Evaluating cassava best management practices towards low fertility soil in West Java, Indonesia

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Abstract. Marginal land with low fertility is a major problem in cassava cultivation. The purpose of this study was to determine the best combination of fertilization to increase the growth and yield of cassava on an Inceptisols soil. Urea (46% N), SP-36 (36% P2O5), KCl (60% K2O), NPK Phonska (15% N:15% P2O5:15% K2O), Poly4 Sirius (14% K2O:17% CaO:6% MgO:19% S), and chicken manure were used as a nutrient source into six treatment combinations. The results showed that fertilizer application significantly affected the plant height, stem diameter, leaf number, diameter of tubers, the total number of tubers, number and weight of marketable tubers, and the total weight of tubers per plant. The highest fresh and dry weight of storage roots was achieved in the best management practice involving application of 138 kg N + 36 kg P2O5 + 60 kg K2O + 37 kg Ca + 13 kg Mg + 41 kg S per hectare compared to other treatments where the weight of marketable tubers was also higher. The right combination of fertilizer rates was needed to achieve high yield targets of cassava and depends on the site-specific conditions of soil fertility and nutrient status.

1. Introduction
Cassava (*Manihot esculenta* Crantz) is a commodity that is used as food, feed, and industrial raw materials. However, its use as food is still more dominant. Cassava is tolerant to drought stress and has wide adaptability from marginal land to fertile land so that cassava can grow and produce [1]. The major soil types producing cassava in Indonesia are Alfisols, Ultisols, and Inceptisols [2].

In 2017, Indonesia was the fourth country as the world’s largest cassava producer with a production of 19.05 million tons [3]. In Indonesia, cassava is cultivated on dry land in monoculture or intercropping with upland rice, corn, and peanuts. The data [4] shows a decrease in the area of cassava planted over five years (2013-2017), from 1,066 million ha in 2013 to 0.773 million ha in 2017 or a 27.5% decrease in five years. Cassava production also decreased by 20.4% in the period 2013-2017, from 23.94 million tons.
tons in 2013 to 19.05 million tons in 2017. In contrast, in the same year period, cassava productivity increased from 22.46 t/ha in 2013 to 24.65 t/ha in 2017 or an increase of 9.8%. The five largest cassava-producing regions in Indonesia are Lampung (28.6%), Central Java (16.5%), East Java (15.3%), West Java (10%), and D.I. Yogyakarta (5.4%). The increase in cassava production by expanding harvested areas and productivity in production centers in Indonesia has a direct effect on the development of agro-industry and national export performance [5].

The productivity of cassava in Indonesia is still relatively low. In long-term farming, cassava productivity will quickly decline on marginal land conditions without fertilization. Fertilization is very necessary to obtain high cassava yields where high yields can be maintained if the dose of fertilizer applied is equivalent to the nutrients transported at harvest [6]. The results [7] show that productivity of 25-40 t/ha can be achieved with good management. Productivity of 50 t/ha can be achieved with fertilizer application doses of 135 kg N/ha, 36 kg P$_2$O$_5$/ha, and 90 kg K$_2$O/ha on non-acid soil [8] and 37.8 t/ha on acid soil [9]. Nutrients uptake of cassava is quite high, especially potassium (K). At a yield rate of 21 t/ha fresh tubers, cassava requires 87 kg N, 37.6 kg P, and 117 kg K/ha [10], 136 kg N, 17.6 kg P, dan 131.9 kg K/ha [11], while at a yield level of 30 t/ha, cassava requires 147.6 kg N, 20.7 kg P, and 148.8 kg K/ha [7]. This shows that K fertilization plays an important role in cassava productivity. However, the nutrient uptake of cassava varies depending on the variety, plant growth rate, climatic conditions, and soil fertility status [12]. Potassium application at a dose of 60 kg K$_2$O/ha on Alfisol in South Malang with a K-dd of 0.07 cmol(+)/kg increased the yield by 92% [13]. Optimal cassava productivity of 31.4 t/ha can be achieved by fertilizing 60 kg K$_2$O/ha on Ultisol soil in Metro and Tulangbawang (Lampung) with K-dd 0.06-0.12 cmol(+)/kg [14]. The decrease in cassava yield can be suppressed by fertilizing 100 kg K/ha on Inceptisol soil at CIAT with K-dd 0.18 cmol(+)/kg [15]. On Ultisol soils in Nigeria with K-dd 0.11 cmol(+)/kg, optimal yields were achieved by application of potassium fertilizer at a dose of 105 kg K/ha [16]. The consistent response to K also occurs in Vietnam [17]. Although K is important for cassava, farmers rarely apply K, and the majority only fertilize with N and P. The high price of K fertilizer is the main reason for farmers not to apply K fertilizer [18]. Therefore, there is a need for an alternative to cheaper K source fertilizers such as Polyhalite or Poly4 Sirius.

Polyhalite [K$_2$Ca$_3$Mg(SO$_4$)$_4$·2H$_2$O] is mineral-rich in potassium. Polyhalite is effectively used directly as fertilizer. Polyhalite at a dose of 214 kg/ha improves soil fertility and can provide peanut yields of 2.86 t/ha or 24% higher than the farmer method and increases profits up to 98% [19]. Application of 70-140 kg K$_2$O/ha sourced from Polyhalite does not cause toxicity or salinity effects, increases K uptake, and improves rice plant growth on Oxisol soils in Brazil [20]. The application of polyhalite at a dose of 500 kg/ha increased the uptake of K, Ca, Mg and S, as well as increasing the weight of wheat biomass compared to without Polyhalite, and the broadcast fertilization method was more efficient [21]. In Tanzania, the application of 20 kg K$_2$O/ha sourced from Poly4 resulted in 621 kg/ha higher maize yields than that sourced from KCl [22]. The study [23] in Indonesia reported that Poly4 Sirius (257 kg/ha) had almost the same quality as KCl (100 kg/ha) as a source of K which obtained production that was not significantly different for maize. The purpose of this study was to determine the best combination of fertilization to increase the growth and yield of cassava on an Inceptisols soil.

2. Materials and Methods

2.1. Description of the study sites and soil sampling analysis

The study was conducted from February to November 2020 with field experiments on farmers' land in Warungkiara District, Sukabumi Regency, West Java Province. The condition of the experimental field is rainfed lowland with no irrigation during the study and water requirement only depends on rainfall conditions. The total annual rainfall and rainy days in 2020 were 3738 mm/year with 155 rainy days, while the average monthly rainfall and rainy days were 340 mm/month with 14 rainy days/month. The dry month period with rainfall of <100 mm and 4 rainy days/month. The dry month period with rainfall of <100 mm and 4 rainy days occurred for two months in July (95 mm) and August (33 mm). The condition of the experimental field was located at an altitude of ±300 m above
sea level with irradiation time ranging from 36% to 85%, and temperatures ranging from 16.2 °C to 31.8 °C [24].

Soil samples were taken in the topsoil layer with a depth of 0-20 cm using a soil drill prior to the experiment. Soil sampling was carried out using the composite method from 30 soil subsamples and three composite soil samples were taken representing each block on the experimental field. Soil sampling was carried out systematically (systematic sampling) which represented the overall condition of the land area. Soil samples were air-dried, mixed, and sieve further the soil of 1 kg analyzed for the soil physical and chemical properties. Soil analysis was carried out at the testing laboratory of the Soil Research Institute, Bogor, West Java. The physicochemical characteristics of the topsoil at a depth of 0-20 cm prior to the experiment were carried out are presented in Table 1.

Table 1. Physicochemical characteristics of topsoil (0–20 cm depth) of the experimental site.

| Soil properties                  | Unit       | Value (n = 3) | Low level of nutrient requirements* |
|----------------------------------|------------|--------------|-------------------------------------|
| pH (water)                       |            | 4.4 ± 0.1    | 3.5−4.5                             |
| Organic matter                   | %          | 1.62 ± 0.20  | 1.0−2.0                             |
| Total N                          | %          | 0.18 ± 0.01  |                                     |
| C/N                              |            | 9.00 ± 1.00  |                                     |
| Available P                      | mg/kg      | 1.7 ± 0.3    | 2.0−4.0                             |
| Exchangeable bases:              |            |              |                                     |
| - K                              | cmol(+)/kg | 0.14 ± 0.05  | 0.1−0.15                            |
| - Ca                             | cmol(+)/kg | 2.39 ± 0.33  | 0.25−1.0                            |
| - Mg                             | cmol(+)/kg | 1.00 ± 0.04  | 0.2−0.4                             |
| - Na                             | cmol(+)/kg | 0.26 ± 0.09  |                                     |
| Exchangeable acidity             | cmol(+)/kg | 0.11 ± 0.02  |                                     |
| Cation exchange capacity         | cmol(+)/kg | 12.05 ± 0.81 |                                     |
| Base saturation                  | %          | 32 ± 4       |                                     |
| Na saturation                    | %          | 7 ± 2        | <2.0                                |
| Al saturation                    | %          | 36 ± 3       |                                     |
| Particle size:                   |            |              |                                     |
| - Sand                           | %          | 3 ± 1        |                                     |
| - Silt                           | %          | 37 ± 6       |                                     |
| - Clay                           | %          | 61 ± 7       |                                     |
| Textural class                   |            | clay         |                                     |

*: low level of cassava nutrient requirement [25]

Soil types were classified as Inceptisols with low base saturation and cation exchange capacity. Based on the composition of the soil particle size, the soil texture was classified as clay which was dominated by clay particles (61%). Soil conditions in the experimental field had a low organic matter and total N content with a C/N ratio of 9 [26]. Soil pH was classified as acidic (pH 4.4). This topsoil had a very low available P content with exchangeable bases such as low K, moderate Ca and Mg. In Inceptisols soil, P availability is influenced by clay content, C-organic, and exchangeable Mg in the soil. The availability of P in the soil tends to be high with increasing clay content, C-organic, and exchangeable Mg [27]. The Na and Al saturations were 7% and 36%, respectively, which were classified as moderate [25]. Overall, this soil condition has a low fertility level which can be a limiting factor for plant growth. Acidic soils with low nutrient content will have a poor ability to retain plant nutrients [28].
2.2. Field experiments

The experiment was carried out according to field conditions on farmers' land and a randomized complete block design (RCBD) was used in this study. The experiment consisted of six fertilizer packages as a treatment with three replications. Chemical fertilizers and organic fertilizers were applied according to the rate for each treatment. Chemical fertilizers used were urea (46% N), SP-36 (36% P₂O₅), KCl (60% K₂O), NPK Phonska (15% N, 15% P₂O₅, and 15% K₂O), Poly4 Sirius (14% K₂O, 17% CaO, 6% MgO, and 19% S), while the organic fertilizer used was chicken manure. The treatments in this experiment were: (1) FFP1 – 400 kg urea + 150 kg NPK Phonska per hectare, (2) FFP2 – 400 kg urea + 200 kg NPK Phonska per hectare, (3) FFP3 – 300 kg urea + 150 kg NPK Phonska + 3.75 tons of chicken manure per hectare, (4) FFP4 – 300 kg urea + 200 kg NPK Phonska + 4 tons of chicken manure per hectare, (5) FFP5 – 300 kg urea + 150 kg NPK Phonska + 4.5 tons of chicken manure per hectare, and (6) BMP – 300 kg urea + 100 kg SP-36 + 50 kg KCl + 215 kg Poly4 Sirius per hectare. The fertilizer rate was equivalent to the nutrient content presented in Table 2.

Table 2. Nutrient application rates per treatment on farmer fertilizer practices and best management practices

| Treatment | Nitrogen (kg N/ha) | Phosphorus (kg P₂O₅/ha) | Potassium (kg K₂O/ha) | Calcium (kg CaO/ha) | Magnesium (kg MgO/ha) | Sulphur (kg S/ha) | Manure (t/ha) |
|-----------|-------------------|--------------------------|-----------------------|---------------------|-----------------------|------------------|--------------|
| FFP1      | 207               | 23                       | 23                    | 0                   | 0                     | 0                | 0            |
| FFP2      | 214               | 30                       | 30                    | 0                   | 0                     | 0                | 0            |
| FFP3      | 161               | 23                       | 23                    | 0                   | 0                     | 0                | 3.75         |
| FFP4      | 168               | 30                       | 30                    | 0                   | 0                     | 0                | 4            |
| FFP5      | 161               | 23                       | 23                    | 0                   | 0                     | 0                | 4.5          |
| BMP       | 138               | 36                       | 60                    | 37                  | 13                    | 41               | 0            |

The planting material used was cassava stem cuttings of the Manggu variety. This cassava was a local variety commonly used by local farmers. Stem cuttings with a length of 25 cm and a diameter of ±3 cm was planted at a spacing of 1 m x 1 m so that the planting density was 10,000 plants per hectare. In the treatment of farmer fertilization practices (FFP) and best management practices (BMP), all chemical fertilizers were applied three times at 1, 3, and 6 months after planting (MAP) with the rate of each application was 1/3 of the total dose. Manure was applied once at 1 MAP. During the experimental period, shoot reduction, weeding activities, and other cultivation practices were carried out based on best management practices for cassava [29].

2.3. Plant data collection and statistical analysis

Data collection for variables of growth, yields, and yield components of cassava was carried out at harvest time. Harvesting was done at 10 MAP because the highest yield of cassava was achieved at that age [6]. From each treatment plot, variables of growth and yield components were recorded from three plants. The growth variables of cassava collected were plant height, stem diameter, stem fresh weight, number of leaves, and leaf fresh weight (leaves and petioles). Plant height was measured vertically from the soil surface to the end of the cassava canopy using a tape measure. Stem diameter was measured 10 cm from the base of the main branch using a caliper. The number of leaves is calculated on the number of fresh leaves of cassava at harvest. Variables of yield and yield components collected were the number of tubers, tuber length, tuber diameter, weight of marketable tubers, and fresh tuber yield. Plants were separated from each part of the leaves, stems, and tubers then the total wet weight was weighed. A subsample of about 400 g of fresh weight from each plant part was oven at a temperature of 70 °C for ±48 hours and weighed until the weight was constant so that the water content and dry weight values of each plant part (leaves, stems, and tubers) could be determined. The dry matter weight of each part of cassava (leaves, stems, and tubers) was calculated by multiplying the fresh weight of the plant by the percentage of dry matter content. The harvest index was calculated based on the method [30] which was
calculated by dividing the dry weight of the tubers by the total dry weight of the plant (storage root + shoot dry matter).

The data collected for all plant traits were processed statistically using analysis of variance (ANOVA) at a significant level of $P \leq 0.05$. On-way ANOVA was performed by following the model of RCBD. Based on the results of ANOVA, the treatment that had a significant effect on the responses was continued with the Fisher's least significant difference (LSD) test at a significant level of $P \leq 0.05$ to compare the mean values between treatments. Statistical software of R version 4.0.3 and R Studio was used for all statistical analyses in this study.

3. Results and Discussion

3.1. Cassava growth

Fertilization treatment showed a significant effect on the growth response of cassava such as the variables of plant height, stem diameter, stem fresh weight, number of leaves, and leaf fresh weight (Table 3). The response of cassava plant height was quite varied in each fertilization treatment at harvesting time. The highest plant height was found in the BMP treatment, which was 329.8 cm, but it was not significantly different from the FFP3 and FFP5 treatments. The FFP2 treatment had the lowest plant height compared to other treatments which were not significantly different from the FFP1 treatment. The use of organic fertilizers on FFP3, FFP4, and FFP5 treatment could increase the plant height of cassava. These results are consistent with research [31] which states that the combination of organic fertilizer and NPK can increase the growth of cassava such as plant height and stem diameter. The organic fertilizer such as chicken manure not only contains NPK, but also other nutrients needed by plants. It improves soil conditions which can increase nutrient uptake compared to chemical fertilizers alone. Chicken manure added on FFP3, FFP4, and FFP5 treatments would increase the availability of soil nutrients so that they could be taken by plant roots. The application of organic fertilizers could increase soil nutrients around plant roots to increase the vegetative and generative growth of plants [32].

The response of stem diameter growth to the BMP treatment showed a significant difference. The stem diameter on the BMP treatment had the largest size compared to the FFP1, FFP2, FFP4, and FFP5 treatments, but was not significantly different from the FFP3 treatment. The stem diameter of the cassava on the BMP treatment was 3.14 cm or 37% larger than the FFP1 treatment which was only 2.30 cm. In addition, the stem fresh weight on the BMP treatment also showed a significant response compared to other treatments which were not significantly different from the FFP3 treatment. This indicated that the BMP treatment could increase the stem fresh weight of cassava.

The highest number of leaves and leaf fresh weight was shown on the FFP3 treatment followed by the BMP treatment. The number of leaves in the FFP3 treatment was quite a lot (107 leaves) with a leaf fresh weight of 0.81 kg. Overall, the BMP treatment was the best fertilizer package that could increase the cassava growth in this experiment. The BMP treatment was a fertilizer package that contained higher rates of P and K than the other treatments in this experiment, as well as added Ca, Mg, and S nutrients from Poly4 Sirius. The addition of nutrients into the soil through fertilization with Poly4 Sirius could increase soil nutrients so that the nutrient needs of K, Ca, Mg, and S for plants could be fulfilled.
Table 3. Cassava growth on the application of fertilizer packages on farmer’s practices and best management practices.

| Treatment | Plant height (cm) | Stem diameter (cm) | Stem fresh weight (kg) | Leaf number | Leaf fresh weight (kg) |
|-----------|------------------|-------------------|-----------------------|-------------|-----------------------|
| FFP1      | 236.7 c1         | 2.30 c            | 1.7 c                 | 81 ab       | 0.35 c                |
| FFP2      | 226.5 c          | 2.43 c            | 1.9 bc                | 35 c        | 0.64 ab               |
| FFP3      | 299.0 ab         | 3.02 ab           | 3.8 a                 | 107 a       | 0.81 a                |
| FFP4      | 288.4 b          | 2.61 bc           | 2.5 bc                | 90 ab       | 0.25 c                |
| FFP5      | 319.4 ab         | 2.67 bc           | 2.7 b                 | 71 b        | 0.45 bc               |
| BMP       | 329.8 a          | 3.14 a            | 4.2 a                 | 100 a       | 0.71 a                |

F test 13.41 ** 4.92 * 9.71 ** 8.59 ** 9.67 **

CV (%) 7.13 9.54 20.57 18.89 22.74

LSD 36.80 0.46 1.05 27.67 0.22

**: significant at $P \leq 0.01$, *: significant at $P \leq 0.05$.

1 Means in the same column followed by different letters indicated significant differences according to the LSD test at $P \leq 0.05$.

CV: coefficient of variation.

3.2. Yield components, biomass, and storage root yield

The treatment of fertilization had a significant effect on several yield components of cassava (Table 4). The number of tubers, tuber diameter, weight of marketable tubers, and total tuber weight per plant showed varying results, while tuber length was relatively not significantly different in all fertilization treatments in this experiment. This indicated that the response to tuber length was not affected by differences in fertilizer input. In contrast, the effect of fertilization was shown on the response to the number of tubers per plant and the tuber diameter of cassava.

The number of tubers per plant and tuber diameter in the BMP treatment showed that the average number of tubers produced was more with larger tuber diameters, but these results were not significantly different from the FFP3, FFP4, and FFP5 treatments. This indicated that the application of chicken manure in the FFP3, FFP4, and FFP5 treatments contributed to the total number of tubers per plant and the results were not significantly different from the BMP treatment which had more complete nutrient content (with Ca+Mg+S) and higher P and K rates. Chemical fertilizers usually have higher NPK content than manure, but secondary nutrient (Ca, Mg) and micronutrient (Zn, Cu, Mn, Fe) content in manure also contribute to cassava yields [25]. In addition, the BMP treatment also produced a higher average number of marketable tubers than the FFP1, FFP2, and FFP4 treatments and was not significantly different from the FFP3 and FFP5 treatments. The total number of tubers per plant produced on the BMP treatment was 14.36 tubers and 74% were suitable for marketing. On the other hand, the lowest number of marketable tubers was found in the FFP1 treatment (5.11 tubers).

Total tuber weight per plant showed various responses to fertilization treatment. The highest tuber weight per plant was found in the BMP treatment and also had the highest weight of marketable tubers compared to other treatments in this experiment. The average tuber weight per plant obtained in the BMP treatment was 6.09 kg, of which 5.66 kg (93%) were marketable.

The results of the analysis of variance showed that the application of fertilizer at various rates affected the fresh weight and dry weight of plants, both roots, and shoots (Table 5). The total fresh weight of plants (roots and shoots) on the BMP treatment (11.3 kg/plant) showed higher yields than the other treatments, but not significantly different from the FFP3 treatment (9.02 kg/plant). The fresh weight of cassava in the FFP1 treatment tended to be lower (4.38 kg/plant) which was not different from the FFP2 and FFP4 treatments. In addition, the highest total dry weight of cassava was also found in the BMP treatment which produced 4.34 kg/plant dry weight of cassava, while the lowest dry weight of cassava was found in the FFP1 treatment (1.56 kg/plant) which was not different from the FFP2 treatment. This
indicated that fertilization with BMP treatment was able to increase the total dry matter of cassava (roots and shoots). The N rate in the lower BMP treatment was almost half as much as in the FFP-1 treatment, which did not seem to cause the dry matter yield to decrease. The lower N rate on the BMP treatment (almost half as much as in the FFP1 treatment) did not cause the dry matter yield to decrease. This was caused by the increase in P and K doses, as well as the addition of Ca, Mg, and S nutrients on the BMP treatment. Low fertility soil conditions with relatively low P and K content in this experiment (Table 1) caused a significant dry matter response because more nutrients would be taken up by plant roots to meet their nutrient needs. At low levels of soil nutrient status, cassava had adequate P and K uptake so that it would be advantageous to apply P and K fertilizers [33]. Cassava needed K in large enough quantities because this nutrient played a role in the synthesis and translocation of carbohydrates from the shoot to storage roots (tubers) [34]. Cassava tuberization are affected by N, P, and K fertilizers. Chemical fertilizers usually contain 10-20 times higher N, P, and K nutrients than manure, but manure also contains secondary and micro nutrients that can contribute to higher yields [25]. Nutrients from chemical fertilizers are more readily available and released to plants than nutrients from organic sources [31].

Table 4. Yield components of cassava on the application of fertilizer packages on farmer’s practices and best management practices.

| Treatment | Tubers length/plant (cm) | Tuber diameter/plant (cm) | Total number of tubers/plant | Number of marketable tubers/plant | Total weight of tubers/plant (kg) | Weight of marketable tubers/plant (kg) |
|-----------|-------------------------|---------------------------|-------------------------------|----------------------------------|----------------------------------|-----------------------------------|
| FFP1      | 25.28                   | 3.63                      | 9.89 b                        | 5.11 c                           | 2.38 c                           | 1.87 c                            |
| FFP2      | 26.51                   | 3.94                      | 9.11 b                        | 9.11 ab                          | 3.50 bc                          | 3.33 bc                           |
| FFP3      | 23.10                   | 4.46                      | 14.00 a                       | 9.11 ab                          | 4.37 b                           | 3.87 b                            |
| FFP4      | 28.62                   | 4.23                      | 11.33 ab                      | 8.11 b                           | 3.91 bc                          | 3.53 b                            |
| FFP5      | 23.88                   | 4.48                      | 13.78 a                       | 8.77 ab                          | 4.39 b                           | 3.81 b                            |
| BMP       | 29.29                   | 4.63                      | 14.36 a                       | 10.61 a                          | 5.69 a                           | 5.66 a                            |
| F test    | 2.78**                  | 4.66*                     | 4.67*                         | 6.93**                           | 5.56*                            | 5.55**                            |
| CV (%)    | 9.95                    | 7.18                      | 15.10                         | 14.95                            | 21.87                            | 24.28                             |
| LSD0.05   | -                       | 0.55                      | 3.27                          | 2.19                             | 1.63                             | 1.60                              |

**: significant at P ≤ 0.01; *: significant at P ≤ 0.05; ns: not significant.

Means in the same column followed by different letters indicated significant differences according to the LSD test at P ≤ 0.05.

The treatment of fertilization affects the dry matter of shoots and roots. The results of the analysis of variance showed that the dry matter of shoots and roots had significant differences in various fertilization treatments (P ≤ 0.01) (Table 5). These results are in line with research [35] which reported that above-ground biomass (shoots) and tuber number significantly increased with the application of NPK fertilizer. The highest shoot and root dry matter was found in the BMP treatment which obtained 1.89 kg/plant and 2.45 kg/plant, respectively. Cassava had a higher root dry weight than the shoot. In this study, the value of the root:shoot ratio of cassava was more than 1. This indicated that more photosynthate translocation to the root for tuber formation than to the shoot. Root:shoot ratio indicates the ability of photosynthate storage allocation for root biomass compared to shoot [36]. The dry matter of shoots and roots in the BMP treatment had higher yields, but the value of the root:shoot ratio and harvest index were lower than the FFP2 and FFP4 treatments. Cassava roots tended to have a higher proportion of dry matter than the leaves and stems. There was a significant difference between the harvest index to the fertilization treatment (P ≤ 0.01). The highest root:shoot ratio and harvest index were found in the FFP4 treatment with values of 2.13 and 0.67, respectively. More than half of cassava, dry matter weight was dominated by storage roots. This indicated that more dry matter accumulates in the roots followed by stems and then leaves (Figure 1). In this study, the harvest index (HI) was 0.5 in all treatments. When
Cassava is harvested at 10-12 MAP, the HI values ranged from 0.49-0.77 [37], while the HI value >0.5 is considered acceptable for cassava [12].

Table 5. Biomass and yield of cassava on the application of fertilizer packages on farmer’s practices and best management practices.

| Treatment | Total fresh biomass (kg/plant) | Total dry biomass (kg/plant) | Shoot dry biomass (kg/plant) | Root dry biomass (kg/plant) | Root:shoot ratio | Fresh tuber yield (t/ha) | Harvest index |
|-----------|--------------------------------|-----------------------------|------------------------------|----------------------------|-----------------|------------------------|--------------|
| FFP1      | 4.38 d                         | 1.54 d                      | 0.63 d                       | 0.90 c                     | 1.47 bc         | 19.82 c                | 0.59 b       |
| FFP2      | 6.00 cd                        | 2.06 cd                     | 0.78 d                       | 1.28 bc                    | 1.61 ab         | 29.12 bc               | 0.61 ab      |
| FFP3      | 9.02 ab                        | 3.20 b                      | 1.61 ab                      | 1.60 b                     | 1.01 c          | 36.43 b                | 0.50 c       |
| FFP4      | 6.69 b-d                       | 2.58 bc                     | 0.85 cd                      | 1.73 b                     | 2.13 a          | 32.62 bc               | 0.67 a       |
| FFP5      | 7.56 bc                        | 3.12 b                      | 1.29 bc                      | 1.83 b                     | 1.43 bc         | 36.58 b                | 0.59 b       |
| BMP       | 11.03 a                        | 4.34 a                      | 1.89 a                       | 2.45 a                     | 1.34 bc         | 50.72 a                | 0.57 bc      |

F test | 6.97** | 9.49** | 10.30** | 8.44** | 4.79* | 5.56* | 6.11** |
CV (%) | 20.61 | 19.70 | 23.25 | 19.06 | 19.41 | 21.86 | 6.40 |
LSD0.05 | 2.79 | 1.00 | 0.49 | 0.56 | 0.52 | 13.61 | 0.06 |

*: significant at P ≤ 0.01, *: significant at P ≤ 0.05.

Means in the same column followed by different letters indicated significant differences according to the LSD test at P ≤ 0.05.

Cassava roots were part of the storage so that many nutrients and assimilate accumulate in this part. The fresh tuber yield of cassava resulted in significantly different responses to fertilization treatment. This indicated that the response of the fresh tuber yield of cassava was influenced by the rate of fertilizer applied (P ≤ 0.05). The highest yield was found in the BMP treatment (50.72 t/ha) compared to other treatments in this experiment, while the lowest yield was found on the FFP1 treatment (19.82 t/ha). The N rate on the FFP1 treatment was relatively higher, but it was not balanced by the increase in P and K rates. Cassava was less responsive to N fertilizer if the application of K fertilizer was very low. Nitrogen and K interacted with each other and played an important role in cassava yield. Nitrogen plays an important role in vegetative growth, while K plays an important role in the initiation and bulking of cassava tubers [38].

The addition of P and K nutrients through fertilization was important, especially for the land with low levels of P and K status so that the nutrient needs of plants could be fulfilled. The role of P and K is very important for cassava. The study [39] reported that high yields of cassava (30-40 t/ha) can be achieved when K or NPK fertilizers are applied in sufficiently high doses (100 kg/ha N, 200 kg/ha P2O5, and 150 kg/ha K2O) to maintain the availability of exchanged P and K in the soil. The results of another study [31] stated that the fresh tuber yield of cassava (30 t/ha) could be achieved by a combination of NPK fertilizer application (150N-33P-124.5K kg/ha) with manure at a dose of 2.8 t/ha. On the BMP treatment, the doses of P and K applied were higher than the other treatments. Cassava needs high rates of K nutrients during its life phase for tuber formation. Furthermore, the BMP treatment also included additional Ca, Mg, and S derived from Poly4 Sirius. The study [6] reported that the application of sufficient Ca and Mg could increase the yield of cassava. Nutrient balance is very important in plant physiological processes. Phosphorus is immobile in the soil because most of the P is bounded into a form unavailable to plants [40]. The availability of P for plants is influenced by acidic cations (Al and Fe) and base cations (Ca). Phosphorus will be bound by Al and Fe in acidic soil conditions, while it will be bound by Ca in alkaline soil conditions [41][27].

Cassava dry matter was more abundant in stems and roots than leaves. Cassava dry matter is mainly translocated to storage stems and roots [37]. Response of dry matter and percentage of the dry matter content of cassava in various treatments of fertilizer rates were presented in Figure 1. Dry matter and dry matter content in each part of cassava such as leaves, stems, and tubers varied in each treatment.
This indicated that the dry matter of leaves, stems, and tubers was affected by the fertilization treatment. Fertilization provided additional nutrients in the soil so that it could increase the availability of nutrients to be taken by plant roots to carry out physiological processes, growth, and assimilate formation. The highest dry matter weight per plant was found in the BMP treatment where the dry weight of leaves, roots, and storage roots were 0.21 kg, 1.68 kg, and 2.45 kg, respectively. The dry weight of leaves, stems, and roots of cassava storage in the BMP treatment tended to be higher than the FFP1, FFP2, FFP3, FFP4, and FFP5 treatments, but not for the dry matter content where the FFP4 treatment was the highest. The highest dry matter content of storage leaves and roots was found in the FFP4 treatment, but this treatment had the lowest stem dry matter content. The dry matter content of the leaves, stems, and storage roots on the FFP4 treatment were 32.77%, 30.68, and 44.13%, respectively.

![Figure 1](image)

Figure 1. Biomass and dry matter content in leaves, stems, and storage root of cassava on fertilization packages of farmers practices and best management practices. The different letters above the bar chart show significant differences between treatments according to the LSD test at $P \leq 0.05$ and the error bars are ± SE (standard errors).

Table 6 shows the relationship between the traits of cassava. There was a significant correlation between fresh tuber yield and other traits except for leaf number, harvest index, and dry matter content. The results of Pearson’s correlation analysis showed that fresh tuber yield had a very strong positive correlation with stem diameter ($r = 0.88, P \leq 0.01$), stem fresh weight ($r = 0.89, P \leq 0.01$), diameter of tubers ($r = 0.86, P \leq 0.01$), and weight of marketable tuber ($r = 0.99, P \leq 0.01$). Fresh tuber yield had also a strong positive correlation with plant height ($r = 0.69, P \leq 0.01$) and number of tubers ($r = 0.73, P \leq 0.01$). The relationship between fresh tuber yield and leaf fresh weight had a moderate positive correlation ($r = 0.56, P \leq 0.05$). This meant that these traits contributed to an increase in the economic...
yield of cassava. The leaf number, harvest index, and dry matter content of storage roots were not directly correlated with the fresh tuber yield. Dry matter content was directly correlated to the harvest index ($r = 0.48$, $P \leq 0.05$), but there is no correlation between dry matter content and fresh tuber yield. This result is in line with the study [42] which states that there is no correlation between fresh tuber yield and dry matter content. It may be that dry matter content and fresh tuber yield are independent characters so that differences in dry matter content of storage roots have less impact on fresh tuber yield.

Table 6. Pearson’s correlation coefficients among the traits measured of cassava

| Traits   | PH  | SD  | SFW | LN  | LFW | NT  | DT  | WUM | HI  | DMC  |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| SD       | 0.57* |     |     |     |     |     |     |     |     |      |
| SFW      | 0.69** | 0.94** |     |     |     |     |     |     |     |      |
| LN       | 0.58* | 0.54* | 0.60** |     |     |     |     |     |     |      |
| LFW      | 0.19ns | 0.63** | 0.69** | 0.16ns |     |     |     |     |     |      |
| NT       | 0.72** | 0.74** | 0.72** | 0.54* | 0.34ns |     |     |     |     |      |
| DT       | 0.75** | 0.77** | 0.85** | 0.38ns | 0.55* | 0.60** |     |     |     |      |
| WUM      | 0.65** | 0.85** | 0.86** | 0.35ns | 0.58* | 0.64** | 0.86** |     |     |      |
| HI       | -0.28ns | -0.28ns | -0.46ns | -0.27ns | -0.70** | -0.22 | -0.31ns | -0.14ns |     |      |
| DMC      | 0.32ns | -0.17ns | -0.11ns | 0.15ns | -0.558* | 0.00ns | 0.12ns | -0.05ns | 0.48* |      |
| FTY      | 0.69** | 0.88** | 0.89** | 0.40ns | 0.56* | 0.73** | 0.86** | 0.99** | -0.15ns | -0.03ns |

*: correlation is significant at $P \leq 0.01$, **: correlation is significant at $P \leq 0.05$, ns: not significant.

4. Conclusion

Soil conditions at the study site were characterized by low fertility with low availability of N, P, K, and organic matter. The significant response of cassava to fertilization showed high variability in this study. Application of fertilization in the BMP treatment at a dose of 138 kg N + 36 kg P$_2$O$_5$ + 60 kg K$_2$O + 37 kg Ca + 13 kg Mg + 41 kg S per hectare was able to increase the total biomass of cassava (shoots and storage roots), both fresh weight and dry weight. Nutrients taken by cassava were mostly translocated to the storage roots, which indicated a high root:shoot ratio and harvest index. The results of the highest wet weight and dry weight of storage roots of cassava were also achieved in the BMP treatment compared to other treatments in this experiment where the weight of marketable tubers was also higher. These results indicated that increasing doses of P and K and additional secondary nutrients such as Ca, Mg, and S were the keys to improving cassava yields depending on site-specific and soil fertility or soil nutrient status.

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