, second only to Angola in Southern Africa (FAO, 2011), and has an average tuber yield of approximately 6 tons/ha (Dias, 2012; Promar Consulting, 2011), which is about 40% less than the continent's average (10 tons/ha) (Mkamilo and Jeremiah, 2005) and yields that fail to meet the growing demand for emerging bioethanol, brewery, and cassava-based bread industries. To meet home and commercial demands, there is a need for research to offset the yield gap through work on improved cultivars and planting material including; to determine fertilization rates to offset low soil fertility; developing appropriate farm tools; developing agronomic practices for cassava mono- and polyculture; and evaluating the cassava value chain including transport from rural areas (EC-FAO, 2007).

Agronomic research demonstrates that significant increases in cassava yield are possible when optimum fertilizer rates are applied (Howeler, 1981; Howeler and Cadavid, 1990; Graner and Coury, 1955; Ezui et al., 2016; de Cequeira and Howeler, 1980; Howeler et al., 2006). Kamaraj et al. (2008) reported cassava response to an increased level of N, P and K fertilizer up to 150% over the normal recommended rate of 60-60-160 kg/ha N-P_2O_5-K_2O for optimum yields in a study conducted on poor sandy loam and sandy clay loam soils (classified as Typic Ustropepts) (Soil Survey Staff, 2010) in Northwestern India. Increasing fertilizer rates to 90-90-240 kg/ha also yielded more tubers than a relatively higher rate of 120-120-320 kg/ha. These studies also suggest that fertilizer recommendation rates for high cassava tuber yields can vary widely depending on the region and agro-ecological conditions that determine the nutritional status of the soil.

According to Imas and John (2013) and CIAT (1992), K deficiency in cassava can be corrected with an application of 50 to 100 kg K_2O/ha (as KCl), but the rate is dependent upon soil fertility status. In P depleted soils, high rates of P fertilizer are needed for one or two consecutive cropping seasons to increase the available P in the soil to a level where yield is not limited by its deficiency. Cassava is highly efficient in P use and has low P uptake per ton, subsequent P applications can be gradually reduced. Howeler and Cadavid (1990) recommended application of 50 to 100 kg/ha N per cropping season in soils with low organic matter and available N. Overall, current fertilizer recommendation rates from cassava producing countries, including Latin America and Asia, range from 30 to 100 kg/ha N, 25 to 100 kg/ha P_2O_5, and 60 to 100 kg/ha K_2O (Howeler, 1981). These recommendations are comparable with those of the FAO (2013), which range from 50 to 100, 10 to 20, and 65 to 80 kg/ha for N, P_2O_5 and K_2O, respectively, depending on the nature of the soil and desired yield levels. Even though many cassava producing countries still lack fertilizer rate recommendations for cassava production, research

Table 1. Selected chemical and physical properties of soil of Milha-14, Dondo District, Mozambique.

Parameter	Level	Method of analysis
pH unitless	4.9	KCl (ASTM, 2001)
P mg kg^{-1}	6	Bray extract
K mg kg^{-1}	149	$NH4^{+}$ acetate
Ca mg kg^{-1}	215	$NH4^{+}$ acetate
Mg mg kg^{-1}	60	$NH4^{+}$ acetate
Na mg kg^{-1}	16	$NH4^{+}$ acetate
Organic matter (%)	1.03	Walkley-Black

Methods listed in the table are described by NCR-13(2011). Soil pH was obtained from a 1:2.5 soil:solution ratio. P, K, Ca, Mg, and Na levels are reported in mg/kg.

cited suggests that yields can be increased, but only if fertilizer rate research is conducted regionally with respect to soil type, agroecosystem, and cassava cultivar (Toro and Atlaa, 1980).

The objective of this study was to determine combination(s) of N, P, and K fertilizer rates for high cassava tuber yields for Milha-14 in the coastal Dondo district, Sofala province, Mozambique. A no-till fertilizer study was conducted to determine cassava tuber yield response to different combinations of N, P, and K fertilizer rates under smallholder farmer conditions.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at Milha-14 (19° 25′ 54.0″ S, 34° 43′ 28.6″ E), in the coastal district of Dondo, province of Sofala, in Mozambique, over the 2013/2014 agricultural year. Mozambique is divided into ten agro-ecological regions (MAF, 1996) based upon climate, soil type, elevation, and farming system (Maria and Yost, 2006). The regions are designated by prefix "R" that stands for "region" followed by a number that ranges from one to ten. Milha-14 falls within agro-ecological region R5 (MAF, 1996). R5 has an altitude ranging from 0 to 200 m above sea level, annual average temperature of 24°C, rainfall ranging from 1,000 to 1,400 mm, and soil texture ranging from sand to sandy loam. These agro-ecological attributes make R5 suitable for cassava production (MAF, 1996) despite the low soil pH and nutrient availability as evidenced by soil analysis results shown in Table 1. Nevertheless, the soils at Milha-14 are relatively young, suggesting that they have been eroded and re-deposited by water. On-site observations suggest that it is likely that the soils at Milha-14 are inceptisols with a high water table at or near the surface throughout the year. These characteristics prevent drainage and lead to near continuous waterlogging as evidenced by iron and manganese redoximorphic features. An aquept is likely the dominant suborder (Soil Survey Staff, 2010).

Experimental approach, design and treatments

Despite its overall suitability, Milha-14 lacks basic N, P and K fertilizer recommendations for cassava production and high cassava tuber yield. The experiment was initiated in March, 2013 and encompassed twenty treatments consisting of different combinations of contrasting N, P, and K fertilizer rates shown in Table 2 arranged in a completely randomized design (CRD) with each treatment replicated four times. Fertilizer rates were based upon the oxide forms of P and K and N as elemental (N, P_2O_5, and K_2O). The treatments were derived from general NPK fertilizer recommendation rates for cassava production in tropical regions (FAO, 2013; Howeler, 1981). Each nutrient was applied as a single fixed rate (Table 2: treatments 2 through 4) with N, P_2O_5, and K_2O applied at 60, 60, and 150 kg/ha, respectively and/or (2) combined with two single fixed rates at an increasing rate (Table 2: treatments 5 through 20). The treatments were compared among themselves and against an unfertilized control (check) treatment. Maximum fertilizer rates were defined based on maximum fertilizer response(s) reported in the literature (Howeler, 1981; Howeler and Cadavid, 1990). Cassava yield response is quite sensitive to fertilizer additions above the minimum required; sufficiency of one nutrient can lead to yield decreases when combined with another fertilizer nutrient. Using fertilizer rate relationships from previous studies seemed the most pragmatic approach.

A plot size of 4 m × 4 m was adopted for each fertilizer combination or treatment. Planting was done manually by inserting stem-cuttings into the soil at a spacing of 1 m × 1 m. A local bitter variety named *Tapioca* was used because of its resistance to ACMD, a major yield limiting factor in R5. Fertilizer was applied manually; urea, single super phosphate (SSP), and potassium chloride (KCl) were used as the N, P, and K sources, respectively. The N, P, and K were applied as basal fertilizer. Plots were weeded manually at the onset of the cropping season. The plots had four rows and four plants per row, making a total of 16 plants per plot. Tubers were dug by hand in March, 2014. The area harvested (net plot) consisted of four central plants selected from two central rows from where yield was estimated. During harvesting, traces of charcoal were uncovered in the subsoil, suggesting that the site was used for making charcoal. Charcoal production has many negative impacts on the environment (Msuya et al., 2011) including soil compaction due to wood transportation and the many charcoal burial sites. The site received a total rainfall of 1,832 mm which was unevenly distributed (Figure 1). As a result, the site remained waterlogged most of the cropping season due to poor drainage and a high water table.

Data collection and analysis

Yield data from the harvestable area (net plot) was used for

Table 2. Summary of average cassava tuber yield on fresh weight basis.

Treatment	Fertilizer rate in kg/ha			Tuber yield (tons/ha)
	N	P_2O_5	K_2O	
1	0	0	0	14.7 (2.6)^{bcd}
2	60	0	0	8.5 (1.3)^{d}
3	0	60	0	16.7 (3.8)^{abcd}
4	0	0	150	22.9 (1.9)^{abc}
5	0	60	150	25.5 (7.2)^{ab}
6	25	60	150	25.9 (6.6)^{ab}
7	50	60	150	24.0 (3.8)^{abc}
8	75	60	150	13.1 (1.8)^{cd}
9	100	60	150	20.6 (4.3)^{abc}
10	60	0	150	18.4 (3.5)^{cd}
11	60	30	150	17.3 (1.7)^{cd}
12	60	60	150	13.6 (0.9)^{cd}
13	60	90	150	22.8 (2.6)^{abc}
14	60	60	0	27.7 (3.6)^{a}
15	60	60	30	15.8 (2.4)^{bcd}
16	60	60	60	22.3 (4.7)^{abc}
17	60	60	90	21.5 (4.4)^{abc}
18	60	60	120	20.9 (7.3)^{abc}
19	60	60	150	19.8 (0.7)^{abc}
20	60	60	180	25.9 (2.9)^{ab}
LSD	-	-	-	11.7

Values in parentheses are standard errors of means. Treatments sharing superscripts are not statistically different ($p>0.05$).

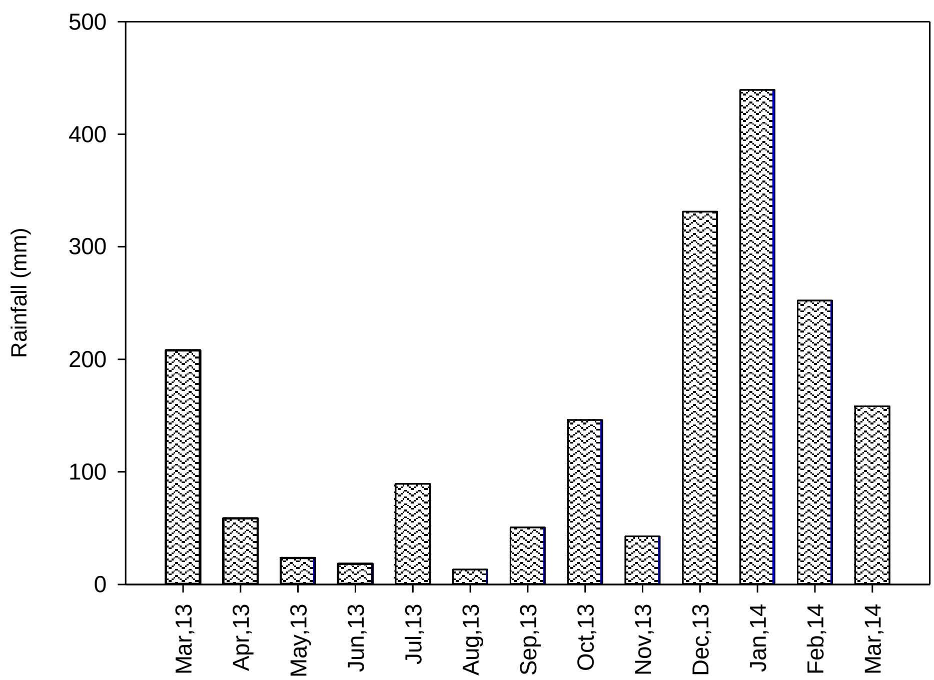

Figure 1. Total monthly rainfall (mm) recorded in 2013/2014 cropping season in Dondo.

statistical analysis which was performed using analysis of variance (ANOVA) and means compared using least significant difference (LSD) comparisons at a Type I error rate of α = 0.05 (SAS, 2011). Data collection also included soil measurements. Six soil samples were randomly collected from a 0 to 30 cm depth interval across the experimental plots and combined into one composite sample which was subject to a series of analyses procedures for selected soil chemical and physical properties shown in Table 1.

RESULTS AND DISCUSSION

Soil analysis

Results of soil analysis showed that the soil at Milha-14 was acidic and low in organic matter and selected nutrients as shown in Table 1, with Ca and Mg in particular, available in low and marginally low amounts, respectively. The soils are inceptisols with aquept as the likely dominant suborder (Soil Survey Staff, 2010), with a high water table at or near the surface throughout the year which leads to near continuous waterlogging, resulting in an overall poor soil fertility and failure to meet the crop's nutritional requirement as described by Howeler (2002).

Yield response

Table 2 summarizes the average cassava tuber yield (fresh weight basis) responses in tons/ha to different combinations of contrasting N, P, and K fertilizer rates. The results showed that there was a significant increase in no-till cassava tuber yield due to fertilizer addition ($p < 0.05$), demonstrating that the crop responds to fertilizer application as was reported in several studies (Polthanee and Wongpichet, 2017; Ezui et al., 2016; Osundare, 2014; Agbaje and Akinlosotu, 2004; Graner and Coury, 1955; Krochmal and Samuels, 1970; de Cequeira and Howeler, 1980).

Application of selected single fixed rate of K resulted in higher yield than that of N but equal to that of P (treatments 4 vs. 2 and 3, Table 2). On the other hand, applying 60 kg/ha N alone (treatment 2: 60-0-0 kg/ha N) yielded lowest (8.5 tons/ha) compared to not applying any fertilizer (treatment 1: 0-0-0; 14.7 tons/ha), suggesting that added N results in additional above ground biomass but not in additional tuber yield. However, applying 60 kg/ha N along with 60 kg/ha P (treatment 14: 60-60-0) yielded highest, 27.7 tons/ha. This yield surpassed that of the unfertilized control treatment almost two-fold and the national average yield (~6 tons/ha dry wt.; Dias, 2012). Increasing N rate along with that of K led to a decrease in the overall cassava tuber yield (Figure 2: treatments 10 through 13 vs. 5 through 9 and 14 through 20). These findings contrast those of Graner and Coury (1955) who reported the poorest tuber yields from a study conducted in Campinas, Brazil, when P was omitted, and N response similar to that obtained when P was added, whereas response to K was much less significant.

Cassava response to P was also reported by Krochmal and Samuels (1970) and de Cequeira and Howeler (1980), whose findings suggest that application of P leads to an increase in tuber yield and increased yield response to both N and K in Brazil's situation. According to Graner and Coury (1955), this high cassava P response is likely due to phosphorylation of starch reserves necessary for vegetative growth in the early stages of development. On the other hand, this response to P may also reflect, to some extent, the amount of P present in the soils at the site (Fermont, 2009) or in the stem-cuttings when they are set out in the field. Howeler and Cadavid (1990) also reported cassava response to P, with its best response found in infertile oxisols with the exception of those soils with high mychorrizal population.

Results of the study suggest that in spite of its role in cassava top growth and tuberization (Agbaje and Akinlosotu, 2004), K does not seem to be a limiting factor of production. Figure 2 shows a decrease in cassava tuber yield with increasing K rates (treatments 14 through 20). These findings contrast a recent study conducted in Northeastern Thailand by Polthanee and Wongpichet (2017), who reported that cassava had removed the greatest quantity of K in the storage roots compared to leaf and stems, and another in West Africa by Ezui et al. (2016) where K was found to be the primary cassava tuber yield limiting nutrient with requirements ranging from 140 to 160 kg/ha (CTCRI, 1983). This decrease in cassava tuber yield with increasing K rates agrees with Agbaje and Akinlosotu (2004); only sufficient K levels are required to stimulate cassava response to other nutrients such as N, as their excess may result in more biomass at the expense of tuber production as is common in sugarbeet production (Moraghan and Horsager, 1991). Conversely, cassava tuber yield was reported to respond positively to K when cassava was grown continuously in the same field (Howeler and Cadavid, 1990), which suggests that both N and P, as well as K individually play important roles in the overall cassava tuber production with its requirements depending more on the agro-ecology (including soil parent material) of the area where its production is intended and management practices adopted.

Factors affecting yield response

Field observations suggest that several biotic and abiotic factors may have contributed to the large variability in the experimental results (Table 2, LSD = 11.7). The high water table and excessive rainfall, lack of land preparation (due to the use of no-till planting which

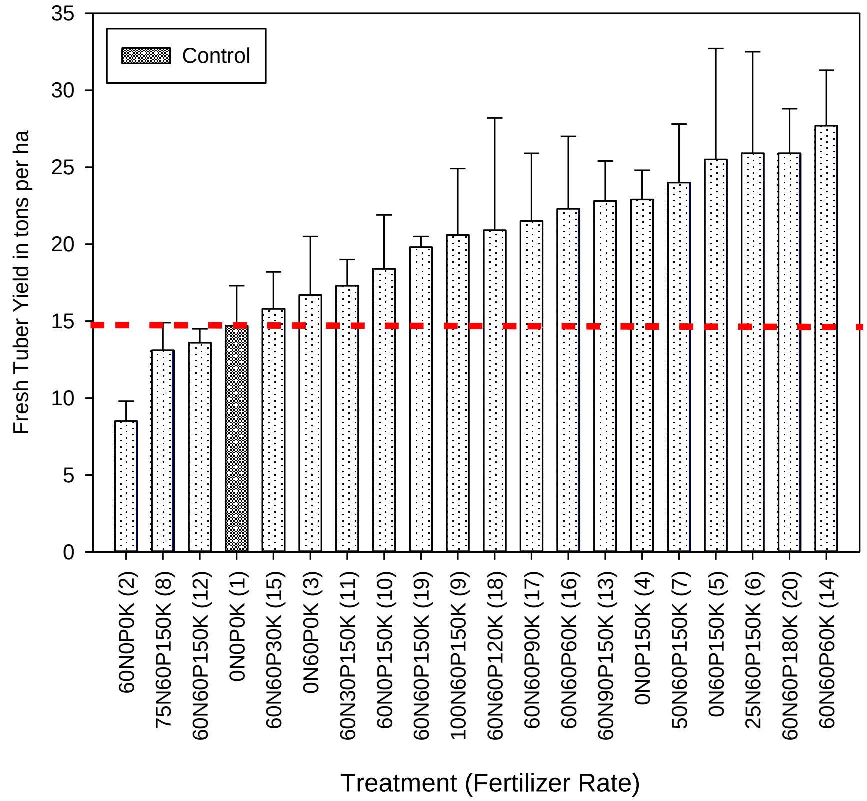

Figure 2. Cassava tuber yield response to different combinations of contrasting N, P, and K fertilizer rates. Yields are reported in fresh weight basis. Bars are the standard error of the mean. The dashed line is the control (no fertilizer) treatment mean. Numbers in parentheses are treatment numbers from Table 2.

obviated the construction of hills for the plants) and quality planting material (too much variability in planting material) are examples of these factors. Despite the shallow water table and in contrast to traditional practices, land preparation at the site did not include tilling the plots and hilling a practice which, according to FAO (2013), is used to keep the roots above the water table. The same source has pointed out that the risk of waterlogging is very high in shallow and poorly drained and heavily compacted soils especially when first rains are intense. During routine field visits it was observed that the site was waterlogged throughout most of the cropping season due to the shallow depth to water table and the fact that the amount of rainfall (1,830 mm total, Figure 1) received during the study period was approximately 50% greater than the average rainfall of that area (1,200 mm annually) (MAF, 1996). According to Agbaje and Akinlosotu (2004), although cassava can thrive in unfavorable conditions, excessive rainfall can affect the lifespan of added fertilizer in the soil, its retention and availability to the crop, and consequently may affect tuber formation and quality (Duluora, 2012; FAO, 2013).

In a study on the influences of temperature and rainfall on the yields of maize, yam and cassava among rural households in Delta State, Nigeria, Emaziye (2015) reported a negative relationship between rainfall and yields of maize, yam and cassava with decreased yield observed in all three crops due to increased rainfall. Mbanasor et al. (2015) also looked at the impact of rainfall on cassava productivity. In their study, they found a positive short-term but negative long-term effect of rainfall on cassava tuber yield. Similarly, a recent analysis of sensitivity of crop yield to extreme weather in Nigeria by Ajetomobi (2016) also found a negative effect of excess within-season rainfall on cassava yield with each 1% increase in rainfall resulting in 2.15% decrease in yield of cassava.

The presence of charcoal in the soil has also been associated with added fertilizer-use efficiency. Charcoal can simulate slow release of N, P, and K because of its effect on nutrient release dynamics and potentially on alterations to the soil microbial population. In their soil fertility work with ammonium sulfate additions to media containers with various levels of charcoal additions, Steiner et al. (2009) observed that less N, undetectable levels of P, and more K was leached in charcoal containing pots due to the chemical composition of K-rich charcoal. In a similar study, Steiner et al. (2008) reported increased retention of applied N fertilizer on a highly weathered Amazonian Oxisol with organic amendments that included charcoal. These findings suggest that once in the field, charcoal adsorption sites can compete with cassava for N and increase available K. Thus, the added fertilizer/nutrient use efficiency can be affected by charcoal additions.

Due to the impact of ACMD and CBSD (Boansi, 2017; Hillocks et al., 2002b), finding sufficient disease-free planting material was difficult at the study onset. Cassava transplant cuttings should be robust (Polthanee and Wongpichet, 2017) including only the middle brown-skinned portions of the stem and approximately 20 to 25 cm long with 5 to 8 nodes (James et al., 2000). Low quality plant material is one of the major causes of poor cassava tuber yields (Polthanee and Wongpichet, 2017) in Africa and Latin America (FAO, 2013). Owing to an increased incidence of ACMD and CBSD in Northern and Central Mozambique (Promar Consulting, 2011), successful cassava production in these areas requires that disease-free and/or disease-resistant material are used.

According to James et al. (2000), stem cuttings taken from portions of the plant other than the middle (top and bottom) dehydrate very quickly, are less hardy and therefore less resistant to pests and diseases, hence they are not suitable for planting and production of high quality tuber(s). In relating the growth and productivity of cassava grown from different portions of the cassava stem to climate parameters in Southeastern Nigeria, Eke-Okoro et al. (1999) also reported poor growth and productivity of stem cuttings taken from the top green and bottom portions of the plant. Coupled with site variability, depth to the water table, and variability of stem cuttings used for planting material, tree stumps between some of the plots may have impacted overall yield response to added fertilizer and led to greater variability in the data. It is important to note that after considerable search for a research site, this was the only site available for this research.

Conclusion

Cassava tuber yield was significantly increased by fertilizer addition. A combined application of 60-60-0 kg/ha is suggested for high cassava tuber yield(s) at Milha-14. On the other hand, taking into consideration the fact that cassava tubers remove more K than N and P, one season's results are not enough for drawing a solid conclusion. More research is needed to verify if this fertilizer combination (rates) can sustain high cassava tuber yields in the long term.

Alternatively, crop removal of K could be estimated and added into the fertilizer mix to avoid K mining as application of single fixed rate of K resulted in higher yield compared with those of N and P. The combined applications of 60-0-0, 75-60-150, and 60-60-150 kg/ha N-P_2O_5-K_2O yielded less compared to the unfertilized control treatment. Results from this study show clearly that there is potential to increase cassava tuber yield towards meeting the growing demand for cassava in an emerging bioethanol, brewery and cassava-bread industry.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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