The impact of ZA substitution with organic fertilizer through red ginger’s growth and yield in mixed cropping with maize and cassava

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Abstract. The study aimed to obtain partial or complete replacement of N in ZA fertilizers with organic fertilizers without reducing, and even increasing yields in the context of sustainable agriculture in mixed crops with maize and cassava. The research was held in Wonorejo Village, Karanganyar, Indonesia in March-August 2020. The research was using one factor RCBD, four treatments, six replications, namely Control, 100% ZA, 50% ZA + 50% organic fertilizer, and 100% organic fertilizer. Data analysis using ANOVA and DMRT 5%. The result showed that 100% organic fertilizer influenced significantly on plant height, number of leaves and tillers, fresh and dry straw weight, stored rhizomes weight, dry weight of maize kernels and cassava tubers. Mixed crops are more efficient in land use than monoculture crops (LER > 1), but not in time used from planting to harvest (ATER < 1). Subsistence farmers are suitable to apply mixed crops because it is more profitable in terms of food needs fulfillment.

1. Introduction
Red ginger (Zingiber officinale var. Rubrum) is a widely developed plant as food ingredients, beverages, cosmetics, and medicine. Ginger can treat various diseases because it is rich in active compounds good for health. The demand for red ginger is relatively high and will continue to increase. However, ginger cultivation has not been supported by sustainable cultivation, so that productivity is low. The decrease in ginger production is caused by planting patterns, soil conditions, and nutrients that are not optimal, so it needs fertilization and changes in planting patterns.

Fertilization aims to provide enough nutrients for plants to increase their growth and yield. ZA fertilizer is an inorganic fertilizer that has been developed to increase the content of nitrogen and sulfur. Nitrogen is an essential element for plant growth and development. Sulfur content is important to increasing protein [1] and activates enzymes. However, the long-term use of inorganic fertilizers causes soil damage, thus reducing land productivity.

The main problem faced in cultivating ginger plants is fertilizers that have not been balanced and efficient. The application of inorganic fertilizers can decrease soil organic matter and soil quality [2], so it is necessary to improve fertilization efficiency by using organic matter. Organic fertilizer serves as a substitute nutrient source derived from inorganic fertilizers and improves soil’s physical, chemical, and biological properties. One of the sources of organic matter that is widely available around farmers is
cow manure compost. The use of cow manure compost can improve the physical fertility of the soil, increase macro and micronutrients, and the activity of soil microbes. Organic matter in cow manure compost can increase the effectiveness of nitrogen fertilization due to the binding of nitrogen elements released from fertilizer so that it is not easily washed. The addition of organic fertilizer in ginger cultivation can increase the growth and yield of plants [3].

Ginger is a commodity that is widely grown along with other crops, such as maize and cassava. Maize and cassava are the most important food crops in the world. Maize shades ginger to reduce evaporation, air temperature, and soil temperature [4]. Cassava is widely grown as a reserve plant if maize crops or other crops fail to be harvested. Mixed crops have the advantages of maximizing land use, reducing costs, and reducing the risk of loss. Mixed crops can reduce evaporation and soil erosion, also increase groundwater content.

2. Materials and method
A field experiment was carried out from March to August 2020 in Wonorejo Village, Jatiyoso District, Karanganyar Regency, Central Java Province, Indonesia. Materials used were ZA fertilizer, cow manure compost, rope, and plant materials, ginger aged four months old, maize aged four months old, and cassava aged five months old. Tools used included lux meter, thermohygrometer, soil thermometer, digital scales, ruler, and scissors. Laboratory analysis was carried out at the Ecology and Management of Plant Production Laboratory and the Chemical and Soil Fertility Laboratory of the Faculty of Agriculture, Sebelas Maret University. The experiment was designed according to Randomized Complete Block Design (RCBD) with one factor and replicated six times. The required number of tiles is 24 tiles. Each tile size is 1.5 m x 2 m. The factor was fertilizers prepared with different doses, consisting of T0: Control, T1: 100% ZA fertilizer (90 g. tile\(^{-1}\) or 0.3 ton. ha\(^{-1}\)), T2: 50% ZA fertilizer (45 g. tile\(^{-1}\) or 0.15 ton. ha\(^{-1}\) ) + 50% organic fertilizer (598 g. tile\(^{-1}\) or 1.99 ton. ha\(^{-1}\)), and T4: 100% organic fertilizer (1196 g. tile\(^{-1}\) or 3.98 ton. ha\(^{-1}\)). Environmental observation including soil temperature, air temperature, relative humidity, and light intensity. Variables observed included plant height, number of leaves, number of tillers, fresh straw weight, dry straw weight, fresh rhizomes weight, stored rhizomes weight, rhizomes size, dry weight of maize kernels, dry weight of cassava tubers, LER, ATER, and analysis of net income. Data from observations were analyzed using analysis of variance, if there were real significant differences followed by Duncan Multiple Range Test (DMRT) 5%.

3. Results and discussion
3.1. General condition of land

| Variable            | Value    | Explanation     |
|---------------------|----------|-----------------|
| N total             | 0.21 %   | Medium          |
| P total             | 0.02%    | Low             |
| K total             | 0.06%    | Low             |
| C-organic           | 1.80 ppm | Low             |
| C/N ratio           | 8.57     | Low             |
| Porosity            | 55.45%   | Good            |
| pH                  | 6.14     | Slightly Acidic |
| Water capacity      | 7.12%    | Low             |
| Particle density    | 2.11 g/cm\(^3\) | -         |
| Bulk density        | 1.17 g/cm\(^3\) | -         |
| Soil organic matter | 3.10%    | Low             |

Description: Result of analysis from soil chemistry laboratory, Faculty of Agriculture, Sebelas Maret University, Surakarta 2020. Basis of scaling according to BALITTANAH 2009.
3.1.1. **Soil condition.** The type of soil at the research site is Latosol. Ginger needs fertile soil to get optimal results. However, the soil content of nutrients and organic matter shows a low value (Table 1), so fertilization is required.

3.1.2. **Environmental conditions.** The research site is located 776 meters above sea level. During the research period, the measurement of air temperature and soil temperature had an average of 30.52°C and 28.06°C with a relative humidity of 71.30%. This corresponds to the optimal temperature for ginger, which is 25°C-30°C [5] with a relative humidity of 60%-90% [6]. The average intensity of light outside the tile is 97,602 lux and inside the tile is 75,676 lux, so the light intensity is 79.61%. Ginger grows well at light intensity 70% - 100% [7].

3.2. **Red ginger’s growth**

| Variable                | T0     | T1     | T2     | T3     |
|-------------------------|--------|--------|--------|--------|
| Plant height (cm)       | 64.37 a| 81.70 b| 69.66 ab| 83.16 b|
| Number of leaves        | 81.16 a| 106.66 ab| 121.00 b| 130.83 b|
| Number of tillers       | 3.33 a | 6.08 ab | 7.16 ab | 8.08 b |
| Fresh straw weight (g)  | 17.53 a| 19.43 a| 29.59 ab| 35.74 b|
| Dry straw weight (g)    | 6.40 a | 10.81 ab| 13.01 b | 15.08 b|

**Description:** The numbers in the line followed by the same letter show no real difference in the DMRT level of 5%

3.2.1. **Plant height.** The increase in plant height occurs during the process of cell division. Plant height increases with a dose of 100% ZA fertilizer and 100% organic fertilizer (Table 2). However, plant height does not differ significantly with a dose of 100% ZA fertilizer and 100% organic fertilizer. Organic fertilizer and ZA fertilizer can increase the nutrients available in the soil, especially nitrogen, which is the main element for vegetative growth. Sufficient amounts of nitrogen will facilitate cell division and stimulate the stems, thus spurring the high growth of plants. Aside from the availability of nutrients, environmental conditions also influence plant height. Ginger is widely cultivated along with other plants because it has good tolerance to shade. The presence of shade can accelerate cell lengthening due to the auxin hormone. Auxin is a plant hormone that acts as a growth stimulant and causes an elongation of the cells at the side that is shielded from the light [8], which stimulates faster cell elongation on the dark side compared to the bright side.

3.2.2. **Number of leaves.** The leaves are the main organs of photosynthesis. Application of 50% ZA fertilizer + 50% organic fertilizer and 100% organic fertilizer in soil media increased the number of leaves of red ginger significantly compared with control plants that were not added with fertilizer (Table 2). Even though there was no significant difference in the number of leaves between the plants supplied with 50% ZA fertilizer + 50% organic fertilizer and 100% organic fertilizer. Sufficient amounts of nutrients cause this, so it is translocated for leaves growth. The increase in the number of leaves is associated with cell lengthening activity that stimulates the formation of leaves. N, P, K play an essential role in plant growth and development [9]. Nitrogen helps the cell division process so that the young leaves reach the perfect shape faster [10]. Phosphorus is required to form sugar phosphates, which plants need during the photosynthesis process. Potassium regulates the opening and closing of stomata. Sulfur in ZA fertilizer is an essential amino acid component associated with nitrogen in metabolism [11], an element in forming proteins, and activates many enzymes.

3.2.3. **Number of tillers.** The number of tillers was influenced by applying 100% organic fertilizer in soil media (Table 2). Organic fertilizer provides macro and micronutrients and improves soil's physical, chemical, and biological. Macronutrients are constituents of proteins, nucleic acids, and chlorophyll. Meanwhile, micronutrients are catalysts for protein synthesis and chlorophyll formation. Organic
fertilizer contains organic matter that can increase the activity of soil microbes in decomposition so that plants can absorb nutrients. The result of photosynthesis is used to grow and develop organs [12].

3.2.4. Fresh straw weight. The fresh straw weight is the result of photosynthate and water contained in the plant. From table 2, it can be seen that the fresh weight of plants was affected strongly by the dose of 100% organic fertilizer. The use of organic fertilizer provides enough nutrients for photosynthesis to produce more carbohydrates and proteins. Carbohydrates will be translocated to the tillers, leaves, and roots of red ginger to increase the fresh straw weight. Organic matter binds soil particles into aggregates, improves water holding capacity, and minimizes erosion [13]. Mixed crops are also one of the environmental factors that affect the growth of red ginger. Plant diversity in mixed crops can increase the abundance and activity of soil microbes that facilitate nutrient absorption [14].

3.2.5. Dry straw weight. The dry straw weight responds significantly to 50% ZA fertilizers + 50% organic fertilizer and 100% organic fertilizer (Table 2). However, there were no significant differences in dry straw weight between the plants supplied with 50% ZA fertilizer + 50% organic fertilizer and 100% organic fertilizer in soil media. ZA and organic fertilizer contain nitrogen. The most important role of nitrogen in the plant is its presence in the structure of protein and nucleic acids, which are the most important building and information substances of every cell [15], so they can influence the growth of plants. Organic matter reduces soil bulk density and improves soil structure, aeration, and cation exchange capacity [16]. Organic fertilizer given in the soil will increase the activity of soil microbes that is useful in the decomposition of organic matter to absorb nutrients more optimally [17].

3.3. Yield of red ginger

Table 3. Effects of ZA substitution with organic fertilizer on yield of red ginger parameters

| Variable                      | T0        | T1        | T2        | T3        |
|-------------------------------|-----------|-----------|-----------|-----------|
| Fresh rhizomes weight (g)     | 271.50 a  | 319.53 a  | 337.63 a  | 363.53 a  |
| Stored rhizomes weight (g)    | 243.90 a  | 292.91 ab | 309.23 ab | 337.89 b  |
| **Rhizomes size**             |           |           |           |           |
| a) Length of rhizomes (cm)    | 10.45 a   | 11.79 a   | 12.50 a   | 12.62 a   |
| b) Width of rhizomes (cm)     | 4.20 a    | 4.25 a    | 4.91 a    | 5.33 a    |
| c) Height of rhizomes (cm)    | 1.87 a    | 1.95 a    | 2.16 a    | 2.29 a    |

Description: The numbers in the line followed by the same letter show no real difference in the DMRT level of 5%

3.3.1. Fresh rhizomes weight. All treatments do not significantly affect the fresh rhizomes weight (Table 3). This is due to the lack of nutrients when ginger enters the rhizome enlargement phase. Ginger plants need potassium elements in the process of forming rhizomes [18]. Availability of potassium nutrients in the soil indicates low availability of potassium. Potassium is used to carbohydrate metabolism, regulate the water content, and activate enzymes to increase the translocation of carbohydrates to the rhizomes of red ginger [19].

3.3.2. Stored rhizomes weight. From table 3, it can be seen that a dosage of 100% organic fertilizer significantly affects the stored rhizomes weight. The application of organic fertilizer can reduce the need for chemical fertilizer and decrease environmental effects. Organic fertilizer contains nitrogen, which is an adequate supply of nitrogen necessary to increase the yield of crops. Nitrogen is a constituent of proteins and enzymes, which have an impact to increase a plant’s growth and yield [20]. Organic matter facilitates nutrient absorption so that rhizomes can develop optimally.

3.3.3. Rhizomes size. From table 3, it can be seen that all treatments showed no significant difference in the rhizomes size namely length of rhizomes, width of rhizomes, and height of rhizomes. This is due to environmental conditions that are external factors and varieties that are internal factors. Ginger plants need a lot of balanced nutrition when entering rhizomes enlarged phase [21]. Lack of nutrients causes
the size of the rhizomes in red ginger not to enlarge. Red ginger has a smaller rhizome size than the other two varieties, namely large white ginger and small white ginger [22].

3.4. Yield of maize and cassava

Table 4. Effects of ZA substitution with organic fertilizer on yield of maize and cassava parameters

| Variable                      | T0       | T1       | T2       | T3       |
|-------------------------------|----------|----------|----------|----------|
| Dry weight of maize kernels (g)| 803.83 a | 828.60 a | 897 ab   | 930.83 b |
| Dry weight of cassava tubers (g)| 1930 a   | 2252 ab  | 2471 b   | 2930 b   |

Description: The numbers in the line followed by the same letter show no real difference in the DMRT test level of 5%

3.4.1. Dry weight of maize kernels. The highest dry weight of maize kernels was obtained from the dose of 100% organic fertilizer (Table 4). Organic fertilizer has a macronutrient content that maize needs, especially nitrogen and phosphorus. Nitrogen and phosphorus are very essential in maize production [23]. Nitrogen improves the process of carbohydrate metabolism, then the results are translocated for the formation of maize kernels [24]. Phosphorus is essential to develop maize kernels [25] in the process of formation and ripening. Sufficient nutrients will produce many photosynthates to be translocated to all parts of the plant. The more photosynthates allocated to the cobs, the more it is transferred to the kernel, thus increasing the weight of the maize kernels.

3.4.2. Dry weight of cassava tubers. Based on table 4, a dose of 50% ZA fertilizer + 50% organic fertilizer and 100% organic fertilizer significantly affected the dry weight of cassava tubers. The dose of 50% ZA fertilizer + 50% organic fertilizer and 100% organic fertilizer does not significantly differ in cassava tubers' dry weight. The availability of sufficient nutrients, especially potassium from organic fertilizers, supports the formation of tubers in cassava. Cassava requires enough potassium nutrients to form tubers and increases the weight of tubers [26]. Potassium is involved in the metabolic process of plants, and the transport of photosynthesis results from leaves to roots for the formation and enlargement of cassava tubers.

3.5. Analysis of yield on mixed crops and monoculture

Table 5. Analysis of yield on mixed crops and monoculture

| Variable                                   | T0       | T1       | T2       | T3       |
|--------------------------------------------|----------|----------|----------|----------|
| LER                                        | 1.03     | 1.05     | 1.19     | 1.25     |
| ATER                                       | 0.80     | 0.82     | 0.93     | 0.99     |
| Analysis of net income in mixed crops of red ginger, maize, and cassava (IDR) | 25,164,000 | 31,233,000 | 33,825,000 | 40,144,000 |
| Analysis of net income in red ginger’s monoculture (IDR) | 38,320,000 | 73,165,000 | 69,300,000 | 100,890,000 |

Description: The numbers in the line followed by the same letter show no real difference in the DMRT test level of 5%

3.5.1. LER. LER (Land Equivalent Ratio) compares the results of two or more plants grown together by comparing the yields of each monoculture-grown plant [27]. LER describes an area required for total monoculture production equivalent to one hectare of mixed crop yield. Mixed crops are generally more profitable than monocultures because land productivity is high, and the risk of failure can be reduced. The calculation result of LER shows that all treatments have a value of LER of more than 1.00 (Table 5). This indicates that mixed red ginger, maize, and cassava crops can increase land productivity more efficiently than monoculture systems. The value of LER in the dose of 100% organic fertilizer is 1.25, which means to get the same production with 1 hectare of mixed crops requires 1.25 hectares of plant monoculture.
3.5.2. **ATER.** ATER (Area Time Equivalent Ratio) is the value of land equality based on time. The profit per unit of land is influenced by planting time and harvest time. The longer a type of plant is in the land, the profit from the time side is getting smaller [28]. ATER values of more than 1 indicate that mixed crops are efficient in land time utilization, but values less than 1 indicate that mixed crops are not efficient in land time use. The ATER calculation result indicates that all treatments have an ATER value of less than 1.00 (Table 5). ATER values of less than 1 indicate that mixed crops take longer to obtain the same results as monoculture crops, meaning mixed crops do not increase land time utilization.

3.5.3. **Analysis of net income.** Analysis of farmers' net income from mixed crops and monocultures is calculated by reducing gross profit with costs in the cultivation process to obtain net income. The results obtained on mixed crops compared to the results obtained in the monoculture of red ginger in an area of 1 hectare (10,000 m²). Mixed red ginger, maize, and cassava crops are more profitable than red ginger's monoculture in fulfilling food needs. This is because farmers need maize and cassava as food commodities. In Indonesia, maize is the second staple food after rice [29], and cassava is the third staple food after rice and maize [30]. Economically, red ginger monoculture is more profitable because it produces higher profits than mixed crops (Table 5).

4. **Conclusion**
The dose of organic fertilizer 100%, namely 3.98 tons ha⁻¹, increases the growth and yield of red ginger in the form of plant height, number of leaves, number of tillers, fresh straw weight, dry straw weight, and stored rhizomes weight on red ginger with a mixture of maize and cassava. The results of LER analysis more than 1 showed that the mixed crops of red ginger, maize, and cassava could improve land-use efficiency. The results of ATER analysis less than 1 showed that mixed crops are not efficient for land time utilization. Analysis of net income shows that a mixed crop of red ginger, maize, and cassava is more profitable in fulfilling food needs, but economically more profitable is the monoculture of red ginger.

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