Journal of Agriculture, Environmental Resources and Management
ISSN2245-1800(paper) ISSN 2245-2943(online)
5(5)650-1220; Jan.2023; pp813-824

www.saerem.com

Examination of Solubilizing Effects of *Trichoderma koningii* and *Trichoderma harzianum* and Impact on Growth Parameters and Yield of *Zea mays*

Chimankpa W. Worlu[1], Fortune N. C. Okogbule[1], Kpekot A. Kpekot[1], and Adedoyin A. Worlu[2]
[1]Department of Plant Science and Biotechnology, Faculty of Science, Rivers State University, Port Harcourt, Rivers State, Nigeria.

[2]Department of Agricultural and Applied Economics, Faculty of Agriculture, Rivers State University, Port Harcourt, Rivers State, Nigeria

Abstract

Solubilizing effects of Trichoderma koningii and Trichoderma harzianum and impact on growth parameters and yield of Zea mays was examined. Trichoderma species were isolated from mushroom (Pleurotus ostreatus) at Dilomat Farms and Services Limited, Rivers State University. The experiment consisted of four treatments namely: T. harzianum+soil, T. koningii+soil and T. koningii +T. harzianum+soil, and Soil only which were replicated at three different levels of concentration (5ml, 10ml and 15ml). The soil was analyzed for physicochemical properties of the soil before planting and 10 weeks after treatment. Data on physicochemical properties of maize soil, number of leaves, stem height, leaf area, and yield were collected and subjected to Anova and Ducan's Multiple Range Test (DMRT) was used for mean separation at 5% level of probability. Results showed that Trichoderma spp. decreased the pH and temperature of the soil, and increased the moisture content and NKP of the soil at the various concentrations when compared to the control. Solubilized minerals varied amongst the treatments at the various concentrations. Trichoderma spp. had higher growth parameter and yield of Zea mays at their various levels of concentration when compared to the control (soil only). Highest percentage yield (%Y) increase was observed at 5ml T. koningii+T. harzianum with 61% increase in yield followed by 15/ml T. harzianum with (40%) and 15ml T. koningii with (37%) yield increase.

Keywords: ***Trichoderma harzianum, Trichoderma koningii,*** **Solubilized minerals, Growth parameters, Yield and Maize**

Introduction

Maize (*Zea mays* L.) is one of the most important food crop commodities that are playing vital roles in national scale (Fakayode *et al*., 2008; Adediran, 2009). Recently, maize products are not only used for human food security but also serves as cattle feed and industrial materials including source of alternative fuels such as biofuels (Balemi and Negisho, 2012). The demand for maize is on the increase by the year and has positively correlates to population growth as a result of increased human food and a source of energy for animal (Ojo, 2000; Ketiku and Naidu, 2005). But, its annual yield of maize is significantly decreased due to due decrease in certain soil mineral nutrients.Agricultural productivity is generally limited by nutrient supply because either the soil does not supply enough of one or more nutrient or sometimes because too much of a nutrient is freely available to a plant (Nnabude and Mbagwu, 2001). Benefits of compost amendment to soil also include pH stabilization, faster water infiltration, enhanced soil aggregation, better or enhanced direct nutrient uptake by plant of specific chemicals needed for the development of the immune system (Okonkwo *et al.*, 2 011). The properties of soil that ensure that there is satisfactory nutrient supply for crops grouped as soil nutrient indices is thus paramount importance before advocacy of intensive input into the soil (Adeniyan and Ojeniyi, 2005).

According to Adekunle and Nabinta (2000) intensification of cultivation with little or no fertility management has been one of the critical factors contributing to the decline in output of maize plants. This in turn poses great difficulty for productivity increase to meet the food and fibre needs of a rapidly growing population, thus, endangering food security (Senjobi, 2007). The depletion of soil nutrients due to continuous cropping reduces the soil organic matter, cause significant acidification and yield reduction (Ajilore, 2008). The importance of mineral and organic fertilizers in improving soil productivity has been documented (Cooke, 2006) There is therefore need for adequate fertilization or manuring and securing of the soil in order to sustain soil productivity for optimum growth and yield of maize plant to ensure the corn is security for the ever increasing growing population (Campos *et al*., 2005; Barroso and Nahas, 2008).

Reports have shown that phosphorus (P) amongst other mineral nutrients makes up about 0.2% plant dry weight but only 0.05 to 10ppm concentration of soluble phosphorous is available to plants in the soil (Rudresh*et al*., 2005). Although, several reports have shown that plant productivity (quality and quantity of yield) does not only depend on the nutrient status in the soil, but also on plant nutritional requirement, genetic constituents and environmental factors. The genus *Trichoderma* is typically anaerobic, facultative and cosmopolitan fungi that can be found in large numbers in agricultural soils, all climatic zones and in other substrates such as decaying wood (Santos *et al*., 2010; Machado *et al.*, 2011). Literatures have also revealed that *Trichoderma* spp. colonize the grain, leaves, and roots of plants (Harman *et al.*, 2004; Druzhinina *et al.*, 2006; Naher*et al.*, 2014). They have an important ecological function, because they participate in the decomposition and mineralization of

plant waste, contributing to the availability of nutrients for the plants, directly and indirectly interfering in their growth (Bononi *et al.,* 2020).
Alongside their role in the control of pathogenic microbes they simulate colonization of rhizosphores, enhance plant defense responses and stimulate plant growth and root growth thereby increasing plant productivity and yields (Harman *et al.,* 2004; Pandya *et al.,* 2011; Tripathi *et al.,* 2013; Dagurere *et al.,* 2014; Keswani *et al.,* 2014). *Trichoderma* spp. have been known from last 70 years for their ability to produce an infinite amount of metabolites such as antibiotics and auxins (Harman, 2006). *T. longipile* and *T. tomentosum* have been reported to promote plant growths (Rabeendran, *et al.,* 2000; Siemonsma and Kouame, 2000). Benitez *et al.* (2004) also reported that there was increase in crop productivity of about 300% in fields after treatment with *T. koningii* and *T. hamatum.*

Reports have also shown that *T. harzianum* and *T. viridi* promoted seed germination, root elongation and shoot length as well as increasing the vigour of plants, thereby boosting yield (Rojoa *et al.,* 2007; Dubey *et al.,* 2007; Mukhtar *et al.,* 2012). The impacts of *Trichoderma* spp. on growth and development of plants have important agronomical and economic implications such as shortening the plant growth period and time in nursery, as well as improving plant vigour to overcome biotic and/or abiotic stresses, resulting in increased plant productivity and yields (Vassilev*et al*., 2006; Behzad, 2010). The use of *Trichoderma* isolates for solubilization of mineral nutrients in the soil is essential in sustaining plant growth, improvement and yield because application of synthetic fertilizer in agriculture is not economical nor desirable but highly hazardous to plants and environment with residual impacts (Rabeerdran *et al.,* 2000; Celar and Valic, 2005; Hoyos-Carvajal *et al.,* 2009; Shanmugaiah *et al.,* 2009). The release of nutrients and organic matter from the soil, increase uptake and translocation of minerals has been attributed to the presence of *Trichoderma* spp. in the soil. Auxins produced by *Trichoderma* are able to trigger plant root development, growth and yield quality (Wang *et al*., 2004; Contreras-cornejo *et al.,* 2009; Yoshioka *et al*., 2012). Vargas *et al.* (2009) has also observed that *Trichoderma* cells are provided with plant derived sucrose that enhance their root colonization and defensive mechanisms which increased uptake of oxygen in leaves resulting in increased rate of leaf photosynthesis. Therefore this research is aimed at examining the solubilizing effect of *T. koningii* and *T. harzianum* and impact on growth parameters and yield of *Zea mays*

Materials and Methods

Collection of Soil Samples

Soil samples were randomly collected from 18x18m^2 areas, with the aid of farm spade which was used to dig a V-shaped to a sample depth (3-6 inches) at the Teaching and Research Institute, Rivers State University, Port Harcourt. The soil cores were homogenized in a clean plate and sterilized at 27 – 35^{o}C for five days then placed in a 17 x 17cm perforated plastic bags.

Collection of Maize Seed

Certified maize seeds (Name: O.P. maize seed, Variety: SAMMAZ, Moisture Content: <12%) were obtained from Premier Seed Nigeria Limited located in Zaria, Nigeria. Following physical examination, the maize seeds were visually sorted and checked for infection, dryness and any form of fungal growth. The seed samples were taken to the experimental site where further viability test was done by dropping the maize seeds into a basin of water. The ones that sank were collected for planting, while the ones that floated where discarded.

Isolation and Identification of *Trichoderma* Species

Trichoderma species were isolated from a contaminated mushroom (*Pleurotus ostreatus*) which was collected from Dilomat Farms and Services Limited, Rivers State University and taken to Plant Science and Biotechnology laboratory. Two grams (2g) contaminated mushroom (*Pleurotus ostreatus*) was inoculated into sterilized Petri plates and then incubated at 28±2^{o}C for 5-7 days. Organisms were isolated from the surface colonies formed and sub-cultured four (4) times to obtain pure cultures of *Trichoderma* spp. Identification was done based on morphological characteristics of the colony by microscopic examinations (Diba*et al.,* 2007; Ratna*et al.,* 2015). The fungi were compared and identified with the help of standard procedure and relevant literatures (Gilman, 2001; Nagamani *et al.,* 2006; Ratna *et al.,* 2015).

Experimental Design

A randomized complete block design experiment was adopted. Viable maize seeds were planted in a polythene bag of about 17cm in height and 17cm in width with 6kg of soil which amounted to a total of 120 viable seeds. Each bag had 4 maize seeds but two weeks after germination (2WAG), 3 seedlings were uprooted from each bag such that only one would be treated with *Trichoderma*spp. The experiment consisted of four treatments namely: *T. harzianum*+soil, *T. koningii*+soil and *T. koningii* +*T. harzianum*+soil, and Soil only which were replicated at three different levels of concentration (5ml, 10ml and 15ml) giving a total of 30 sample size.

Determination of Physicochemical Properties of Soil and Orange Peel Samples

The following properties were determined;

Determination of pH

The pH of soil sample was determined by APHA standard methods (APHA, 2005). The meter was switched on and allowed for some time. It was then calibrated with buffer solutions of higher pH range between 8 and 9 as well as a lower pH range between 1 and 6 by dipping the electrode into the buffer solutions. Ten (10) grams of soil was weighed into 100ml beaker; 50ml of distilled water was then added to allow immersion of the electrode, mixing was carried out by stirring frequently for few minutes. Then beaker was allowed to stand for 15minutes. The electrode was immersed into the slurry. The pH value for each sample were recorded accordingly

Determination of Temperature

The Temperature for each sample was determined using a mercury-in-glass thermometer by adopting APHA

standard methods (APHA, 2005). The thermometer was immersed into the samples such that the mercury bulb was well covered by the samples. The final readings were considered the actual reading and were taken after allowed to stabilize.

Determination of Electrical Conductivity

The electrical conductivity of soil sample was determined using a conductivity meter by adopting APHA standard methods (APHA, 2005). The meter was standardized according to the manufacturer's instructions. The electrical conductivity values for each sample were recorded accordingly.

Determination of Moisture Content

The moisture contents of the samples were determined using clean dried Petri-dishes dried in an oven and weighed on electronic weighing balance (W_1). Ten (10) grams of soil samples was added in the Petri-dishes and weighed (W_2). The samples were then dried to a constant weight at 105^{o}C for 24hours. The final weight of the dried soil and the Petri-dish was recorded (W_3) (APHA, 2005).

$$\text{Moisture content (\%)} \quad W = \frac{(W_2 - W_3)}{(W_3 - W_1)} \times 100$$

W_1 = weight of Petri-dish, W_2 = weight of Petri-dish + wet soil
W_3 = weight of dried soil with Petri-dish

Determination of Nitrate

The nitrate levels for the samples were determined using an ultraviolet (UV) spectrophotometer. The spectrophotometric method was adopted. 5g of samples were weighed into a shaking bottle. 125ml of distilled water was added and shaken for 10minutes on a rotary shaker and then filtered to obtain the extract, 1ml of the extract was transferred into 10ml volumetric flask, 0.5ml of Brucine reagent was added. Subsequently, 2ml of conc. sulphuric acid was rapidly added and mixed for about 30seconds .The flasks were allowed to stand for 5minutes. Two (2) ml of distilled water was then added and mixed for about 30seconds. Flasks were allowed to stand in cold water for about 15minutes. The absorbance of the samples was measured using the spectrophotometer at wavelength of 470nm (APHA, 2005).

Determination of Phosphate

The phosphate levels for the samples were determined using an ultraviolet (UV) spectrophotometer. The phosphate - Nitric acid Digestion method as described by APHA (1995) was adopted and modified by (Oyeyinka and Oyeyinka, 2016). Twenty five (25ml) of 2.5% Acetic acid was added to 1g of sample and shaken for 30minutes. The suspension was filtered through a filter paper; 10ml of the extract was transferred into 50ml volumetric flask. Extract was diluted with distilled water until the flask is about two third full. 2ml of ammonium molybdate reagent was added and mixed with extract, 2ml of stannous chloride was also added and mixed, and the solution was diluted to 50 ml mark with distilled water. The flask was allowed to stand for 30minutes .And the absorbance was measured at wavelength of 690nm.

Determination of Potassium

The potassium levels for the samples were determined. The method as described by APHA (2005) as adopted.25ml of the extracting solution was added to 5g of sample and shaken for 30minutes and the suspension was filtered through a filter paper. 5ml of the extract was transferred into 50ml volumetric flask. 5ml of 50% acetic acid was added and 1ml of H_3PO_4 was added and mixed. The solution was diluted with distilled water to about ¾ of the flask. One gram of Barium chloride was added and mixed. The solution was left to stand for 10 times, then 1ml of 0.5% gum acacia was added to the solution and made up to 50ml with distilled water, and the absorbance was measure at 425nm.

Preparation and Application of Carrier-Based Inoculants

Trichoderma spp. were grown in potato dextrose agar (PDA) and incubated for seven days at 30±2^{o}C, and the spores were harvested and diluted with 20ml distilled water. Thereafter, 2.5ml *T. harzianum*+2.5ml, 5ml *T. harzianum*+5ml *T. koningii* and 7.5ml *T. harzianum*+7.5ml *T. koningii*, 5ml, 10ml & 15ml *T. harzianum* and 5ml 10ml & 15ml *T. koningii* spores suspension were measured into different beakers respectively to form mixture of (broth inoculants). The broth inoculants however were properly mixed. The formula was poured and spread in to the plastic bags containing 6kg of soil. These were applied at two weeks interval for 6 weeks.

Growth parameters

The plant height and leaf area (leaf length x width) were measured using meter rule while the number of leaf per plant was accounted weekly for 6 weeks within the vegetative and growth period.

Yield Assessment

This was based on yield comparisons between infected and apparently healthy plants, between resistant and susceptible plants at the various treatments. Percentage yield loss (%YL) in terms of grain weight was calculated as follows (Cooke, 2006; Mousanejad *et al.*, 2010).

$$\%\ YL = \frac{\text{Yield in intensive protected bag - Yield in particular treatment}}{\text{Yield in intensive protected bag}} \times 100$$

Results

Solubilizing Effects of *Trichoderma koningii* and *Trichoderma harzianum* on Yield of *Z. mays*

***Mays* before planting and 10 weeks after planting**

Table 1 shows solubilizing effects of *T. koningii* before planting and 10 Weeks after treatment of *Z. mays*. The result revealed that pH and temperature decreased with increase in the concentration of *T. koningii* 10WAP. Electrical conductivity, moisture content, NPK increased with increase in concentration when compared to the controls (SO_0 and SO_1) at 10 WAP.

Table 1: Solubilizing Effects of *T. koningii* before planting and 10 Weeks After Treatment of *Z. mays*

Para./treat./conc.	SO_0	SO_1	TK (5ml)	TK (10ml)	TK (15ml)
Ph	7.4	4.81	4.71	4.70	4.04
Temp(°C)	31	27.5	27.8	27.6	28.0
Elect.Con.(us/cm)	93	45000	44000	84000	92000
Moisture Content (%)	1.4	13.77	11.60	11.16	16.37
Chlorine (mg/kg)	<0.01	<0.01	<0.01	0.01	0.01
Bromine (mg/kg)	<0.01	<0.01	0.01	0.02	0.02
Nitrogen (mg/kg)	55	95	98	130	150
Phosphorus (mg/kg)	3.5	1.8	2.9	3.5	5.5
Potassium (mg/kg)	49	24	83	101	105

TK = Trichodermakoningii + Soil, SO_0 = Soil before planting, SO_1 = Soil only during growth

Table 2 shows solubilizing effects of *T. harzianum* before planting and 10 Weeks after treatment of *Z. mays.* The result revealed that pH and temperature decreased with increase in the concentration of *T. harzianum* 10WAP. Electrical conductivity, moisture content, NPK increased with increase in concentration when compared to the controls (SO_0 and SO_1) at 10 WAP.

Table 2: Solubilizing Effects of *T. harzianum* before Planting and 10 Weeks After Treatment of *Z. mays*

Para./treat./conc.	SO_0	SO_1 only	TH (5ml)	TH (10ml)	TH (15ml)
pH	7.4	4.81	4.72	4.71	4.68
Temp(°C)	31	27.5	27.8	27.8	27.8
Elect.Con.(us/cm)	93	45000	28000	55000	143000
Moisture Content (%)	1.4	13.77	13.80	14.20	10.16
Chlorine (mg/kg)	<0.01	<0.01	0.01	0.01	0.01
Bromine (mg/kg)	<0.01	<0.01	0.02	0.02	0.02
Nitrogen (mg/kg)	55	95	55	90	130
Phosphorus (mg/kg)	3.5	1.8	4.7	6.5	7.5
Potassium (mg/kg)	49	24	65	71	83

TH = Trichodermaharzianum, SO_0 = Soil only before planting, SO_1 = Soil only during growth

Table 3 shows solubilizing effects of *T. koningii+T. harzianum* before planting and 10 Weeks after treatment of *Z. mays.* The result revealed that pH and temperature decreased with increase in the concentration of *T. koningii+harzianum* 10WAP. Electrical conductivity, moisture content, NPK increased with increase in concentration when compared to the controls (SO_0 and SO_1) at 10 WAP.

Table 3: Solubilizing Effects of *T. koningii+T. harzianum* before planting and 10 Weeks of Treatment of *Z. mays*

Para./treat./conc.	SO_0	SO_1 only	K/H (5ml)	K/H (10ml)	K/H (15ml)
pH	7.4	4.81	4.75	4.28	4.17
Temp(°C)	31	27.5	27.8	27.6	27.6
Elect.Con.(us/cm)	93	45000	37000	53000	69000
Moisture Content (%)	1.4	13.77	16.33	14.97	11.18

Chlorine (mg/kg)	<0.01	<0.01	0.01	0.01	0.02
Bromine (mg/kg)	<0.01	<0.01	0.02	0.02	0.04
Nitrogen (mg/kg)	55	95	48	50	89
Phosphorus (mg/kg)	3.5	1.8	4.8	5.5	6.0
Potassium (mg/kg)	49	24	65	71	79

K/H = Trichoderma koningii + Trichoderma harzianum, SO_0 = Soil only before planting (control), SO_1 = Soil only during growth

Effects of *Trichoderma koningii* and *Trichoderma harzianum* on Growth Parameters

Tables 4, 5 and 6 show the mean comparison of growth parameters of *Zea mays* amongst the treatments at 5ml, 10ml and 15ml concentrations to the control. There were significant differences in the number of leaves, stem height, and leaf areas of *Zea mays* amongst the various treatments at 5ml and 10ml concentration when compared to the control at 6 WAP (Tables 4 and 5) but there were no significant differences in the growth parameters of maize treated with 15ml (Table 6).

Table 4: Mean Comparison of the Effects of Treatments at 5g/15ml Concentration on Growth Parameters of *Z. mays* (6 WAP).

Treatment	No. of leaves	Stem height (cm)	Leaf area (cm^2)
T. koningii + T. harzianum	9.67 ± 0.58^{b}	$37.33\pm9.30^{a-b}$	$365.67\pm67.80^{a-c}$
T. harzianum	$8.67\pm0.58^{a-b}$	$34.00\pm5.20^{a-b}$	$355.67\pm68.30^{a-b}$
T. koningii	10.67 ± 0.58^{b}	$33.00\pm6.30^{a-b}$	$404.33\pm15.04^{a-c}$
Soil Only	7.00 ± 0.00^{a}	28.67 ± 4.04^{a}	231.67 ± 98.40^{a}

Means with different letters down the column are significantly different at p<0.05(Duncan's Multiple Range Test)

Table 5: Mean Comparison of the effects of Treatments at 10g/15ml concentration on Growth Parameters of *Z. mays* (6 WAP).

Treatment	No. of leaves	Stem height (cm)	Leaf area (cm^2)
T. koningii + T. harzianum	$9.67\pm0.58^{b-c}$	$33.33\pm5.86^{a-b}$	$348.67\pm94.35^{a-b}$
T. harzianum	$8.00\pm1.00^{a-b}$	$37.33\pm8.74^{a-c}$	$344.33\pm50.36^{a-b}$
T. koningii	$9.67\pm0.58^{b-c}$	$38.33\pm8.20^{a-c}$	$445.33\pm24.11^{b-d}$
Soil Only	7.00 ± 0.00^{a}	28.67 ± 4.04^{a}	231.67 ± 98.40^{a}

Means with different letters down the column are significantly different at p<0.05 (Duncan's Multiple Range Test)

Table 6: Mean Comparison of the Effects of Treatments at 15g/15ml Concentration on Growth Parameters of *Z. mays* amongst (6 WAP).

Treatment	No. of leaves	Stem height (cm)	Leaf area (cm^2)
T. koningii + T. harzianum	6.67 ± 5.86^{a}	24.00 ± 21.63^{a}	297.67 ± 257.83^{a}
T. harzianum	9.00 ± 0.00^{a}	42.00 ± 14.42^{a}	370.33 ± 55.20^{a}
T. koningii	10.67 ± 0.58^{a}	39.33 ± 13.65^{a}	457.67 ± 15.04^{a}
Soil Only	7.00 ± 0.00^{a}	28.67 ± 4.04^{a}	231.67 ± 98.40^{a}

Means with different letters down the column are significantly different at p<0.05 (Duncan's Multiple Range Test)

Effects of *Trichoderma koningii* and *Trichoderma harzianum* on Yield of *Z. mays*

There was exponential and differential percentage yield increment in all the treatments at all levels of concentration when compared to the control (Fig. 1). *T. koningii+T. harzianum* had the highest percentage yield increase (61%) at 5ml, followed by 15ml (30%) and 10ml (10%). *T. harzianum* had the highest percentage yield increase (40%) at 15ml followed by 10ml (31%) and 5ml (26%). Finally, *T. koningii* had the highest percentage yield increase (37%) at 15g/ml, followed by 5g/ml (32%) then, 10g/ml (31%). From the table, the highest percentage yield (%Y) increase was observed at 5ml *T. koningii+T. harzianum* with 61% increase in yield followed by 15/ml *T. harzianum* with (40%) and 15ml *T. koningii* with (37%) yield increase.

Discussion

Agricultural productivity is affected by the availability and accessibility of soil nutrient amongst other factors. However availability of certain nutrients in the soil is not equal to accessibility and absorbability. From this research therefore, *Trichoderma* spp. at the various concentration were found to have high nutrient solubilizing effects on maize soil. There was substantial increase in the NPK amongst the various treatments and concentrations, when compared to the control. The increase in the amount of nitrogen in the soil supports the work of Li *et al* (2016) who stated that *Trichoderma* spp. have the ability to break down nitrogen compounds into available nitrogen and lower nitrate. The positive increase observed in the amount of phosphorus has been reported by Anil and Lakshmi (2010) that the unavailability of Tricalcium phosphate (TCP) within 72h indicated that *Trichoderma* spp. have high potential for solubilization of inorganic bound phosphate (TCP) in the soil. Rudresh *et al*. (2005) also submitted that inoculation of *Trichoderma* spp. into the soil enhanced solubilization of phosphorus which impacted on the growth of chickpea grown in p-deficient soil.

Increase in the availability and accessibility of nutrients which enhanced the absorbability, translocation and utilization of NPK by maize plant might be due to alterations in some of the physicochemical properties such as pH, temperature, electrical conductivity and moisture content of the soil by *Trichoderma* spp. This alteration resulted in the solubilization and free release of nutrients to maize. However, Nnabude and Mbagwu (2001) reported that nutrients in the soil vary due to the fact that soil lacks nutrient or does not supply one or more of the nutrients or much of the nutrients are freely available to plants.

Saravanakumar *et al*. (2017) also reported that *Trichoderma* spp. posses the capacity to solubilize mineral elements by altering the pH of the soil apart from their numerous and diverse biocontrol, growth promoting and bio-catalyzing activities. A similar observation was made by Illmer and Schinner (1992) that a decline in pH was associated with a gradual rise in nutrient solubilization by *Pseudomonas* and *Penicillium* in liquid cultures. Kpomblekou and Tabatabai (1994) proved that microorganism that tends to reduce the pH of a medium during growth period is efficient Phosphate solubilizers. This goes further to confirm that the decrease in pH at 10 WAP was as a result of the growing and sporulation period of *Trichoderma* spp. which effectively increased nutrient contents and enzymatic activities that resulted in the amendment of the soil and promotion of maize growth.

Furthermore, the decrease in soil pH, temperature as well as increase in the electrical conductivity and moisture content of the soil positively influenced the uptake of NPK which might had impacted greatly on the photosynthetic activities of maize that promoted growth and yield. This suggests that *Trichoderma* solubilzed orange peel amendment (the compost) stabilized and enhanced water penetration and soil composite and aggregation that brought about nutrient uptake in maize plant. Okonkwo *et al.* (2011) reported that the advantages of compost amendment to soil also include stabilization of pH, faster water infiltration, positive soil aggregation, and better direct nutrient uptake of specific chemicals needed by plant for development of immune system. This uptake and utilization of nutrient might also be due to secretion of certain organic acids that dissolved mineral and activated nutrient solubilization and circulation in the soil which led to absorption and utilization by maize plant. This corroborates to the findings of Li *et al*. (2016) which reported that *Trichoderma* spp. promoted uptake of nutrient by secreting organic acids which dissolve and activate mineral nutrient resulting in increased distribution and utilization by plant. It is also possible that *Trichoderma* spp. solubilized nutrients by parasitizing on soil microbial cells which led to change in soil microbial community. Li *et al*. (2016) reported a similar result that *Trichoderma* spp. solubilzed and increased soil nutrients via gradual breakdown of soil microbial cells leading to the change in the soil microbial community structure. This is similar to the findings of Yedidia *et al*. (2001) and Vargas *et al*. (2009) who stated that *Trichoderma* root colonization in the soil will result in higher photosynthetic rate which would increase the uptake of oxygen in the leaves of plants and consequently, yield increase of cucumber plants.

In addition, availability and solubilization of mineral nutrient in the maize soil especially NKP through *Trichoderma* solubilized orange peel is more promising and ecosystem friendly than the inorganic source and method of fertilizer application. The above observation was also noted by Tuttobene *et al.* (2009) who reported that poor and reckless use of inorganic fertilizer changes physical, chemical and biological properties of the soil as well as reduces the fertility status of the soil. This also corresponds to the observations made by Hawamdah and Ahmad (2001), Gottlied *et al.* (2002), Moslem *et al.* (2009) and Akinpelu *et al*. (2014) who submitted that the usefulness of naturally available phytochemicals and mineral nutrients have shown good promise in retarding the activities of some undesirable fungal pathogens may be more accurate and environmentally sustainable technique for promoting and protecting plants (fruits and seeds) from nutrient deficiencies and infections. Mbah and Mbagwu (2006), and Iren *et al*. (2015) also reported that most plant peels are commonly found in farms and processing sites as heaps that are generally perceived as environmental pollutants, but could be effectively and

sustainably utilized through recycling because of their organic matter and plant nutrients potentials.

Conclusion

Trichoderma spp. decreased the pH and temperature of maize soil, and increased the moisture content and NKP of the soil at the various concentrations. Solubilized minerals varied amongst the treatments at the various concentrations. *Trichoderma* spp. also had positive impact on growth parameter and yield of *Zea mays* at their various levels of concentration, where the highest percentage yield (%Y) increase was observed at 5ml *T. koningii*+*T. harzianum* with 61% increase in yield followed by 15/ml *T. harzianum* with (40%) and 15ml *T. koningii* with (37%) yield increase. From the research, it can be said that *T. koningii* and *T. harzianum* possess bio-nutritional potential amongst their multifaceted bioactive potentials. *T. koningii* and *T. harzianum* are therefore bio-nutrient solubilizers and soil status booster which will impact on the growth parameters of plant thereby resulting in yield increase.

REFERENCES

Adediran, G. (2009). Nutrient Composition and Weight Evaluation of Small Newly Developed Maize Varieties in Nigeria. *Journal of Food Technology*, 7, 25-35.

Adekunle, B. &Nabinta, G. (2000). Suppression of Damping-off Caused by *Pythium* spp. in Soil from the Indigenous Chinampa Agricultural System. *Soil Biology and Biochemistry*, 19, 501-508.

Adeniyan, O. N. &Ojeniyi, S. O. (2005). Effect of Poultry Manure and NPK 15-15-15 Combination of their Reduced Levels on Maize Growth and Soil Chemical Properties. *Nigeria Journal Soil Science*, 15, 34-41.

Akinpelu, D. A., Aiyegoro, O. A. & Akinpelu, O. F. (2014). Stem Bark Extract and Fraction of *Persea Americana* (Mill) Exhibits Bactericidal Activities against Strains of *Bacillus cereus* Associated with Food Poisoning. *Molecule*, 20(1), 416-429.

Ajilore, N. N. (2008). Potential of Cassava Peels as Soil Amendment II. *Journal Environmental Quality*, 14, 44-56.

American Public Health Association (APHA) (2005). Standard Methods for the Examination for Water and Wastwater (19th edition). ByredPrepess Springfield, Washington, cited in *Journal of Biomedical Engineering and technology*, 2(1), 5-9.

Anil, K. & Lakshmi, T. (2010). Phosphate Solubilization Potential and Phosphatase Activity of Rhizospheric*Trichoderma*spp. *Journal of Microbiology*, 51, 312-317

Balemi, T. &Negisho, K. (2012). Management of Soil Phosphorus and Plant Adaptation Mechanisms to Phosphorus Stress for Sustainable Crop Production: a Review. *Journal of Soil Science and Plant Nutrition*, 12(3), 547-562.

Behzad, H. (2010). Effects of some Iranian *Trichoderma*Isolates on Maizeseed Germination and Seedling Vigor. *African Journal of Biotechnology*, 9(28), 4342-4347.

Benitez, T., Rincon, A. M., Limon, M. C. & Codon, A. C. (2004). Biocontrol Mechanisms of *Trichoderma* Strains. *International Microbiology*, 7(4), 249−260.

Bononi, L., Chiaramonte, J., Camila, P. &Moitinho, M. (2020). Phosphorus-Solubilizing *Trichoderma* spp. from Amazon Soils Improves Soybean Plant Growth. *Scientific Reports*, 10(2858), 1-13.

Campos, A., Lino, C. M. & Cardoso, S. M, (2005). Organochlorine Pesticide Residues in European Sadine, Horse Mackerel and Atlantic Mackerel from Portugal. *Food Addit Contamination*, 22(7), 642-646.

Celar, F. &Valic, N. (2005). Effects of *Trichoderma*spp. and *Gliocladiumroseum*Culture Filtrates on Seed Germination of Vegetables and Maize. *Journal of Plant Disease*, 112, 343-350.

Contreras-Cornejo, H. A., Macías-Rodriguez, L., Cortés-Penagos, C. &López-Bucio, J. (2009). *Trichoderma virens*, a Plant Benefcial Fungus, Enhances Biomass Production and Promotes Lateral Root Growth through an Auxin-Dependent. *Plant Physiology*, 149(3), 1579–1592.

Cook, C. G., Escobar, D. E., Everitt, J. H., Cavazos, I. Robinson, A. F. & Davis M. R. (1999).Utilizing Airborne Video Imagery in Kenaf Management and Production. *Industrial Crops and Products*, 9, 205–210.

Cooke, B. M. (2006). Disease Assessment and Yield Loss. In: The Epidemiology of Plant Diseases, pp.43-75, (Cooke, B.M., Jones, D.G. and Kaye, B., eds). Springer, the Netherlands. Culture médium. Pesqui. Agropecu. *Bras*, 43(4), 529-535 (in Portuguese).

Diba, K., kordacheh, P., Mirhendi, S. M., Rezaie, S. &Mahmoudi, M. (2007). Identification of *Asergillus* Species using Morphological Characteristics. *Pakistan Journal of Medical Science*. 23 (6), 867-872.

Daguerre, Y., Siegel, K., Edel-Hermann, V. & Steinberg, C. (2014). Fungal Proteins and Genes Associated with Biocontrol Mechanisms of Soil-Borne Pathogens: a Review. *Fungal Biology Review*, 28(4), 97-125.

Druzhinina, I. S., Kopchinsky, A. G. &Kubicek, C. P. (2006). The First 100 *Trichoderma* species Characterized by Molecular Data. *Mycoscience*, 47(2), 55−64.

Dubey, S. C., Suresha, M. &Singha, B. (2007). Evaluation of *Trichoderma*species against *Fusariumoxysporum f. sp. ciceris* for Integrated Management of Chickpea wilt. *Biological Control*, 40, 118-127.

Fakayode, U., Akanbi, W. B., Baiyewu, R. A. &Tairu, F. M. (2008). Effect of Organic Based Fertilizer and Spacing on Growth and Yield of *Celosia* (*C. Argentea*L.). *Journal of Agricultural Forest and Fishery.* 1, 5-10.

Gottlieb, O. R., Borin, M. R. &Bito, N. R. (2002). Integration of Ethnobotany and Phytochemistry: Dream or Reality? *Phytochemistry*, 60, 145-152.

Harman, G. E (2006). Overview of Mechanisms and Uses of *Trichoderma* spp. *Phytopathology*, 96, 190-194.

Harman, G. E., Petzoldt, R., Comis, A. & Chen, J. (2004). Interactions between *Trichoderma harzianum* Strain t22 and Maize Inbred line mo17 and Effects of these Interactions on Diseases caused by *Pythium ultimum and Colletotrichum graminicola. Journal of Phytopathology,* 94, 147-153.

Hawamdeh, A. S. & Ahmad, S. (2001). *In-vitro* Control of *Alternaria solani*, the Cause of Early Blight of Tomato. *Journal of Biological Science*. 1(10), 949-950.

Hoyos-Carvajal, L., Ordua, S. &Bissett, J. (2009). Growth Stimulation in Bean (*Phaseolus vulgaris* L.) by Trichoderma. *Biological Control*, 51, 409-416.

Illmer, P. &Schinner, F. (1992). Solubilization of Inorganic Phosphates by Microorganisms Isolated from Forest Soils. *Soil Biology and Biochemistry.* 24, 389-395.

Iren, O. B. (2015). Factor Productivity in Maize Production in Ondo State, Nigeria. *Applied Tropical Agriculture.* 15(1), 57-63.

Kpomblekou, A. K. &Tabatabai, M. A. (1994). Effect of Organic Acids on the Release of Phosphorus from Phosphate Rocks. *Soil Science*, 158, 112-118.

Keswani, C., Mishra, S., Sarma, B., Singh, S. & Singh, H. (2014). Unraveling the Efficient Applications of Secondary Metabolites of Various *Trichoderma* spp. *Applied Microbiology and Biotechnology*, 98(2), 533-544.

Ketiku, R. J. & Naidu, R. (2005). Influence of Lime, Fertilizer and Manure Applications on Soil Organic Matter Content and Soil Physical Conditions: a Review. *Nutrient Cycling in Agroecosystems*, 51, 123-137.

Li, Y., Sun, R., Yu, J., Saravanakumar, K. & Chen, J. (2016). Antagonistic and Biocontrol Potential of *Trichoderma asperellum* ZJSX5003 against the Maize Stalk rot Pathogen *Fusarium graminearum*. *Indian Journal of Microbiology*, 56, 318–327.

Machado, R. G., Sá, E. L. S., Damasceno, R. G., Hahn, L., Almeida, D., Moraes, T., Camargo, F. A. O. &Reartes, D. S. (2011). Promotion of Growth in Plants *Lotus corniculatus* L. (birdsfoot trefoil) and *Avenastrigosa*Schreb (black oat), by Inoculation with Rhizobia and *Trichoderma harzianum*. *Science Nature*. 33 (2), 111-126 (in Portuguese).

Mbah, C. N. &Mbagwu, J. S. C. (2006). Effect of Animal Wastes on Physic-Chemical Properties of a dystric Leptosol and Maize Yield in Southern Nigeria. *Nigerian Journal of Soil Science* 16, 96-103.

Moslem, M. A. & El-Kholie, E. M. (2009). The Effect of Neem (*Azardirachtaindica A. Juss*) Seeds and Leaves Extract on some Plant Pathogenic Fungi. *Pakistan Journal of Biological Science,* 12(14), 1045-1048.

Mousanejad, S., Alizadeh, A. & Safaie, N, (2010). Assessment of Yield Loss due to Rice Blast Disease in Iran. *Journal of Agricultural Science and Technology*, 12, 357-364.

Mukhtar I., Hannan A., Atiq A. &Nawz A. (2012). Impact of Trichoderma Species on Seed Germination in Soybeen. *Pskistan Journal of Phytopathology*, 24(2), 159-162

Nagamani, A., Kumar, I. K. &Manoharachary, C. Hand Book of Soil Fungi, I. K. (2006). International Publishing House Pvt Ltd, New Delhi, India. 215.

Nnabude, P. C. &Mbagwu, J. S. C. (2001). Pysico-Chemical Properties and Productivity of a Nigerian Typic-Haplustult Amended with Fresh and Burnt Rice-Mill Wastes. *Bioresource Technology*, 76, 265-272.

Ojo, B. (2000). Maize Research and Production in Nigeria. *African Journal of Biotechnology*, 3(6), 302-307.

Okonkwo, C. Onyibe I. &Mbah C. N. (2011). Influence of Different forms of Cassava Peel on Physicochemical Properties of an Ultisol and Yield of Maize (*Zea may L.*) in Abakaliki South Eastern-Nigeria. *Journal of Agriculture and Biological Sciences*, 2 (4), 78-83.

Oyeyinka, T. A. & Oyeyinka, S. A. (2016). *Moringa oleifera* as a Food Fortificant: Recent Trends and Prospects. *Journal of the Saudi Society of Agricultural Sciences*, 2, (2), 5-10.

Pandya, J. R., Sabalpara, A. N. &Chawda, S. K. (2011). *Trichoderma*: A Particular Weapon for Biological Control of Phytopathogens. *Journal of Agriculture and Technology*, 7(5), 1187-1191.

Rabeendran, N., Moot, D. J., Jones, E. E. & Stewart, A. (2000). Inconsistent Growth Promotion of Cabbage and Lettuce from *Trichoderma*isolates. *New Zealand Plant Protection.* 53, 143-146.

Ratna, P. K. K., Hemanth, G., Shiny, N. P. & Samuel K. K. (2015). Isolation and Identification of Soil Mycoflora in Agricultural Fields at Tekkali Mandal in Srikakulam District. *International Journal of Advances in Pharmacy, Biology and Chemistry*.4(2), 484-489.

Rojoa, F. G., Reynosoa, M. M., Fereza, M., Chulze, S. N. & Torres, A. M. (2007). Biological Control by *Trichoderma*species of *Fusariumsolani*Causing Peanut Brown Root Rot under Field Conditions. *Crop Protection*, 26, 549-555.

Rudresh, D. L., Shivaprakash, M. K. & Prasad, R. D. (2005). Tricalciumphosphate Solubilizing Abilities of *Trichoderma spp*. In relation to Puptake& Growth Yield Parameters of Chickpea (*Cicerarietinum*L.). *Canidian Journal of Microbiology.* 51, 217-226.

Santos, H. A., Mello, S. C. M. &Peixoto, J. R. (2010). Association of Isolates of *Trichoderma*spp. And Indole-3-Butyric Acid (iba) in Promoting root and Growth of passion. *Bioscience Journal*, 26(6), 966-972 (in Portuguese).

Saravanakumar, K., Li, Y., Yu, C., Wang, Q. Q., Wang, M., Sun, J. & Chan, J. (2017). Effect of *Trichodermaharzianum* on Maize Rhizosphere Microbiome and Biocontrol of *Fusarium* Stalk Rot. *Scientific Reports*, 7, 1-13.

Senjobi, P. (2007). Induction of Systemic Resistance in Cucumber against Angular Leaf Spot by Plant Growth-Promoting Rhizobacteria. *Phytopathology*, 85, 843-847.

Shanmugaiah, V., Balasubramanian, N., Gomathinayagam, S., Monoharan, P. T. &Rajendran, A. (2009). Effect of Single Application of *Trichodermaviride*and *Pseudomonas fluorence*son Growth Promotion in Cotton Plants. *African Journal of Agricultural Research*, 4(11), 1220-1225.

Siemonsma, J. S. & Kouame, C. (2000). *Abelmoschus esculentus*(L.) Moench. Wageningen Agricultural University, Wageningen, Netherlands. Singh, A., Birinchi K., Singh, H. B. &Upadhyay, R. S. (2014). *Trichoderma*: A Silent Worker of Plant Rhizosphere. *Biotechnology and Biology of Trichoderma*, 3(2), 533-542.

Tripathi, P., Singh, P. C., Mishra, A., Puneet, S. C, Dwivedi, S., Thakur, R., Deo, B. &Tripathi, R. (2013). *Trichoderma*: a Potential Bioremediator for Environmental Cleanup. *Clean Technology and Environmental Policy*. 15(4):541-550.

Tuttobene, R., Avola, G., Gresta, F. & Abbate, V. (2009). Industrial Orange Waste as Organic Fertilizer in Durum Wheat. *Agronomy for Sustainable Development.* 29(4):557-563.

Vargas, W. A., Mandawe, J. C. &Kenerley, C. M. (2009). Plant-Derived Sucrose Is a Key Element in the Symbiotic Association between *Trichodermavirens* and Maize Plants. *Plant Physiology*, 151, 792–808

Vassilev, N., Vasileva, M. A. &Nikolaeva, L. (2006). Simultaneous Phosphate solubilizing and Biocontrol Activity of Microorganisms: Potentials and Future Trends. *Applied Microbiology and Biotechnology*, 71(2), 137-144.

Wang, Y. R., Yu, L., Nan, Z. B. & Liu, Y. L. (2004). Vigor Tests used to Rank Seed Lot Quality and Predict Field Emergence in Four Forage Species. *Crop Science*, 44: 535-541.

Yedidia, I., Srivastva, A. K., Kapulnik, Y. & Chet, I, (2001). Effect of *Trichoderma harzianum*on Microelement Concentrations and Increased Growth of Cucumber Plants. *Plant Soil*, 235, 235-242.

Yoshioka, Y., Ichikawa, H., Naznin, H. A., Kogure, A. &Hyakumachi, M. (2012). Systemic Resistance Induced in *Arabidopsis thaliana* by *Trichoderma asperellum* SKT-1, a Microbial Pesticide of Seed-Borne Diseases of Rice. *Pest Management Science*, 68(1), 60-66.

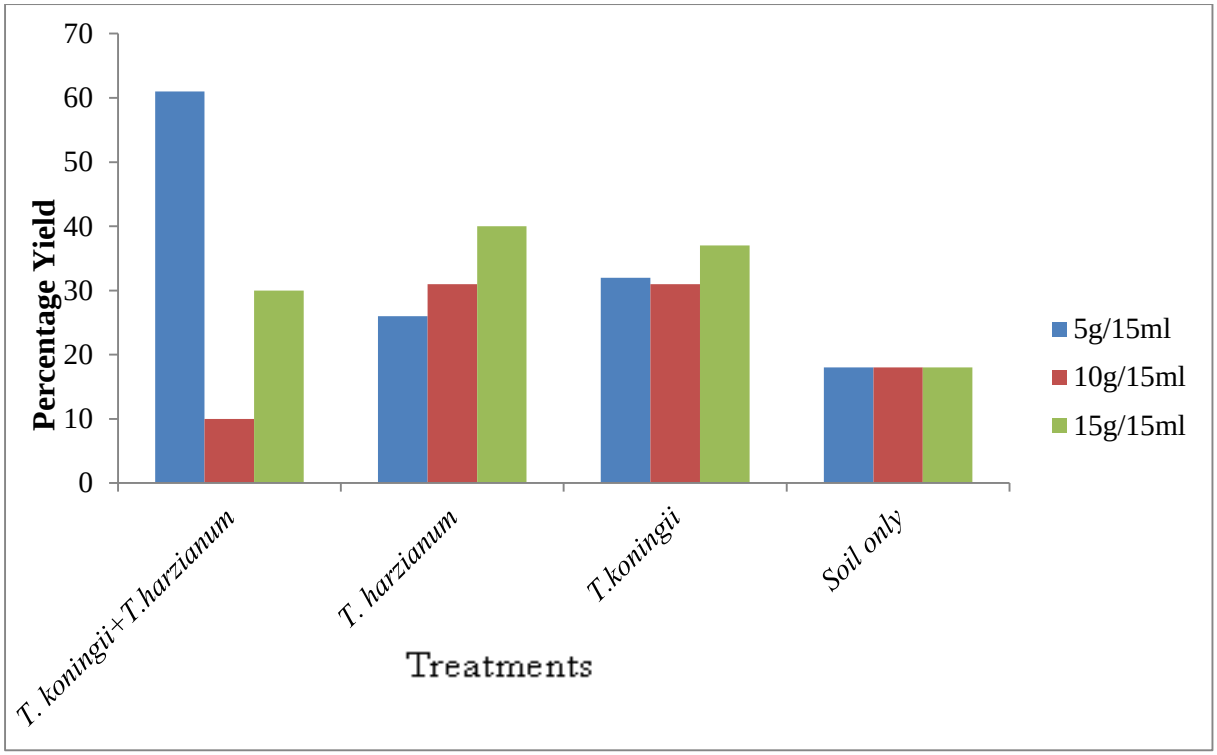

Fig. 4.16: Effects of Treatments on Yield of *Z. mays*