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# Potassium Fertilisation Is Required to Sustain Cassava Yield and Soil Fertility

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**Abstract:** Cassava is often grown in low-fertility soils and has a reputation for having modest nutrient requirements. The storage roots that are harvested, however, contain relatively large amounts of potassium (K). We carried out a field experiment in Laos to determine the growth response to K fertiliser and to examine the field's K balance over the cropping season. Four different rates of K (0-40-80-120 kg $K_2O$ equivalents $ha^{-1}$) were applied to cassava variety Rayong11. Harvests were done at 8 and 10 months after planting, when the crop was at early and full maturity respectively, to assess if any benefits for productivity or K balance could be achieved by early harvest. We found a positive effect of K fertiliser (up to 39% yield increase compared to no K fertiliser at early harvest, 21% at late harvest) and a positive effect of late harvest (on average a 35% increase compared to early harvest) on cassava root yield. Low-K crops benefited more from a late harvest. At 10 months, the harvested cassava contained 99–142 kg K $ha^{-1}$, indicating that there was a net removal of K from the fields, even at high K fertilisation levels. This experiment was carried out in comparatively fertile soil with relatively high background K levels, yet, yield benefits of K fertilisation were observed and soil K reserves were depleted by the harvest. It can be concluded that K fertilisation of cassava is advisable for better yields and to avoid progressive depletion of the soil K capital.

**Keywords:** cassava; potassium; soil fertility; nutrition

## 1. Introduction

Cassava (*Manihot esculenta* Crantz) is a rainfed crop grown in tropical and subtropical countries of Latin America, Africa and Asia [1–3]. It is reputed to grow in soils with low fertility and is also drought and acid tolerant [2,4,5]. As the world's third most important crop, it acts as a staple food for at least 500 million people worldwide; its tuberous roots are a main source of calories [4–8].

In Asia, elimination of soil constraints, such as low fertility, could increase cassava yields by 35% [9]. In Laos, a majority of farmers engage in traditional subsistence agriculture and make minimal use of purchased inputs such as inorganic fertilisers [10]. Furthermore, Smith et al. [11] reported that less than

1% of households apply inorganic fertilisers and understand what nitrogen (N), phosphorus (P) and potassium (K) i.e., NPK fertilisers are, and only 4% have seen fertiliser demonstrations. Nevertheless, cassava yields in Laos are among the highest in Southeast Asia (on average 32.2 t fresh root ha$^{-1}$) as farmers tend to grow on relatively new lands compared to other countries in the region; country-wide production is 3.1 million t fresh root on ~100,000 ha of land, and it is increasing [1].

Continuous cropping without inputs results in a decline in yields and soil nutrient capital [2,12]. Cassava is highly responsive to NPK fertilisers, therefore, proper management of soil nutrients is important to maintaining yield [13]. Application of appropriate fertilisers helps to replenish nutrients that were lost due to removal of yield and residues from the field [2,14].

Cassava roots are rich in K. Among tropical crops, the harvested product of cassava has a much higher K:N ratio, 3.9, than other crops, e.g., banana (*Musa X paradisiaca*) 2.88, sugarcane (*Saccharum officinarum)* 1.89, rice (*Oryza sativa*) 0.43 and maize (*Zea mays*) 0.82 [2]. Due to the higher ratio of K to N, K has to be supplied in sufficient amounts to help increase root yield and improve root quality [15–17]. However, care is needed in fertiliser rate decisions, as exceeding a critical amount of K can result in decreased starch content due to the decreased absorption of calcium (Ca) and magnesium (Mg), leading to Mg deficiency [17–19].

Traditionally, in Southeast Asia the clonal propagated cassava crop is grown for ~10 months to achieve optimum yield and to ensure adequate time for re-planting of the following crop at the onset of the rainy season. Nevertheless, timing of the industrial cassava crop harvest is often driven by the market price of fresh root, and early harvest may fetch more income for smallholder farmers. However, this may significantly alter fertilizer utilization and soil K balance.

This study is aimed at identifying the K fertiliser rate required to optimise yield and K balance of the field, i.e., a fertiliser rate that produces a high yield without depleting the soil's K reserves. It is hypothesized that (i) as the fertilisation rate of K increases, there is a corresponding rise in root yield, however, this process results in a diminishing return in starch yield and (ii) at the K fertiliser rate producing maximum yield, there is no net deficit of K due to cassava cultivation.

## 2. Materials and Methods

The experiment was conducted between 30 March 2018 and 18 January 2019 at the National Agricultural and Forestry Research Institute (NAFRI) at Naphok, Vientiane, Laos (18°0′45.1′′ N; 102°44′20.7′′ E). The soil at the station was a sandy loam with a pH of 4.5 (1:5 soil and water suspension), containing 17 g organic matter/kg dry soil, 600 mg total N/kg dry soil (Kjelldahl extraction), 12.7 mg available P/kg dry soil (Bray-2 extraction) and the following exchangeable cations ($NH_4$-acetate extraction): 164 mg K/kg dry soil, 9.2 mg Na/kg dry soil, 194 mg Ca/kg dry soil and 39.6 mg Mg/kg dry soil. Amounts of soil N, P, and K present at the experimental site are regarded as low, medium and adequate, respectively [20]. On this land, prior to the current experiment, maize (*Zea mays*) was grown for three years (2014–2017), without any fertiliser, and mangos (*Mangifera indica*) for 20 years (1994–2013). Rainfall and temperature records were collected from a nearby weather station (~1 km). A blanket irrigation was applied for even sprouting and establishment of the crop. The site received a total of 1776 mm rain between April 2018 and January 2019, with an average temperature of 28.3 °C. Weeding was carried out manually when necessary after crop establishment to keep the plots weed free. Cassava variety Rayong11 stakes (25 to 30 cm long) were handplanted vertically. As farmers are influenced by the market price at the time of harvest, a first harvest was done at 8 months after planting (early) and a second harvest at 10 months after planting (mature crop).

### *2.1. Experimental Design*

The experiment was laid out in completely randomized block design with three replicates, with each treatment allocated to a plot. Each plot size was 54 m$^2$ (6 m × 9 m) and plant spacing was 1 m × 1 m. For the first harvest, 12 plants were sampled from one side of the plot, leaving the border row. This was repeated for the second harvest at the other side of the plot. These 12 plants were used to measure starch content and tuber yield. Three plants were used for the detailed measurements described in the next two sections.

Two months after planting, five fertiliser treatments were applied 25–30 cm away from each cassava stake at 10 cm depth and covered with soil. The treatments are characterised as follows, following the convention to express rates as N, $P_2O_5$ and $K_2O$ (kg ha$^{-1}$): $T_1$ 0-0-0, $T_2$ 40-20-0, $T_3$ 40-20-40, $T_4$ 40-20-80 and $T_5$ 40-20-120. Nitrogen was applied in the form of urea, P as triple superphosphate (TSP) and K as muriate of potash (KCl). The actual rates of elemental N, P and K were as follows: $T_1$ 0-0-0, $T_2$ 40-8.7-0, $T_3$ 40-8.7-33.2, $T_4$ 40-8.7-66.5 and $T_5$ 40-8.7-99.7.

### *2.2. Fresh Weights, Stem Lengths and Estimates of Leaf Loss*

These variables were quantified using three plants per plot. Prior to the harvest, the number of leaves present and the number of shed leaves was estimated as follows. For all stems, the lengths with leaves still attached to the stem and the lengths with leaf scars were measured. For these sections, the internode lengths were estimated by counting the number of leaves or scars per unit length. Total numbers of live and shed leaves were then estimated by dividing stem section lengths by internode lengths. The average shed leaf dry weight and K concentration (see below) allowed the estimation of the total amount of shed leaf dry weight (and K contained in it), representing K returned to the soil.

Harvested plants were separated into aboveground (i.e., stem and leaves) and tubers. Four different tubers were selected and 1–2 cm thick discs were cut from each. Bulk fresh weights were recorded for all plant parts. All plant parts were placed into separate air-tight plastic bags and put onto ice to avoid any moisture loss prior to further analysis.

Leaves with petioles, upper stem (defined by the presence of green leaves) and lower stem were separated. Ten randomly chosen young fully expanded leaf and petioles were separated, and three sections of approximately 3–4 cm were cut from the upper stem and lower stem, and fresh weights recorded. Ten senesced (recently shed) leaves were also collected from each plot from the three selected plants. Fresh weights of all these subsampled plant parts were recorded. Dry weight of aboveground plant samples were recorded after 72 h and tubers after 120 h drying in an oven at 70 °C. Dry matter content (dry weight/fresh weight * 100%) and water content ((fresh weight-dry weight)/fresh weight * 100) were calculated. The harvest index (HI) was calculated as tuber dry weight/total plant dry weight.

### *2.3. Starch Content*

Starch content (%) was measured following the procedure described by Howeler [18]. Briefly, ~5 kg of fresh roots (cut in 2–4 cm pieces) were placed in a light-weight nylon mesh bag and its weight recorded (i.e., weight in air). Then, with a 1000 g capacity hanging balance, the roots in the nylon mesh bag were completely immersed in water in a big bucket, and their underwater weight recorded. The starch content was estimated from specific gravity (SG) defined as follows:

SG = weight in air/(weight in air−weight in water)

Starch content = 210.8 SG−213.4

Starch yield (t ha$^{-1}$) was calculated from the tuber fresh weight and starch content (%).

### *2.4. Analysis of K and Other Nutrients*

Pulverised samples were used for nutrient analysis. Potassium was extracted in 0.5 M $HNO_3$ by shaking for 48 h at room temperature. $K^+$ was determined in dilutions of the extract using a flame photometer (Flame Photometer 410, Sherwood, Cambridge, UK). A plant reference sample was also analysed, yielding a recovery for K of 101%. Data were not adjusted. Site K balance was estimated by comparing amounts of K removed (total K contained in root yield) with K supplied in the form of fertiliser.

### 2.5. Data Analysis

Data were analysed by calculating means, standard errors, regression and analysis of variance (ANOVA), where appropriate using GenStat 19 for Windows statistical software (VSN International). Significant difference refers to $P > 0.05$. To find significant differences between means, a Tukey's test was carried out separately for harvest 1 and harvest 2, where appropriate.

## 3. Results

### 3.1. Plant Growth

Plant biomass and total stem length benefitted from higher K treatments and later harvest, but to a relatively modest degree (Table 1). The increase of total biomass and total stem length from harvest 1 to harvest 2 was on average 26% and 25% respectively, across treatments. The high K treatment (T5) had 39% and 26% higher biomass than the treatment that did not receive any K, that is, T1 (no fertiliser) and T2 (only N and P), respectively, in Harvest 1. Similarly, the high K treatment (T5) had 17% and 15% higher biomass than the treatment that did not receive any K, that is, T1 and T2, respectively, in harvest 2. The K treatment × harvest interaction was not significant for either measure of plant growth (Table 1), indicating that any treatment effects present in the first harvest were similar at the later harvest. A separate ANOVA was done on treatments T2–T5 only (omitting T1), for a comparison of the effect of K without differences in N and P fertiliser. This analysis (see Supplementary Materials Table S1) yielded results that were very similar to those shown in Table 1.

**Table 1.** Total stem length (cm), total plant dry weight (g), harvest index (HI), starch content (%) and starch yield (t ha$^{-1}$) at harvest 1 (8 months growth) and at harvest 2 (10 months growth) in response to five fertiliser treatments (N-$P_2O_5$-$K_2O$, kg ha$^{-1}$), $T_1$ 0-0-0, $T_2$ 40-20-0, $T_3$ 40-20-40, $T_4$ 40-20-80 and $T_5$ 40-20-120. Means are followed by standard errors (n = 3). Values within a column followed by different letters are significantly different ($P < 0.05$). The comparisons were made separately for harvest 1 and harvest 2.

| Treatment | Total Stem Length (cm) | Total Plant Dry wt. (g) | Harvest Index HI | Starch Content (%) | Starch Yield (t ha$^{-1}$) |
|---|---|---|---|---|---|
| Harvest 1 | | | | | |
| $T_1$ | 411 $^{a}$ ± 62.3 | 1416 $^{a}$ ± 284.5 | 0.69 $^{a}$ ± 0.007 | 29.1 $^{a}$ ± 1.18 | 7.1 $^{a}$ ± 1.50 |
| $T_2$ | 581 $^{ab}$ ± 51.8 | 1718 $^{ab}$ ± 125.7 | 0.69 $^{a}$ ± 0.006 | 28.8 $^{a}$ ± 0.66 | 8.7 $^{ab}$ ± 0.74 |
| $T_3$ | 609 $^{ab}$ ± 60.7 | 1756 $^{ab}$ ± 6.0 | 0.72 $^{a}$ ± 0.014 | 30.7 $^{a}$ ± 0.79 | 8.9 $^{ab}$ ± 0.65 |
| $T_4$ | 753 $^{b}$ ± 52.3 | 2243 $^{b}$ ± 92.4 | 0.71 $^{a}$ ± 0.005 | 29.3 $^{a}$ ± 1.08 | 11.9 $^{b}$ ± 0.53 |
| $T_5$ | 699 $^{b}$ ± 62.0 | 2331 $^{b}$ ± 214.0 | 0.72 $^{a}$ ± 0.030 | 29.0 $^{a}$ ± 0.24 | 12.4 $^{b}$ ± 0.85 |
| Harvest 2 | | | | | |
| $T_1$ | 729 $^{a}$ ± 118.9 | 2127 $^{a}$ ± 319.5 | 0.75 $^{a}$ ± 0.023 | 34.6 $^{b}$ ± 0.50 | 10.9 $^{a}$ ± 1.46 |
| $T_2$ | 636 $^{a}$ ± 66.5 | 2176 $^{a}$ ± 85.8 | 0.77 $^{a}$ ± 0.007 | 33.5 $^{ab}$ ± 0.47 | 11.6 $^{a}$ ± 0.52 |
| $T_3$ | 810 $^{a}$ ± 142.0 | 2473 $^{a}$ ± 153.1 | 0.75 $^{a}$ ± 0.012 | 34.5 $^{b}$ ± 0.10 | 12.7 $^{a}$ ± 0.64 |
| $T_4$ | 746 $^{a}$ ± 129.8 | 2260 $^{a}$ ± 244.9 | 0.75 $^{a}$ ± 0.006 | 32.4 $^{ab}$ ± 0.98 | 11.7 $^{a}$ ± 1.38 |
| $T_5$ | 742 $^{a}$ ± 75.6 | 2560 $^{a}$ ± 409.0 | 0.79 $^{a}$ ± 0.020 | 30.3 $^{a}$ ± 1.00 | 13.4 $^{a}$ ± 2.28 |
| Treatment (T) | $P = 0.164$ | $P = 0.008$ | $P = 0.212$ | $P = 0.019$ | $P = 0.009$ |
| Harvest (H) | $P = 0.028$ | $P < 0.001$ | $P < 0.001$ | $P < 0.001$ | $P = 0.002$ |
| T × H | $P = 0.282$ | $P = 0.208$ | $P = 0.428$ | $P = 0.118$ | $P = 0.198$ |

#### 3.1.1. Tuber Production

Tuber yield was greater at the later harvest across all treatments (Figure 1). This can be attributed to the overall growth of plants between harvest 1 and 2, as seen in an increased total plant biomass, and also to an increased allocation of biomass to the roots, as seen in a statistically higher harvest index (Table 1). On average, the harvest index increased from 0.71 to 0.76 between the harvests. There was no significant effect of K treatments on the harvest index or any K treatment x harvest interaction (Table 1).

While tuber yield did increase with K fertilisation (treatment effect $P = 0.003$), a reasonable yield was achieved in unfertilised plots (9.9 t ha$^{-1}$ dry wt. in harvest 1, 15.9 t ha$^{-1}$ dry wt. in harvest 2). The maximum increase due to K fertilisation, comparing $T_2$ (40-20-0 NPK) to $T_5$ (40-20-120 NPK), was 4.7 t ha$^{-1}$ (+39%) in harvest 1, decreasing to 3.5 t ha$^{-1}$ (+21%) in harvest 2. Treatments with low levels or no K fertiliser seemed to benefit most from the later harvest, as their yield increased more in that later period. The interaction K treatment × harvest was however not statistically significant ($P = 0.228$). Fertilisation with nitrogen and phosphorus alone had a moderate positive effect on tuber yield: tuber yield in $T_2$ (40-20-0 NPK) was 2.1 and 0.7 t ha$^{-1}$ higher than in $T_1$ (0-0-0 NPK) in harvests 1 and 2, respectively.

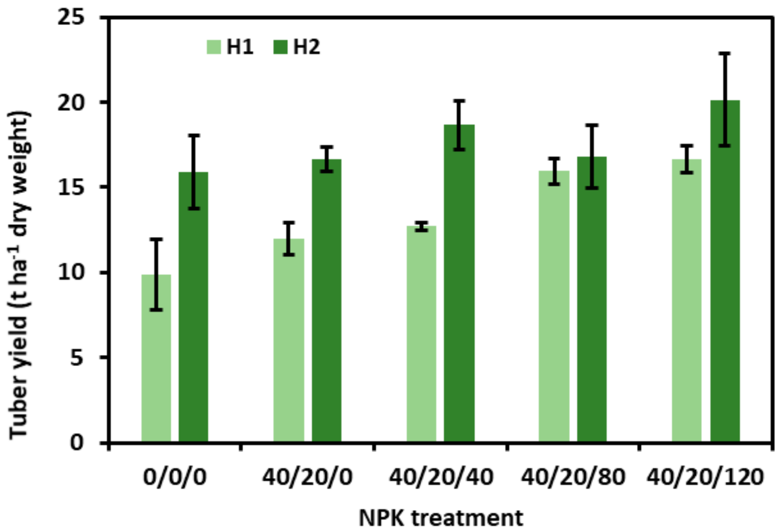


**Figure 1.** Tuber yield (t ha$^{-1}$ dry weight) at harvest 1 (H1, pale green) and harvest 2 (H2, dark green) in response to five fertiliser treatments of N-$P_2O_5$-$K_2O$ (kg ha$^{-1}$), $T_1$ 0-0-0, $T_2$ 40-20-0, $T_3$ 40-20-40, $T_4$ 40-20-80 and $T_5$ 40-20-120. Values are means of three replicates ± s.e. Treatment, $P = 0.003$; harvest, $P < 0.001$; treatment × harvest, $P = 0.228$.

#### 3.1.2. Starch Yield

Starch content increased on average 1.13-fold, from 29.4% to 33.1%, between harvest 1 and harvest 2 ($P < 0.001$, Table 1). There was a significant K treatment effect on starch content. The Tukey's tests showed that treatment means at harvest 1 were not significantly different; however, at harvest 2, means were significantly different, with the higher K treatments having lower starch content. As tuber yields were increased by K fertilisation and by later harvest, total starch yield (t ha$^{-1}$) showed similar treatment and harvest effects (Table 1).

### *3.2. K Uptake, Distribution and Export in Yield*

K concentrations of cassava storage roots were not highly variable across treatments and harvest dates, staying within 0.58–0.80 mg K g$^{-1}$ DW (for details on K concentrations in roots and other plant parts see Supplementary Materials Table S2). Root K concentrations decreased on average by 9% from the first to second harvest, and while the highest K concentrations were observed in the 120 K treatment, the lowest K concentrations were not found in the unfertilised treatments but in the 40 K treatment. K concentrations of aboveground parts of the plant differed from those of roots: they were either higher (leaf blades, 17% higher overall) or lower (leaf petioles, 52% lower; upper stems, 38% lower). K concentrations of the lower stems were 14% higher than those of roots at the first harvest, but 7% lower at the second harvest. Overall, mean aboveground and belowground tissue concentrations were not very different, such that the proportion of K held belowground was similar to the proportion of dry weight (equalling the harvest index), though slightly increased in the later harvest (77%) compared to the first harvest (69%).

The total K contained in the cassava plants increased with increasing K fertilisation (Figure 2). In the period between the first and second harvest, additional K was taken up mainly by the treatments that received 0–40 kg K ha$^{-1}$ as fertiliser, whereas the treatments that received higher K fertiliser doses did not show evidence of further K uptake. The increase in K content from the first to the second harvest was due to growth in biomass, as K concentrations decreased somewhat in all plant parts. There was net remobilisation after the first harvest from leaves and upper stems to roots, while the lower-stem K content remained similar (Figure 2).

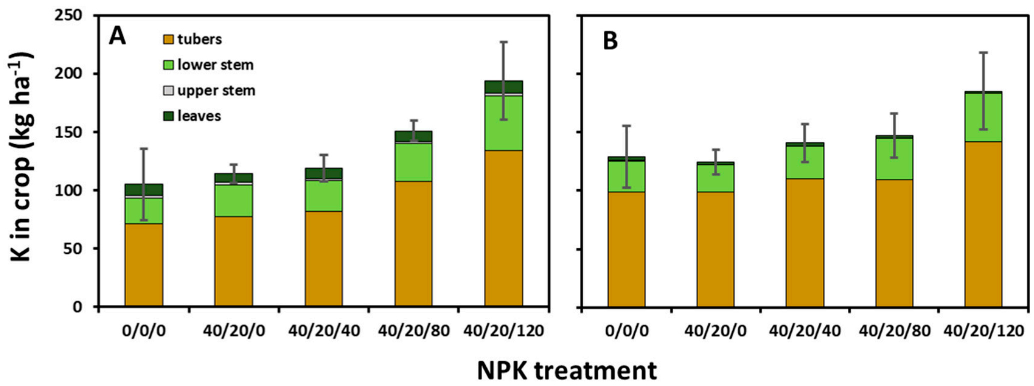


**Figure 2.** The distribution of K in tubers, lower stems, upper stems and leaves at harvest 1 (**A**) and harvest 2, 8 and 10 months after planting, respectively, (**B**) in response to five fertiliser treatments of N-$P_2O_5$-$K_2O$ (kg $ha^{-1}$), $T_1$ 0-0-0, T2 40-20-0, T3 40-20-40, T4 40-20-80 and T5 40-20-120. Where the upper stem K is not visible, the amounts are too small compared to the K in other plant fractions to distinguish them. Standard error bars refer to whole plant K (n = 3).

Due to the large amount of K contained in the cassava roots (Figure 2), harvesting removes a significant amount of K from the field. In this experiment, the cassava harvest caused a net negative K balance in all treatments, in both the first and second harvest. While K fertiliser input decreases the K deficit, from 99 to 42 kg K $ha^{-1}$ in the second harvest, even the highest K fertiliser rate was not sufficient to compensate for the K removal in terms of yield (Figure 3). The estimates in Figure 3 assume that only roots are removed from the field and all the aboveground material remains in the field. Removal of leaves (especially at an early harvest or before harvest), and in particular removal of lower stems (as planting material or fuel), would further increase the K deficit.

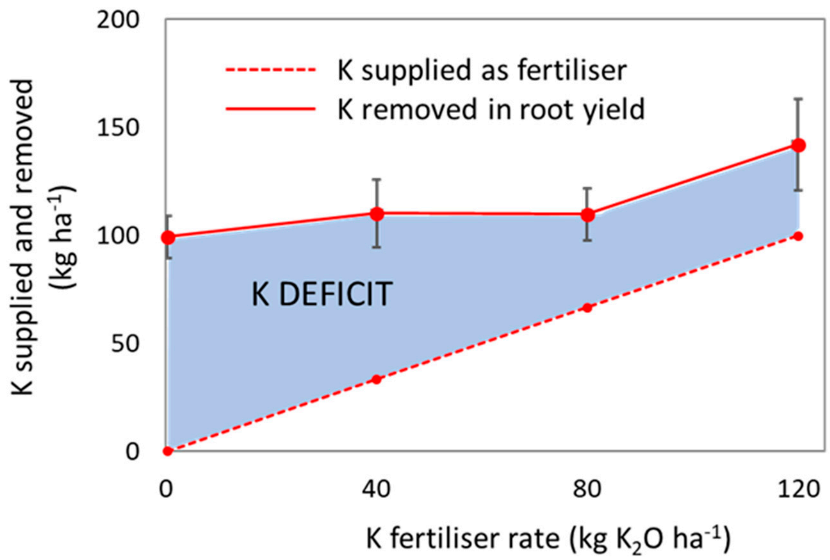


**Figure 3.** K balance of the cassava crop. The graph shows amounts of elemental K supplied as fertiliser (dotted line) and removed in tuber yield (solid line) at harvest 2, for N-$P_2O_5$-$K_2O$ (kg $ha^{-1}$) treatments $T_2$ 40-20-0, $T_3$ 40-20-40, $T_4$ 40-20-80 and $T_5$ 40-20-120. Values are means of three replicates ± s.e. for K removed in tuber yield.

## 4. Discussion

Several studies have exposed cassava crops to different fertiliser treatments to determine the optimum rates of N, P and K to produce maximum yield or maximum net income in a particular soil or region [12,21], however, the current study contributes new insights into the K balance in a K fertiliser response trial. Our results highlight the large amount of K accumulated in tubers compared to other plant parts and other crops, which is eventually removed from the field as harvested product. Application of K fertiliser increased the amount of K in tubers but only to a modest level, thus offsetting some of the deficit of soil K.

### 4.1. K Fertilisation Increased Tuber Yields

Cassava tuber yield has been observed to decline after continuous cropping without adequate fertiliser inputs, which has been attributed to the exhaustion of soil K along with other nutrients [12,22]. In long-term trials, K fertilisation of 125 and 66 kg K ha$^{-1}$ was required to maintain near-potential yield levels and soil K at sites in Colombia and Vietnam respectively [2,12]. In the current experiment, fertilisation with K resulted in higher yields compared to unfertilised controls, and the highest tuber yield of 20.16 t ha$^{-1}$ dry weight was achieved at the highest fertiliser rate at harvest 2. The modest 1.3 to 1.7-fold yield increase compared to yield without K fertiliser observed by us contrasts with the 7-fold yield increase reported for the long-term study in Vietnam [2]. Since in both cases N and P was applied, the limited response to K in the current experiment can probably be attributed to high background levels in soil K at our experimental site. The role of K in different cellular activities such as enzyme activation and stomatal movement, and thus photosynthesis and ATP generation [23–27], presumably contributed to the positive effect on tuber yield. The lowest yield (i.e., 9.88 t ha$^{-1}$ dry wt.) was observed in the treatment without any fertilisation. This yield was still higher than some other experiments [13,28], which is probably due to the relatively high fertility level of the soil at the experimental site. Indeed, soil assay results (see Methods) indicate that the levels of N, P and K at the site were relatively low for N, medium for P and adequate for K. Nevertheless, higher doses of fertiliser K did increase yield.

### 4.2. K Fertilisation Affects Starch Content

Fertiliser treatments resulted in modest but significant differences in starch content, and starch content increased over time. Studies show that exceeding a critical amount of K can cause Mg deficiency due to cation competition, resulting in a decreased starch content [2,17,19,29]. This may have contributed to the lower starch content in treatments receiving higher K inputs, for the late harvest.

Starch content is also influenced by rainfall and age [30–33]. The 12.5% increase in starch content at 10 months was accompanied by an 8.0% decrease in water content (data not shown); this could be partly due to dehydration and partly due to an increase in tuber fibre content over time [30,34]. The two-month period between the first and second harvest was dry without any rainfall.

Most cassava in South-East Asia is grown for the industrial production of starch. In several countries, the industry pays a higher price for roots that have a higher starch content. Our results show that farmers' decisions about K fertilisation and the timing of their harvest are likely to influence not only yield levels but also the price per ton paid by the industry.

### 4.3. More K Moved to Tubers Later in the Season

In both harvests, tubers contained most of the K taken up by the plant, regardless of treatment. At the late harvest, very little K remained in leaves and upper stems, but lower stems retained a significant amount of K (Figure 2). High K content of cassava tubers was also found in a meta-analysis conducted by Howeler [2] across 15 studies, concluding that on average 56.2% of the whole plant's K resided in the tubers. The high K content of cassava tubers means that large amounts of K are exported from the field with the harvested product, resulting in a large soil K depletion. Tuber yield was the most important factor determining K export in yield, since tuber K concentrations were relatively stable (Supplementary Materials Table S2).

### *4.4. High K in Lower Stems may Benefit K Balance and Future Yield*

Retention of K in the lower stems, even at the late harvest, could potentially benefit the next crop, as stems (stakes) are commonly harvested and used as seeding stock for the next cropping season. Indeed, the nutritional content of the stems affects stake quality and, in turn, the yields of subsequent crops [2,35]. Furthermore, Keating et al. [36] demonstrated that stakes taken from fertilised plants had a faster sprouting rate than stakes taken from low-fertility soils. The early vigour was presumably due to the higher starch and sugar content of the stakes from fertilised plants [2]. Our current results suggest that late harvest may also improve stake quality through increased K content. This higher K content may reduce K fertiliser requirement at an early cropping stage. It is also important, however, to note that the high K content of lower stems means that stems that are not used as planting stakes should be retained as residues on the field, to minimise K deficits.

### *4.5. Reduction of K Deficit*

In common practice, stakes used as future seeding stock and tubers for sale are removed from the field, potentially causing nutrient depletion and soil degradation [2,18,37]. K contained in crop biomass (and therefore deficit upon harvest) is highest if the crop is harvested late (Figure 2), especially for crops that receive low or no K, which seem to mature later (Figure 2). From the point of view of retaining mineral nutrients and organic matter in the soil, returning crop residues in the field is best practice [2,18,38,39], and an early harvest would minimise K export from the field. Any leaching of soil K that may occur during or between cropping cycles will further increase K deficits and would require additional fertiliser K inputs to sustain cassava yield levels.

Crop response to K fertilisation can be expected to vary considerably due to edaphic and climatic variation, as well as management. Multi-year, multi-site trials will be needed to improve K balance estimates and optimise K fertiliser recommendations.

## 5. Conclusions

In this study, tuber exports of K were observed to be much higher than K supplied (Figure 3). Although early harvest and crop residue retention could help to decrease K deficit, it would be at the cost of a small yield loss. The high and rather constant K content of cassava tubers means that cassava cropping will progressively reduce soil K availability unless fertiliser is used to compensate for the K exported as tuber yield. All crop residues should be returned to the soil no matter what the time of harvest to improve soil K and reduce the need for additional fertiliser inputs, but also to retain other nutrients. With low fertiliser input, later harvests appear to benefit yield, but also increase K deficits, which may cause a longer-term decrease in yields. Other factors such as the availability of inorganic and organic inputs, crop rotation, cassava market prices and access to different cultivars would need to be assessed in the future for a more accurate and longer-term assessment of costs and benefits of K fertilisation practice.

**Supplementary Materials:** The Supplementary Materials are available online at http://www.mdpi.com/2073-4395/10/8/1103/s1. Table S1. Total stem length (cm), total plant dry weight (g), harvest index (HI), starch content (%) and starch yield (t ha$^{-1}$) at harvest 1 (8 months growth) and at harvest 2 (10 months growth) in response to five fertiliser treatments (N-$P_2O_5$-$K_2O$, kg ha$^{-1}$), $T_1$ 0-0-0, $T_2$ 40-20-0, $T_3$ 40-20-40, $T_4$ 40-20-80 and $T_5$ 40-20-120. Table S2. Potassium (K) concentrations (μg g$^{-1}$ dry weight) of different plant parts.

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