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AUGMENTING OF PRIMARY AND SECONDARY MACRONUTRIENTS BY CHOPPED *LEUCAENA* LEAVES USED AS ORGANIC MATTER IN COMPOSTED SWEET POTATO MOUNDS UNDER TROPICAL HUMID LOWLAND CONDITIONS

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Abstract

The importance of chopped *leucaena* leaves as an organic matter amendment in mounds used for sweet potato production was investigated. Fresh leaves were collected, sun-dried, chopped, and applied to land that was plowed, and mounded with four treatments. The first treatment was set as the control, 1 kg of chopped leaves was applied but not planted in the second, no chopped leaves were applied and planted in the third, and chopped leaves were applied and planted with sweet potato in the fourth treatment, respectively. These were replicated four times and set up for six months in the field. A 500 g of soil samples were taken from the top 0 – 60 cm of the mounds, processed, and analyzed for macronutrients, electrical conductivity, and pH using standard analytical procedures. The results showed that adding the chops increased the content of all the macronutrients. In almost all cases, the application of the chopped leaves and concurrent planting sustained the availability of the nutrients compared to the depletion that occurred when no amendment was made nor planted. The changes in electrical conductivity and pH were within acceptable ranges. These findings have implications for soil fertility management in the humid tropics.

Keywords: *Leucaena* leaf, macronutrients, organic matter, PNG, sweet potato

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Introduction

Despite the importance of sweet potato (*Ipomoea batatas* L.) being a staple crop in PNG, several constraints affect production (Hartemink, 2003; Michael, 2020a). These include improved planting materials, soil fertility issues, pests and diseases, climatic extremes, and marketing (Peter and Michael, 2023a). A number of these, an assessment of the suitability of agricultural land for sweet potato, and a description of farming systems have been addressed (Michael, 2019a; b). Among these, understating how soil fertility is managed in rural village gardens remains one of the biggest challenges for the sustainable production of sweet potato. Soil fertility management is essential in light of climate change (Michael, 2019a; Aipa and Michael, 2019), extreme weather patterns, and the evolution of possible new pests and diseases. In line with the soil fertility issue and understanding of how rural people manage it, brings into perspective the composted mounds used in the higher altitude areas of PNG highlands for sweet potato production (Taraken, 2012) and not common in the lowlands. This is important in light of climate change, where extreme changes in soil moisture and significant decline in soil fertility are predicted because of land-use changes. Moreover, it to help sustain mound-making, introduce new and improved sweet potato cultivars, maintain soil nutrients, and promote organic matter application (Michael, 2020b; c). The relevance of the use of organic matter in mound making is that the plant materials are readily available and relatively cheap (Michael *et al.*, 2014) compared to inorganic fertilizers, which are expensive and availability is an issue in poor economies (Michael, 2018a; b; c; Michael *et al.*, 2015; 2016; 2017). Sweet potato production in PNG is a communal responsibility in the rural setting, and labor requirement is not an issue. There is, however, a need to understand the type of organic matter, the methods used to prepare it, and how the application is made (Fig. 1).

A piece of land that was previously fallowed is manually cleared of vegetation using simple handheld tools (e.g., spades and bush knives), and the cleared materials are allowed to dry up by direct exposure to sunlight for 4 to 8 weeks (depends on the type of vegetation). During this period, the targeted plant materials in the form of leaves or whole plants used as organic matter in the mounds are collected from the nearby fallowed food gardens or bushes and dried by direct exposure. Once the cleared plant materials are dry enough (to enhance decomposition and to minimize regrowth and become weeds) to be easily moved, they are gathered into oval heaps with other dirt and soil using a spade, and mounding stations are formed (in a straight line) throughout the whole cleared land.

As shown (Fig. 1), the heaps are covered entirely with the plant materials (hereafter referred to as organic matter) collected and dried for use. Once that is done, the soil around the mounding stations is dug up and placed on the organic matter until a complete composted mound is made (decided based on experience). Completing the composted mound-making processes is always signified by a bundle of sweet potato vines (up to 5) planted around the top of the mounds in 5 or more spots. The amount of organic matter addition determines the size of the mounds and where it is made, with those in the highlands (>600 meters above sea level, m. a. s. l.) much larger than the ones made in the lowlands (0 – 600 m.a.s. l.).

In line with the composted mound making, understanding the biochemical processes that occur (Zhang *et al.,* 2016) during the decomposition of the organic matter, changes in soil chemical and physical compositions in the mounds as a consequence of that, and the time-dependent release of nutrients need to be understood (Waramboi *et al.,* 2012). The time-dependent acquisition of nutrients from the decomposition of organic matter by the sweet potato, conversion of the type and kind of nutrients to plant growth and development, and nutrient storage by tubers need further assessment (Michael, 2020b; Peter and Michael, 2023b). Understanding the chemical, physical, and biological processes is essential to composted mound-making and sweet potato production. This study investigated the importance of using high nitrogen content organic matter in mounds for sweet potato production.

Figure 1. The sweet potato production processes undertaken in composted mounds in the PNG central highlands (Peter and Michael, 2023a). Clearing and slashing a fallowed land (a), making mounding stations as shown by the red cycle (b), adding composts (c), loosening the soil by boys (d), mound construction by girls (e), vine planting (f), and a new composted mound with sweet potato growing.

Materials and Methods

Study site

The study was conducted at the Papua New Guinea University of Technology (Unitech) Agriculture Farm (6°67'0.07" S and 146°99'6.72" E) in Lae (6°43'19.49" S and 146°59'4.88" E), PNG (6°15'52.52" S and 148°57'49.85" E) (Fig. 1). Before setting up, a piece of land (~10 m^2) was chosen and plowed, harrowed, and ridges made using a tractor (Massy Ferguson brand) and allowed to settle for two weeks. Light harrowing was done again to loosen up the soil and bury the weeds that emerged before making the composted mounds and planting. The mineral nutrient compositions of the farm soil and the organic matter used are shown in Table 1.

Figure 2. Map showing the location of the study site in Lae, Morobe Province, Papua New Guinea.

Table 1. The nutrient compositions of the study site and organic matter used.

Nutrient (mg kg^{-1})	Soil	Leucaena	Weeds*	Total nutrients
Nitrogen	0.36±0.2	3.93±0.4	0.63±0.3	4.95±0.4
Phosphorus	1.54±5.1	2.99±1.2	1.49±2.2	5.982±2.3
Potassium	1.28±0.5	15.35±3.7	3.63±3.1	20.26±0.5
Calcium	1.54±3.2	24.01±4.5	2.81±1.5	28.36±0.1
Magnesium	3.42±0.5	2.74±1.8	2.12±1.3	8.26±0.6

The values are mean ± standard error (s.e.) of three replicates (*n*=*3*). *Weeds were grasses worked into the soil during harrowing.

Organic matter preparation, composted mound making and planting

To make the composted mounds, approximately 5 kg of lecucaena (*Leucaena leucocephala* L.) leaves were collected and chopped into fine pieces (~0.5 – 1 cm in length) and sun-dried for two weeks by direct exposure. The composted mounds were made as shown in Fig. 2. The mounding station was formed by gathering debris and dirt in rows (1 m apart within and between rows) in a straight line (as in Fig. 2 b and c), forming a heap and the dry chopped leaves (henceforth chops) were placed over the heaps (as in Fig. 2 c and d) and covered with topsoil (Fig. 2 e), forming a dome shape of 1 m in length and 60 cm in height. In each mound, five vines containing at least five leaves were held by the cut ends (Fig. 2 f) and planted around the top end of the mounds (40 cm from the base), forming several planted spots (Fig. 2 g). Each planted spot was 20 cm apart, with 25 vines in a composted mound. During production, weeding was manually done every two weeks for five months.

Treatments

A total of 16 composted mounds were made as per the treatments and quantity of chopped leaves (1.41 tones ha^{-1}): **Treatment 1**: Control, no leaves and no plants; **Treatment 2 –** chops amendment, no plants**; Treatment 3** – No leaves amendment and planted; **Treatment 4** – chopped leaves amendment and planted. All the treatments were replicated four times, set up in a completely randomized block design (CRBD) under field conditions, and allowed to run for three months until harvested.

Sampling and laboratory analysis

In each treatment, ~2 kg of wet soil samples was collected from within the top 60 cm of the mounds, placed in pre-labeled self-sealing plastic bags, and brought to the laboratory for processing. The samples were air-dried in the laboratory (24±2 ˚C) for three days by exposure and sieved using a 0.5 mm sieve (e.g., Michael, 2020a, b, c). Approximately 500 g of these were packed into labeled paper bags and sent to the analytical laboratory to analyze for the selected primary and secondary macronutrients. All the analyses were done at the PNGUoT Analytical Services Laboratory (USAL) in this manner using standard analytical procedures as follows: available nitrogen by UV, available phosphorus by Olsen extraction method, and exchangeable bases (K, Mg, and Ca) by ICP-OES. Samples from only three replicates (*n*=3) were analyzed. Samples from the fourth replicate were kept frozen as security against loss.

Statistical analysis

The data for each treatment were averaged, and a treatment average was obtained by taking the mean of the three replicates. The significant differences between the control and treatment means were determined by two-way ANOVA using statistical software JMPIN, AS Institute Inc., SAS Campus Drive, Cary, NC, USA 27513. In all the data figures, an asterisk was used to indicate the significant difference ($p<0.05$) between the control and the treatments.

Results and discussion

The total N content increased following organic matter amendment from an initial content of 0.11 mg kg^{-1} compared to the control soil, which was higher than the initial content by 0.07 mg kg^{-1} (Fig. 3). When planted without amendment, it decreased by 0.03 mg kg^{-1}. The highest increase was measured in the soil amended and planted with 0.3 mg kg^{-1}, an increase of 0.19 mg kg^{-1}. These results showed that organic matter increased the N content and, more so, in the soil plants were co-existing, indicating that the live plants contributed a small amount of N. The decrease in N in the planted soil without organic matter showed the nutrient was used by the plants. The increase in the control soil may have been caused by recalcitrant N that became available due to tillage and microbial respiration (Michael, 2020b; Alabi et al., 2022).

Nitrogen is the most limiting nutrient in soil under general land use and management conditions. When N becomes limited, it needs to be managed by supplemental fertilization such as inorganic NPK. Compared to chemical fertilizer which is expensive and availability is an issue, organic matter is cheap and readily available with its unique properties, known to recruit beneficial soil microbes and help build soil nutrients, which probably occurred as observed. The results supported the common knowledge that plant matter in the form of leaf litter and twigs from standing leucaena plants under field conditions increase the N contents (Michael, 2020d). Plants are expected to use the N for growth and development (Xiao-guang *et al*., 2015), and this was evident. The N content was smaller in the planted soil without amendment (Fig. 3). More interesting was a bit of N being added to the soil by sweet potato, a non-leguminous plant, and exciting for further research. Mulongoy and Gasser (1993) reported that the addition of leaves of leucaena did not increase the mineral N content, disagreeing with our results. The probable reason for this could be the soil type and agroclimatic conditions under which the experiment was conducted.

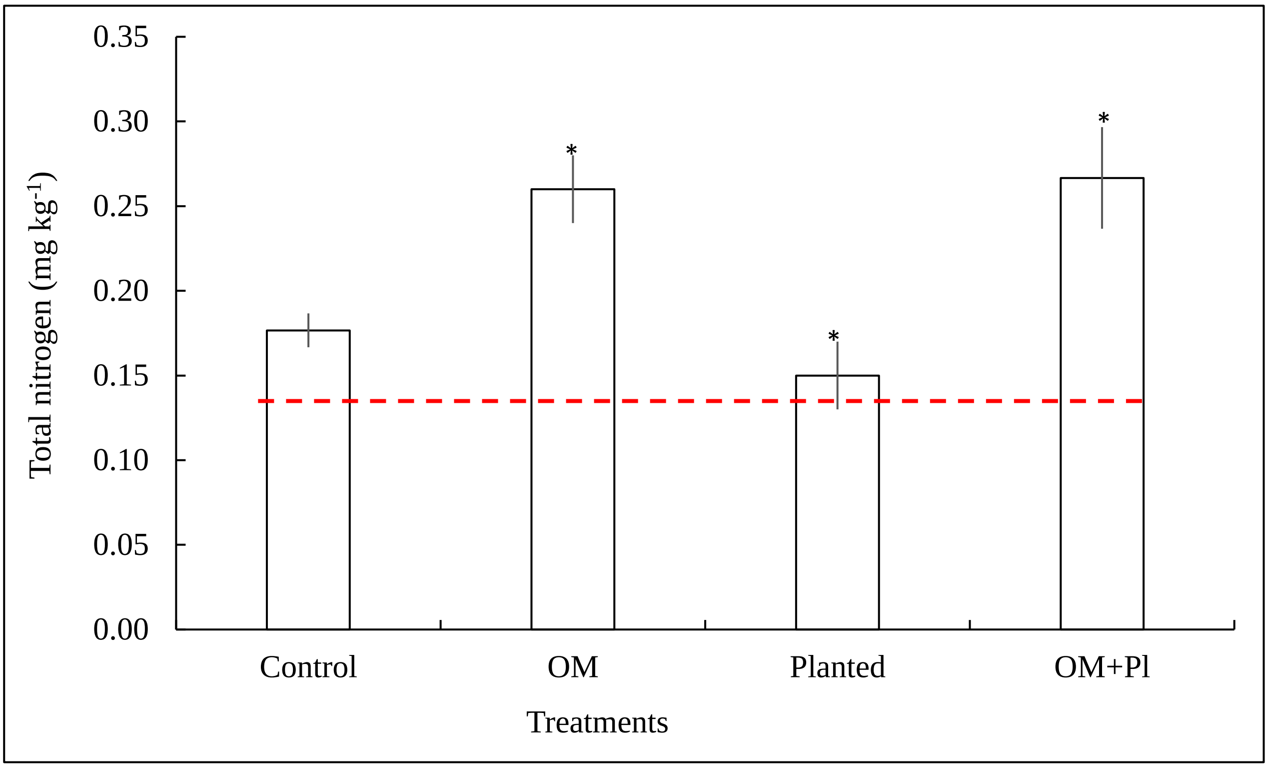

Figure 3. Total nitrogen measured in mounds ± organic matter amendment. The values are mean ± s.e. of three replicates (*n*=*3*).

The changes in the soil content measured are shown in Fig. 3. Organic matter amendment increased the P content by 24.4 mg kg^{-1}. Planting in the unamended soil increased it by nearly 14 mg kg^{-1} compared to the control but lower than the native P content. The amended and planted increased by 25 mg kg^{-1} but lower than the amended soil where no planting was done (OM). The order of changes was amended soil (OM)>amended and planted (OM+Pl)>planted without amendment (planted)>control (Fig. 4). These results showed that organic matter addition significantly increased the P content, similar to the results of Muktamar *et al.* (2020). This is a crucial optional practice in sweet potato production, and planting in soil without any organic matter amendment depletes the P content (Michael, 2020b). The results showed that sweet potato co-existing with organic matter still depletes the P content but not as much as in the soil planted without amendment (Fig. 4). For example, when the in control soil P was 26 mg kg^{-1}, organic matter addition increased it to 55 mg kg^{-1}. Even that, organic matter amendment and planting had 50 mg kg^{-1} when in the planted soil without amendment was 40 mg kg^{-1} (Fig. 4). Plants need P to convert all other nutrients into usable building blocks (Samarakoon and Seran, 2023). Unlike N (Fig. 3), P comes from weathered parent materials, and its management is essential to support crop yield. This study showed that sweet potato significantly uses soil P, and adding organic matter when planting is critical for its sustainability as pointed out in earlier studies (e.g., Michael, 2018c).

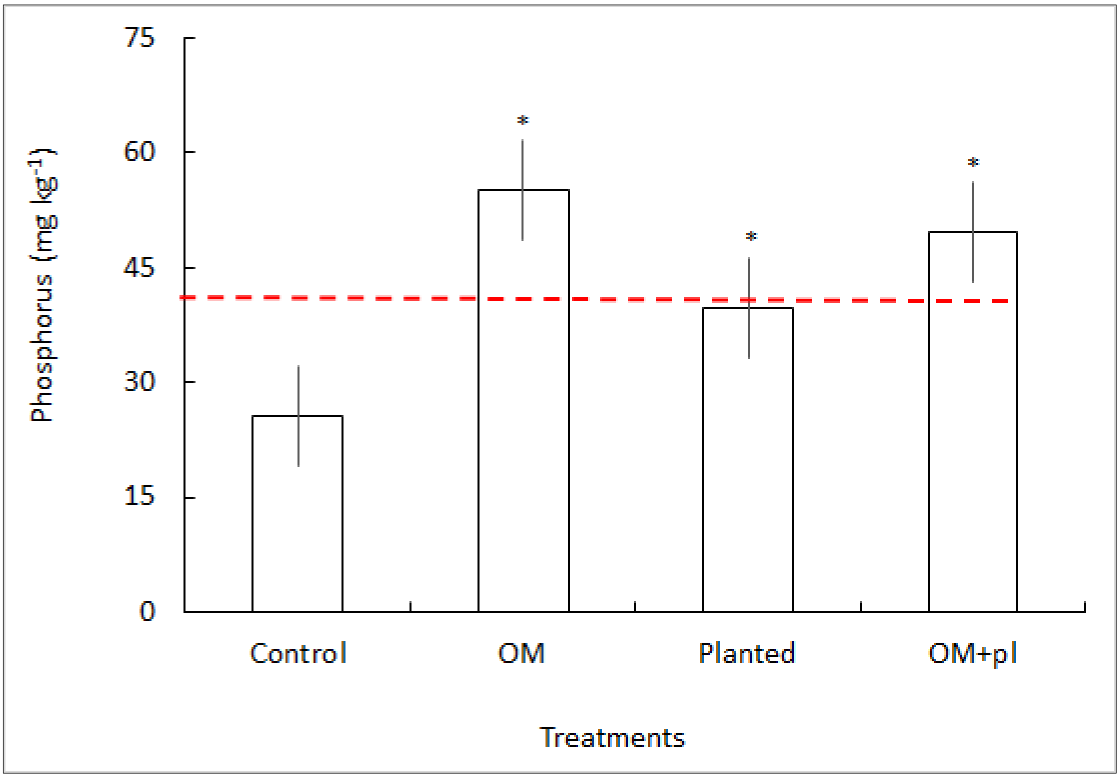

Figure 4. Available phosphorus in mounds ± organic matter addition. The values are mean ± s.e. of three replicates (*n=3*).

Generally, organic matter amendment alone increased the K content by 0.81 mg kg^{-1} (Fig. 5). In the amended and planted soil, the K content was lower than the amended and planted soil. As shown, the organic matter of high N content did contribute much to the soil K content, and planting without amendment depleted it. In a recent study using organic matter of low N content addition in mounds, Michael (2020b) reported that the K content was increased by nearly 50 percent—contradicting the results of the current study. Potassium is the third most limiting soil nutrient and is vital for plants' soil water and energy relationships. And in that, an essential component of the stomata guard cells to regulate water and soil nutrient, disease resistance in plants, withstand extreme weather conditions, and, most importantly, enhances the overall yield and quality of the crop (Michael, 2020b). Planting sweet potato alone without organic matter amendment decreased the K content by nearly 70% (Fig. 5), indicating the management option is adding organic matter (Bob and Michael, 2022), particularly in the soil planted. Our results showed K content was higher by 30% in the soil amended with organic matter and co-existed with sweet potato compared to the soil planted without amendment (Fig. 5), indicating that organic matter amendment sustains K availability and planting sweet potato depletes it.

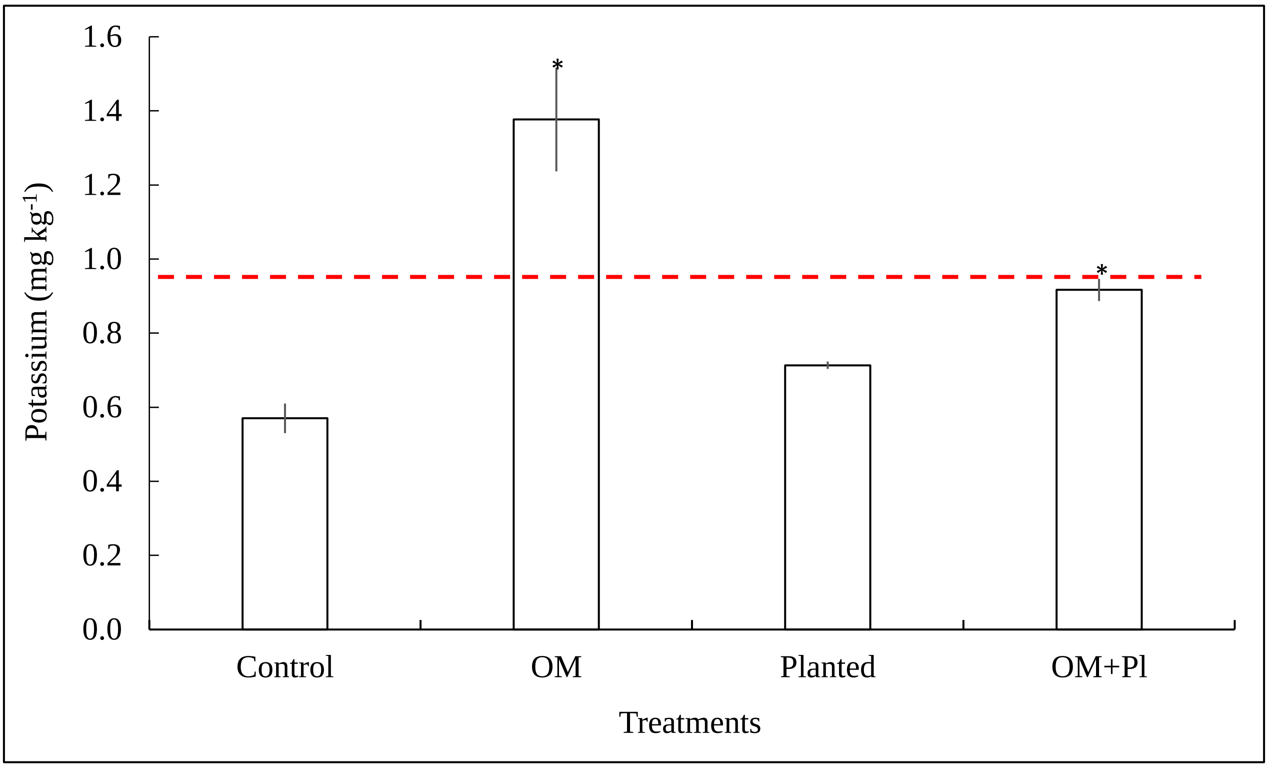

Figure 5. Available potassium in mounds ± organic matter addition. The values are mean ± s.e. of three replicates (*n=3*).

The subsequent cation to increase in concentration following organic matter amendment was calcium. Organic matter addition caused the Ca content to increase by 14 mg kg-1 compared to the control soil (Fig. 6). In the planted soil without organic matter addition, the calcium content increased by 5 mg kg-1 compared to the unamended control and in the amended and planted soil was higher than Ca present in the initial native soil. Interestingly, the amount estimated in the organic matter amended and amended and planted soil was similar and the difference was only 5 mg kg-1, indicating plant need for Ca. Calcium is not mobile like the primary macronutrients (NPK), and its plant requirement is small, agreeing with the findings that planting decreases the native Ca by a minimal amount and that small use was replenished when organic matter was added, as shown by the amended and planted soil (OM+Pl).

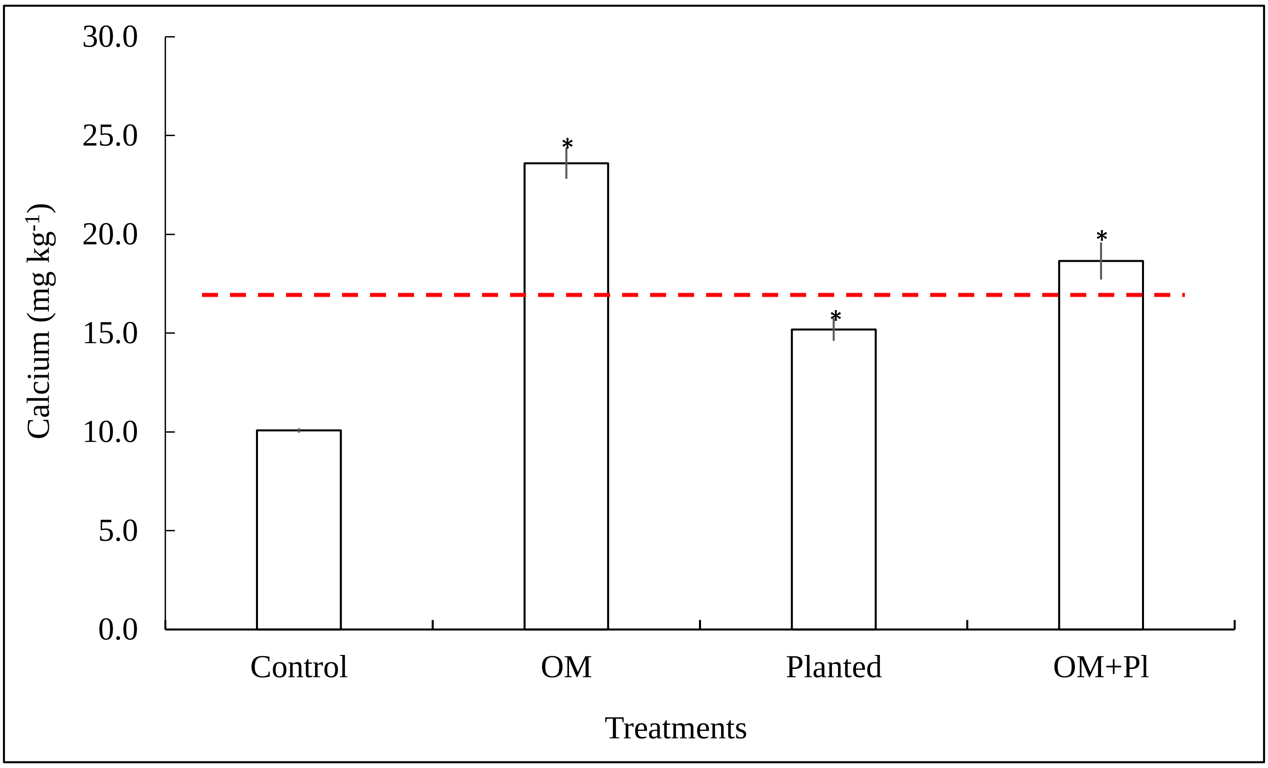

Figure 6. Available calcium in mounds ± organic matter addition. The values are mean ± s.e. of three replicates (*n=3*).

The changes in magnesium content measured are shown in Fig. 7. A general trend similar to the first two cations (K and Ca) was observed. The Mg contents remained nearly unchanged in control, and organic matter amended alone or amended and planted increased soil Mg except in the planted soil without amendment (Fig. 7). In the planted soil, the Mg content decreased by 1.8 mg kg-1, indicating the plants depleted Mg. The overall changes in Mg content measured were OM>OM+Pl>control>planted only. The soil Mg is essential for photosynthesis, and its deficiency affects the chlorophyll contents, its source of origin being the soil. Lowering the native Mg in the planted soil has shown that this secondary macronutrient is vital for sweet potato, and organic matter addition in composted mounds is an important management strategy.

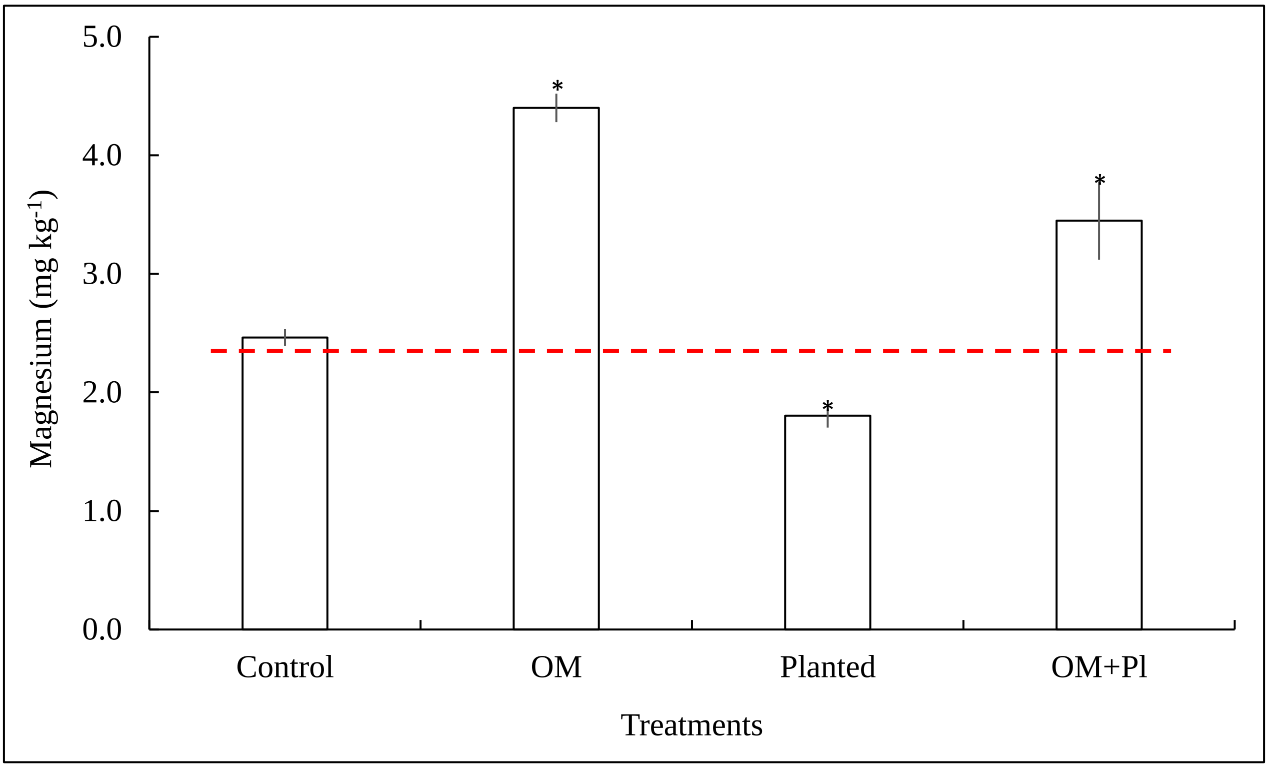

Figure 7. Available magnesium in mounds ± organic matter addition. The values are mean ± s.e. of three replicates (*n=3*).

Electrical conductivity (EC) is a measure of nutrient availability and pH affects the biochemical processes that make nutrients to be available in soil. The smaller EC values, e.g., measured in the control, planted, and organic matter amended and planted (OM+Pl) treatments, showed the nutrient contents of these were low compared to the amended (OM) treatment (Fig. 8). The significant decrease in EC in the planted treatments showed that the plants used nutrients, that is a decrease in nutrient content, demonstrating that EC is a good measure of nutrient availability in soil (e.g., Peter and Michael, 2023a). Organic matter addition increased the pH by 0.56 units and planting without an amendment, and amended and planted decreased it by 0.60 and 0.77 units, respectively (Fig. 8). Generally, the higher the EC and pH were, the higher the nutrient contents of the treatments. The decrease in pH of the planted soil, whether there was an OM amendment or not, generally confirmed the established knowledge that hydronium (H^+) ion and organic acids were released into the rhizosphere by the plant roots and decomposition of organic matter (Michael, 2018a; b), respectively.

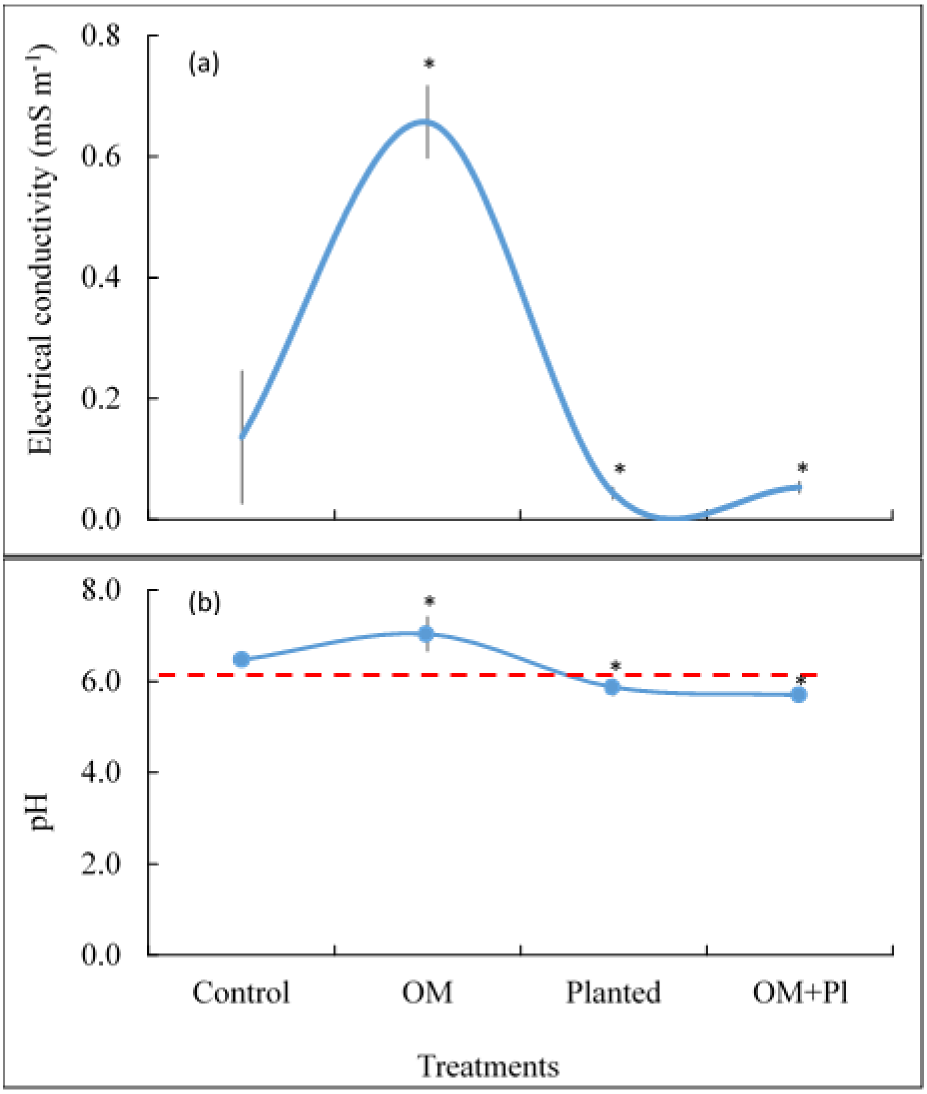

Figure 8. Changes in electrical conductivity (a) and pH (b) in mounds ± organic matter addition. The values are mean ± s.e. of three replicates (n=3).

Conclusions

Sweet potato is a strategic staple crop for humans and livestock throughout PNG. Despite its importance, its production on a larger scale is affected by various issues, including soil fertility. This study investigated an alternative means to address soil fertility using an organic matter of high N content, which is relatively cheap and available compared to chemical fertilizer in the humid tropics. The results showed that chopped leaves of *leucaena* used as organic matter is beneficial for managing all primary and secondary macronutrients. Furthermore, live sweet potato plants depleted all the macronutrients, and in almost all cases, the effect was the opposite when live plants and organic matter co-existed. The EC and pH measured also reflected the availability and status of the soil mineral nutrients. Therefore, the findings of this study have implications for the management of soil fertility and the sustainable production of sweet potato in composted mounds in the lowlands of the humid tropics.

Authors contribution statement

Peter Topas: Methodology, investigation, data acquisition, data analysis, writing- original draft, review, and editing. Ruben Y. Chung: Resources, data analysis, writing – review on draft and editing. Patrick S. Michael: Conceptualization, methodology, supervision, writing – final draft, review and editing, resources, and project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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