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Micronutrient Biofortification with Fe, Zn and Cu for Enhanced Growth, Increased Yield and High Profitability of Purple Yam

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ABSTRACT

The importance of micronutrient biofortification in improving the growth and yield of crops is needed nowadays due to the rapid decline in crop yield caused by soil infertility and the prevalence of malnutrition among young children. Micronutrients (Fe, Zn, and Cu) were added to NPK fertilizers to investigate their effects on the growth and yield of purple yam tubers and assess the profitability of their addition on yam production. The different treatments used in the study were: T_1 = control; T_2 = 150-50-150 kg/ha (N-P_2O_5- K_2O); T_3 = T_2 + 8 kg/ha Zn; T_4 = T_2 + 8 kg/ha Fe; and T_5 = T_2 + 8 kg/ha Cu. The results showed that the addition of micronutrients such as Fe, Zn, and Cu to NPK fertilizers statistically increased the growth and yield of purple yam. The addition of 8 kg/ha Fe and Cu to 150-50-150 kg/ha N-P_2O_5-K_2O increased the size of tubers and the intensity of purple coloration. These treatments likewise produced high yields equivalent to 29.39 to 29.83 tons/ha. This was about 129 to 133 percent higher than the control group which yielded only 12.80 tons/ha. Moreover, treatment T_5 which is a combination of 150-50-150 kg/ha N-P_2O_5-K_2O + 8 kg/ha Fe, has produced the highest net income of PhP1,420,704.00/ha. This was 155% higher than the net income obtained by the control group that only amounted to PhP 557,790.00.

Keywords: micronutrient biofortification, purple yam, growth, yield, profitability

INTRODUCTION

Today's rapid population growth has led to a greater demand for food for human survival. Yet, even a sufficient food supply cannot guarantee the full nutrient content that the body requires. This lead to the occurrence of malnutrition among different groups of people in the world. Worldwide, over 2 billion people suffer from extreme micronutrient deficiencies involving iron (Fe), zinc (Zn) and other multiple micronutrient deficiencies. This problem is greatly aggravated in Africa especially among the low and middle income families, where the estimated micronutrient deficiencies is high (Joy et al., 2014). In Asia, for instance, malnutrition affects11% of its population, particularly the rural poor who has limited access even to basic

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needs (FAO et al 2020). In the Philippines, the population has significantly increased to over 100 million in 2015 (PSA 2018). This could affect a considerable number of people, especially children, who will experience hunger and malnutrition. With the application of developed technologies and strategies, current problems on malnutrition could be alleviated.

One of these technologies is biofortification. Biofortification increases the content and availability of essential vitamins and minerals in staple crops through plant breeding or agronomic practices to improve their nutritional status (Finkelsen et al 2017).Thus, is it essential to counter the problems of malnutrition or hidden hunger, especially in developing countries (Garcia-Casal et al 2016; White and Broadley 2005). Hidden hunger is a form of micronutrient deficiency that occurs when the intake and absorption of essential nutrients such as zinc, iron, and iodine are too low to sustain proper health and development. The deficiency of important micronutrients such as iron and zinc are the major cause of extensive problems in developing countries (Manwaring, Bligh and Yadav 2016). Although a higher proportion of the burden of hidden hunger is prevalent in the developing world, iron deficiency is also widespread in developed countries (FAO, IFAD, and WFD 2013). The application of mineral micronutrient fertilizers to soils or plant leaves is crucial to increase the micronutrient content in edible parts of crops. This can, potentially fight hidden hunger. Agronomic biofortification can increase yields and the nutrient content of staple crops. Aside from the beneficial effects of micronutrient biofortification in improving the nutritional contents of crops, it was also reported to enhance crop yields. Agronomic zinc biofortification increased grain yield in wheat, wherein highest grain yield of 5.41 t/ha was obtained with the application of 5.00 kg/ha Zn (Akram et al 2020). Application of iron sulphate ($FeSO_4$) and zinc sulphate ($ZnSO_4$) singly or in combination either through soil or as foliar sprays increased the heights of plants, number of tillers, spike length, thousand grain yield, economic yield, biological yield, and harvest index of wheat (Ramzan et al 2020). In addition Malakouti (2008) reported that the addition of Zn and Fe increased the average yield of canola by 29 % for Zn biofortication and 28% for Fe biofortification. Likewise, the addition of Fe and Zn to NPK fertilizers increased the average yield of potato by 16% and sugar beet by 8%.

Micronutrient fertilization is most effective in combination with macronutrient fertilizers containing nitrogen (N), phosphorus (P) and potassium (K), some organic fertilizers, and high yielding crop varieties. Agronomic biofortification provides a direct and effective route to improve micronutrient concentrations in root crops and other edible crops. Root crops are among the most adaptable crops grown in the Philippines because they can grow in a wide variety of soils. Root crops are primarily grown for their edible underground parts or tubers which provide energy and essential nutrients needed by the body. They are also good sources of dietary fibers, vitamins, and minerals that the body needs to improve the immune system and prevent various diseases. One of the nutritious root crops is purple yam. It is rich in carbohydrates and dietary fibers. It is also a good source of vitamins B3 (niacin), B9 (folate), and the antioxidant purple pigment anthocyanin. Thus, this is a highly nutritious crop that could be used for the production of healthy food products.

Purple yam is one of the most expensive and highly demanded tubers and rootcrops in the food processing industry because of its purple color and medicinal properties, being rich in anthocyanin and antioxidants (Tulin 2014). However, farmers' yield of yam is generally very low. Aside from this, the source of planting materials is also the harvested tubers. This practice discourages most farmers to venture into yam production. Thus, innovations that will boost yam production and maintain its deep purple coloration are needed to make it more profitable and sustainable (Tulin 2007, 2008, and 2009). One such innovation is the macro and micronutrient biofortification of the soil.

However, in developing countries like the Philippines, the use of micronutrients in rootcrops and field crops is not common. The adoption of this technology is slow even though results show that this increases crop yield (Phillips 2002). This is primarily due to the lack of awareness of the problem at the field level, high cost of soils and plant tissue analyses, among others. Furthermore, there is a scarcity of information on the use of micronutrients in yam in the country. This research focused on the three most essential micronutrients: Fe, Zn, and Cu, and its effects on the growth and yield of purple yam, as well as the profitability of their addition in purple yam production.

MATERIALS AND METHODS

Experimental Layout

The field experiment was set-up using RCBD at the PhilRootcrops Experimental Areas in Barangay Pangasugan, Baybay, Leyte, with five treatments replicated four times for one cropping season from May 2017 to February 2018.The different treatments were as follows:

$T_{1=}$ control
T_2 = 150-50-150 kg/ha (N-P_2O_5- K_2O)
T_3 = T2 + 8 kg/ha Zn
T_4 = T2 + 8 kg/ha Fe
T_5 = T2 + 8 kg/ha Cu

Planting and Pre-treatments of tuber setts

The planting materials used were 100 grams of VSU-2 purple yam tuber setts, characterized by their deep purple color. Before planting, these were coated with ash and treated with Dithane fungicide to prevent the occurrence of anthracnose disease in the tubers. The tuber setts were planted at 10cm deep in the soil.

Fertilizer Application

Two weeks after planting, yam tuber setts started to sprout. This is when different levels of fertilizers were applied to represent varying levels of macro and micronutrient fertilizers as specified in the treatments. The sources of fertilizers for macronutrients included the following: complete fertilizer (14-14-14), muriate of potash (60% K_2O), and urea (45% N). Micronutrient sources for Fe, Zn, and Cu included commercially available $FeSO_4$, $ZnSO_4$ and $CuSO_4$. The fertilizers were applied by boring four holes around the sprouted yam tuber setts.

Care and maintenance of the yam plants

The recommended cultural management such as watering, weeding, and pesticide application was applied when necessary during the growing period of yam in the field. The yams were allowed to grow in the area for nine months before harvesting. Purple yams were planted in May 2017 and harvested in February 2018 when all the leaves have already senesced.

Harvesting and Sorting of Purple Yam Tubers

All the plants were harvested nine months after planting. The tubers were dug carefully from the soil using a yam tuber harvester. After that, they were cleaned and weighed.

Data Gathered

The various yield data gathered at harvest included the number and weight of yam tubers collected in a per hill and plot basis. Then tuber weight was expressed in tons/ha values.

RESULTS AND DISCUSSION

Effects of micronutrient biofortification on the growth of purple yam

Figures 1 and 2 show the growth of purple yam in the field as affected by micronutrient biofortification during the early growth of the plant in the area (Figure 1) and at five months after planting (Figure 2). Figure 2 shows the effects of the addition of 8 kg/ha of Zn, Fe, and Cu to 150-50-150 kg/ha N- P_2O_5 – K_2O on the growth of yam compared to the control and the application of NPK fertilizers only. Treatments 4 and 5 added with 8 kg/ha Fe and Cu produced profuse vegetative growth, while the control showed the least vegetative growth. This finding has important implications in the translocation of photosynthates from the leaves to the tubers. Normally, if rootcrops such as yam have profuse vegetative growth, these are expected to produce more tubers compared to yams which have tiny leaves and stunted vegetative growth.

As reported by Phillips (2002), micronutrients usually act as catalysts to many biochemical reactions that facilitate plant growth and survival. Zn is necessary for the production of the growth hormone auxin, which is vital for photosynthesis, and Fe, is crucial in chlorophyll synthesis and formation.

Effects of micronutrient biofortification on the yield of purple yam

Figure 3 shows the effects of the addition of Zn, Cu, and Fe to macronutrient fertilizers on the purple coloration and sizes of purple yam tubers. The pictures show that the addition of micronutrients (T_3, T_4, and T_5) resulted in darker purple coloration and bigger tubers compared to the control and those applied with NPK fertilizers only. From the results, it was evident that the addition of micronutrients enhanced the purple coloration of purple yam by increasing the anthocyanin content usually associated with dark-colored pigments. As reported by Tulin (2009),the darker the purple coloration in yam, the greater its demand in the market. Pure purple yam also has high anthocyanin and micronutrient content, which makes it a healthy food product. These results were further supported by the yield data presented in Table 1. The table shows the statistically higher yield produced in the treatments added with macro and micronutrient fertilizers compared to the control. Treatments 4 and 5 added with 8 kg/ha Cu and Fe, respectively, have produced high yields equivalent to about 29.39 to 29.83 tons/ha, respectively. This increase in tuber yield was about 129 to133%higher than the control group which yielded only 12.80 tons/ha.

Figure 1. Purple yam field experiment as affected by micronutrient biofortification

Legend: T_1 – control; T_2 – 150-50-150 N-P_2O_5-K_2O; T_3 –T_2 + 8 kg Zn; T_4 – T_2 + 8 kg Fe and T_5 – T_2 + 8 kg/ha Cu

Figure 2. Purple yam field experiment at five months after planting

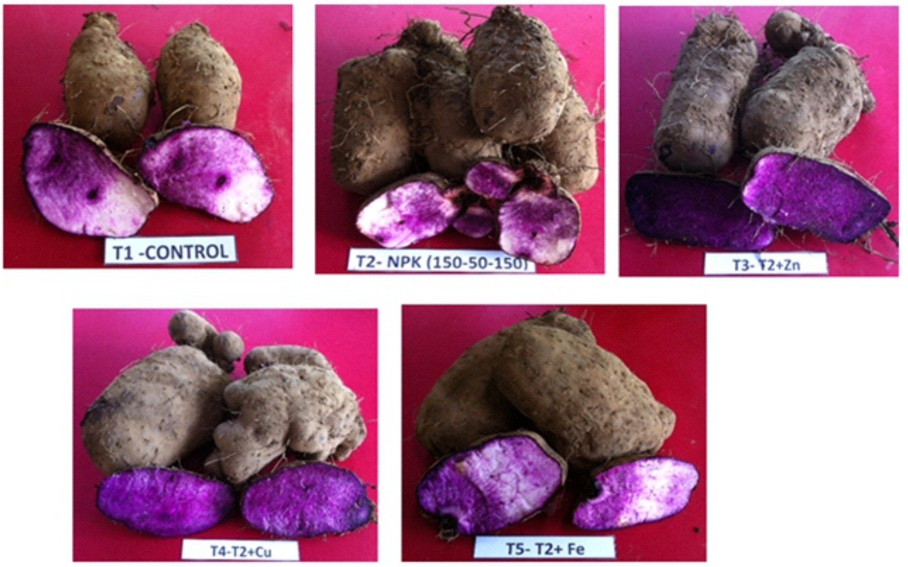

Figure 3. Harvested purple yam tubers as affected by micronutrient biofortification

These results further signify the vital contribution of micronutrient biofortification to the yield of yam tubers. Micronutrients such as Cu, Mn, Zn, and B are mainly involved in the reproductive phase of plant growth and development (Kirkby and Roemheld 2004). Malakouti and Tehrani (2005) and Malakouti (2007) reported that the addition of micronutrient fertilizers to micronutrient deficient soils is associated with improved yield and crop quality for cereals, corn, beans, forages, and oilseeds. Micronutrients also improve the efficiency of the use of macronutrient fertilizers (Kirkby and Roemheld 2004). These findings will significantly boost the production of purple yam to meet the demand for the crop both as a significant source of food and raw material for processing yam in the food industry. Aside from the increase in yield, Tulin (2009) reported that the addition of micronutrient soil conditioner such as Biozome-200 to 150-50-150 kg/ha N- P_2O_5-K_20 increases the amounts of total N, total K, total P, Fe, Mn, Zn, and Cu in the plant tissues, thus improving the nutrient content of purple yam.

Table 1. Number and weight of purple yam tubers as affected by different treatments

Treatments	No. of Tubers	Tuber weight (g /plot)	Tuber weight (ton/ha)
T_1– Control	61.2 a	25600 b	12.80 b
T_2 -150-50-150 kg N-P_2O_5 – K_2O/ha	64.2 a	52125 a	26.06 a
T_3 – T_2+ 8 kg Zn/ha	69.0 a	54125 a	27.06 a
T_4 – T_2 + 8 kg Cu/ha	66.8 a	58788 a	29.39 a
T_5 – T_2+ 8 kg Fe/ha	62.8 a	59650 a	29.83 a

Means within a column with similar letters are not significantly different at α=0.05 of Tukey's Honest Significant Difference (n=4)

Effects of micronutrient biofortification on the profitability of purple yam production

One of the crucial components of this study was the profitability of yam production using micronutrient biofortification. This is to encourage farmers, not only to grow this crop, but also to apply agronomic biofortification as well. The profitability of micronutrient biofortification on yam production was determined using cost and return analysis. The net income was computed after deducting the total cost of production from the gross income. The gross income was calculated based on the yield obtained in tons/ha multiplied by the prevailing purple yam market price, which was PhP60.00/kilo at the time of the study. The total cost of production included both variable and fixed costs. These included the cost of fertilizers, planting materials, labor, bamboo poles, land rental, and depreciation of tools and structures. Table 2 presents the results of the cost and return analysis.

Table2. Total tuber yield, gross income, the total cost of production, and net income as affected by micronutrient biofortification

Treatments	Total Yield (tons/ha)	Gross Income* (Pesos)/ha	Total Cost of Production (Pesos)/ha	Net Income (Pesos)/ha
T_1–control	12.80 b	768,000.00	210,210.00	557,790.00
T_2 -150-50-150 kg N- P_2O_5 –K_2O/ha	26.06 a	1,563,600.00	231,786.00	1,331,814.00
T_3–T_2+ 8 kg Zn/ha	27.06 a	1,623,600.00	351,398.00	1,272,202.00
T_4- T_2 + 8 kg Cu/ha	29.39 a	1,763,400.00	357,088.00	1,406,312.00
T_5–T_2+ 8 kg Fe/ha	29.83 a	1,789,800.00	369,096.00	1,420,704.00

**Computed using the prevailing purple yam price of PhP60.00/kilo*

Table 2 shows that the highest net income of PhP 1,420,704.00/ha was fromT_5, which was a combination of 150-50-150 kg/ha N-P_2O_5-K_2O + 8 kg/ha Fe. This was155% higher than the net income obtained from the control, which only amounted toPhP557,790.00. The second highest net income(PhP 1,406,312.00/ha) was fromT_4, which was a combination of 150-50-150 kg/ha N-P_2O_5-K_2O + 8 kg/ha Cu. This was 152% higher than the control group. Based on the cost and return analysis, yam production with macro and micronutrient biofortification was highly profitable. Tulin (2014), in her earlier studies on purple yam, reported that in terms of profitability, the application of higher levels of macronutrient and micronutrient fertilizers significantly improved the growth and yield of purple yam, and enhanced its profitability, making it an excellent and viable crop for agricultural production and development.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

In terms of plant growth, T_4(8kg/ha Fe added to 150-50-150 kg/ha N-P_2O_5-K_2O) and T_5, (8 kg/ha Cu added to 150-50-150 kg/ha N- P_2O_5-K_2O) produced profuse vegetative growth and much bigger leaves. Treatment 5 produced the highest yield, which was equivalent to about 29.83 tons/ha. Treatment 4 produced the second highest yield, which was equivalent to about 29. 39 tons/ha. These were 133 and 129 percent higher than the control, which yielded only 12.80 tons/ha.Moreover, T_5 produced the highest net income of PhP1, 420,704.00/ha, which was about 155% higher than the net income obtained from the control, which amounted to PhP557,790.00/ha only. Treatment 4 (T_4)generated the second-highest net income of PhP1, 406,312.00/ha,which was 152% higher than the control.

Recommendations

To further verify the technologies tested in this study, it is highly recommended to replicate the study on-farm with farmers' participation and on a commercial-scale in various yam-producing areas in the country such as Leyte, Bohol, Misamis Oriental, and La Union. Likewise, other important properties of purple yam, such as antioxidant properties, anthocyanin content, and its resistance to pest and diseases as affected by macro and micronutrients biofortification, should be determined in future researches.

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