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Investigating the effectiveness of integrating plant growth promoting microbes (biofertilisers) in traditional maize cropping systems of Malawi

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Abstract

Maize production is facing an array of soil nutrient related problems throughout tropical countries. In most tropical soils, phosphorous, zinc, potassium, boron, and other nutrients are often in fixed form and extensive research has shown potentiality of indigenous microbes that solubilise these fixed minerals. The experiments were, therefore, conducted to evaluate the response of integrating a concoction of indigenous plant growth promoting microbes (PGPM)- with ability to fix nitrogen and solubilise phosphorous, potassium and zinc in traditional maize cropping systems for reduced production cost and environmental degradation that emanate from the use of inorganic fertilizers. A concoction of indigenous PGPM, a product of LOGO TECH operating under trade secrets was used in this study. Field layout followed completely Randomized Block Design with three replications and 13 treatments (based on different rates of inorganic fertilizers). Results showed PGPM significantly influenced yield and its components of maize in the study sites. However, maize yield and agronomic traits were significantly higher when PGPM were integrated with 69kg of nitrogen in medium altitude districts. The application of basal fertilizer negatively affects the performance of PGPM due to heavy metals associated with phosphate rocks, a raw material used in the production of phosphate based fertilizers.

Keywords: PGPM, Biofertilisers, Inorganic Fertilizers, Indigenous Microbes, Maize, Malawi.

Introduction

Soil fertility is complex and dynamic due to interaction of several factors involved in nutrient release to the rhizosphere[1]. Attempt to increase agricultural productivity from a degrading land and ecological footprint has huge negative impact on agro-ecosystems[2]. The current strategy for improving and maintaining crop productivity, involves the use of green revolution techniques, promote usage of inorganic chemicals in which inorganic fertilisers provide selective nutrients viz. potassium (K), nitrogen (N) and phosphorous (P)[3,4]. Crops uses mall quantity of inorganic fertilizers high rate of fixation into insoluble complexes and denitrification[5–9]. This results into frequent and regular application of N,P,K and Zn based inorganic fertilizers which is costly and pollutant to the environmental[10]. The use of inorganic fertilisers in maize farming system results into long-term accumulation of P and K together with heavy metals, such as cadmium and fluoride besides accelerating eutrophication via leaching and run-off to waterways[11]. These contaminants can be passed in the food chain and are potentially toxic to animals and humans.

Like other tropical countries, Malawi agriculture soils contain high reserves of insoluble P, K and Zn [12], that has been deposited due to persistent inorganic fertilizers application and the parent material (also in form of rock phosphate)[12,13]. The current levels of total P is above 1000mg/kg of soil yet soluble P is extremely deficient with the concentration that can't meet crop demand[14]. Large portion of soluble P from other sources is rapidly immobilized and fixed because of high sorption to form compounds like tricalcium phosphate, aluminum phosphate (Al_3PO_4), iron phosphate (Fe_3PO_4), etc.[15,16]. Strong bonds between PO_4 and iron or aluminumin low pH soils and with Calcium and magnesium in high pH soils leads to high sorption[17].

Potassium is 7th common element and constitutes about 2.5% of the lithosphere and is the 3rd important plant nutrient[18]. Mica and feldspar are the most available sources of commercial K with values of above 90% [19]. This element is an essential macronutrient for activation of metabolic processes, plant growth and has a significant role in plant resistance to diseases and insects[20]. Like P, Potassium is an abundant element in soil ranging from 0.04-3.00% but only less than 2% is available to plants, because it's easily fixed by other minerals and therefore unavailable to plants[21].

Zn is also one of the most important micronutrient in reproduction and growth but demanded in low concentration (5–100mg/kg). Deficiency leads to reduction in production of auxins, sugars, cytochromes, chlorophyll and nucleotides[22–26]. Deficiency of Zn also has a huge impact on crop susceptibility to heat stress while in high concentration due the excess use of Zn fertilizers has negative implication in absorption of iron and copper in humans[23,24,27]. Tropical soil are deficient in soluble Zn because its solubility depends on moisture levels[28].

Naturally plant growth promoting microbes (PGPM) *viz.* phosphate solubilising microorganisms (PSM), potassium solubilising microorganisms (KSM) and zinc solubilising microorganisms (ZSM) transform organic and fixed (inorganic) P, K and Zn into soluble elements respectively[3,29,30]. PGPM, viz. nitrogen fixing bacteria, PSM, ZSM and KSM, have been proposed as a sustainable solution to agriculture productivity. PGPM has an implication on growth, nutrition, root pattern, abiotic stress and disease incidence[30–36]. Nitrogen fixing microbes are subdivided into ammonia and nitrite oxidizing microbes beside the free fixing microbes.

The use of biofertilisers is being done in legumes as a way of reducing the cost of fertilizer and increase soil fertility. But no research has been done on inoculating maize (combination of PGPM and inorganic fertilizers) in Malawi as an option to reduce fixation or increasing solubility of fixed nutrients in line with other research studies conducted on the same elsewhere[33,39–42]. These studies have exploited indigenous microbes that can be commercialized for solubilisation of fixed minerals and nitrogen fixation and potentiality of coinoculation. Exploitation of indigenous microbeshas an implication on adaptation to edaphic biotic and abiotic factors for high efficiency in terms of solubilisation and degradation compared to commercial ones. Therefore, the current study provided valuable economic feasibility using microbes involved in solubilisation of fixed minerals in Malawi.

The purpose of the study was to investigate potentiality of inoculating indigenous plant growth promoting microbes (Biofertiliser) (with ability to fix nitrogen and solubilise phosphorous, potassium and zinc) in maize cropping system to increase yield and yield components for smallholder farmers in Malawi. The study evaluated maize inoculant with the hope of solubilising fixed minerals in maize production. The outcome of the study has a positive impact to development of cheap and eco-friendly maize farming systems with high productivity.

Methodology

Study sites: The study was conducted at Chitedze Agricultural Research Station, GPS location 13°85'S. and 33°38'E at an altitude of 1,146m above sea level representing medium altitude areas. The same study was extended to high potential areas of on-farm conditions in Thyolo representing high altitude and acidic soils, Dowa and Chitipa districts representing diverse medium altitude with e soils of Malawi. The sites largely conform to mid and high altitude areas in Malawi and was conducted in 2018/2019-2019/2020 cropping seasons under both rain-fed and irrigation conditions.

Treatments and experimental design and management: One maize variety (SC 627) of medium maturity was used in the study. The experiment was conducted in a randomized complete block design (RCBD) with 3 replications. Under on-farm conditions, each farmer hosted the trial as a replicate. All the treatments were subjected to normal management practices for maize production in Malawi under both rain-fed and irrigation conditions. The land used for the trial had no history of inoculation of any microorganisms. i. Full rate recommended inorganic fertilizer application containing 92kgNha^{-1} (FB and FT), ii. Bio fertilizers plus half rate basal and full rate top dressing of recommended inorganic fertilizers (BHB and FT), iii. Bio fertilizers plus quarter rate of basal and full rate of top dressing of recommended inorganic fertilizers (BQB and FT), iv. Bio fertilizers plus nitrogen for basal and top dressing 23kg Nha^{-1} (BN and FT-23), v. Bio fertilizers plus top dressing with N fertilizers 23kgNha^{-1} (B and FT-23), vi. Bio fertilizers plus top dressing with N fertilizers 69kgNha^{-1} (B and FT-69), vii. Biofertilizers plus nitrogen for basal and top dressing 69kgNha^{-1} (BN and FT-69), viii. Bio fertilizers plus nitrogen for basal and top dressing 92kgNha^{-1} (BN and FT-92), ix. Bio fertilizers plus top dressing with N fertilizers 92kgNha^{-1} (B and FT-92), x. Bio fertilizers plus nitrogen for basal and top dressing 115kgNha^{-1} (BN and FT-115), xi. Bio fertilizers plus top dressing with N fertilizers 115kgNha^{-1} (B and FT-115), xii. Bio fertilizers only, xiii. No bio fertilizer nor inorganic fertilizer application (Control).

The 13 plots in each site measured 10 ridges×10m spaced at75 cm apart and intra-row spacing of 25cm. During the planting period for all cropping seasons, the various fertilizer treatments were assigned to their respective plots. For each bio fertilizer treatment, the maize seeds were inoculated with PGPM before planting and where inorganic fertilizer treatments were involved, application was done using dollop method in between the maize plants at basal and top dressing periods; thoroughly mixed with the soil. One maize seed was planted per hill in order to attain a plant population of 53,333 plants per hectare. Standard management practices for maize production were enforced for both on-station and on-farm fields.

Data collection and statistical analysis: In each field, soil samples were collected and analysed to determine their initial soil fertility in terms of pH, Nitrogen, Phosphorous, Potassium, Calcium, Magnesium, Iron, Manganese, CEC, Organic matter and Total Carbon. Grain and Stover yields were measured from each treatment. From the measured yields, the shelling percentage and harvest index were also computed. Maize plant nutrient content was also analysed to compare and contrast the performance of the treatments.

The collected data on yield and yield components was subjected to analysis of variance (ANOVA) using GenStat 18th edition and Minitab statistical software packages. Significant differences were assessed at 5% level and data mean separation was done using Fisher's protected least significant difference (LSD) procedure. After preliminary analysis of data, the presence of non-homogeneity in the data sets among the sites prompted a separate analysis for each site. The analysis was also done separately for irrigation and rain-fed conditions.

Results and Discussion

Native soil nutrient levels was diverse from low to high depending on soil depth and location as shown in Table-1. For soil P, Thyolo, Chitipa, Dowa and chitedze had adequate (19 - 25ug/g medium) to high (above 34ug/g). Zomba and chitedze average results indicated presence of low P for N, OM, and OC. In all sites Zn levels was extremely low.

The yield results revealed that integrating PGRMis dependent on rate of fertiliser and native nutrient levels not application pattern as shown by decrease of yield when rate increased to 115kg of nitrogen per hectare as shown in Table-2 to 5. Grain yield was different based on location for treatments with biofertiliser only which also had different native nutrient levels. Higher yields were obtained under irrigation in all sites for potential treatments. The effects of location and treatments on grain was significant, except for the season. Grain yield was economically achieved at the rate of 69kg of N per hectare (B-FT-69). The result predict that usage of low urea is a result of nitrifying microbes (ammonia and nitrite oxidizing microbes) which improve efficiency of urea[40]. The efficiency is a result of fast and percentage change to nitrate without loss through ammonia or ammonium as gas[41]. There was no significant difference in yield of grain if fertiliser split pattern was used.

Combined results shows that PGRM significantly improve nutrient absorption and plant growth shown by increase in nutrient content in grain and folder as shown in Table-12 and Figure-1 which is in line with other studies[42]. PGPM integration mainly where urea was the only inorganic fertiliser significantly increased nutrient content of maize grain and stalks (folder) as compared to where 23:10:56 Zn was applied Figure-1. This could be the effect of low cfu of solubilising microbes as shown in Figure-2 and Table-12 which is in line with other studies of applied fertiliser nutrients due to absence of solubilising microbes[9,43]. The application of phosphate based fertiliser has a negative impact to PGRM due to heavy metal contamination hence no solubilisation and oxidation of native and applied nutrients. These finding are in agreement with the previous reports that the increase in crop productivity to solubilizing and oxidizing microbes[44,45]. The increase in yield in terms of grain could be attributed by seed size as shown in Table-9 to 11. The results gives insight why grain produced using 100% inorganic fertilisers have low nutrient contents compared to those grown organically. This brings to the attention of incorporation of microbes in the soil either by biostimulation or inoculation in organic fertilisers or direct to soil.

The recorded results show significant differences within the treatments (average) of grain yield per plot or hectare, 100 grains, and folder (biomass). The maximum values of grain yield per hectare were obtained by usage of biofertilisers and top dressing with N fertilisers between 23-69kgN/Ha (B and FT). Use of PGRM (biofertilisers) has a positive influence due to direct and indirect production of phyto-hormones, solubilisation of fixed nutrients, nitrogen fixation and nutrient absorption by creation of high membrane potential in roots[4646]. Other study by Vacheron J, et al[47] found an increase in yield and nutrient parameters in treatments where inorganic fertilisers and bio-fertilizers were applied. The combined application of inorganic fertilisers and bio-fertilizer to crops compensates the deficiency of both micro and macro nutrients.

Table-1: average site native soil analysis result.

District	Soil Depth	pH	% OC	% OM	% N	P (ug/g)	K Cmol/Kg	Ca Cmol/Kg	Mg Cmol/Kg	Zn ug/g
Chitipa	0-20cm	5.41	0.594059	1.024158	0.051208	82.96005	2.974196	1.4897	0.1265	0.0234
	20-40cm	4	0.415842	0.716911	0.035846	55.17039	0.80816	0.3065	0.0339	0.3892
Dowa	0-20cm	4.98	0.80198	1.382614	0.069131	36.803	0.826491	1.6144	0.3735	0.034234
	20-40cm	5.31	0.891089	1.536238	0.076812	20.90887	1.296062	1.7534	0.5406	0.029467
Zomba	0-20cm	6.6	0.089109	0.153624	0.007681	16.30994	0.402988	0.575647	0.0054	0.030573
	20-40cm	7.14	0.80198	1.382614	0.069131	18.37683	0.373694	0.390964	0.006	0.030851
Chitedze	0-20cm	7.55	0.534653	0.921743	0.046087	15.22422	0.367255	0.675339	0.0057	0.063761
	20-40cm	7.28	0.861386	1.48503	0.074251	7.046608	0.294804	0.510382	0.0071	0.030573
Thyolo	0-20cm	6.22	1.572	2.710128	0.135506	105.876	0.0016	0.0392	0.004705	0.362961
	20-40cm	6.49	1.404	2.420496	0.121025	47.51157	0.0016	0.0253	0.006251	0.455184

Positive effect on grain nutrient levels in other treatments with same soil native nutrients may be a result of PGRM capability to solubilise insoluble nutrients based on type and levels of applied inorganic fertiliser[45]. The inorganic fertiliser affect number of inoculated PGRM in the soil. Photosynthetic capacity of crops is affected by absorbed micro and macro nutrients and that combination of inorganic and organic fertiliser supplies both[45,48]. The results showing nitrogen fixing microbes, nitrifying microbes and KSM availability regulating the interaction of other microbes as shown in Table-12 is responsible for increase in grain nutrient content which is in line with other studies[10,49,50].

The significant effects of biomass based on treatments as shown in Table-6 to 8 is in line with other researchers found that enhanced N, P, K and Zn released increases grain yield, biomass and 100-seed weight[51]. This is because nitrogen is an important nutrient in the soil and has implication on nutrient uptake, soil microbial diversity and general soil chemistry[52]. Grain nutrient content increase is due to microbial activity through solubilisation, oxidation, sorption, bioremediation and fixation factor[23,34,53–55]. The implication of inoculating PGRM results in increased change in microbial structure and functionality besides the numbers[23,30,56,57] as shown in Figure-2. Research[58] has reported that microbial diversity (species evenness and richness) was affected by application of fertiliser without integration of organic fertilisers. Increased microbial biomass and diversity by inoculation of PGRM improves soil health due to bioremediation as some microbes possess laccase gene besides solubilising traits. The decrease in grain nutrient content in treatments with NPK is as a result of xenobiotics associated with inorganic fertilisers which affected the CFU of PGRM as shown in Table-12 and Figure-2 [60].

Table-2: Grain yields (kg/ha) response to fertilizer application at Chitedze research station.

Treatments	Cropping season		Mean
	Irrigation	Rain-fed	
Control	893	893	893
B_0	1921	1637	1826
B_FT_115	5034	4907	4992
BN_FT_23	5168	5174	5170
BN_FT_115	5115	5374	5202
B_FT_23	5815	5056	5562
B_FT_92	5525	6204	5751
BQB_FT	5814	6326	5985
BN_FT_92	6230	6274	6245
BHB_FT	6190	6519	6300
BN_FT_69	6076	6889	6347
FB_FT	7172	6893	7079
B_FT_69	7277	7107	7220
	5249	5327	5257
	Treatment	Crop. season	Treatment x Crop. Season
F.Pr	<0.001	NS	NS
LSD	538	-	-
CV%	11	11	11

Table-3: Grain yields (kg/ha) response to fertilizer application in Dowa district.

Treatments	Cropping season		Mean
	Irrigation	Rain-fed	
Control	792	673	752
B_0	1216	1275	1236
B_FT_92	5729	5419	5625
BQB_FT	5782	5450	5671
BN_FT_92	5768	5605	5713
B_FT_23	5944	5424	5771
FB_FT	5965	5490	5806
BN_FT_115	5982	5758	5907
B_FT_115	6108	6129	6115
BHB_FT	6437	6044	6306
BN_FT_23	6542	6246	6443
B_FT_69	6706	6014	6475
BN_FT_69	6755	6233	6581
	5364	5058	5262
	Treatment	Crop. season	Treatment x Crop. Season
F.Pr	<0.001	<0.001	NS
LSD	287	120	431
CV%	6	6	6

Table-4: Grain yields (kg/ha) response to fertilizer application in Chitipa district.

Treatments	Cropping season		Mean
	Irrigation	Rain-fed	
Control	537	645	573
B_0	1210	1236	1219
B_FT_23	5777	4915	5490
B_FT_92	5842	4910	5531
BQB_FT	5848	4924	5540
FB_FT	5996	4809	5600
BN_FT_92	5904	5242	5683

BN_FT_115	6083	5333	5833
B_FT_115	6282	5513	6026
BN_FT_23	6399	5419	6072
BHB_FT	6454	5452	6120
BN_FT_69	6743	5507	6331
B_FT_69	6698	5716	6371
	5367	4586	5107
	Treatment	Crop. Season	Treatment x Crop. season
F.Pr	<0.001	<0.001	<0.002
LSD	327	136	490
CV%	9.7	9.7	9.7

Table-5: Grain yields (kg/ha) response to fertilizer application in Thyolo districts.

Treatments	Cropping season		Mean
	Irrigation	Rain-fed	
Control	891	836	873
B_0	1813	3081	2236
B_FT_23	3840	3909	3863
BN_FT_23	3874	4391	4046
B_FT_115	5030	4714	4925
BN_FT_115	4981	4919	4960
B_FT_92	5404	5940	5583
BQB_FT	5497	5985	5660
BN_FT_92	5881	6343	6035
BHB_FT	5866	6444	6059
BN_FT_69	5927	6447	6101
B_FT_69	7206	7107	7173
FB_FT	7243	7049	7179
	4881	5167	4976
	Treatment	Crop. season	Treatment x Crop. season
F.Pr	<0.001	<0.001	<0.005
LSD	368	153	552
CV%	11	11	11

Table-6: Stover yields (kg/ha) response to fertilizer application at Chitedze research station.

Treatments	Cropping season		Mean
	Irrigation	Rain-fed	
Control	7269	6173	6904
B_0	8216	7951	8127
BN_FT_115	8301	8593	8398
BHB_FT	8271	8780	8441
BN_FT_69	8396	9284	8692
B_FT_23	8984	9185	9051
BQB_FT	8914	9481	9103
B_FT_69	9066	9679	9270
BN_FT_92	9735	8588	9352
B_FT_115	9584	9185	9451
FB_FT	9081	11062	9741
BN_FT_23	9033	11309	9792
B_FT_92	10675	11012	10788
	8887	9252	9009
	Treatment	Crop. Season	Treatment x Crop. season
F.Pr	<0.001	NS	<0.02
LSD	915	-	1372
CV%	11	11	11

Table-7: Stover yields (kg/ha) response to fertilizer application in Chitipa district.

Treatments	Cropping season		Mean
	Irrigation	Rain-fed	
Control	6564	6069	6399
B_0	8154	7143	7817
BHB_FT	8779	7611	8390
BN_FT_115	8841	7488	8390
BN_FT_92	9109	8203	8807
BN_FT_69	9217	8007	8814
B_FT_23	9192	8137	8841

BQB_FT	9384	8230	8999
B_FT_69	9578	8351	9169
B_FT_115	9933	8681	9516
BN_FT_23	10260	8950	9823
FB_FT	10234	9178	9882
B_FT_92	10914	9104	10311
	11217	10068	10834
	Treatment	Crop. Season	Treatment x Crop. season
F.Pr	<0.001	<0.001	NS
LSD	528	220	0
CV%	8.9	8.9	8.9

Table-8: Stover yields (kg/ha) response to fertilizer application in Thyolo districts.

Treatments	Cropping season		Mean
	Irrigation	Rain-fed	
Control	7557	8598	7904
B_0	7912	8771	8198
BHB_FT	8142	9026	8436
BN_FT_115	8181	9005	8456
BN_FT_69	8257	9046	8520
FB_FT	8695	9787	9059
B_FT_23	8805	9710	9107
BQB_FT	8816	9733	9122
B_FT_115	9003	10018	9341
B_FT_69	9089	10078	9418
BN_FT_92	9229	10342	9600
BN_FT_23	9856	10721	10144
B_FT_92	10598	11582	10926
	8780	9724	9095
	Treatment	Crop. season	Treatment x Crop. season
F.Pr	<0.001	<0.001	NS
LSD	397	165	0
CV%	6.6	6.6	6.6

Table-9: Seed size (100 seed weight in grams) response to fertilizer application at Chitedze research station

Treatments	Cropping season		Mean
	Irrigation	Rain-fed	
Control	34	34	33
B_0	34	31	36
B_FT_115	37	34	37
B_FT_69	37	39	38
BN_FT_115	37	40	38
FB_FT	39	39	38
BN_FT_69	38	39	38
B_FT_92	38	37	38
BHB_FT	37	39	39
BN_FT_23	39	38	39
BN_FT_92	38	39	39
BQB_FT	39	38	39
B_FT_23	38	36	39
	39	38	38
	Treatment	Crop. season	Treatment x Crop. season
F.Pr	<0.001	NS	<0.004
LSD	2		2
CV%	4	4	4

Table-10: Seed size (100 seed weight in grams) response to fertilizer application in Chitipa districts

Treatments	Cropping season		Mean
	Irrigation	Rain-fed	
Control	30	30	30
B_0	33	32	33
B_FT_115	35	34	35
BN_FT_115	36	35	35
BN_FT_92	37	36	36
BN_FT_23	37	36	36
B_FT_92	37	36	37

BQB_FT	37	36	37
B_FT_69	37	36	37
FB_FT	38	35	37
BHB_FT	38	36	37
BN_FT_69	38	36	37
B_FT_23	38	37	38
	36	35	36
	Treatment	Crop. season	Treatment x Crop. season
F.Pr	<0.001	<0.001	NS
LSD	0.68	0.28	-
CV%	2.9	2.9	2.9

Table-11: Seed size (100 seed weight in grams) response to fertilizer application in Thyolo districts

Treatments	Cropping season		Mean
	Irrigation	Rain-fed	
Control	33	35	34
B_0	35	36	35
FB_FT	35	38	36
B_FT_115	36	38	36
BN_FT_69	36	38	37
B_FT_69	36	38	37
BN_FT_115	36	39	37
BHB_FT	37	39	38
B_FT_92	37	39	38
BN_FT_92	37	39	38
BN_FT_23	37	40	38
BQB_FT	37	40	38
B_FT_23	38	40	38
	36	39	37
	Treatment	Crop. season	Treatment x Crop. Season
F.Pr	<0.001	<0.001	NS
LSD	0.62	0.26	
CV%	2.5	2.5	2.5

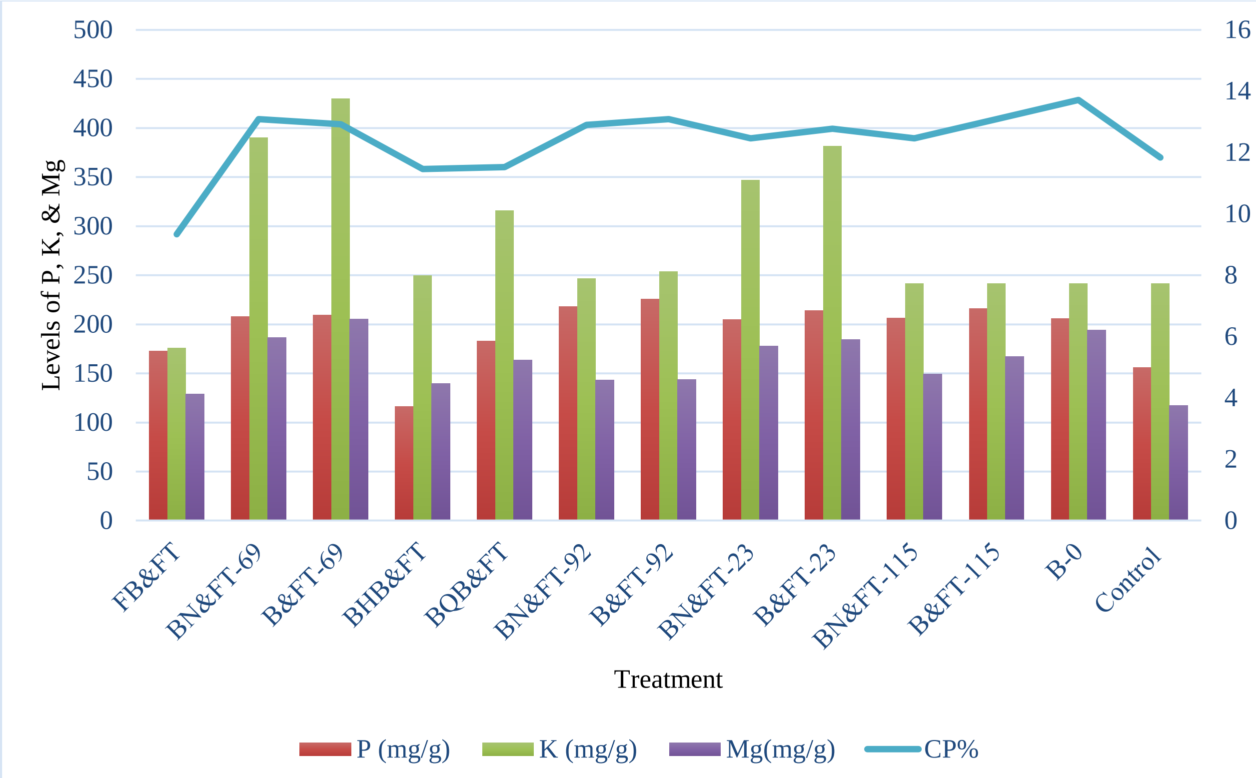

Figure-1: Effect of integrating PGPM on grain nutrient levels for Dowa district.

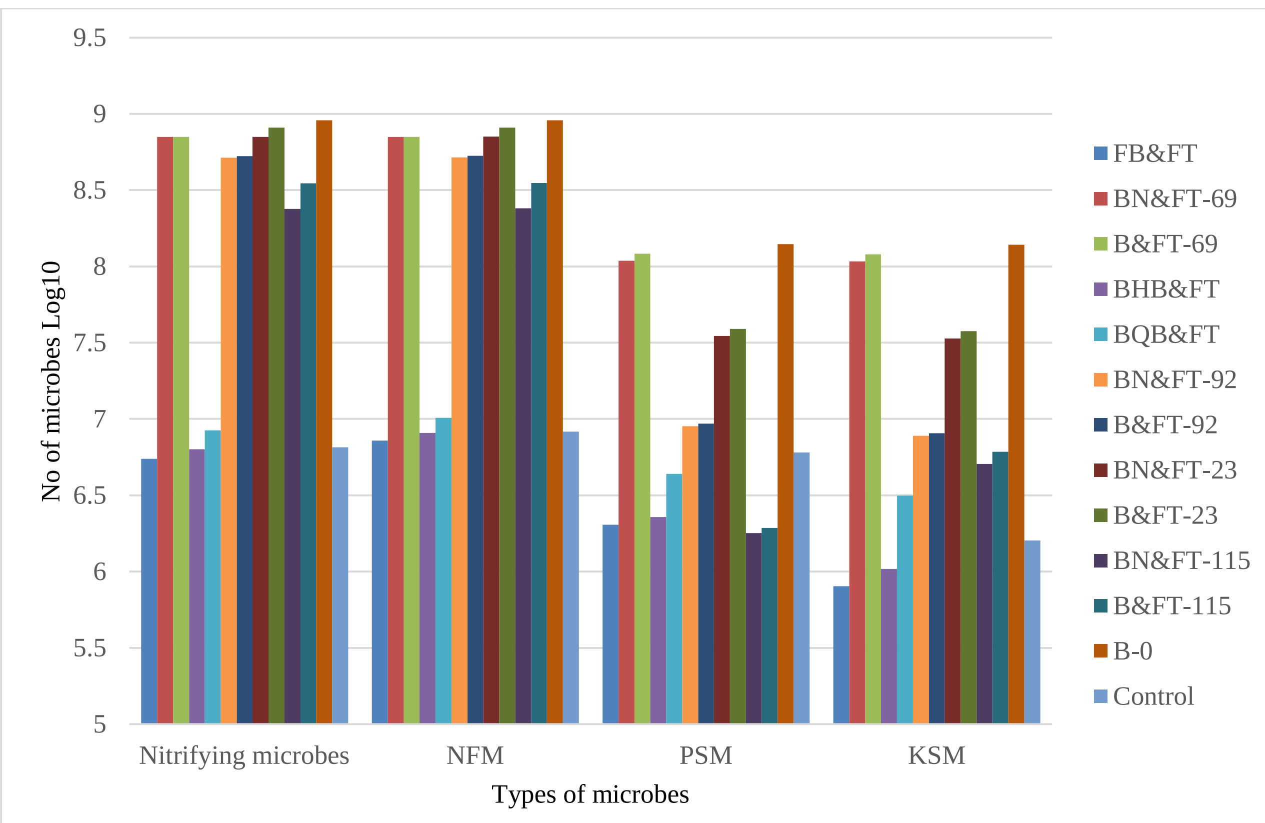

Figure-2: cfu levels of PGRM in different treatments at flowering stage.

Table-12: Correlation between diverse PGRM and grain nutrient content.

	treatment	Yield perha	Nitrif~s	NFM	PSM	KSM	N	P	K	Mg	Ca	CP	S
Yield perha	-0.7738	1											
	0												
Nitrifying~s	0.1319	-0.0468	1										
	0.4233	0.7771											
NFM	0.1319	-0.0468	1.0000*	1									
	0.4233	0.7771	0										
PSM	-0.1485	-0.0468	0.7367*	0.7367*	1								
	0.6061	0.7018	0	0									
KSM	-0.0791	-0.0506	0.7424*	0.7424*	0.9991*	1							
	0.6322	0.7596	0	0	0								
N	0.3224*	-0.0024	0.5431*	0.5431*	0.3736*	0.3800*	1						
	0.0453	0.9885	0.0004	0.0004	0.0192	0.017							
P	0.1532	0.1327	0.6607*	0.6607*	0.2859	0.3017	0.3358*	1					
	0.3518	0.4206	0	0	0.0777	0.0619	0.0366						
K	-0.2409	0.1973	0.5416*	0.5416*	0.5304*	0.5262*	0.4657*	0.2552	1				
	0.1396	0.2285	0.0004	0.0004	0.0005	0.0006	0.0028	0.1168					
Mg	0.4860*	0.0553	0.7871*	0.7871*	0.7966*	0.8084*	0.4921*	0.4860*	0.7545*	1			
	0.0017	0.8274	0	0	0	0	0.0015	0.0017	0				
Ca	0.4887*	-0.3437	0.085	0.085	-0.1954	-0.1856	-0.0936	0.2277	0.0553	0.0471	1		
	0.0396	0.1625	0.7373	0.7373	0.4372	0.4609	0.7119	0.3634	0.8274	0.8527			
CP	0.3224*	-0.0024	0.5431*	0.5431*	0.3736*	0.3800*	1.0000*	0.3358*	0.4657*	0.4921*	-0.0936	1	
	0.0453	0.9885	0.0004	0.0004	0.0192	0.017	0	0.0366	0.0028	0.0015	0.7119		
S	0.0187	0.2146	-0.1433	-0.1433	-0.0363	-0.0401	0.2145	0.0187	0.2146	0.087	-0.0007	0.2145	1
	0.9412	0.3925	0.5706	0.5706	0.8864	0.8746	0.3927	0.9412	0.3925	0.7315	0.9979	0.3927	

The findings show that inoculation of PGRM significant increase microbial biomass and activity due to correlation between nutrient levels and microbial count which is in line with other studies[61]. In general, the total CFU in inoculated treatments were deemed as sufficient for solubilisation, oxidation and fixation. The significant correlation of PGRM in the rhizosphere is due to the microbial ability to respond chemo tactically[62].

Grain and folder yields benefits by the use of biofertiliser has an implication to maize production due to decrease in productioncost[45]. Studies have also shown that long term application of biofertiliser has an implication on soil health which is in line with other studies[28,63].

Conclusion

The study has implicated potentiality of inoculating indigenous plant growth promoting microbes in maize cropping system in Malawi. The outcome of the study is showing positive impact of developing cheap and eco-friendly maize farming systems with high productivity.

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