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Research article

Potential use of burnt rice husk to substitute for potassium applied for cassava grown in a low K-reserve soil

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Abstract

Importance of the work: Burnt rice husk (BRH), a valuable organic amendment that contains high potassium (K), can be a low-cost, alternative source of K for cassava in low K-reserve soils.

Objectives: To investigate the growth, yield and nutrient uptake of cassava in response to the application rate of BRH and K-fertilizer.

Materials & Methods: A field experiment was conducted in a K-deficient sandy soil based on a split plot design with fours levels of BRH applied (0 t/ha, 6.25 t/ha, 12.5 t/ha or 25.0 t/ha) in the main plot and six levels of K fertilizer (0 kg K_2O/ha, 25 kg K_2O/ha, 50 kg K_2O/ha, 75 kg K_2O/ha, 100 kg K_2O/ha or 125 kg K_2O/ha) in the subplot.

Results: The fresh tuber yield (FTY) obtained from the control plot was not significantly different from the plots added with a sole application of BRH or K fertilizer at all rates; however, BRH significantly increased soil K availability. Across all combined rates of BRH and K fertilizer, cassava produced significantly greater FTY by 62.6–170% over the control, where the highest yield was from the plot amended with 12.5 t/ha BRH and 100 kg K_2O/ha. The use of 25.0 t/ha of BRH together with K fertilizer reduced the uptake of Mg and Ca, resulting in a significant adverse decrease in the FTY. There was no clear interactive impact of BRH and K fertilizer on the starch yield and aboveground biomass, though it did stimulate the uptake of some plant nutrients.

Main finding: BRH application increased soil K and partially substituted for applied K in cassava growth; however, K fertilizer was still required when BRH was applied at a low rate (less than 12.5 t/ha).

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Introduction

Cassava (*Manihot esculenta* Crantz), a tuberous economic crop, is well known to require larger amounts of potassium (K) than the other crops (Carsky and Toukourou, 2005; Mandal, 2006; Howeler, 2017). This is due to K being the most important nutrient for cassava tuberization, in which K plays roles in the stimulation of net photosynthetic activity and the translocation of photosynthates or carbohydrates to the tuberous roots that, in turn, increases the starch content and decreases the hydrocyanic acid content (Biratu et al., 2018; de Souza Gonçalves et al., 2022). Hence, the tuber quality is heavily dependent on K nutrition. Furthermore, when cassava is grown in K-deficient soils, root growth is reduced and the flour yield is lower than normal (Havlin et al., 2013; Fernandes et al., 2017; Howeler, 2017). In Thailand, most cassava is planted in upland Ultisols that have naturally low fertility status and low plant nutrient reserves, especially of K (Anusontpornperm et al., 2009). Consequently, K becomes the primary limiting nutrient for cassava growth. Thus, proper K fertilization is essential to the growth and yield of cassava as reported in several studies. For example, Munyahali et al. (2017) indicated that K fertilization at the rate of 150 kg K_2O/ha significantly increased soil K availability over the control and also increased fresh tuber yield and stem yield in a 2 yr experiment. Similar results were observed for two growing seasons by Prombut et al. (2022), where cassava responded best to a rate of greater than 100 kg/ha K_2O, producing a significantly greater fresh tuber yield than the control with no K fertilization. In addition, Adekayode and Adeola (2009) reported that an increasing rate of K fertilizer positively contributed to an increase in cassava yield.

Burnt rice husk (BRH) is an agricultural waste derived mainly from rice milling and ethanol manufacture, with substantial amounts available locally, while it is also associated with some environmental problems. This organic waste is a very light material due to its micro-porous structure and has a rather high pH (Haefele et al., 2011; Satbaev et al., 2021; Chaiyapo et al., 2023) which, in turn, can be used to improve water holding capacity and the retention of soil nutrients, as well as to alleviate the problem of soil acidity (Okon et al., 2005; Oguike et al., 2006). Using BRH is an option to amend sandy soils that have been used extensively for cassava cultivation in Thailand, because these soils have low fertility and a low ability to retain water and plant nutrients. In addition, it could be a reasonable way to reduce the adverse impact of BRH as environmental waste and the cost of waste disposal. Fertility wise, BRH contains several plant nutrients, with K being the most dominant (Haefele et al., 2011; Mushtaq et al., 2019), because the raw rice husk contains high K (Taktuan et al., 2018; Satbaev et al., 2021). When applied to the soil, BRH releases K into the soil through mineralization and this K becomes available for uptake by the growing crop; thus, the BRH could partly substitute for the K fertilizer applied to the plant. However, BRH normally has a wide range in its carbon-to-nitrogen (N) ratio (Prombut et al., 2022; Chaiyapo et al., 2023), leading to a low mineralization rate to solely provide readily sufficient K. Hence, the right proportion of BRH and K fertilizer should be tested in the context of improving cassava yield and maintaining soil K availability, particularly in low K-reserve soils. Therefore, this study was carried out to investigate the cassava response to application rates of BRH and K fertilizer in a low K-reserve sandy soil. This research should provide an alternative technology for agricultural waste utilization, potentially as a partial substitution for K fertilizer in addition to adopting more efficient K fertilizer use for cassava production in humid tropical regions where loamy sand soils that are K-deficient are commonly used for growing cassava.

Materials and Methods

Test plant and burnt rice husk sample

The test plant was cassava variety, Huay Bong 80, a readily adaptable plant for light-textured soils in a drought environment (such as in the current study). It can be characterized by a straight main bole and silver-green stems, with its yield potential in the range 30.6–34.4 t/ha and an average starch content in the tuber of 27.3% (Thai Tapioca Development Institute, 2021).

BRH, a renewable by-product waste available locally and considered as a potential part-replacement of K fertilizer for cassava, was sampled from a rice milling manufacturer. Of the plant nutrients in this waste, K (5.41 g/kg K) was the highest, with its dominant characteristics being non-saline (electrical conductivity, 1:5 BRH to H_2O ratio in H_2O = 0.29 dS/m), slightly alkaline (pH, 1:5 BRH to H_2O ratio in H_2O = 8.13) with a high cation exchangeable capacity of 17 $cmol_c$/kg. In addition, other elemental components were: 2.80 g/kg calcium (Ca), 2.01 g/kg N, 1.28 g/kg phosphorus (P), 1.05 g/kg magnesium (Mg), 1575 mg/kg iron (Fe), 234 mg/kg manganese (Mn), 19.4 mg/kg zinc (Zn) and 5.31 mg/kg copper Cu).

Field site and soil characteristics

The trial of cassava response to different rates of K fertilization and BRH was established in Huay Bong subdistrict, Dan Khun Thot district, Nakhon Ratchasima province, northeast Thailand (Map 47P 763526^{E}, 1679543^{N}) in the 2021 growing seasons. The soil at the experimental site was in the Satuk (Suk) soil series (classified as Typic Paleustults), which originally developed from conglomeratic sandstone. The relevant chemical properties of the background surface soil (0–30 cm) before commencing the trial were: sandy texture (916 g/kg sand, 80 g/kg silt, 6 g/kg clay), 5.8 g/kg organic matter, 6.56 mg/kg available P extracted using the Bray II method (Bray and Kurtz, 1945), 0.8 $cmol_c$/kg cation exchange capacity, and 5.1 pH (in H_2O, 1:1 ratio).

Experimental design and set up

First, land preparation involved clearing native weeds and leaving the site fallow for 2 wk. Then, BRH was broadcasted onto the main plot and incorporated into the soil using a 3-disc plough (disc diameter = 72 cm). The experimental area was left for 2 wk before loosening the topsoil using a 7-disc plough to construct across-slope ridges (height = 30 cm) with a spacing of 120 cm between the ridges. Cassava cuttings (approximate length = 25 cm) were planted vertically on top of the ridges with a spacing of 0.8 m between plants. The cuttings were planted under rainfed conditions in May 2020 and harvested at age 10 mth. According to meteorological data obtained from the Kritsana station, Si Khio district, Nakhon Ratchasima province (the closest station to the experimental site), the annual rainfall during the growth period was 1,342 mm with a slight variation in mean monthly temperature (23.4–29.3°C) during the studied period.

The experiment was arranged in a split plot design with three replications. There were four rates of BRH (0 t/ha, 6.25 t/ha, 12.5 t/ha, 25.0 t/ha) applied on a fresh weight basis with 82% dry matter in the main plot (12.0 m × 13.5 m) with three replications. The waste was incorporated into the soil during the first plough event. When the cassava was aged 2 mth, each main plot was equally split into six subplots (each 6.0 m × 4.5 m) with one of 0 kg/ha, 25 kg/ha, 50 kg/ha, 75 kg/ha, 100 kg/ha or 125 kg/ha of K_2O as potassium chloride (60% K_2O) being applied in these subplots. Each plot received a blanket fertilizer dose of 120 kg N/ha and 60 kg P_2O_5/ha applied using urea (46% N) and diammonium phosphate (18% N and 46% P_2O_5), respectively, at the same time as K fertilization with respect to the designed treatments. All fertilizers were placed in a small hole on the top of the ridge between two plants, and then buried with soil.

Sampling and analysis of assessed parameters

The fresh weights of tubers and aboveground biomass (stem base, stem and leaf plus branch) were recorded in the field from an area of 8.64 m^2 during harvest. The starch content in the cassava tuber was measured using a Riemann™ balance (Thai Sang Metric Co., Ltd; Bangkok, Thailand) also at the time of harvest. The starch yield was estimated by multiplying the fresh tuber weight by the starch content. After uprooting the plant, the plant was portioned into four parts (tuber, stem base, stem and leaf plus branch). These plant samples were washed with tap water and oven-dried at 70°C before being finely ground and stored in sealed plastic bags. All the plant parts of the cassava were separately analyzed for their N, P, K, Ca and Mg concentrations. The concentration of each nutrient was multiplied by the dry weight of each plant part to quantify the nutrient uptake content. The uptakes of all plant parts were summed to obtain the total nutrient uptake in the cassava, expressed in kilograms per hectare.

In addition, topsoil samples (0–30 cm depth) were collected randomly from each main plot at 2 wk after the incorporation of the BRH into the soil (before planting the cassava). The soil samples were air-dried, ground to pass through a 2 mm sieve and then analyzed for different forms of K (water-soluble, exchangeable- and non-exchangeable) using a sequential extraction technique (Pratt, 1965). Potassium in all forms was quantified using an atomic absorption spectrophotometer (model AA240; Agilent Technologies; Santa Clara, CA, USA).

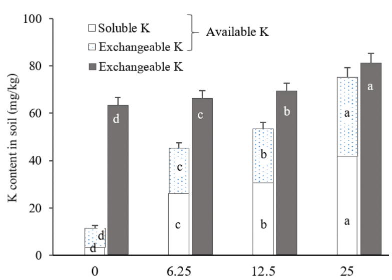
Statistical analysis

A two-way analysis of variance was performed to determine the significant effects of treatments for all parameters. Significant ($p < 0.05$) differences between the treatments were tested based on Duncan's multiple range test (Gomez and Gomez, 1984). All statistical analyses were computed using the SPSS program software (Version 21.0; SPSS Inc.; Chicago, IL, USA).

Results and Discussion

Effect of burnt rice husk on chemical fractionation of soil K

The soil in the study area without BRH amendment inherently had low K reserves to supply plants because the non-exchangeable K content was less than 300 mg/kg (Rao et al., 2010), while the content of available K (water-soluble K + exchangeable K) was also insufficient for the plant (Fig. 1). This was mainly due to the nature of the soil parent materials (sandy-grained sedimentary rocks), coupled with a low organic matter content that supplied only a slight amount of initial K for the plant. The BRH acted as a supplemental K source as it clearly increased the K contents in the soil, with the K contents being significantly increased with increasing rates of BRH, where the highest contents of water-soluble K (41.95 mg/kg), exchangeable K (33.31 mg/kg) and non-exchangeable K (81.03 mg/kg) were recorded from the plot applied with 25 t/ha of BRH (Fig. 1). Furthermore, the available K contents in all BRH-amended soils were likely to be sufficient for cassava K requirement, since the critical soil level for this plant is at least 30 mg/kg (Howeler and Cadavid, 1990; Sittibusaya, 1996). Therefore, BRH can be a potential K reserve to maintain adequate K status throughout the cassava-growing period and in the long-term because it provides a substantial amount of non-exchangeable K (Fig. 1). Notably, the available form of soil K were in the water-soluble K rather than in the exchangeable K when BRH was applied. In fact, plants take up K from the soil in the water-soluble form more than the exchangeable form; however, the former is easily lost through leaching, particularly in sandy soils where cassava can seldom take up K that rapidly against the loss mentioned (Havlin et al., 2013; Sukkaew et al., 2022).



K content in soil (mg/kg) on Y axis
BRH rate (t/ha) on X axis

Fig. 1 Effect of burnt rice husk BRH rate (t/ha) applied at different rates on soil K contents in topsoil horizon (0–30 cm depth), where values are mean ± SD (for available K and non-exchangeable K) represented by vertical bars, n = 3 Different lowercase letters in bars grouped within the same K form indicate are significantly ($p < 0.05$) different.

Interactive effect of burnt rice husk and K fertilizer on cassava yield components

The available K content of 11.47 mg/kg in the non-amended soil has been reported to be insufficient to promote satisfactory cassava growth (Howeler and Cadavid, 1990), which were reaffirmed by the positive response of cassava growth and yield to the K fertilization and BRH used as a partial K source. Without the BRH application, the sole application of K fertilizer hardly boosted cassava yields due to the fresh tuber yield (21.0–29.1 t/ha) obtained from all the K rate applied (25–125 kg K_2O/ha), not being significantly different to the control (19.0 t/ha), as shown in Fig. 2.

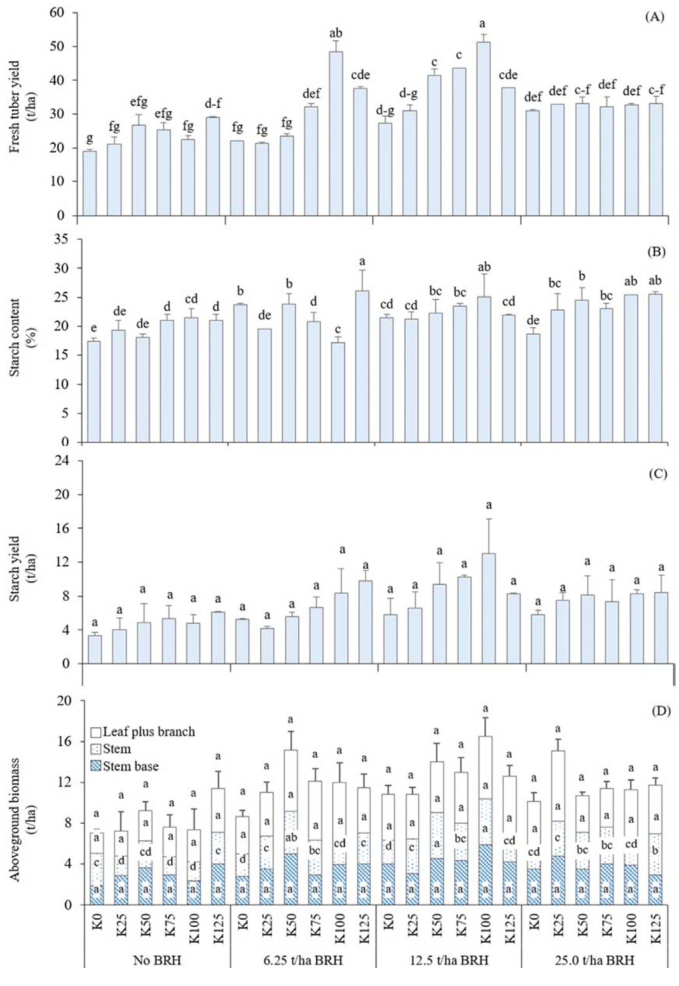


Fig. 2 Interactive effect of burnt rice husk (BRH) and K fertilizer on yield components of cassava: (A) fresh tuber yield; (B) starch content; (C) starch yield; (D) aboveground biomass, where K0, K25, K50, K75, K100 and K125 are K fertilization at 0 kg/ha, 25 kg/ha, 50 kg/ha, 75 kg/ha, 100 kg/ha and 125 kg/ha of K_2O, respectively, different lowercase letters on/in bars grouped within same parameter are significantly ($p < 0.05$) different, values are means ± SD represented by vertical bars, with no SD shown for fresh weight of stem base and for stem and leaf plus branch and n = 3.

Since the broadly recommended K rate for cassava grown in light-textured Ultisols in Thailand is 100 K_2O/ha (Sittibusaya, 1996), the current results with respect to this recommended rate indicated there was still insufficient K to obtain reasonable cassava growth and yield when grown in the studied soil, despite 1.25 times the recommended rate being tested in the current study. On the other hand, the rates of 6.25 t/ha and 12.5 t/ha of BRH applied induced fresh tuber yields of 22.2 t/ha and 27.2 t/ha, respectively; however, these were not significantly different from the control with zero-BRH addition (Fig. 2A), despite these two rates increasing the soil-available K to the level expected to be sufficient for this plant (Fig. 1). This could be attributed to the critical K deficiency level in soils not having been precisely defined for cassava. In addition, K mineralized from BRH might partly be lost via leaching or other pathways, especially in highly weathered soils with coarse texture such as the soil in the experimental area; hence, the addition of K fertilizer should still have been inadequate, even when BRH was used as the K source. As shown by the current results, the partial substitution of K fertilizer by BRH clearly provided crop growth requirements, thereby significantly increasing the cassava fresh tuber yield (by 62.6–170% over the control, Fig. 2) and, thus, achieving the highest yield of up to 170% more than the control when using BRH at 12.5 t/ha combined with 100 K_2O/ha. This supported the broader consensus that K was of considerable importance for tuber crops (Carsky and Toukourou, 2005; Fernandes et al., 2017; de Souza Gonçalves et al., 2022); hence, the quality of the tuber is much dependent on K nutrition. Furthermore, when cassava is grown in K-deficient soils, root growth is reduced and the amount of flour is lower than normal, as it has roles in photosynthesis, the accumulation and translocation of newly formed carbohydrates and their translocation to the tuber to increase the size of the cassava tuber (de Souza Gonçalves et al., 2002; Mandal, 2006). Apart from BRH providing substantial amounts of plant nutrients (particularly K in this case), this waste also contributed a rather considerable amount of organic carbon that should improve nutrient retention, moisture storage and other soil physical properties of this soil, which was inherently poor, as well as providing some secondary nutrients and micronutrients. Consequently, adequate inputs of BRH effectively enhanced K fertilization to increase the yield of cassava planted in this light-textured soil.

Notably, the use of BRH at the rate of 25 t/ha together with K fertilization at all rates tested in this study was not adequate. It can be assumed that the whole K from these two sources was excessive for cassava as it resulted in a significant decrease in cassava fresh tuber yield (Fig. 2). In this context, the presence of high K in the soil might have posed an antagonistic effect on Ca due to this plethora of K competitively inhibiting Ca uptake (Spear et al., 1978; Fageria, 2001; Rhodes et al., 2018;) and also Mg uptake (Karley and White, 2009; Gransee and Führs, 2013). This was reaffirmed by the correlations among the plant nutrients accumulated in the different cassava plant parts (Fig. 3), with only K in the stem base having a significantly positive correlation with fresh tuber yield (correlation coefficient, r = 0.379**), indicating that high concentrations of K in this plant part typically contributed to high growth and yield of cassava. However, K in the stem base was negatively correlated with Ca in the leaf plus branch (r = -0.647**) and the tuber (r = -0.582**) and with Mg in the tuber (r = -0.493**), as shown in Fig. 3. This indicated that the uptake levels of Mg and Ca by the plant were adversely affected by high K accumulated in the plant that would be responsible for the decrease in the cassava yield when a large amount of K was applied (Fig. 2). Generally, both Ca and Mg deficiency symptoms are seldom seen in agronomic crops, including cassava (Howeler, 2017). However, cassava may respond to Ca and Mg deficiency by slowing the growth rate coupled with stunted growth (Howeler, 2017), and there was subsequent reductions in the growth and starch content (Charoenphon et al., 2021; Sukkaew et al., 2022). This negative impact was observed even though K in the stem base was positively correlated with N in the leaf plus branch (r = 0.256*) and the stem (r = 0.394**) and with P in the tuber (r = 0.407**), where ** = highly significant ($p < 0.01$) and * = significant ($p < 0.05$), as shown in Fig. 3.

In fact, an adequate K supply was important for the synthesis and translocation of starch to the tuber to increase the starch content, resulting in a high quality of storage roots for cassava (Ezui et al., 2016; Fernandes et al., 2017); however, K from the BRH and K fertilizer hardly boosted the starch yield in the current study, even though there was an observed effect of K on the starch content in the cassava tuber (Fig. 2). An increase in starch in the tuber was unlikely to be dependent upon the quantity of K applied due to the significantly highest content being similarly in plots applied with 6.25 t/ha BRH + 125 kg K_2O/ha, 12.5 t/ha BRH + 100 kg K_2O/ha, 25 t/ha BRH + 100 kg K_2O/ha and 25 t/ha + 125 kg K_2O/ha, which produced 43.3–49.1% increases over the control. Nonetheless, the aboveground plant parts of cassava showed no response to the interactive effect of BRH and K (Fig. 2), except for the stem weight which for most of the treated soils resulted in significantly lower amounts than for the control soil.

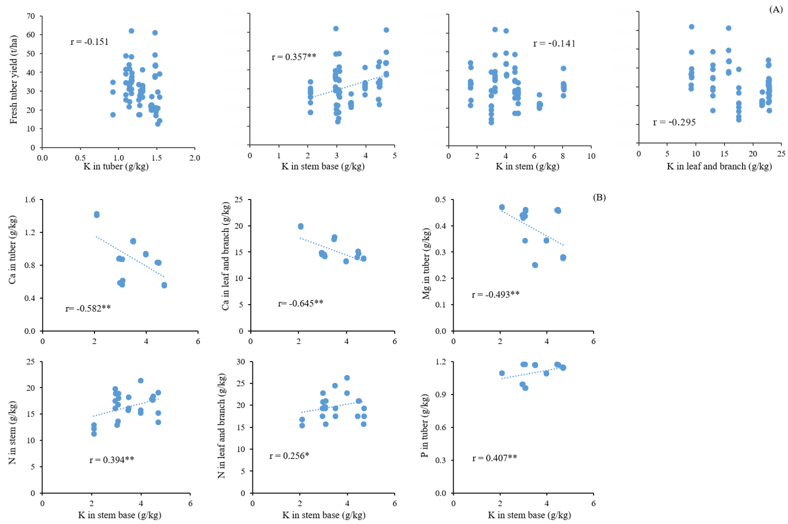


Fig. 3A-3: K in stem, change R2 = 0.0199 into r = -0.141
Fig. 3A-4: K in leaf pls branch, change R2 = 0.1558 into r = -0.295
Fig. 3 Linear relationships (dotted lines) between: (A) fresh tuber yield and K concentration in different cassava plant parts; (B) K concentration in stem base and Ca, Mg, N and P concentrations in different cassava plant parts, where n = 72, ** = highly significant (p < 0.01), * = significant (p < 0.05), r = correlation coefficient.

Interactive effect of burnt rice husk and K fertilizer on plant nutrient uptake by cassava

To some degree, the interactive effect of BRH and K fertilizer on the uptake of plant nutrients in cassava was slightly positive. For the same rate of BRH applied, cassava took up more N, P, K and Mg with increasing rates of K fertilizer; however, the treatment combinations that stimulated the highest contents varied among the nutrients (Fig. 4) due to the BRH containing some essential plant nutrients that became available for the cassava to take up during its growth period. The application of 12.5 t/ha BRH + 100 kg K_2O/ha stimulated the significantly greatest N uptake in the stem and leaf plus branch, P uptake in the tuber and K uptake in the tuber and leaf plus branch, while the greatest Mg uptake in the tuber and leaf plus branch, as well as Ca uptake in the tuber, were detected when this K rate was applied with one-half of that BRH rate. In addition, in the 12.5 t/ha of BRH-amended plot, the significantly highest N uptake in tuber was observed when 25 kg K_2O/ha was applied, while adding 50 kg K_2O/ha significantly induced the highest uptake of K and Mg in the stem.

Regarding the total uptake of major plant nutrients in the whole plant, cassava took up N in the highest amount, followed by K, whereas P uptake was far lower, with the average proportion of NPK being approximately of 5:1:3. It has been widely reported that cassava takes up mainly K and requires a large quantity of N, with P being the least with NPK ratios of 5:1:10 (Chaem-Ngern et al., 2020), 5:1:8 (Leitch et al., 2023) and 6:2:9 in sandy loam soil with the contribution of BRH and K fertilizer (Prombut et al., 2022). In addition, the total nutrient uptake in the whole cassava plant in certain growing areas of the world reported by Byju and Suja (2020) was 93–202 kg/ha of N, 12–46 kg/ha of P and 81–485 kg/ha of K, to obtain a fresh tuber yield of 15–45 t/ha. However, in the current study, considering for example, the highest yield obtained of 51.3 t/ha in the plot that received BRH at 12.5 t/ha and 100 K_2O/ha, the amounts of N, P and K taken up by cassava were far lower than the quantities reported. The rather noticeable difference in the nutrient uptake from the other reports, as well as the lower uptake portion of K, was unlikely because of the contribution of the BRH and K fertilizer; nonetheless, the variations in genotype, as well as the difference in soil conditions during the cassava-growing period, would likely have been responsible for this observation (Byju and Suja, 2020).

Nitrogen, K and Mg were taken up in tuber and stem base in somewhat identical amounts, which was two-fold that taken up in the stem and leaf plus branch. P was taken up mostly in the tuber, proportionally accounting for more than 68.9% of the total uptake of this nutrient. In contrast, Ca was taken up in the highest amount in the stem base accounting for a two-fold higher uptake than that in the other plant parts (Fig. 4). Nutrient uptake in the cassava stem base was the second highest compared to the other parts. This plant part is normally left in the field as plant residue and during land preparation for growing cassava, the stem bases are always incorporated into the soil; hence, the nutrients stored in

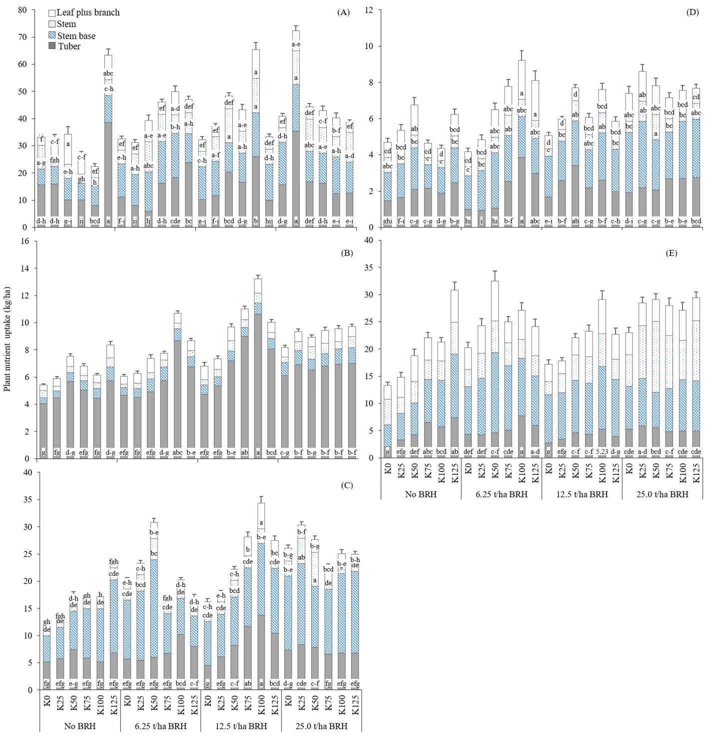


Fig. 4 Interactive effect of burnt rice husk (BRH) and K fertilizer on plant nutrient uptake by cassava: (A) nitrogen; (B) phosphorus; (C) potassium; (D) magnesium; (E) calcium, where K0, K25, K50, K75, K100 and K125 are K fertilization at 0 kg/ha, 25 kg/ha, 50 kg/ha, 75 kg/ha, 100 kg/ha and 125 kg/ha of K_2O, respectively, different lowercase letters on/in bars grouped within same parameter are significantly ($p < 0.05$) different, values are means ± SD (only for total plant nutrient uptake by whole plant) represented by vertical bars.

this plant part could be made available for the plant's future use (Howeler, 2017; Munyahali et al., 2017). Notably, the highest uptake of most plant nutrients was in the tuber which could severely deplete nutrient reserves in soils by the considerable amounts of these nutrients being removed from the soil within the harvested cassava tubers. The current results suggested that adequate fertilization is essential for cassava cultivation in this type of soil; otherwise, nutrient levels, particularly of N and K, would decline and subsequently become a limiting factor for successful cassava production.

BRH is available locally and recognized for use in ameliorating some problems of sandy soils for growing field crops. The current findings indicated that BRH could be a useful potential source of K for cassava in a sandy soil with low K reserves, with the BRH having a low cost, although the soil K as affected by BRH was at an insufficient level when the amount added was less than 12.5 t/ha, which then required an additional K requirement in the form of chemical fertilizer. Growing cassava without BRH or K fertilization produced inferior yields to that from adding BRH plus K fertilizer. In the current study, with the low K reserves in the sandy soil, the co-application of 12.5 t/ha of BRH with 100 kg/ha of K_2O should be recommended to enhance cassava to take up more nutrients and attain the highest fresh tuber yield instead, despite this having a less positive impact on the starch yield and aboveground biomass. The current soil with its low fertility level, required the constant application of a sufficient quantity of BRH as an option to improve the soil to the level that the cassava yield can be sustained at a satisfactory level. However, K released from BRH applied at the rate of 25.0 t/ha or more under a longer-term trial should be monitored as in this single-year study, which showed a slight plethora of K, especially when applied with K fertilizer. This can lead to an antagonistic impact of reduced accumulation of Ca and Mg in cassava, which was relevant to the decreased cassava yield.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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