Biological Forum – An International Journal **13(3a): 807-811(2021)**

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Growth and Yield Components of Maize (*Zea mays* L.) as influenced by Pink Pigmented Methylotrophic Bacteria in Integrated Nutrient Management

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(Received 19 July 2021, Accepted 30 September, 2021)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Maize is exhaustive crop and hence requires integrated approach for nutrient management. To address the same, Pink pigmented methylotrophic bacterial (PPMB) culture was applied as solid and liquid formulations (Basal and split) along with 100 % and 75 % RDF in maize. A field experiment was conducted during the summer season of 2021 at Shivamogga. The experiment was laid out in a randomized complete block design having twelve treatments with three replications. Among the treatments tested, application of 100% RDF + PPMB (Basal application of either solid/liquid formulations or split application of liquid formulation) recorded significantly higher plant height (206- 208 cm), leaf area (6100-6600 cm^2), dry matter (284- 297 g plant^{-1}), cob length (14- 15 cm), number of grains cob^{-1} (516- 543). By virtue of above parameters, said treatments recorded maximum grain (6167 to 6235 kg ha^{-1}), straw (8209- 8410 kg ha^{-1}) yield.

Keywords: PPMB, Solid, Liquid, Basal, Split, Maize, RDF.

INTRODUCTION

Maize (*Zea mays* L.) is the third important cereal crop after wheat and rice. India occupies third place in cultivated areas and production after rice and wheat (Anonymous, 2021). The crop is regarded as the queen of cereals because of its high production potential and wider adaptability. It is one of the important strategic crops with multiple uses for agricultural and industrial fields, used as basic raw material for the production of oil, starch, protein, alcoholic beverages, food sweeteners, syrup and used as feed for poultry etc. Being an exhaustive crop, it captures all the opportunity to use the available resources utmost.

Soil is a living entity and is regarded as a valuable resource for agricultural productivity and food security. Agricultural productivity rests on the microbial diversity present in the soil. Biofertilizers are essential components of Integrated Nutrient Management (Chauhan *et al.*, 2010). The potential biological fertilizers would play a key role in the productivity and sustainability of the soil. They serve as a renewable source of plant nutrients to supplement chemical fertilizers in the sustainable agricultural system (Mohammadi and Sohrabi 2012) by promoting plant growth and development by releasing phytohormones (Prasad *et al*., 2019). They also serve as a cost-effective input for the farmers and protect the soil environment as they are eco-friendly. Hence, plant growth-promoting rhizobacteria (PGPR) has emerged as an essential tool for sustainable agriculture. As a part of PGPR, PPMB is captivating field applications. In the present study, PPMB was tested for its efficacy to promote the growth and yield of maize under STZ of Karnataka.

MATERIALS AND METHODS

The study was conducted during the summer, 2021 at the College of Agriculture, Shivamogga (13°58′N to 14°1′N Latitude and 75°34′E to 75°42′E Longitude) with an altitude of 615 m MSL situated in the southern transition zone (STZ) of Karnataka. The soil of the experimental site was sandy loamy in texture, acidic in reaction (5.9), low in nitrogen (225.73 kg/ha) status, high and medium status with respect to phosphorous (64 kg/ha) and potassium (203 kg/ha) respectively. The crop was sown during the First fortnight of January and spaced at 60 × 30 cm. The experiment was laid out in Randomized Complete Block Design with three replications. The treatment details include T_1 -100 % RDF, T_2 - 75 % RDF, T_3- 100 % RDF + PPMB (Basal application of solid formulation), T_4 -100 % RDF + PPMB (split application of solid formulation), T_5: 100 % RDF + PPMB (Basal application of liquid formulation), T_6: 100 % RDF + PPMB (Split application of liquid formulation), T_7: 75 % RDF + PPMB (Basal application of solid formulation), T_8: 75 % RDF + PPMB (split application of solid formulation), T_9: 75% RDF + PPMB (Basal application of liquid formulation), T_{10}: 75% RDF + PPMB (split application of liquid formulation), T_{11}: 100% RDF + PSB + KSB (Basal application of solid formulation) and T_{12}: 100 % RDF + PSB + KSB (Basal application of liquid formulation). The organisms used were Pink pigmented methylotrophic bacteria, *Bacillus megaterium* (PSB) and *Frateuria aurentia* (KSB). Chosen biofertilizers were applied @12.5 kg ha^{-1} of solid culture and @625 ml ha^{-1} of liquid culture in the selected treatments along with 100 % RDF (150:75:40 kg ha^{-1} NPK) and 75 % RDF (112.5:56.25:30 kg ha^{-1} NPK). Wherein, the sources of nutrients applied were in the form of urea (46% N), Single super phosphate (16% P_2O_5) and Muriate of potash (60% K_2O). Farm yard manure @ 10 t ha^{-1} and *Azospirillum* @ 625 ml ha^{-1} were applied uniformly to all the plots. Irrigation was applied as and when required depending upon the climatic conditions.

RESULTS AND DISCUSSION

Plant height, number of leaves, and expansion are the important visible traits influenced by different applied treatments in the experiment. Statistical variations in the above parameters are observed. As seen from the data with time scale, both tallness and leafiness realized high, achieved about 185-200 cm with 12-15 leaves at 90 DAS, irrespective of treatments (Table 1). Application of 100 or 75% RDF (T_1 and T_2) did not reflect much difference either in plant height (190+ cm at 90 DAS) or number of leaves (13 + at 90 DAS). However, the leaf expansions do change, wherein 100% RDF achieved a leaf area of 6352.19 cm^2 $plant^{-1}$ (Kumar *et al.,* 2005) against 5872.13 cm^2 $plant^{-1}$ by 75% RDF application at the peak period of growth i.e. at 90 DAS. Further, in tune with the above trend, the leaf expansion remained a little different, in that 100 % RDF along with PPMB basal or split application of solid or liquid formulations achieved better most results (6100-6600 cm^2 $plant^{-1}$). This might be due to increased activity of meristematic cells, increased cell division and cell elongation and synergistic PPMB with native population of microorganisms and indirectly boosted the plant growth due to the synthesis of phytohormones and improving the local availability of nutrients. An increase in the number of leaves $plant^{-1}$ might be related to the rise in the uptake of nutrients through applied sources and biological nitrogen fixation by *Azospirillum* (Davaran *et al.,* 2015; Lucas *et al.,* 2018), which was used uniformly to all treatments. The results obtained were in accordance with the findings of Madhaiyan *et al.,* (2006), where PPFM foliar spray significantly influenced the leaf area. Increased leaf area promoted by methylotrophs was also observed by Pattanashetti *et al.,* (2013) in *Coleus forskohlii* under pot culture conditions. It is always true that better growth ends up in better yields. In the treatments T_3 to T_{12}, the microbial agents were added, reflected in the betterment of tallness, number of leaves and leaf expansion. From the data, it is envisioned that 100 % RDF along with PPMB (T_3 to T_6) marginally improved the tallness and number of leaves closely followed by 75 % RDF along with PPMB (T_7 to T_{10}) compared to without PPMB application (T_1 and T_2). It is also interesting to note that the application of 100 % RDF and PSB + KSB treatments (T_{11} and T_{12}) performed equally competitive. Similar results were also observed by Madhaiyan *et al.,* (2006) with the application of PPFM (Pink pigmented facultative methylotrophic bacteria) as a foliar spray. Further similar results were also reported by Radha *et al.,* (2009); Dhale *et al.,* (2010).

Table 1: Plant height, number of leaves, leaf area and total dry matter/plant at 90 days after sowing as influenced by the Pink pigmented methylotrophic bacteria.

Treatments	Plant height (cm)	Leaves (Number $plant^{-1}$)	Leaf area (cm^2)	Total dry matter (g $plant^{-1}$)
T_1	199.70	13.13	201.49	6352.19
T_2	192.83	13.07	203.31	5872.13
T_3	202.67	14.00	230.63	6537.91
T_4	190.00	12.73	247.90	6348.72
T_5	203.50	14.50	255.67	6606.84
T_6	201.83	13.47	256.04	6173.24
T_7	192.27	13.20	285.80	5971.84
T_8	195.27	13.00	295.35	6032.10
T_9	195.77	13.30	296.20	6051.81
T_{10}	187.00	12.27	309.67	5391.00
T_{11}	189.13	13.46	319.60	6258.85
T_{12}	195.66	12.40	322.08	6261.92
S.Em ±	3.66	0.41	12.94	216.04
CD at 5%	10.74	1.21	37.79	633.64

Data permits to infer that different treatments differed statistically for total dry matter accumulation (Table 1). It is concluded that the treatments 100 % RDF + PPMB (Basal application of solid or liquid formulations) recorded highest dry matter (248.77 and 252.10 g plant^{-1} at 90 DAS) closely followed by 100 % RDF + PPMB (Split application of solid or liquid formulations) and 75 % RDF + PPMB (Basal application of solid or liquid formulations) application as the values varied from 213.10 to 245.77 g plant^{-1} at 90 DAS. Higher dry matter production associated with the higher plant height, higher number of leaves signifies higher assimilatory area resulting more accumulation of photosynthates and with the higher proportion of nutrients supplied through RDF and duly supported by solubilization of PPMB and *Azospirillum* that enhanced further the crop growth and ultimately results in higher dry matter production. The study is supported by Raja and Sundaram (2006) indicated that individual and combined inoculation effect of PPFM and other bio inoculants on cotton, which resulted in increased seedling vigour and dry matter production. It is seen from the data (Table 3) that plant height and number of leaves correlated significantly, while leaf area and the dry matter remained highly significant. Together they contributed 62 per cent of variations in yield.

Table 2: Cob length, number of grains cob^{-1}, grain yield, straw yield and harvest index as influenced by the pink pigmented methylotrophic bacteria.

Treatments	Cob length (cm)	Number of Grains cob^{-1}	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)
T_1	13.87	514	5942	7861	43.07
T_2	13.23	495	5499	7944	40.96
T_3	14.17	524	6229	8333	42.80
T_4	13.87	458	5999	8161	42.37
T_5	14.43	543	6235	8410	42.57
T_6	14.03	516	6167	8209	42.91
T_7	13.20	458	5812	8083	41.89
T_8	13.60	508	5719	8067	41.55
T_9	13.60	472	5738	7842	42.31
T_{10}	12.57	445	5515	7774	41.12
T_{11}	13.83	456	5863	8092	42.00
T_{12}	13.06	460	5931	8148	42.13
S.Em ±	0.35	9.25	117.83	285.50	0.95
CD at 5%	1.02	27.15	345.58	NS	NS

Table 3: Correlation and regression studies of yield v/s growth and yield components.

Correlation		Regression equation
Plant height (x_1)	0.4018*	$Y= 1697.92- 0.94x_1 + 10.06 x_2 + 0.21 x_3 + 12.58 x_4$ (R^2 =0.6170)
No. of leaves (x_2)	0.3664*	
Leaf area (x_3)	0.6370**	
Dry matter (x_4)	0.7283**	
Cob length (x_1)	0.6257**	$Y= 2415.28+ 182.06 x_1 + 2.04x_2$ (R^2 = 0.4321)
No. of grains (x_2)	0.5062**	

Note: Y= Dependent factor (Yield) x= Independent factor; Number of observations = 36; $P_{0.05}$ = 0.325; $P_{0.01}$ = 0.419
*- Significant; ** - Highly significant

Comparatively lower growth performance resulting yield parameters was seen in the treatments without bio-agents. On the other hand, upon application of PPMB influenced the different yield parameters to a significant level. Plots receiving 100 % and 75 % RDF (T_1 and T_2) recorded 13.87 and 13.03 cm cob length and 514 and 495 grains cob$^{-1,}$ respectively. It is to be noted here that basal application of solid or liquid PPMB along with 100 % RDF improved cob length to 14.17 and 14.43 and grains cob^{-1} to 524 and 543, respectively. On the other hand, solid formulations of PPMB with 75 % RDF with split application also improved the number of grains cob^{-1} to 508 and became competitive for achieving better yields. Cob length and the number of grains cob correlated to yield with highly significant, wherein, together contributed 43 per cent of variations in output. The synthesis, accumulation and translocation of photosynthates depend on the efficient source and sink relationship and the growth and development of plants at early stages. Hence, the influence of PPMB extended from better growth to the number of grains cob^{-1} which distinctly differed in different treatments. This might be due to the mineralization of immobile nutrients resulting higher nutrient uptake and efficient translocation of photosynthates from source to sink. Abd El-Gawad *et al.*, (2015) reported that PPFM alone increased the pod number and yield per plant and further improved the pod quality by increasing their concentration for amino acid, protein, total sugars and ascorbic acid in snap beans. The results are also corroborating the findings of Madhaiyan *et al.*, (2006).

Morphological, physiological and environmental parameters constantly influence the growth habit of plants and together dictate the economic part. In the present study, grain yield differed significantly due to PPMB application with variations from 5499 to 6235 kg ha^{-1}. Among the treatments, the application of 100 % RDF yielded 5942 kg ha^{-1}. Compared to this, PPMB basal application along with 100 % RDF, the yield level rose to 5999-6229 kg ha^{-1} but without any statistical significance. On similar lines, plots receiving 75 % RDF yielded 5499 kg ha^{-1} whereas, PPMB application along with 75 % RDF resulted in enhancing the yield levels to 5515 to 5812 kg ha^{-1}, again without statistical significance. It is observed that basal application of either solid or liquid formulations yielded numerically better over split application of either formulation. In that, plots receiving 100 % RDF + basal application of PPMB either solid (6229 kg ha^{-1}) or liquid (6235 kg ha^{-1}) formulation out-yielded other treatments and found statistically significant over plots receiving 75 % RDF (5499 kg ha^{-1}) or 100 % RDF + PSB + KSB (Basal application of solid formulations) (5863 kg ha^{-1}) and 75 % RDF along with PPMB applications (5515-5812 kg ha^{-1}). In fact, the chosen two treatments were closely followed by 100 % RDF + split application of PPMB either liquid (6167 kg ha^{-1}) or solid (5999 kg ha^{-1}) formulations. An increase in grain yield could be due to the application of PPMB along with RDF and *Azospirillum* inoculation (Hungria *et al.,* 2010) made the nutrients available to plant throughout the growing period as reflected by increased growth components and dry matter, resulting in higher number of grains and cob weight. PPMB synergistically influenced the native microbial population and directly affected the nutrient solubilization and mobilization in soil. The results are akin to the findings of Pattanashetti *et al*., (2013); Raja and Sundaram (2006); Nysanth *et al.*, (2019). Straw yield not differed significantly, but numerically the values are high for 100 % RDF with the basal or split application of either solid or liquid PPMB (8161- 8410 kg ha^{-1}) against 100 % RDF (7861 kg ha^{-1}) and 75 % RDF with PPMB application (7774- 8083 kg ha^{-1}) and without application of PPMB (7944 kg ha^{-1}). This might be due to higher dry matter production as influenced by PPMB. The results were following Abd El-Gawad *et al*., (2015); Thangamani and Sundaram (2007).

CONCLUSION

As a part of integrated nutrient management, it was found that use of PPMB (Basal or Split application of liquid formulations and Basal application of liquid formulations) along with 100 per cent RDF recorded higher plant height, leaf area, dry matter, yield parameters and grain yield.

FUTURE SCOPE

1. The developed PPMB consortia need to be evaluated on different region crops under both greenhouse and field conditions.
2. The compatibility of the PPMB with other PGPR should be evaluated for sustainable crop production.

Conflict of Interest. None.

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How to cite this article: Vedavani, R., Kumar D. M., Nandish M.S., Veeranna, H.K. and Salimath, S.B. (2021). Growth and Yield Components of Maize (*Zea mays* L.) as influenced by Pink Pigmented Methylotrophic Bacteria in Integrated Nutrient Management. *Biological Forum – An International Journal, 13*(3a): 807-811.