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Maize Response to Chemical and Microbial Products on Two Tanzanian Soils

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Abstract

Low soil fertility has been a major factor to low maize yields in smallholder farms in sub-Saharan Africa. Technologies have been proposed including inorganic, fertilizers and plant growth promoting microorganisms. A study was conducted under greenhouse and field conditions to evaluate the effects of liquid inorganic fertilizer and microbiological products on growth, nutrient uptake and yield of maize. Products evaluated were Teprosyn (nitrogen, zinc phosphorus), BioSoil Crop Booster (BSCB) (*Pseudomonas fluorescens*), and Bio Soil Nitro plus (BSN^+) (*Acetobacter* sp.). Treatments were: products alone (low and high rate), product + half rate phosphorus (10 kg P ha^{-1}), half rate P, full rate P (20 kg P ha^{-1}) and Control. All products were analysed for quality. None of the products met the label claims in nutrient/organism concentration. An increase of biomass was observed in the greenhouse for half rate P + BSCB low rate and high rates for BSCB and BSN^+ compared to Control. Half rate P + BSN^+ low rate gave the highest grain yield which was similar full rate nitrogen and P. BSCB and BSN^+ at low rates with P half rate resulted in an increase in biomass yield in the greenhouse. Efficacy of low rate BSN^+ + half rate P was demonstrated when applied at the recommended rates and combined with half rates of N and P. A package of inorganic and Bio-fertilizers should be developed based on soil fertility status, and the quality of the inputs verified to ensure that they are conform to the label guarantee analysis.

Keywords: phosphate solubilization, nitrogen fixation, liquid fertilizer, quality control, efficacy testing

1. Introduction

The most important constraint to high crop yields in developing countries, and especially among resource-poor farmers, is low soil fertility status (Mohamadi & Sohrabi, 2012). To sustainably produce enough food on dwindling land sizes requires a combination of approaches for example revised fertilizer formulation, better plant nutrition management, combination of organic and inorganic resources and improvement of agronomic practices at farm scale level. These must be geared towards sustainability both socially and environmentally to keep agriculture as a viable enterprise. Enhanced and sustainable soil fertility can be attained, among other things, through cultivation of crops capable of biological nitrogen fixation (BNF) and use of chemical and microbiological products (Gothwal et al., 2007; Woomer, 2012).

Microbiological products are composed of living microorganisms such as nitrogen (N) fixers, potassium (K) solubilizers and phosphorus (P) solubilizers, and molds or fungi which, when applied to seed or soil, colonize the rhizosphere and promote growth by converting nutritionally important elements (*e.g.* N and P) from unavailable to available forms through biological processes such as nitrogen fixation or solubilization of insoluble phosphates (Rokhzadi et al., 2008). Microbiological products are cost-effective inputs for farmers (Hameeda et al., 2006), and have been used to increase crop yields in several countries. For example, in Cuba, several microbiological products composed of strains of *Azotobacter*, *Rhizobium*, *Azopirillum* or *Burkhoderia* are commercially produced and used in the cultivation of different crops. These microbiological products have proved to increase root and shoot elongation as well as yields of rice, beans, wheat, maize and sorghum (Ahmed, 2010). Phosphate solubilizing micro-organisms (PSM) (Khan et al., 2007) have been found to associate with the roots of plants, thus playing an important role in increasing P-availability to plants and thereby increasing the growth and crop yields (Kamlesh et al., 2010). Phosphate solubilizing microorganisms include bacteria of the genera *Pseudomonas*, *Bacillus* and *Enterobacter*, along with fungi like *Penicillium* and *Aspergillus* (Tilak et al., 2005).

Similarly, N_2-fixing bacteria, mainly members of the genera *Azotobacter* and *Azospirillum,* have been isolated from the rhizospheres of various cereals and tested as bio-fertilizers to increase yields of the cereals and legumes through fixing atmospheric nitrogen (Bakulin et al., 2007; Gupta, 2004). Furthermore, Kaya et al. (2006) reported that treating seeds with commercial chemical products containing micro- and macro-nutrients has proved to improve germination and seedling establishment of wheat, soybean, sunflower and maize. However, based on studies conducted in Ethiopia, Kenya, and Nigeria, Jefwa et al. (2014) demonstrated that the efficacy of most of such products found in the marketplace were not generally granted because of poor quality and even ‘snake oils’. Deficiencies in the regulatory framework in most countries of sub-Saharan Africa may explain the presence of sub-standard agricultural inputs in the marketplace (Masso et al., 2013). Selected microbial products and specialty fertilizers (*e.g.* liquid formulations) introduced in the Tanzanian and most of sub-Saharan Africa markets have not been sufficiently evaluated under local farming conditions of the country. With the recent improvement and enforcement of the regulatory framework by the relevant authorities in Tanzania, using such products calls for quality control to prevent fraud and protect the end-users against economic losses. This study was therefore carried out to evaluate the quality and efficacy of selected commercial products intended for the Tanzanian farmers.

2. Materials and Methods

2.1 Materials

The products used in the study are listed in Table 1 including label claims on mode of action, active ingredient and application rates. The application rates indicated were adopted in the study.

Table 1. A summary of label claims of the products tested

Product	Active ingredient/s	Guarantee analysis	Application rate	Benefits to plants	Manufacturer	Product source
Teprosyn	NP +Zn	4.6 % (W/V) = 146 g L^{-1} N (9% W/W) (9% ureic nitrogen) 24% (W/V) = 243 g L^{-1} P_2O_5 (15% W/W) (4.5% P_2O_5) 29% (W/W) = 291 g L^{-1} Zn (18% W/W)	Maize: 8 or 16 ml kg $^{-1}$ of seed	- Role in plant morphological and physiological growth through early seedling establishment, strong root systems and early development of crop plants	Yara UK Ltd, Pocklington, York	Tanzania Fertilizer Regulatory Authority (TFRA)
Bio-soil Crop booster	*Pseudomonas fluorescens*	CFU count shown on label is 1×10^8/ml (No method shown how this CFU was counted)	Seed treatment: 5-10 ml kg^{-1} of seeds Soil application: 2.5 L ha^{-1} mixed with organic manure Foliar spray: 2.5 L ha^{-1}	- Highly effective on root and stem rot, damping off and bacterial wilts. -Effective against powdery and downy mildew.	Aadicon Biotechnologies Ltd, Mauritius	From Mauritius through TFRA
Bio-soil Nitro+	*Acetobacter* sp.	CFU count shown on label is 1×10^8/ml (No method shown how this CFU was counted)	Seed treatment: 5-10 ml kg^{-1} of seeds NB: Depending on field conditions and type of crop, dose can vary	- Endophytic nitrogen fixing living organism, it plays an important role in germination of plants - Promotes growth by supplying 80% of nitrogen requirements	Aadicon Biotechnologies Ltd, Mauritius	From Mauritius through TFRA

2.1.1 Soil Analysis

A clay soil (characterized as an Acrisol) was obtained for use in a greenhouse experiment which was conducted at the Department of Soil Science, Sokoine University of Agriculture (SUA), Tanzania located at latitude of 06°50′ S and longitude 37°38′ E at an altitude of 525 m above sea level. The bulk surface soil sample was ground to pass through a 2-mm sieve. The physico-chemical properties of the experimental soil were determined by standard procedures for pH, total N, extractable P, organic carbon, calcium, magnesium potassium, Cation Exchange Capacity, Zn, Copper, Iron and Manganese (Bray & Kurtz, 1945; Bremner & Mulvaney, 1982; Chapman, 1965; McLean, 1986; Nelson & Sommers, 1982; Lindsay & Norvell, 1978).

2.1.2 Characterization of Teprosyn

The total nutrient contents (*i.e.* N, P, and Zn based on the label guarantee analysis) in Teprosyn product (a liquid fertilizer) were determined using established laboratory procedures as follows for three batches. Total nitrogen in the Teprosyn product was determined by the micro-Kjedahl digestion-distillation method according to the procedure described by Bremner and Mulvaney (1982). Total P in the Teprosyn product was determined using the method as described by Murphy and Riley (1962). The total Zinc in Teprosyn was determined using the method as described by Lindsay and Norvell (1978).

2.1.3 Microbiological Populations in Products

Products from three different batches were evaluated for the total number of microorganisms in Bio Soil Crop Booster (BSCB) and Bio Soil Nitro plus (BSN^+) was enumerated using the pour plate method in both undiluted and diluted aliquots of the product, using nutrient agar (NA). The average numbers of colonies were used to determine the number of microorganisms (CFU/ml) of BSCB or BSN^+ product. The number of colonies from the three replicate plates was determined and the number of total microorganisms of CFU was calculated using the following Equation 1:

$$\text{Number of CFU/ml} = \text{Number of CFU counted} \times \text{Total dilution/Volume plated (ml)} \quad (1)$$

2.2 Methods

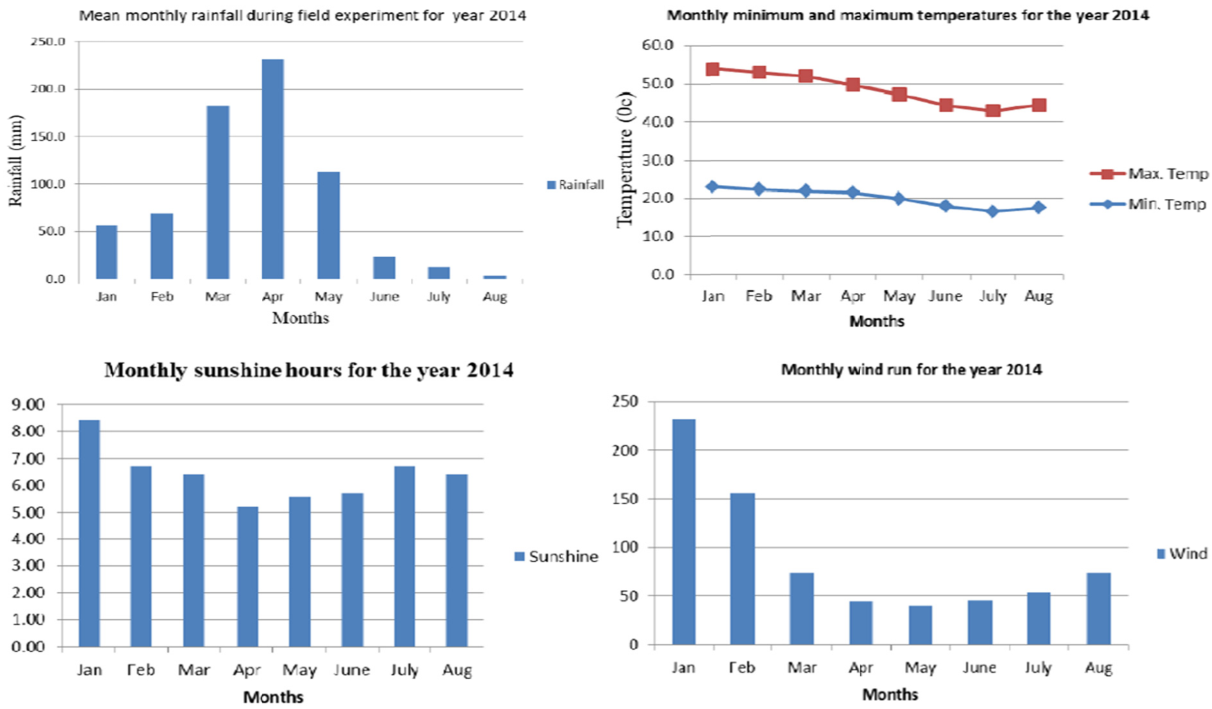
2.2.1 Greenhouse Experiments

The pot experiments were conducted in the greenhouse of the Department of Soil Science, SUA in Morogoro region in February 2014 (before the onset of long rain season). Three kg of the bulk soil sample were placed into 4-L plastic pots, and arranged in a complete randomized design (CRD) with three replications. The treatments were: products (*i.e.* BSCB, BSN^+ and Teprosyn) alone at low rate (10 ml kg^{-1} of seed) and high rate (20 ml kg^{-1} of seed), product + 10 kg P ha^{-1} (half rate P), 10 kg P ha^{-1}, 20 kg P ha^{-1} (full rate P) and absolute Control with no inputs. Potassium di-phosphate (K_2HPO_4) was used as a source of P. The volume of Teprosyn product recommended by the manufacturer for coating 1 kg maize seeds was 8 ml (low rate) or 16 ml (high rate) kg^{-1} of seed and both were used. The seeds were placed in a small plastic bag and Teprosyn was added. The mixture was agitated gently for 1 minute. Subsequently, the treated seeds were placed on a sheet of filter paper and allowed to dry indoors for 30 minutes, before being planted in the pots. The BSCB (contained *Pseudomonas fluorescens*) inoculant was prepared in a plastic bucket by mixing 2.5 ml of the concentrated BSCB with 2 liters of water and 2.5 g of sugar and left for 12 hours. This is equivalent to the manufacturer's instruction to mix 250 ml of product with 200 L water and 250 g sugar. Thereafter, 10 ml of the mixture was used to inoculate one kilogram of maize seeds half an hour before planting. Similarly, the BSN^+ product (containing *Acetobacter*) was prepared by dissolving 2.5 ml of BSN^+ product into 2 L of water. Thereafter, 10 ml of the mixture was used to inoculate one kilogram of maize seeds half an hour before planting.

Three seeds of certified untreated SITUKA maize variety were planted on the potted soils and were thinned to two plants per pot 12 days after planting (DAP). Rates of 0.26 g N from urea ($CO(NH_2)_2$) was applied to potted soils. To satisfy the suggested rates of P (*i.e.* 10 and 20 kg P ha^{-1}) in treatments for evaluating the commercial products, 0.23 g P (10 kg P ha^{-1}) and 0.449g P (20 kg P ha^{-1}) respectively, as K_2HPO_4 were applied. Nitrogen as Urea rate of 60 kg N ha^{-1} was split applied (30 kg N ha^{-1} for each application) at planting time and 21 days after planting (V3 growth stage). All treatments for Teprosyn and the other fertilizers were applied at planting time. The soils in the pots were watered to its field water holding capacity throughout the experimental period. At 35 DAP (V5-V6 growth stage), shoot dry matter was also determined after cutting the shoots of the two plants at 1 cm above the soil surface, drying in an oven at 65 ^oC to constant weight. The dried plant samples were cut into small pieces grounded and passed through a 0.5 mm sieve for analysis to determine the plant uptake of P and Zn.

2.2.2 Field Experiments

A field experiment was conducted in on a clay soil (Acrisol) during the 2013/14 growing season to assess the effects of commercial products on growth and yields of SITUKA maize variety at SUA farm, where the soil used in the pot experiment was collected from SUA farm (before establishment of the field trial). The field was prepared by a tractor followed by harrowing. The products were evaluated using a randomized complete block design (RCBD) with three replications. The experimental unit size was 3 × 3 m and the treatment structure was identical to the one used in the greenhouse. YaraMila cereal fertilizer (23:10:5+3S+2 MgO+0.3Zn) was used as a source of P. Nitrogen was applied at two splits of 30 kg N ha^{-1} for a total of 60 Kg N ha^{-1} for all treatments except treatments with BSN^+ and BSCB (both low and high rates) alone or in combination with P which received at 30 kg N ha^{-1}at planting, and the Control (no N applied). Biomass sampling was done at tasseling stage for the tissue analysis to determine Zn, P and N uptake. Harvesting was done at physiological maturity for determination of grain yield.



Month	Jan	Feb	Mar	Apr	May	June	July	Aug
Rainfall	56.0	69.4	182.7	231.0	113.0	24.0	13.0	4.0
Min. Temp	22.9	22.2	21.8	21.3	19.8	17.8	16.4	17.4
Max. Temp	31.0	30.8	30.1	28.3	27.4	26.6	26.5	27.1
Sunshine	8.40	6.7	6.4	5.20	5.60	5.7	6.7	6.4
Wind	231.8	156.2	73.5	44.1	39.7	44.9	53.6	73.8

Figure 1. Weather data recorded during field experiment at SUA farm

2.3 Statistical Analysis

The collected data were analyzed for variance using the SAS 9.3 computer software. Treatment means were compared using the Tukey Test at $p < 0.05$.

3. Results

3.1 Soil and Commercial Products Analysis

The physical-chemical properties of the experimental soil are presented in Table 2. The soil was classified as clay, while the chemical properties were rated according to Landon (1991), Okalebo, Gathua, and Woomer (2002), and Motsara and Roy (2008). Based on the classification, the levels of target nutrients (N, P and Zn) were low; hence, the soil was suitable for the trial. Total nutrient contents (macro and micronutrients) in Teprosyn, as determined in the present study are found in Table 3. There was 9.32% N which was similar to the expected amount of 9% as specified on the label, however levels of P (%) and Zn (%) were much lower than expected (2.72% and 5.54% respectively) compared to 15% and 18% as indicated on the product label. Hence, when applied at the rates recommended on the product label, the user may not obtain the expected results as the amounts of P and Zn used will be less. Hence, quality control of agricultural inputs in the marketplace is crucial for farmers to obtain the value of their money and expected crop yields. The microbiological populations (CFUs) in BSCB and BSN^+ and in the experimental soil are shown in Table 3. The Laboratory values of CFU determined for each microbiological product were lower than the CFU specified by the manufacturer as quoted in the respective label. This in turn lowers the numbers of effective microorganisms delivered to the seed on inoculation lowering the chance of successful inoculation. However, it's noteworthy that the products contained the indicated organisms without contamination with undeclared micro-organisms. Both the liquid fertilizer and the microbiological products were sub-standard, demonstrating the need for better marketplace monitoring to enforce the quality standards for agricultural inputs and prevent fraud to protect the consumers as well as the credibility of the industry and the regulatory authority. Such issues could explain the low adoption of bio-fertilizers as result of insufficient promotion due the various uncertainties related to their field performance.

Table 2. The Physco-chemical characterization of the soil used

Property, unit	Unit	Value	Fertility level
Sand	%	41.0	
Silt	%	3.0	
Clay	%	56.0	
pH (H_2O)	-	6.33	Medium
Organic carbon	%	1.72	low
Total nitrogen	%	0.14	Low
Bray 1 P	Mg kg^{-1}	1.02	Low
Exchangeable Ca	$Cmol_c$ kg^{-1}	6.35	Medium
Exchangeable Mg	$Cmol_c$ kg^{-1}	3.22	High
Exchangeable Na	$Cmol_c$ kg^{-1}	0.26	Low
Exchangeable K	$Cmol_c$ kg^{-1}	1.10	Medium
CEC	$Cmol_c$ kg^{-1}	23.0	Medium
DTPA extractable Fe	$Cmol_c$ kg^{-1}	38.0	Very high
DTPA extractable Mn	$Cmol_c$ kg^{-1}	67.5	Very high
DTPA extractable Zn	$Cmol_c$ kg^{-1}	0.34	Very low
DTPA extractable Cu	$Cmol_c$ kg^{-1}	2.43	High

Table 3. Characterization of products used in the trials

Product	Parameter/active ingredient	Laboratory results	Manufacturer results
BSCB	*P. fluorescens* (CFU ml^{-1})	1.9×10^4	1.0×10^8
BSN^+	*Acetobacter* sp. (CFU ml^{-1})	1.1×10^2	1.0×10^8
Teprosyn	N (%)	9.32±0.15	9
	P (%)	2.72±0.08	15
	Zn (%)	5.54±0.11	18

3.2 Greenhouse Trial

3.2.1 Nutrient Uptake

There were significant differences in the P uptake ($p < 0.001$) (Table 4). The highest P uptake was obtained in the P (half rate) + BSCB (lower rate) (1.653 g $plant^{-1}$) and P (half rate) + BSN^+ low rate (1.075 g $plant^{-1}$) treatments compared to the untreated Control treatment 0.392 g $plant^{-1}$ and the P alone treatments at the full rate P and the half rate which gave 0.217 g $plant^{-1}$ and 0.399 g $plant^{-1}$ respectively (Table 4). The lowest P uptake was obtained from the three products when applied alone (no external P) when applied at recommended lower rate but when the rates of the products applied at the high rates, the P and Zn uptake more than doubled for both BSN^+ and BSCB but no significant increases were observed for Teprosyn (Table 4).

Zinc showed significant differences in uptake between treatments with P (half rate) + BSCB (lower rate) having the highest amounts (1.192 mg $plant^{-1}$) compared to the untreated Control (0.4 mg $plant^{-1}$) and Teprosyn (high rate) which had 0.252 mg $plant^{-1}$ (Table 4). The three products alone at the lower rates gave significantly low Zn uptake compared to the untreated Control (0.146, 0.171 and 0.217 mg $plant^{-1}$) for Teprosyn, BSCB and BSN^+ respectively.

Table 4. Maize shoot biomass yield and nutrient uptake from greenhouse trial

Treatment	P uptake (mg plant^{-1})	Zn uptake (mg plant^{-1})	Shoot Biomass (g plant^{-1})
Control	0.390	0.400	0.650
P (half rate)	0.40	0.270	0.480
P (full rate)	0.22	0.120	0.260
Teprosyn (low rate)	0.150	0.150	0.270
BSCB (low rate)	0.190	0.170	0.280
BSN+ (low rate)	0.210	0.220	0.320
Teprosyn (high rate)	0.210	0.250	0.350
BSCB (high rate)	0.650	0.590	1.29
BSN+ (high rate)	0.750	0.890	1.480
P (half rate) + Teprosyn (low rate)	0.580	0.290	0.54
P (low rate) + BSCB (low rate)	1.650	1.190	1.710
P (low rate) + BSN$^+$ (low rate)	1.08	0.390	0.700
Mean	0.540	0.410	0690
CV (%) †	41	32	33
SED‡	0.18	0.10	0.18

Note. †Coefficient of Variation in percentage; ‡ Standard error of the difference.

3.2.2 Biomass

Statistical analysis of biomass gave significant differences ($p < 0.001$) between treatments. The highest biomass being obtained from P (half rate) + BSCB (low rate) (1.705 g) which similar BSCB and BSN$^+$ (both at the high rate) (1.285 and 1.483 g) respectively. The products alone at the low rate recommended by the manufacturer generally gave the lowest amount of biomass.

3.3 Field Trial

3.3.1 Nutrient Uptake

There were significant differences in levels of N uptake due to treatments effects ($p < 0.05$) (Table 5). Low N uptake was mainly observed when the products were applied alone (both low and high rates) all giving less than 2 g of N kg^{-1} of biomass which was similar to the Control treatment. When the products were applied at the low rate with half rate P, there was an increase in N uptake and all the products had at more than 2 g of N kg^{-1} of biomass. However the amount of N uptake was similar to that obtained when P was applied without the three commercial products suggesting P was the main driver of N uptake.

Table 5. Maize grain yield and nutrient uptake from field trial

Treatment	N Uptake (g kg^{-1})	P Uptake (g kg^{-1})	Zn Uptake (mg kg^{-1})	Grain Yield (t ha^{-1})
Control	1.859	0.204	0.9	2.210
P (half rate)	2.026	0.209	0.9	2.490
P (full rate)	2.104	0.244	0.9	3.300
Teprosyn (low rate)	1.943	0.207	0.9	2.440
BSCB (low rate)	1.707	0.190	0.7	2.590
BSN+ (low rate)	1.553	0.173	0.9	1.990
Teprosyn (high rate)	2.112	0.260	1.0	2.180
BSCB (high rate)	1.707	0.233	0.7	1.380
BSN+ (high rate)	1.787	0.203	1.1	2.170
P (half rate) + Teprosyn (low rate)	2.065	0.267	1.0	2.260
P (low rate) + BSCB (low rate)	2.090	0.267	0.8	2.280
P (low rate) + BSN$^+$ (low rate)	2.150	0.243	0.9	3.690
Mean	1.930	0.23	0.9	2.41
CV (%)†	8	10	19	9
SED‡	0.12	0.01	0.02	0.19

Note. †Coefficient of Variation in percentage; ‡ Standard error of the difference.

There were significant differences in P uptake due to treatment ($p < 0.05$) (Table 5) with the lowest P uptake being obtain when both Biofertlizers were applied at the lower rate with no P (less than 0.2 g kg^{-1} of biomass). However when combined with P application at the half rate, the P uptake rates increased to 0.243-0.267 g kg^{-1} of biomass suggesting a positive 2 way interaction of P application and the two Biofertlizers which was similar to P full rate. This indicated it may be possible to increase P uptake by use of the Biofertlizers with less P application. Zinc uptake did not give significant differences ($p < 0.05$) due to the treatments applied with the lowest amount of Zn uptake being 0.7 mg kg^{-1} for BSCB alone at both rates and the highest 1.1 mg kg^{-1} BSN^+ (high rate) (Table 5). Hence, it is recommendable to revisit the application rate and mode of placement of Teprosyn (containing Zn) based on further investigation.

3.3.2 Grain Yield

There were significant differences ($p < 0.05$) in grain yields due to treatment effects (Table 5). The highest grain yield was obtained from P (half rate) + BSN^+ (low rate) +30 kg N ha^{-1} and P (full rate) + 60 kg N ha^{-1} with at least 3 t ha^{-1} grain yield. The lowest grain yields were obtained from Biofertilizers with no P application (BSCB (high rate) and BSN^+ (low rate), both yielded less than 2 t ha^{-1} grain). The yields of P (half rate) + BSCB (low rate) and P (half rate) + Teprosyn (low rate) were comparable (2.277 and 2.257 t ha^{-1}) respectively.

4. Discussion

4.1 Quality of Agricultural Inputs Versus Efficacy and Adoption

All the three products tested in this study were sub-standard based on the guarantee analyses on the product labels; hence, they didn't conform to the regulatory requirements. This meant that the rates of application as indicated on the product label did not deliver the desired quantities of the active ingredients per unit amount of seeds. This would have consequently affected the crop performance. There is a strong need to enforce the quality standards through regular marketplace monitoring and education of product proponents and retailers of inputs to ensure that the product quality is maintained across the whole commercialization chain and product stored in good conditions to ensure that the shelf life is not affected by poor storage. Collaborative work between the regulatory authorities and the product proponents would be useful to identify at which level the product quality is deteriorated (*e.g.* sub-standard products at the package time, adulteration once in the marketplace, or poor storage among others). Similar efforts have resulted in better control quality of products in the market and even higher usage of Biofertilizers (Catroux et al., 2001).

Even though the market potential for Biofertilizers is huge in sub-Saharan Africa, the level of adoption remains limited and this is likely due to inappropriate formulations and a poor level of quality control capacity in the region. Similar challenges have been sighted in other parts of the world where market potential for Biofertilizers is high than actual consumption (Herrmann & Lesueur, 2013; Bhattacharyya & Jha, 2012). In addition to market control education of farmers on use and storage of the inoculants is critical. Based on the result of this study combination of bio-fertilizers with reduced rate of inorganic fertilizer may have a comparative advantage. For example, use of P at 10 kg ha^{-1}+ 30 kg N ha^{-1} + BSN^+ gave similar yields to 20 kg P + 60 kg N ha^{-1}; integration of BSN^+, when applied at a correct rate, may therefore have an economic benefit given the low cost of BSN^+ per unit area compared to inorganic N and P fertilizers. Both BSN^+ and BSCB products on their own did not show increase above the Control for any of the parameters tested which could be probably due to the application rate being below expected, the effectiveness of the strains or other limiting nutrients other that N for BSN^+ and P for BSCB.

4.2 Efficacy of Agricultural Inputs Versus Initial Soil Fertility

The tested soil showed low N, P, Zn level as shown by the soil characterization. For specialized microorganisms such as Rhizobia to optimally function, other limiting factors should be well-controlled to maximize the performance of the tested products in terms of nutrient uptake, crop biomass, and yield. Sources of P were added to selected treatments in this study to determine whether additional P could improve the performance of the tested products. Results from the greenhouse trial indicated an increase in biomass production with a combination of P and the *P. flourescens* and *Acetobacter* sp. products at the higher rate. The findings of Peltonen-Sainio, Kontturi, and Peltonen (2006) who evaluated the effect of P seed coating on oat and found that P seed coating enhanced early growth of oats but without increasing yields. However, Karanam and Vadez (2010) reported an increase in shoot biomass of two- and four-week-old seedlings due to P seed coating of pearl millet compared with non-coated seeds and panicle yield increases of 45-65% above the untreated Control. Tissue P concentration in the greenhouse trial showed enhanced P uptake in the plants receiving 10 kg P ha^{-1} + biofertilizer (BSN^+ and BSCB) but in the field trial the P uptake generally remained below the optimal tissue concentration range of 0.4-0.8% (Lockman, 1969; Vandamme, 2008) even in the positive control with an application of 20 kg P ha^{-1}; the Zn concentration was also below the optimal ranged reported by the two authors (20-50 mg Zn/kg biomass) This may have contributed to the overall low yields observed. To address soil fertility limiting factors, such as N, P, Zn, and organic matter content in the case of the study soil, there is a need to ensure that adequate application rates are used; this would take improvement of fertilizer recommendations in the context of integrated soil fertility management to tailor the directions for use to the initial soil fertility, the crop specific nutrient requirements, and local conditions. For instance, the current recommendation of 20 kg P ha^{-1} may not be sufficient and further investigation is required to determine the effective application rate of P for the study soil. Equally important, other soil fertility limiting factors such as the low N, P, Zn and organic matter content among others in the study soil should be properly addressed to improve maize response to the tested commercial products. This is particularly important in most sub-Saharan Africa countries where most smallholder farmers apply blanket recommendations of fertilizers and other commercial agricultural inputs intended to improve soil fertility without adequate soil fertility diagnosis. Even when the quality of seed applied fertilizers such as Teprosyn or bio-fertilizers (*e.g.* BSCB and BSN^{+}) is good, studies have shown that they should be used in a complete fertilization program (*i.e.* in conjunction with other nutrients taking into consideration the initial soil fertility level) for adequate plant growth and yields as most soils suffer from multiple soil deficiencies (Ortas et al., 2012; Okalebo, 2009). Such products could be just used as complements and not substitutes to conventional fertilizers and soil conditioners (Jefwa et al., 2014; Richardson, Barea, McNeill, & Prigent-Combaret, 2009).

The highest amounts of N in the ear leaf were observed when P was combined with the three products suggesting that there was increased N uptake when P was added. Similar findings have been reported by Vendan and Sundaram (1997), reported increased N-uptake in rice due to inoculation of *Azotobacter* and/or *Azospirillum*, in the presence of inorganic P. Similarly, inoculation with BSCB in the presence of P led to an increase in P uptake which has been reported elsewhere in soybean, strawberry (*Fragaria ananasa*) and cotton (Iman & Azouni, 2008; Ahmad et al., 2012). These findings demonstrated that even for N fixing microorganisms or P solubilizers, there is a need of starter N or P to improve the performance of the microorganisms. The critical challenge that may require further investigation is to determine the threshold values of N or P required in various agro-ecological zones and for different crops above which the efficacy of the microbiological inoculants would be compromised.

4.3 Performance of the Commercial Products on the greenhouse Versus Field

When the performance of the products in the greenhouse and field the results do not show a direct correlation for nutrient uptake, biomass, and grain yield. Both microbial products alone at the higher rate did result in increased uptake of P, Zn and biomass in the greenhouse probably due to better watering than when subjected to field conditions where soil moisture may have not been optimal for them throughout the growing season. The soils used in the study were deficient of both P and Zn and when applied together sometimes there is a Zn-P antagonism significantly reducing Zn uptake and this could explain the Zn uptake in the field trial not showing significant differences in uptake. The imbalance of Zn and P could have been created when the intended levels of both nutrients were below the expected proportions. This has been previously observed by Ryan et al. (2008) and Zhang et al. (2012) who reported that application of macronutrient fertilizers high in phosphorus can significantly decrease plant Zn availability, and thus uptake from the soil due to complex Zn-P interactions that alter both soil and plant factors. In both greenhouse and field trials, addition of P and Zn did not show any correlation with biomass or grain yield and this is attributed to both the poor quality of the product.

5. Conclusions

The three products did not meet the label claims when subjected to laboratory verification. There is a need to enforce existing and newly established quality standards for agricultural inputs to prevent fraud so that farmers have access to effective and high-quality products for use to improve crop productivity. This study in fact demonstrated that use of sub-standards products has little benefit on plant growth and crop yield. However, slight adjustment of the application rate (*i.e.* double of the manufacturer's recommendations) in combination with P- and / or N-fertilizer resulted in significant increase in growth parameters and biomass yields indicating the need to verify the commercial product quality so as to modify the application rate accordingly and integrate them into complete fertilization programs to improve crop response. The study has hence demonstrated the need to develop packages for use alongside the Biofertilizers and seed coating products such as Teprosyn as use of the products alone did not show any improvement on the yield above the untreated Control. The overall response to the currently recommended P- fertilizer rate in this study site indicated the need to revise fertilizer recommendation rates in the region probably not only for P, but also for other plant nutrients. This study was conducted in the greenhouse and the field using only one site and a few commercial products, there is a need for further investigation at multiple locations using a large gamma of similar agricultural inputs before the current findings are generalized.

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