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Assessing the Impact of Eucalyptus Cultivars on Soil Properties in Three Districts of Uganda

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Abstarct: The present study investigated the influence of Eucalyptus cultivation on soil properties across the three districts of Uganda: Kabarole, Mpigi and Rakai which are part of Western Highlands, Lake Victoria Crescent and South Western Agroecological zones respectively. The study aimed at evaluating the effect of two dominant Eucalyptus cultivars GU7 (Improved) and E. grandis (Local) within these regions. A total of three treatments composed of the two above cultivars and the control plot with no eucalyptus were considered for this study. These were each replicated three times making a total of 9 replications per district and a total of 27 replications across the three districts. From each replicate across the three districts, a total of 5 composite soil samples were picked at a depth of 0-30cm making a total of 135 soil samples across the three districts. These were taken to the soil laboratory for analysis of major soil nutrients which included; total nitrogen, available phosphorus, potassium, exchangeable magnesium, calcium, soil organic carbon and pH. Statistical analysis, with R software version 4.3.3, was performed to obtain differences in their means. Results showed a general decline in major soil nutrients (N, P and K) across the Eucalyptus stands in all three districts, with a more significant ($P<0.005$) decline observed under GU7 cultivar plantations. Additionally, results showed that Mg and Ca were inherently low and the most deficient nutrients in both Kabarole and Rakai while pH was significantly ($P<0.05$) higher (6.6) in Mpigi compared to the other two districts in the control plot but also significantly ($P<0.05$) reduced under GU7 plantations in the same district compared to the two districts. The study also revealed that P is the most deficient nutrient in Rakai district for Eucalyptus production while N and SOM are the most deficient in Mpigi. Potassium (K) was significantly ($P<0.05$) low in both Kabarole and Rakai soils compared to Mpigi district.

Conclusively, this study shows a significant negative effect on major soil nutrients (N, P, K) associated with Eucalyptus GU7 cultivar compared to E.grandis across the three districts.

Key points: Eucalyptus, soil nutrients, Uganda.

1.0 Introduction

Eucalyptus (genus *Eucalyptus)* trees are the most widely grown trees worldwide (Stanturf, 2013, Singh *et al*., 2021), with over 500 species (Demel, 2000). Several Eucalyptus varieties have been introduced in Uganda. More genotypes are still in the breeding pipeline in the designated forestry sectors of the country. Many of these are said to be fast maturing (NFA, 2019). However, limited research has been conducted on their effect on soil properties in Uganda. Unfortunately, assessment reports in the country have indicated that 4-12% of Gross National Product (GNP) is lost from environmental degradation, of which 85% is from soil erosion, nutrient losses and unsustainable changes in land use (CIAT *et al*., 2017; Cooper, 2018). For the latter, this is particularly attributed to the conversion of forest cover to other land uses such as Eucalyptus production with attendant loss in critical ecosystem services. There is increasing demand for forest products such as timber, fuel wood, paper, herbal medicines and control of soil erosion, and restoration of degraded land among others (Takele *et al*., 2023). Therefore, there is a need to conserve forest cover for such ecosystem services including carbon sequestration both in standing biomass and below-ground roots/soil organic matter as well as boosting soil health.

In Uganda, among the many tree species being promoted to fill the increasing demand for forest products to slow down deforestation is Eucalyptus (FAO, 2009; NFA, 2021). Eucalyptus was first introduced in Uganda around 1912 with aim of supplying fuel wood for railways and administrative centres including draining of swamps to reduce malaria disease. To-date, Eucalyptus is grown for various uses including among other; fuel for curing tobacco, provision of poles and posts for fencing and electric transmission lines, construction poles, domestic and industrial energy (e.g. tea and sugar drying, baking, charcoal for steel and cement manufacturing); aesthetic use as ornamental trees in urban areas, lowering the water table in wetlands and putting infertile soils or degraded land to productive use. By end of 1975 there were a total of 11,528 ha of Eucalyptus plantations in Uganda, without including small woodlots, and roadside ornamental and shade trees. Generally, many farmers in countries like Uganda appreciate Eucalyptus as a profitable business (FAO, 2009; Bukenya *et al*., 2009; Dessie, 2011) due to low production cost.

The most widely adopted Eucalyptus species according to the recent survey conducted in the three districts is *E. grandis* and GU7 cultivars (Nankya et al., 2013-Un published report). The rapid spread is due to its multipurpose uses, fast maturity and ready market (Gombya-Ssembajjwe, 2015). Eucalyptus has adapted well in the tropical environments, growing in a diversity of biophysical niches, depending on a given variety (NFA, 2021).

Natural forests and woodlands in Uganda can no longer keep pace with the required demand for forestry products from a diversity of communities and the resulting deforestation is degrading the environment (Gombya-Ssembajjwe, 2015). This has led to the accelerating expansion of eucalyptus plantations in low-income communities in Uganda driven by the growing demand for timber, other forest products and the afforestation campaign by the Uganda Government through the Ministry of Water and Environment (National Forestry Profile, 2022). Therefore, is the reason why Eucalyptus production is gaining momentum in Uganda and information from Ethiopia, with similar socio-economic challenges like Uganda, shows that eucalyptus expansion has increased from 20% in the last 20 years to 35% in year 2020 (Nyambati and Oballa, 2021). It is most likely that the same scenario could be happening in Uganda, which threatens the food security of the country (Igamba, 2021; Read, 2022).

Farmers are rapidly getting attracted to its production to the extent of encroaching on arable land, with different production goals, hence growing different eucalyptus species at different densities and different harvest intensities (Calabrese, 2021) with little extension advice on appropriate agronomic and soil fertility management practices. It is therefore more likely that the poor management of Eucalyptus may affect soil fertility in the short or long run. This study therefore aimed to determine the effect of dominant Eucalyptus cultivars GU7 and *E.grandis* on soil chemical properties, mainly focusing on soil nutrients in the three target districts of Uganda.

2.0 Materials and Methods

2.1. Description of study areas.

The study was conducted in three districts which include Mpigi, Rakai and Kabarole which represent the three agroecological zones that is Lake Victoria, South Western and Western agroecological zones. The three agroecological zones were selected due to their increasing trend of eucalyptus production compared to other agroecological zones in Uganda. The geographical location of the representative districts includes Mpigi (latitude: 0°04’60.00” and 32°00’0.00 E 0.2274°, Rakai (latitude: 0°39’59.99” and longitude: 31°24’59.99”) and Kabarole (latitude: 10°27′0″ and 39°07′0″) longitude. The altitude in Kabarole district varies between 626 m - 2,919 m above sea level, in Mpigi district it ranges from 1,124 m to 1,344 m, and in Rakai district 1,150 m to 1,541 m above sea level. Annual precipitation received per study district include 1,431 mm, 184 mm and 1,500 mm for Mpigi, Rakai and Kabarole respectively.

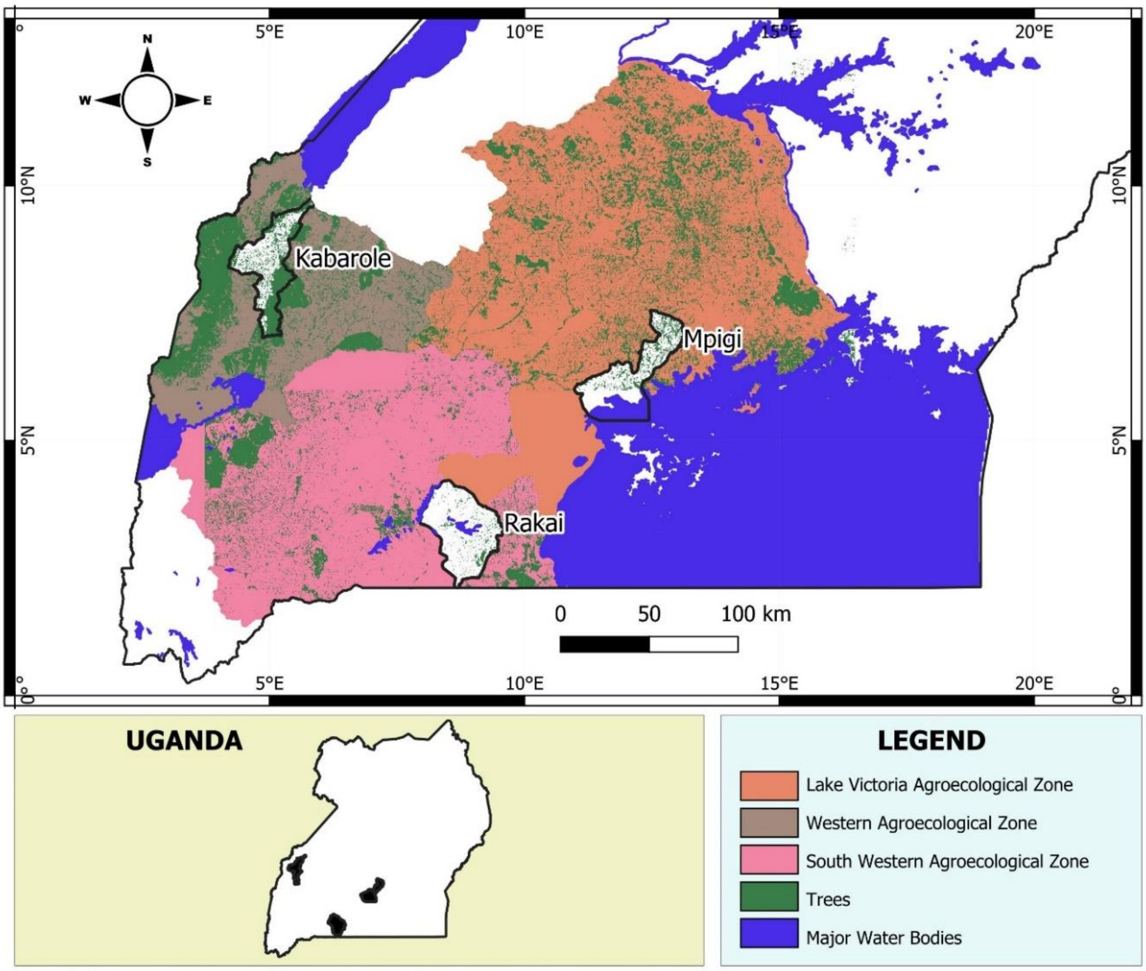


Figure**:** 1. Map representing study districts in the three agroecological zones. The green color represents trees of approximately 15 m height or higher in 2022 as derived from Land use/Land cover raster file built from Sentinel-2 of resolution 10 m (Karra *et al*., 2021).

The soils in Mpigi district are typical ferralitic red/yellow sandy/clay loams (latosols) with pH of 5.5-6, rather leached but generally well drained (Mpigi district local government annual report 2023); in Rakai district, over 75% of the soils in the district are ferralitic representing an almost final stage of weathering with little or no weatherable mineral reserves left (Wortmann, and Kaizzi *et al*., 2019). Some heavy clay varieties have decent fertility but sandy soils are particularly poor in nutrients. Other types include lithosols (soils without horizons and thus young and stony or bare rocks), alluvial and lacustrine sands and alluvial clays. Whereas, in Kabarole district, it is covered with good soils conducive for agriculture where geological divisions show that 90% of the district is covered with black loam (volcanic) soil while a few places especially in Busoro and parts of Hakibaale sub counties have red sandy clay loams occasionally underlain by literates (Kabarole District master plan, 2018).

2.2. Soil Sampling

Soil samples were collected during the month of May 2023 from the purposively selected farmers’ eucalyptus fields in the three districts of Mpigi, Rakai and Kabarole. A total of 3 farms of 1 acre were sampled per district (Plot under GU7 stands, *E.grandis* and the control plot which had no Eucalyptus. These were each replicated three times making a total of 9 plots per district; that is 3 farms of GU7, 3 farms of *E.grandis* and 3 farms of control plots. Similar experimental set up was done across the three districts making a total of 27 farms of overall replicates across the three districts. From each replication, a total of 5 composite soil samples were picked per replication making a total of 15 samples per treatment/district which brought the total number of collected samples to 45 per district and 135 soil samples across the three districts. Soil samples were taken from a depth of 0-30 cm using a soil auger and all the soil sampled points were geo-referenced using etrex 10 GPS. The soil samples were well packed and labelled then taken to the laboratory for analysis.

2.3. Laboratory analysis

Firstly, the collected soil samples were air-dried, ground and sieved through a 2 mm sieve and then analysed using the standard methods (Okalebo *et al*., 2002). The analysis included: pH, total organic carbon (TOC), total nitrogen (N), available phosphorus (P), exchangeable calcium (Ca), magnesium (Mg), potassium (K) and soil texture. Soil pH was measured using a pH meter (1: 2.5 soil: water); SOM and total N were determined using Walkley and Black method and Kjedhal method, respectively. Soil texture was determined using Bouyoucos hydrometer method (Bouyoucos, 1960). Exchangeable bases were determined by the procedures described by Okalebo *et al*. (2002). Five (5 g) of air-dried soil, 100 ml of ammonium acetate was added in a clean plastic bottle and shaken for 30 minutes. The contents were filtered through number 42 Whatman paper and this constituted the extract for measuring K, Ca and Mg. Potassium was measured on a flame photometer while Ca and Mg were determined by atomic absorption spectrophotometer at wave length of 422.7 nm and 285.2 nm respectively.

Soil particle analysis to estimate the percentage sand, silt and clay (texture) was determined using the hydrometer method. The hydrometer method of determining the proportions of sand, silt and clay depends on particle size of the differential settling velocities in a water column. The settling velocity is a function of liquid temperature, viscosity and specific gravity of the falling particle.

2.4. Statistical Analysis

Data collected on soil chemical properties during the study were entered in Microsoft excel for cleaning and then imported into the R statistical package for different types of analyses. Both descriptive and inferential statistical analytical tools were used in the study. Summary statistics (means, variances) were used to compare soil chemical properties from different geographical locations. Analysis of variance was performed and tested at $\alpha=0.05$ level of significance using the F-test to determine the difference between the cultivars and soil nutrients using R programing language version 4.3.1 Significant means for main and interactions were separated using Duncan`s Multiple Range Test (DMT).

3.0 Results and Discussions

3.1 General observation about the results

Results (Figure 2) of the study showed that eucalyptus irrespective of cultivar negatively affects soil nutrients, across the three districts under study, although significantly ($P<0.05$) with GU7 cultivar compared to *E.grandis*. Results also indicate that the improved cultivar GU7 absorbs more soil nutrients across the zones (Table 1). Below are the specific soil parameters that were considered under this study, described and discussed as follows:

3.2 Soil Organic Matter

Generally, Soil Organic Matter (Table 1) was significantly ($P<0.05$) higher in Kabarole followed by Rakai, with Mpigi having the least (Figure 2). It is worth noting that Soil organic matter (SOM) is a crucial component of sustainable soil quality and productivity. The variation of SOM across the three districts is probably because in Kabarole, more animal grazing within eucalyptus plantations was higher compared to the other districts according to the previous survey conducted, which contributes to manure, a source of SOM that keeps it in balance. Similar results were obtained by Manaman *et al*., (2020) who revealed that SOM may vary from one ecology to another depending on various factors such as temperature, inputs, and disturbances among others. Additionally, SOM in both Mpigi and Rakai was significantly (P<0.05) lower in GU7 plantations compared to *E.grandis*. Similar findings were obtained by Bikila *et al*., (2020 who revealed that SOM can differ by species. This is due to the recycling of nutrients through decomposition of different tree parts, meaning that cultivars with more upon decomposition leads to accumulation of more SOM in the soil which is the case with the improved eucalyptus cultivars.

3.3 Total Nitrogen

Results also indicate that Nitrogen was significantly (P<0.05) higher in Kabarole followed by Rakai with Mpigi containing the least. This is probably because Kabarole has volcanic soils which are richer in Nitrogen concentration than other areas under study. Findings also revealed that cultivar GU7 plantation had lesser Nitrogen levels compared to that of cultivar *E.grandis*. This is probably because more soil Nitrogen was absorbed by the tree parts in the GU7 plantation which is observed in Figure 2 (a) with mostly the leaves and twigs. Studies conducted by Lubis *et al*., (2020) revealed that if the volcanic ash is thicker, N concentration becomes high. Again, it should be noted that volcanic soils are rich in organic materials rich in soil nutrients of N is inclusive.

3.4 Phosphorus (P)

Results (Figure 2_d) of the study show that in the control, P was higher in Kabarole and Mpigi and significantly (P<0.05) lower in Rakai. This is possibly because of the low pH levels observed in Rakai (Figure 3b). The optimum soil pH range for phosphorus availability is 6.0 to 7.0. At lower pH levels, phosphate tends to bind with aluminum or iron compounds in the soil, making less available for plant uptake. These findings are in agreement with that of Turner and Blackwell (2013) who revealed that Soil pH influences the chemistry, dynamics and biological availability of phosphorus (P) whereby at a normal pH of 6.0 to 7.0, P becomes available for plant uptake. However, results again indicate that P significantly (P<0.05) reduced under GU7 plantations across the three districts compared to *E.grandis.* This is possibly because of high P absorption by GU7 trees as observed in Figure 4(b) may be due to their fast maturity period, the species utilize more Phosphorus for growth compared to *E.grandis.* Similar findings were obtained by Bulgarelli *et al*., (2019) who revealed that different Eucalyptus species respond differently to P in the soil.

3.5 Potassium (K)

Findings of the study (Figure 2_g) indicate that potassium was generally low in soils of Kabarole and Rakai compared to soils of Mpigi. However, results indicate that much as K was higher in Mpigi, there was no significant difference in its absorption by cultivars from the soil. The low K levels in Kabarole and Rakai could be attributed to continuous harvesting of K which is lost through different plant parts like leaves, bark, branches and twigs leading to K mining. Similar findings were obtained by Rodolfo *et al*., (2019) who stated that Potassium (K) is one of the most heavily accumulating nutrients among Eucalyptus cultivars and therefore, is highly exported through harvesting of wood. Rodolfo *et al*., (2019) added that its availability in the soil of Brazilian plantations is very low, mainly in the regions of the Cerrado biome, which has soils with inherent low fertility and marked water deficits, implying a lack of nutrient availability and supply. However, soils in Mpigi may possibly be having inherent high levels of K. More studies conducted in Hawaii, early this year (2024), also indicated that under acidic conditions, aluminum and manganese toxicities may cause poor root development, which hinders potassium uptake. When acidic soils are limed, exchangeable K increases due to increases in the cation exchange capacity, which could have been the reason for low K availability in the soil in Kabarole and Rakai across treatments.

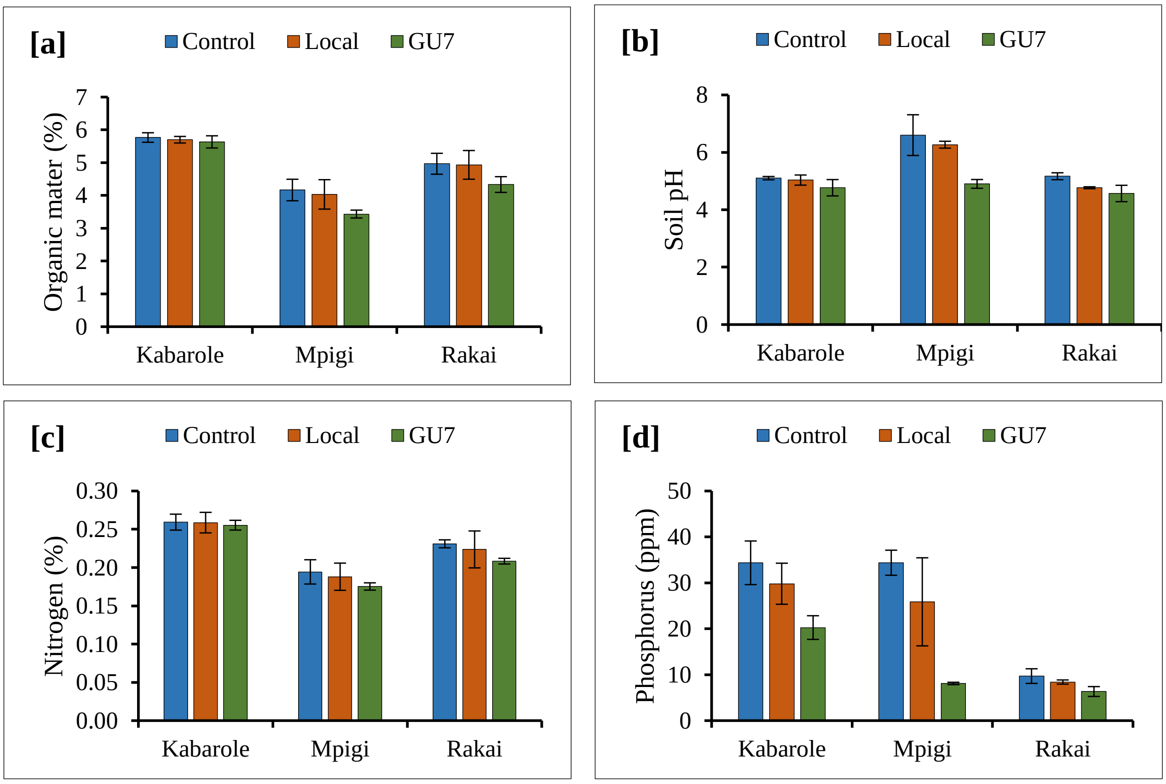
3.6 Calcium (Ca) and Magnesuim (Mg)

Generally, the two nutrients were significantly (P<0.05) lower (Tabe 1) in Kabarole and Rakai regardless of cultivar compared to Mpigi. (Figure 2_b).

Calcium and Mg were observed to be lower in both GU7 and *E.grandis* plantations than the control according to the ANOVA results (Table 1), although both were significantly lower under GU7 plantation soils across the three districts. Magnesium deficiency in majority of weathered soils, is becoming a critical issue where it is subjected to potential leaching and interaction with aluminium, which is the case with the soils in the three districts under study especially for Kabarole and Rakai. Related studies were conducted by Francisco *et al*., (2021) who revealed that in soils with low fertility, leaching of Mg can be as high as 25 kg ha^{-1}, while it can be increased up to 40–70 kg ha^{-1}, depending upon numerous variables such as soil and crop type, environmental conditions, and drainage volume which is a likely cause with most of the soils Kabarole and Rakai and to some extent Mpigi district.

3.7 Soil pH

Study findings (Table 1) revealed that pH was significantly ($P<0.05$) higher in Mpigi compared to the other two districts. This could be the reason why there as increased up take of nutrients by the two cultivars especially GU7 in Mpigi compared to the other two districts. These results are in agreement with results from the study conducted by Diego *et al*., (2020) for E. benthamii and E. dunnii eucalyptus cultivars which showed that when lime was applied to the rest of the treatments (NPK), there was a significant difference in growth of eucalyptus compared to the control where lime was not applied. Normal pH levels provide a favorable environment for nutrient absorption. Results also indicate that pH was lower in both GU7 and *E.grandis* plantations in Rakai compared to the control. This means both cultivars might have lowered pH. Similar results were obtained by Abdoulaye *et al*., (2015) who found that Eucalyptus camaldulensis litter leads to changes in soil pH and phenol content under Sahelian acacia's fields. This could mean that since GU7 produces more biomass than *E.grandis*, during litter decomposition, there is a release in acids which leads to reduced pH. Again similar results were obtained by Yahannes and Zalalem (2023) who observed during their study that soil pH, CEC increased in further distance from the Eucalyptus trees. This implies that some eucalyptus species release acids through their decomposed litter which reduces soil pH. Amare (2019) also obtained related results where pH was significantly ($P<0.05$) in eucalyptus land uses compared to other land uses.



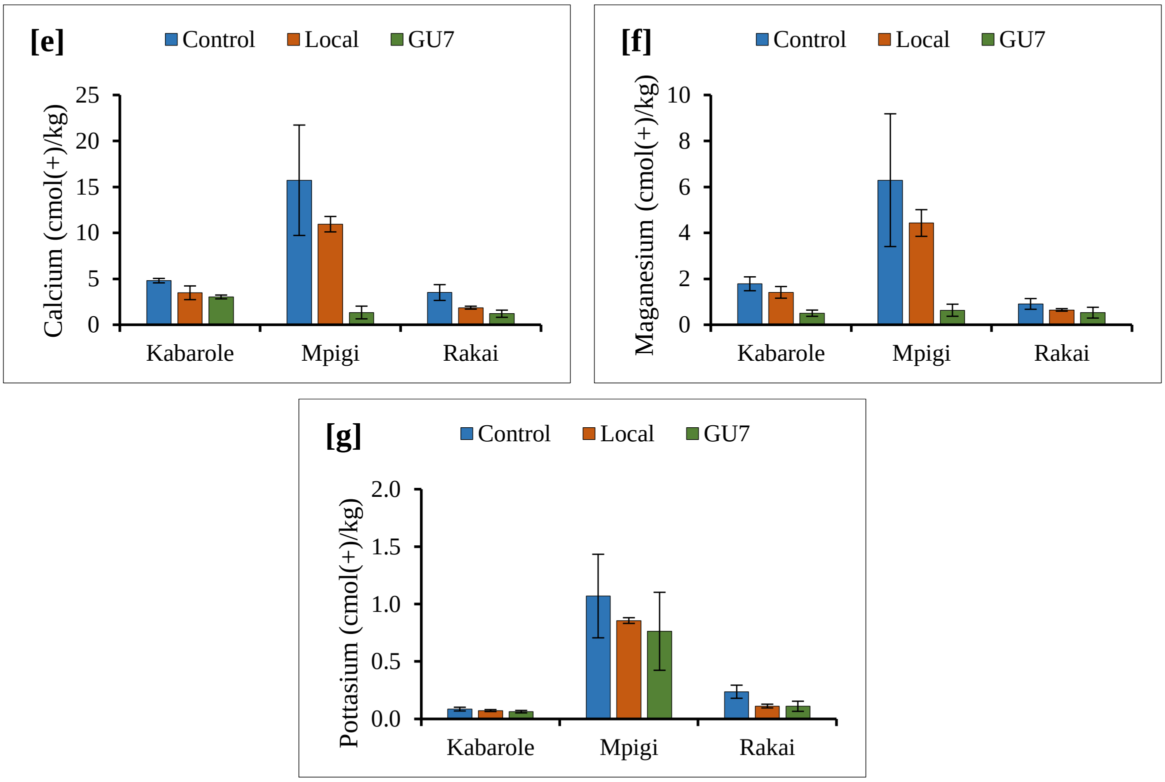


Figure 2: Effect of eucalyptus cultivars on soil nutrient composition under different agroecological zones. [a] Organic matter, [b] Soil pH water, [c] Nitrogen, [d] Phosphorus, [e] Calcium, [f] Magnesium, [g] Pottasium. Error bars indicate standard error.

Table 1: Effect of eucalyptus cultivars on soil nutrient composition under different ecological zones.

Ecological Zones (E)	**Varieties (V)**	**pH**	**OM (%)**	**N (%)**	**P (ppm)**	**K (cmol(+)/kg)**	**Ca (cmol(+)/kg)**	**Mg (cmol(+)/kg)**
Kabarole	Control	5.10^{b}	5.77^{a}	0.26^{a}	34.37^{a}	0.09^{b}	4.8^{bc}	1.78^{bc}
	Local	5.03^{b}	5.70^{a}	0.26^{a}	29.81^{ab}	0.07^{b}	3.48^{c}	1.41^{bc}
	GU7	4.77^{b}	5.63^{a}	0.26^{a}	20.26^{bc}	0.06^{b}	3.03^{c}	0.50^{c}
Mpigi	Control	6.60^{a}	4.17^{bc}	0.19^{bcd}	34.38^{a}	1.07^{a}	15.72^{a}	6.29^{a}
	Local	6.27^{a}	4.03^{bc}	0.19^{cd}	25.86^{ab}	0.86^{a}	10.94^{ab}	4.43^{ab}
	GU7	4.90^{b}	3.43^{c}	0.18^{d}	8.09^{cd}	0.76^{a}	1.34^{c}	0.63^{c}
Rakai	Control	5.17^{b}	4.97^{ab}	0.23^{ab}	9.69^{cd}	0.24^{b}	3.51^{c}	0.91^{c}
	Local	4.77^{b}	4.93^{ab}	0.22^{abc}	8.40^{cd}	0.11^{b}	1.86^{c}	0.65^{c}
	GU7	4.57^{b}	4.33^{bc}	0.21^{bcd}	6.33^{d}	0.11^{b}	1.20^{c}	0.53^{c}
F-Test								
E	Na	***	***	***	***	***	**	**
V	Na	**	ns	ns	**	ns	*	*
E X V	Na	ns	ns	ns	ns	ns	*	ns

pH, pH water; OM, Organic Matter; N, Nitrogen; P, Phosphorus; K, Pottasium; Ca, Calcium; Mg, Magnesium.

Na, not applicable; ns, not significant; * Significant ($p \leq 0.05$); ** Significant ($p < 0.01$); ** Significant ($p < 0.001$).

Means within columns followed by the same letter do not differ significantly at $p<0.05$ by Duncan`s Multiple tests.

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

From this study, results showed that both Eucalyptus cultivars (GU7 and *E.grandis*) negatively affected soil nutrients (N, P, K), although significantly observed with the improved cultivar GU7 across the three districts. Soil pH was inherently acidic in Kabarole and Rakai with exception of Mpigi whose pH was inherently at normal range although observed to have been significantly reduced further under GU7 plantations. The study again revealed that N and Soil organic matter are the most deficient in Mpigi compared Kabarole and Rakai district. Findings of this study also revealed that Ca and Mg were significantly lower under GU7 plantations across the districts compared to *E.grandis*. Finally, it was concluded from this study, that Eucalyptus have a negative effect soil properties although this varies with cultivar and ecology.

4.2 Recommendations

Based on the findings of this study, zonal fertilization plans and packages should be developed per Eucalyptus cultivar also putting into account a given ecology. This will enhance improved Eucalyptus yield, optimization of soil nutrients and sustainability of the production systems in the study areas.

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