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Effect of Drip Fertigation of Nitrogen, Potassium and Microbial Consortium on Growth, Yield, Water Productivity and Economics of *Rabi* Maize (*Zea mays* L.)

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ABSTRACT

A field experiment was conducted on maize (*Zea mays* L.) during *rabi* (November to February), 2018–19 to study the effect of drip fertigation of Nitrogen (N), Potassium (K) and microbial consortium (MC) on growth, yield, water productivity and economics at Water Technology Centre, PJTSAU, Hyderabad, Telangana state, India. The experiment was laid out in randomised block design and replicated thrice. The treatments, comprising of two fertility levels viz., 75% and 100% recommended dose (RD) of N and K as first factor and biofertigation of Microbial Consortium (MC) as second factor. The interaction effect between RD of N and K and biofertigation of MC was not significant. Significantly higher LAI, DMP, grain yield and water productivity was recorded with fertigation of 100% RD N and K compared to 75% RD N and K. Biofertigation of MC 5 times and 3 times recorded significantly higher LAI, DMP, grain yield and water productivity. Net returns recorded with fertigation of 75% and 100% RD of N and K were not significantly different. Among biofertigation of MC, significantly higher net returns were observed in biofertigation of MC five times and was on par with biofertigation of MC three times. 75% RD of N and K recorded higher B:C ratio and was on par with 100% RD N and K in fertigation levels. Among biofertigation of MC, there was no significant difference in B:C ratio was observed between biofertigation of MC five times and three times and were significantly superior over soil application of MC.

KEYWORDS: B:C ratio, biofertigation, dry matter production, leaf area Index

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1. INTRODUCTION

Maize is the second most important crop in terms of global acreage. It can be grown in wider range of Agro-climatic zones (Joshi et al., 2005). In India it is cultivated in an area of 9.8 mha with an average production of 30.2 mt and productivity of 3057 kg ha^{-1} (Anonymous, 2020). Use of modern irrigation technologies become inevitable to earn good revenue by the farmers (Berbel et al., 2018). Efficient irrigation management and seed priming can increase maize yield and water productivity in arid environments (El-Sanatawy et al., 2021). Micro-irrigation systems, a system wherein higher yields can be obtained by utilizing the limited water resources (Du et al., 2015). Drip irrigation eliminates water loss over flooding (Ahadi et al., 2013). Drip irrigation slowly delivers water directly to a plant's root system (Plusquellec, 2009). Drip irrigation offers most suitable alternative for higher fertilizer and water use efficiency (Seema et al., 2022). Drip irrigation can save water up to 40 to 70% (Reddi and Reddy, 2017). Drip irrigation increased net profit by 23%, and reduced water application by 57% (Zhang et al., 2021). Drip irrigation had positive effects on improving maize yield (Cao et al., 2022). Fertilizer usage can also be optimized using drip fertigation (Smith et al., 2016). Surface drip irrigation increased water productivity by 259% in maize over furrow irrigation (Sandhu et al., 2019). Surface drip fertigation increased the water productivity of maize by 28% over rainfed situation and recommended for increased economic benefit in sandy soils (Wu et al., 2019). Water productivity and net returns generally increased as drip irrigation and fertilization amount increased in maize (Zou et al., 2020). Optimum economic yield and water use efficiency of silage maize can be obtained with reduced doses of Nitrogen (186 kg N ha^{-1}) using drip fertigation (Demir et al., 2021). Drip fertigation led to significantly higher water productivity (26.4%) over furrow or flood irrigation (Li et al., 2021). The water use efficiency for drip irrigation treatments increased by 13.9–39.2% over mulched furrow irrigation (Wang et al., 2021a). Grain yield, economic benefit, water productivity and nitrogen use efficiency were significantly affected by plant density, N rate and their interaction under drip fertigation in maize (Lai et al., 2022).

Any integrated plant nutrient management (IPNM) strategies that manage the NPK status and dynamics in the soil are a promising avenue for improving the growth and productivity of maize grown in the arid agro-ecosystem (Al-Suhaibani et al., 2021). Combined application of bio-fertilizers and fertilizers along with cow urine has enhanced soil physical and microbiological properties and addition of nutrients in soil with saving of at least 50% of water (Kumar et al., 2017). The application of biofertilizers increased the diversity and richness of the bacterial community in the maize rhizosphere soil (Wang et al., 2021b). Biofertilizers promote plant growth by supplying essential nutrients, such as nitrogen and phosphorus (Afanador-Barajas et al., 2021). Maximum gross, net returns and B:C ratio were noticed with integration of 75% RDF with 25% N through FYM in conjunction with biofertilizers in preceding *kharif* baby corn (Preetham et al., 2020). Highest net returns and B:C ratio possible through application of 75% RDF+vermicompost @ 2.5 t ha^{-1}+mixed bio-fertilizers in baby corn (Mahapatra et al., 2018). The maximum gross returns, net returns and B:C ratio were recorded by liquid bioinoculants and mulch in soybean (Rahangdale et al., 2022). Biofertilizers and drip irrigation are the fastest growing segments in India. Hence, the present study was planned to evaluate the effect of fertigation of biofertilizers and inorganic fertilizers (N and K) on growth, yield, water productivity and economics of *rabi* maize.

2. MATERIALS AND METHODS

2.1. *Study site*

A field experiment was conducted on *rabi* maize (*Zea mays* L.) at Water Technology Centre, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad, Telengana State, India during *rabi* (November–February), 2018–19. The farm is geographically situated at 17°32'37'' N Latitude, 78°40'88'' E Longitude and altitude of 534 m above mean sea level. The experimental soil was loamy in texture, moderate in infiltration rate, slightly alkaline and non-saline in reaction. The fertility status of the experimental soil was low in organic carbon, low in available N, medium in phosphorus, high in available potassium contents and sufficient in available Zn status.

2. 2. *Details of experiment*

The treatments, comprising of 2 fertility levels viz., 75% and 100% recommended dose (RD) of nitrogen and potassium (N and K) as first factor and biofertigation of Microbial consortium (MC) viz., soil application of MC (SMC), biofertigation of MC three times (MC_3), biofertigation of MC five times (MC_5) and without application of MC (MC_0) as second factor. The recommended dose of (RD) nutrients were 240:80:80 kg $N:P_2O_5:K_2O$ ha^{-1}. The spacing adopted for sowing was 80×15 cm^2. N and K was applied in different doses (75% and 100% RDF) through fertigation at an interval of 3 days in the form of urea and SOP (white) and drip irrigation was scheduled at 1.2 Epan during the entire crop growth period. The recommended dose of fertilizers i.e., 240:80:80 kg of $N:P_2O_5:K_2O$ ha^{-1} were applied during fertigation treatments. The entire dose of phosphorus was applied to soil as basal whereas nitrogen and potassium were applied through fertigation at 3 days interval by dissolving the required quantity of fertilizer as per the crop need plot^{-1} and applied through venturi system. The liquid Microbial consortium consisted of *Azotobacter chrococcum* (Non symbiotic heterotrophic N_2 fixing bacterium), P solubilizing bacteria (*Pseudomonas flourescens*), K releasing bacteria (*Bacillus mucilaginaceous*) and Zn solubilizing bacteria (*Bacillus edapicus*). It was applied through drip irrigation system @ 1.5 L (with microbial count of 10^{12} cell ml^{-1}) diluted in 500 L of water for one hectare (except for soil application). Fertigation of microbial consortium was started from 10 days after sowing (DAS) at 10 days interval. In three times application the scheduling was at 20, 30 and 40 DAS and in 5 times application it was extended up to 60 DAS. Soil application of microbial consortium was done at 10 DAS @ 1.5 L (with microbial count 10^{12} cell ml^{-1}) mixed with 150 kg of vermicompost for one hectare and applied along the plant rows.

2. 3. Method of data collection

2.3.1. Leaf area index (LAI) & dry matter production (kg ha^{-1})

The total leaf area was measured at 30, 60, 90 DAS and at harvest with LI 3100 leaf area meter (LI-COR, INC. Lincoln, Nebraska, USA) and the leaf area index was calculated and for dry matter production, from each plot, five plants were uprooted carefully at same intervals and samples were first air dried in shade for one day and then oven dried at 60 ^{O}C till a constant weight was obtained. The mean dry weight of plant samples was expressed as kg ha^{-1}.

2.3.2. Yield attributes & Yield (kg ha^{-1})

Data on yield attributes like number of rows cob^{-1}, cob weight plant^{-1}, number of grains cob^{-1}, grain weight cob^{-1}, test weight and shelling percentage was collected from five randomly selected maize cobs in each net plot and the mean value was computed and was also calculated using cob weight and grain weight of five randomly selected maize cobs in each net plot. Yield parameters (Grain and stover yield) were recorded from net plot area including the yield obtained from selected five plants and expressed as kg ha^{-1}. Harvest index (%) was calculated using grain and stover yield and expressed in percentage.

2.3.3. Water productivity (WP, kg m^{-3})

Water productivity is the ratio of economic yield (grains) produced to the unit quantity of water consumed.

2.3.4. Economics

The Gross returns (₹ ha^{-1}) were calculated using grain and stover yield with existing market price. Net returns were calculated by subtracting the cost of cultivation from gross returns for each treatment and expressed in ₹ ha^{-1}. The benefit cost ratio (BCR) was worked out by using the gross and net returns.

2.4. Statistical Design and Analysis

The experiment was laid out in randomized block design with maize hybrid DHM-117 and replicated thrice. The data generated in this study were analyzed using standard statistical methods through factorial concept as there was significant variation among the treatments was observed.

3. RESULTS AND DISCUSSION

3.1. Leaf area index (LAI)

The leaf area index (LAI) was significantly influenced by fertigation with RD N&K and biofertigation of MC at 60 and 90 DAS and was not significant at 30 DAS and at harvest. The interaction effect between RD N&K and Biofertigation of MC was not significant at all growth stages of crop (Table 1).

Table 1: Effect on leaf area index (LAI) of *rabi* maize

Treatment	30 DAS	60 DAS	90 DAS	At harvest
RD N & K				
100% RD N&K	0.80	4.68	5.08	1.82
7% RD N&K	0.76	4.42	4.85	1.81
SEm±	0.02	0.04	0.03	0.01
CD (*p*=0.05)	NS	0.11	0.10	NS
Biofertigation				
MC_0	0.76	4.40	4.84	1.80
SMC	0.78	4.50	4.96	1.81
MC_3	0.79	4.61	5.01	1.83
MC_5	0.80	4.68	5.05	1.83
SEm±	0.02	0.05	0.05	0.01
CD (*p*=0.05)	NS	0.15	0.15	NS
Interaction between RD N&K and biofertigation				
SEm±	0.03	0.07	0.07	0.01
CD (*p*=0.05)	NS	NS	NS	NS

RD of N and K: 100% RD (240:80 kg N:K_2O ha^{-1}); 75% RD (180:60 kg N:K_2O ha^{-1}); Biofertigation: MC_0: Without microbial consortium (MC); SMC: Soil application of MC; MC_3-Biofertigation of MC three times; MC_5: Biofertigation of MC five times

At 30 DAS and at harvest there was no significant difference in LAI either due to fertigation of RD N&K or biofertigation of MC and interaction effect between them. However, LAI was ranged from 0.74 to 0.82 at 30 DAS and 1.79 to 1.83 at harvest.

Significantly higher LAI at 60 and 90 DAS was recorded with fertigation of 100% RD N&K (4.68 and 5.08) compared to 75% RD N&K (4.42 and 4.85).

The LAI increased at 60 and 90 DAS with increase in fertigation of RD N&K level from 75% to 100% and this was due to increase in availability of nitrogen and P_2O_5 and there by uptake of NPK caused leaf area increase due to chlorophyll increase, cell division, photosynthesis and vegetative growth in the plants.

At 60 and 90 DAS biofertigation of MC five times recorded significantly higher LAI (4.68 and 5.05) than that of treatment where MC was not applied (4.40 and 4.84) and was on par with the biofertigation of MC three times (4.61 and 5.01). Similarly, significantly lower LAI at 60 and 90 DAS was observed in treatment without MC which was on par with soil application of MC (4.50 and 4.96). LAI observed at 60 and 90 DAS in soil application of MC was on par with biofertigation of MC three times. The increase in leaf area is due to the promotion of nitrogen fixation by Azotobacter, an increase in cell division and enlargement as well as its effect in metabolic processes in plant organs and promotion of root systems and increased absorption of food elements by solubilizing insoluble phosphates through reactions in rhizosphere therefore resulted in increased availability of nutrients and uptake of NPK which increase growth and in turn leaf area.

3.2. Dry matter production (kg ha^{-1})

Dry matter of rabi maize increased progressively with advance in age of crop up to harvest. DMP was significantly influenced by fertigation of RD N&K and biofertigation of MC. The interaction effect between RD N&K and biofertigation of MC was not significant at all growth stages i.e. 30, 60, 90 DAS and at harvest. There was no significant difference in DMP recorded with fertigation of RD N&K and biofertigation of MC at 30 DAS. However, it ranged from 579.2 to 593.1 kg ha^{-1}.

Fertigation with 100% RD N&K recorded significantly higher dry matter at 60, 90 DAS and at harvest (8563, 17608 and 19081 kg ha^{-1}) compared to 75% RD N&K (7844, 16681 and 18145 kg ha^{-1}).

Increase in dry matter was observed due to increase in fertigation of RD N&K from 75 to 100% and it might be due to higher availability and uptake of nutrients NPK and DMP resulting in higher plant height, number of leaves and leaf area plant^{-1} and there was a significant and positive correlation between growth parameters at 90 DAS and DMP at harvest resulting in higher DMP with higher fertigation level.

Among biofertigation of MC, significantly higher DMP at 60, 90 DAS and at harvest was observed in biofertigation of MC five times (8567, 17555 and 19180 kg ha^{-1}) and three times (8389, 17347 and 18957 kg ha^{-1}) than the treatment in which MC was not applied (7693, 16481 and 17785 kg ha^{-1}) and was on par with soil application of MC (8165, 17194 and 18529 kg ha^{-1}). Significantly lower DMP was observed treatment without application of MC at 60 DAS and at harvest and was on par with the soil application of MC at 90 DAS.

DMP, which reflects the total plant growth, increased with increase in plant height and LAI which might be due to rapid release of nutrients in soil through organic and inorganic resources by Azotobacter, PSB, KRB and ZnSB microorganism in microbial consortium. Besides these, they also release biologically active substances such as auxins, cytokinins, amino acids and vitamis which could be attributed to increased root growth which in turn enhances the nutrient and water uptakes from soil and there was a significant and positive correlation between uptake of N, P and K and DMP which contributes to more buildup of DMP by plant (Table 2).

Table 2: Effect on Plant dry matter production (kg ha^{-1}) of *rabi* maize

Treatment	30 DAS	60 DAS	90 DAS	At harvest
RD N & K				
100% RD N&K	591	8563	17608	19081
7% RD N&K	582	7844	16681	18145
SEm±	4	142	180	166
CD (*p*=0.05)	NS	432	546	504
Biofertigation				
MC_0	584	7693	16481	17785
SMC	587	8165	17194	18529
MC_3	588	8389	17347	18957
MC_5	588	8567	17555	19180
SEm±	6	201	254	235
CD (*p*=0.05)	NS	611	772	713
Interaction between RD N&K and biofertigation				
SEm±	8	285	360	332
CD (*p*=0.05)	NS	NS	NS	NS

RD of N and K: 100% RD (240:80 kg N:K_2O ha^{-1}); 75% RD (180:60 kg N:K_2O ha^{-1}); Biofertigation: MC_0: Without Microbial Consortium (MC); SMC: Soil application of MC; MC_3: Biofertigation of MC three times; MC_5: Biofertigation of MC five times.

3.3. Yield (kg ha^{-1})

3.3.1. Yield attributes

The data collected on yield attributes (Table 3) indicated that there was significant difference due to drip fertigation of 75% or 100% RD N&K and due to biofertigation of MC and the interaction effect between RD N&K and biofertigation of MC on yield attributes was not significant.

3.3.1.1. Number of rows cob^{-1}

Higher number of rows cob^{-1} of 14.9 was observed with fertigation of 100% RD N&K and was significantly superior over 75% RD N&K (14.5). There was no significant difference in number of rows cob^{-1} between biofertigation of MC five times (15.0) and three times (14.8) and both were significantly superior to soil application of MC (14.6)

Table 3: Effect on yield attributes of *rabi* maize

Treatment	Rows cob^{-1} (No.)	Cob weight $plant^{-1}$ (g)	Grains cob^{-1} (No.)	Grain weight cob^{-1} (g)	Seed index (g)	Shelling (%)
RD N & K						
100% RD N&K	14.9	240.3	479	149.8	31.15	62.4
7% RD N&K	14.5	230.1	449	137.2	30.91	59.6
SEm±	0.1	1.3	5	2.2	0.08	1.1
CD (p=0.05)	0.2	3.9	17	6.8	NS	NS
Biofertigation						
MC_0	14.3	226.3	442	134.5	30.93	59.4
SMC	14.6	233.5	458	141.2	31.00	60.5
MC_3	14.8	238.8	474	147.5	31.05	61.7
MC_5	15.0	242.2	482	151.0	31.14	62.4
SEm±	0.1	1.8	8	3.2	0.11	1.6
CD (p=0.05)	0.3	5.5	25	9.7	NS	NS
Interaction between RD N&K and biofertigation						
SEm±	0.1	1.84	8	3.2	0.16	1.6
CD (p=0.05)	NS	NS	NS	NS	NS	NS

RD of N and K: 100% RD (240:80 kg N:K_2O ha^{-1}); 75% RD (180:60 kg N:K_2O ha^{-1}); Biofertigation: MC_0-Without Microbial Consortium (MC); SMC-Soil application of MC; MC_3: Biofertigation of MC three times; MC_5: Biofertigation of MC five times

and without application of MC (14.3). Biofertigation of MC three times and soil application of MC was on par with other. However, number of rows cob^{-1} observed with soil application of MC was on par with the treatment where no MC was applied.

3.3.1.2. Cob weight $plant^{-1}$

Significantly superior cob weight $plant^{-1}$ (240.3 g) was recorded with fertigation of 100% RD N&K compared to 75% RD N&K (230.1 g). Biofertigation of MC five times recorded maximum cob weight $plant^{-1}$ (242.2 g) which was on par with the biofertigation of MC three times (238.8 g) and was significantly superior to soil application of MC (233.50 g) and without application of MC (226.3 g). However, biofertigation of MC three times was on par with soil application of MC.

The increased nutrient uptake due to fertigation of RD N&K and biofertigation of MC resulted more photosynthetic area, photosynthesis and translocation of photosynthates increased the cob length, cob girth and number of rows cob^{-1}, this contributed to the increasing the cob weight $plant^{-1}$.

3.3.1.3. Grain number cob^{-1}

Drip fertigation with 100% RD N&K recorded significantly higher number of grains cob^{-1} (479) than that of 75% RD N&K (449). Maximum number of grains cob^{-1} (482) was observed with biofertigation of MC five times which was on par with the biofertigation of MC three times (474) and soil application of MC (458) and significantly superior over without MC (442). The treatment without MC recorded significantly lower grain number cob^{-1} than biofertigation of MC five and three times and was on par with the soil application of MC.

Increased LAI facilitated more synthesis and translocation of photosynthates to sink due to more uptake of nutrients besides producing vitamins and plant growth promoting substances which increased the cob length, cob girth and number of rows cob^{-1}, this contributed to the increasing the number of grains cob^{-1}.

3.3.1.4. Grain weight cob^{-1}

Drip fertigation of 100% RD N&K recorded higher grain weight cob^{-1} (149.9 g) and was significantly superior to 75% RD N&K (137.2 g). Among biofertigation, significantly maximum grain weight cob^{-1} (151.0 g) was recorded with biofertigation of MC five times compared to soil application of MC (141.2 g) and without application of MC (134.5 g) and was on par with biofertigation of MC three times (147.5 g). There was no significant difference between soil application of MC and biofertigation of MC three times. Significantly lower grain weight cob^{-1} was recorded without application of MC than biofertigation of MC five and three times and was on par with the soil application of MC.

This might be due to positive effect of inorganic fertilizers (N&K) and biofertilizers (Azotobacter, PSB, KRB and ZnSB) on better root development which resulted in increase in nitrogen, phosphorus, potassium and other nutrient availability and their uptakes which resulted in higher plant height, increased LAI there by synthesis and translocation of photosynthates to sink besides producing vitamins and plant growth promoting substances which increased the cob length, cob girth and number of rows cob^{-1}, this contributed to the increasing the number of grains cob^{-1} and finally the grain weight cob^{-1}.

3.3.1.5. Shelling percentage

Shelling percentage was not significantly influenced by fertigation with RD N&K and biofertigation of MC, however it was ranged from 58.3 to 62.4%.

3.3.1.6. Test weight (100 grain)

There was no significant difference on test weight of maize grains was recorded with fertigation of RD N&K and biofertigation of MC. However, the test weight was ranged from 29.70 to 31.35 g.

3.3.2. Grain yield (kg ha^{-1})

The yield attributes, grain, stover and biological yield of rabi maize was significantly influenced by fertigation with RD N&K and biofertigation of MC and there was no significant influence by their interaction (Table 4).

Among the biofertigation treatments, maximum grain yield (7304 kg ha^{-1}) was achieved with biofertigation of MC five times which was on par with the biofertigation of MC three times (7230 kg ha^{-1}), soil application of MC (7118 kg ha^{-1}) and was significantly superior over the treatment without application of MC (6758 kg ha^{-1}).

Table 4: Effect on grain, stover, biological yield (kg ha^{-1}) and harvest index (%) of *rabi* maize

Treatment	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
RD N & K				
100% RD N&K	7254	11828	19082	38.0
7% RD N&K	6951	11194	18145	38.4
SEm±	73	126	166	0.3
CD (p=0.05)	222	382	504	NS
Biofertigation				
MC_0	6758	11028	17786	38.0
SMC	7118	11412	18530	38.4
MC_3	7230	11728	18958	38.2
MC_5	7304	11877	19181	38.1
SEm±	103	178	235	0.4
CD (p=0.05)	314	541	713	NS
Interaction between RD N&K and biofertigation				
SEm±	146	252	332	0.6
CD (p=0.05)	NS	NS	NS	NS

Significantly higher grain yield (7254 kg ha^{-1}) was recorded with fertigation of 100% RD N&K than that of 75% RD N&K (6951 kg ha^{-1})

The higher grain yield in drip fertigation of RD N&K and biofertigation of MC might be due to combined effect of biofertilizer microbial consortium with conventional N&K fertilizers which increases the availability of nutrients and transport of major nutrients like N, P and K and there was a significant and positive correlation between uptake of NPK and grain yield, besides secreting plant growth promoting substances such as Indole acetic acid, gibberilins and abscisic acid for maize which resulted in increase in plant height, number of leaves and leaf area which in turn lead to higher production and translocation of photosynthates and yield attributes like cob length (cm), cob girth (cm), number of rows cob^{-1}, cob weight (g), grain weight (g) and there was a significant and positive correlation between yield attributes and grain yield. The results of increase in LAI with application of biofertilizers were in similar trend with the results reported by Preetham et al. (2020a) in baby corn and Shravani (2018) in greengram.

3.3.3. Stover yield (kg ha^{-1})

Significantly higher stover yield (11827 kg ha^{-1}) was recorded with 100% RD N&K over 75% RD N&K (11195 kg ha^{-1}). Stover yield recorded with biofertigation of MC five times (11877 kg ha^{-1}) and three times (11728 kg ha^{-1}) was significantly higher than that recorded without application of MC (11412 kg ha^{-1}) and was on par with soil application of MC (11027 kg ha^{-1}). The lower stover yield was recorded with treatment without application of MC and was on par with soil application of MC.

The increase in stover yield might be due to combined effect of biofertilizer microbial consortium with conventional N&K fertilizers which increases the availability of nutrients and transport major nutrients like N, P and K, besides secreting plant growth promoting substances which resulted in increase the plant height, number of leaves and leaf area which in turn lead to higher production and translocation of photosynthates and more dry matter production plant^{-1}. The results are in similar trend with the results reported by Abdelhamid et al. (2011) through biofertigation and through seed inoculation in baby corn by Preetham et al. (2020a).

3.4. Harvesting index (%)

The RD N&K levels and biofertigation of MC and their interactions did not record any significant influence on harvest index. However higher harvest index of 38.4% was recorded with 100% RD N&K and biofertigation of MC five times (38.1%).

3.5. Water productivity (WP, kg m^{-3})

Water productivity of drip irrigated *rabi* maize varied with fertigation of RD N and K, biofertigation of MC and was not influenced by their interaction effect and significantly higher water productivity (1.56 kg m^{-3}) was recorded with fertigation of 100% RD N and K compared to 75% RD N and K (1.50 kg m^{-3}). Biofertigation of MC five times and three times recorded significantly higher water productivity (1.57 and 1.56 kg m^{-3}) than that of without application of MC (1.46 kg m^{-3}) and was on par with soil application of MC (1.53 kg m^{-3}). Significantly lower water productivity was observed in treatment without application of MC which was on par with soil application of MC (Table 5).

This increase in WP with increase in fertilizer dose and biofertigation of MC was because of increased yield due to fertigation of 100% RD N and K and biofertigation of MC five times, three times and soil application of MC, at same quantity of water applied. The results i.e., increasing water productivity with drip fertigation are in agreement with the results obtained by Wu et al. (2019), Sandhu et al. (2019) and Zou et al. (2020) in maize.

3.6. Economics

Significant variation in economics of *rabi* maize was observed with fertigation of RD N and K and biofertigation of MC and their interaction effect was not significant.

Table 5: Effect on water productivity of *rabi* maize

Treatment	Water applied (mm)	Effective Rainfall (mm)	Total water applied (mm)	Total water applied (m^3)	Water Productivity (kg m^{-3})
RD N & K					
100% RD N&K	445.1	19.3	464.4	4644	1.56
7% RD N&K	445.1	19.3	464.4	4644	1.50
SEm±	-	-	-	-	0.02
CD (p=0.05)	-	-	-	-	0.05
Biofertigation					
MC_0	445.1	19.3	464.4	4644	1.46
SMC	445.1	19.3	464.4	4644	1.53
MC_3	445.1	19.3	464.4	4644	1.56
MC_5	445.1	19.3	464.4	4644	1.57
SEm±	-	-	-	-	0.02
CD (p=0.05)	-	-	-	-	0.07
Interaction between RD N&K and biofertigation					
SEm±	-	-	-	-	0.03
CD (p=0.05)	-	-	-	-	NS

RD of N and K: 100% RD (240:80 kg N:K_2O ha^{-1}); 75% RD (180:60 kg N:K_2O ha^{-1}); Biofertigation: MC_0: Without microbial consortium (MC); SMC: Soil application of MC; MC_3: Biofertigation of MC three times; MC_5: Biofertigation of MC five times

3.6.1. Cost of cultivation (₹ ha^{-1})

Cost of cultivation varied from ₹ 70,917–₹ 75,488 ha^{-1} in fertigation of RD N and K and among biofertigation of MC it was ranged from ₹ 71,573–₹ 75,973 ha^{-1} of *rabi* maize. Main variation in cost of cultivation was due to biofertigation; cost of fertilizers and man power required for biofertigation.

3.6.2. Gross returns (₹ ha^{-1})

Significantly higher gross returns (₹ 1,32,797 ha^{-1}) were recorded with fertigation of 100% RD N and K compared to 75% RD N and K (₹ 1,27,068 ha^{-1}). There was no significant difference in gross returns among biofertigation of MC 5 times (₹ 1,33,665 ha^{-1}) and 3 times (₹ 1,32,301 ha^{-1}) and were significantly superior than soil application of MC (₹ 1,30,118 ha^{-1}) and without application of MC (₹ 1,23,645 ha^{-1}). The higher gross returns were recorded due to higher yield with biofertigation of MC than soil application (Table 6).

3.6.3. Net returns (₹ ha^{-1})

Net returns recorded with fertigation of 75% and 100% RD N and K (₹ 56,151 and ₹ 57,309 ha^{-1}, respectively) were not significantly different, even though higher yield was recorded with fertigation with 100% RD N and K but the cost of input fertilizers is more in 100% RD N and K compared to 75% RD N and K which recorded lower yield than 100% RD N and K. Among biofertigation of MC, significantly higher net returns were observed in biofertigation of MC five times (₹ 60,892 ha^{-1}) compared to soil application of MC (₹ 54,146 ha^{-1}), without application of MC (₹ 52,072 ha^{-1}) and was on par with biofertigation of MC 3 times (₹ 59,808 ha^{-1}). The net returns obtained with biofertigation of MC 3 times was on par with soil application of MC. Similarly, the net returns observed in soil application of MC was on par with the treatment where MC was not applied (Table 6.).

Table 6: Effect on economics of *rabi* maize

Treatment	Gross returns (₹ ha^{-1})	Cost of cultivation (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
RD N & K				
100% RD N&K	132797	75488	57309	1.76
7% RD N&K	127068	70917	56151	1.79
SEm±	1279	-	1279	0.02
CD (p=0.05)	3881	-	3881	0.05
Biofertigation				
MC_0	123645	71573	52072	1.73
SMC	130118	75973	54146	1.71
MC_3	132301	72493	59808	1.83
MC_5	133665	72773	60892	1.84
SEm±	1809	-	1809	0.02
CD (p=0.05)	5488	-	5488	0.07
Interaction between RD N&K and biofertigation				
SEm±	2559	-	2559	0.03
CD (p=0.05)	NS	-	NS	NS

RD of N and K: 100% RD (240:80 kg N:K_2O ha^{-1}); 75% RD (180:60 kg N:K_2O ha^{-1}); Biofertigation: MC_0: Without microbial consortium (MC); SMC: Soil application of MC; MC_3-Biofertigation of MC three times; MC_5-Biofertigation of MC five times

The similar results of higher net returns by combining inorganic and biofertilizers were observed by Mahapatra et al. (2018) and Preetham et al. (2020b) in baby corn, Jena et al. (2017) in oats, Rahangdale et al. (2022) and Lynrah and Nongmaithem (2022) in soybean.

3.6.4. B:C ratio

75% RD N and K recorded higher B:C ratio (1.79) and was on par with 100% RD N and K (1.76) in fertigation levels. This may be due to lower fertilizer cost in 75% RD N and K compared to 100% RD N and K. Among biofertigation of MC, there was no significant difference in B:C ratio was observed between biofertigation of MC 5 times (1.84) and 3 times (1.83) and were significantly superior over soil application of MC (1.71) and with treatment without application of MC (1.73). This may be due to relative increase in yield with biofertigation of MC proportional to increased cost of inputs (Table 6.).

The similar results of higher net B:C ration by combining inorganic and biofertilizers were observed by Mahapatra et al. (2018) and Preetham et al. (2020b) in baby corn, Jena et al. (2017) in oats, Rahangdale et al. (2022) and Lynrah and Nongmaithem (2022) in soybean.

3.7. Analysis

There was no significant interaction effect due to RD of N&K and biofertigation of MC on growth parameters, yield, water productivity, gross and net returns and B:C ratio.

Growth parameters like leaf are index (LAI), dry matter production (DMP) at 30 DAS were not significantly influenced by RD N&K, biofertigation of MC. DMP was significantly influenced by RD N&K and biofertigation of MC at all growth periods i.e., 60, 90 DAS and at harvest. The results obtained indicated that fertigation with 100% RD N&K recorded significantly DMP (8563, 17555 and 19081 kg ha^{-1}) than 75% RD of N&K at 60, 90 DAS and at harvest, respectively. Significantly higher LAI (4.68 and 5.08) was recorded with fertigation of 100% RD N&K

over 75% RD N&K (4.42 and 4.85) at 60 and 90 DAS, respectively.

Biofertigation of MC five times and three times recorded significantly higher DMP (8567 and 8389, 17555 and 17347 and 19181 and 18958 kg ha^{-1}) than the treatment where MC was not applied and was on par with soil application of MC at 60, 90 DAS and harvest, respectively. Biofertigation of MC five times and three times recorded significantly higher LAI than the treatment where MC was not applied, biofertigation of MC three times was on par with soil application of MC.

Maize grain, stover and biological yield (7254, 11828 and 19082 kg ha^{-1}) recorded with 100% RD N&K were significantly higher compared to 75% RD N&K (6951, 11194 and 18145 kg ha^{-1}, respectively). Biofertigation of MC five times and three times were on par and recorded significantly higher grain, stover yield and biological yield (7304 and 7230, 11877 and 11728 and 19181 and 18958 kg ha^{-1}, respectively) compared to treatment without application of MC (6758, 11028 and 17786 kg ha^{-1}). Significantly lower grain, stover and biological yield (7118, 11412 and 18530 kg ha^{-1}) were observed under treatment without application of MC, however the stover yield was on par with soil application of MC.

Significantly higher water productivity was observed with fertigation of 100% RD N and K (1.56 kg m^{-3}) than that of 75% RD N and K (1.50 kg m^{-3}) and there was no significant difference in water productivity recorded with five times and three times biofertigation and soil application of MC (1.57, 1.56 and 1.53 kg m^{-3}) and soil application of MC was on par with treatment where MC was not applied (1.46 kg m^{-3}).

Significantly higher gross returns were observed in fertigation with 100% RD N and K (₹ 1,32,797 ha^{-1}) compared to 75% RD N and K (₹ 1,27,068 ha^{-1}) and there was no significant difference statistically in gross returns with biofertigation of MC five times, three times and soil application of MC (₹ 1,33,665 and ₹1,32,301 and ₹ 1,30,118 ha^{-1}) and were significantly superior over treatment where MC was not applied (₹ 1,23,645 ha^{-1}). Net returns were not differed statistically by RD N and K levels, which ranged from ₹ 56,151–₹ 57,309 ha^{-1}. Significantly, higher net returns were observed with five times (₹ 60,892 ha^{-1}) compared to soil application of MC (₹ 54,146 ha^{-1}), treatment without MC application (₹ 52,072 ha^{-1}) and was on par with 3 times biofertigation of MC (₹ 59,808 ha^{-1}). Significantly lower net returns were observed in treatment where MC was not applied and was on par with soil application of MC.

Fertigation of 75% RD N and K recorded higher B:C ratio (1.79) followed by 100% RD N and K (1.76). Higher B:C ratio was observed with 5 times MC biofertigation (1.84) and three times MC biofertigation (1.83). Significantly Lower B:C ratio was observed in treatment without application of MC (1.73) and soil application of MC (1.71).

4. CONCLUSION

The 100% RD N and K recorded higher growth, yield data, Gross and Net returns and water productivity compared to 75% RD N and K. 75% RD N and K recorded significantly higher B:C ratio. Among biofertigation, biofertigation of MC 5 times recorded higher growth, yield data, Gross and Net returns, Water productivity and B:C ratio and was on par with the biofertigation of MC 3 times. Hence, it was concluded that 75% RD Nand K combined with 5 or 3 times biofertigation of MC recommended for economic yield and soil sustainability.

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