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Effect of different fertigation levels and microbial consortia on yield and water use efficiency of broccoli (*Brassica oleracea* L. *var. italica*) under drip irrigation

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Abstract
The experiment entitled "Response of broccoli (*Brassica oleracea* L. var. *italica*) to different fertigation levels and microbial consortia under drip irrigation" was conducted during the rabi season of 2023-24 at the Interfaculty Department of Irrigation Water Management, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahmednagar (Maharashtra). The study aimed to evaluate the effect of fertigation levels and microbial consortia on the growth and yield of broccoli. The experimental field had well-drained clay loam soil (45 cm depth) with low available nitrogen (258.4 kg ha^{-1}), medium phosphorus (19.80 kg ha^{-1}), and very high potassium (395.1 kg ha^{-1}), slightly alkaline in reaction (pH 7.91) and electrical conductivity of 0.38 dS m^{-1}. The experiment was laid out in a split-plot design with three replications. The main plots comprised three fertigation levels: 50% RDF (F_1), 75% RDF (F_2), and 100% RDF (F_3). Five microbial consortia were allotted to subplots: control (C_0), MPKV consortium (C_1), VNMKV Biomix (C_2), Arka microbial consortium (C_3), and IFFCO NPK liquid biofertilizer consortium (C_4). Biofertigation was applied at transplanting and at 15, 30, and 45 days after transplanting. The application of 100% RDF fertigation resulted in the highest curd yields across all harvesting intervals that is 19.47 q ha^{-1} (first harvest), 20.88 q ha^{-1} (second), 22.21 q ha^{-1} (third) and 20.39 q ha^{-1} (fourth), culminating in the maximum total curd yield of 82.95 q ha^{-1}. This was at par with the 75% RDF fertigation level, which yielded 79.05 q ha^{-1}. The application of 100% RDF through fertigation demonstrated the highest water use efficiency (32.82 kg ha^{-1} mm^{-1}), outperforming the other fertigation levels. However, it was statistically at par with the 75% RDF fertigation level, indicating that both treatments were similarly effective in optimizing water utilization for yield production. Biofertigation schedule involving the MPKV Consortium demonstrated a significant positive effect on curd yield of broccoli across all harvest intervals: first harvest (25.00 q ha^{-1}), second harvest (24.30 q ha^{-1}), third harvest (30.07 q ha^{-1}), fourth harvest (24.70 t ha^{-1}) and a total curd yield of 104.07 t ha^{-1}. The combination of 100% RDF fertigation with biofertigation using the MPKV Consortium resulted in the highest water use efficiency (41.19 kg ha^{-1} mm^{-1}) also the combination of 75% RDF and MPKV Consortium (37.76 kg ha^{-1} mm^{-1}) was found at par with superior treatment.

Keywords: Broccoli, fertigation levels, microbial consortium, drip irrigation, yield, growth parameters

Introduction
Broccoli (*Brassica oleracea* L. var. *italica*) is a widely cultivated cole vegetable of the family Cruciferae, bearing close similarity to cauliflower but characterized by its green, compact edible heads formed on both terminal and lateral shoots. The crop is nutritionally rich, containing substantial amounts of vitamins A and C, minerals, dietary fiber, and antioxidant compounds. In India, broccoli cultivation is gaining popularity owing to rising consumer awareness and its adaptability to varied agro-climatic regions, especially in states such as Maharashtra, Himachal Pradesh, Uttarakhand, and Tamil Nadu. Fertigation, which involves the application of fertilizers through drip irrigation, allows accurate and efficient placement of nutrients in the root zone. This practice enhances nutrient absorption, improves water and fertilizer use efficiency, and consequently leads to better crop growth, yield, and quality (Bar-Yosef, 1999; Solaimalai *et al*., 2005) [1, 13]. Previous research has indicated that fertigation can result in fertilizer savings of 20-60 percent along with yield improvements ranging from 8 to 41 percent in various vegetable

crops (Jucilene *et al*., 2009; Singh *et al*., 2010) [5, 11]. Apart from fertigation, microbial consortia contribute significantly to sustainable nutrient management in crops. Beneficial microorganisms such as *Azotobacter*, phosphate-solubilizing bacteria (PSB), *Trichoderma*, and potassium-solubilizing bacteria (KSB) improve nutrient availability by transforming nutrients into plant-available forms, thereby enhancing plant growth and soil health (Selim *et al*., 2009) [8]. The application of these beneficial microbes through irrigation water, known as biofertigation, provides an environmentally friendly and economically viable strategy for integrated nutrient management (INM).In view of the limited research on fertigation and biofertigation practices for broccoli under Indian agro-climatic conditions, the present study entitled **"**Response of Broccoli (*Brassica oleracea* L. var. *italica*) to different fertigation levels and microbial consortia under drip irrigation" was conducted to evaluate their effects on growth and yield.

Materials and Methods

The experiment was carried out at the Instructional Farm of the Inter-Faculty Department of Irrigation Water Management, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, during the rabi season of 2023-24. The experimental soil was well-drained with a clay loam texture. It was low in available nitrogen (258.4 kg ha^{-1}), medium in available phosphorus (19.8 kg ha^{-1}), and high in available potassium (395.1 kg ha^{-1}). The soil reaction was slightly alkaline, with a pH of 7.91, and it contained 0.51 percent organic carbon. The electrical conductivity of the soil was 0.38 dS m^{-1} at 24 °C. The field capacity and permanent wilting point were 38.11 percent and 19.90 percent, respectively, while the bulk density was 1.11 g cm^{-3}.The experimental site falls under the agro-climatic scarcity zone of Maharashtra and is characterized as drought-prone. The study involved three fertigation levels assigned to the main plots: F_1 (50% of the recommended dose of fertilizers), F_2 (75% RDF), and F_3 (100% RDF). The subplot treatments comprised five microbial consortia, namely C_0 (control), C_1 (MPKV consortium), C_2 (VNMKV Biomix), C_3 (Arka microbial consortium), and C_4 (IFFCO NPK liquid biofertilizer consortium). Biofertigation was applied at transplanting and subsequently at 15, 30, and 45 days after transplanting (DAT). The broccoli variety 'Saki' was used for the experiment. Seedlings were transplanted on December 5, 2024, at a spacing of 45-75 cm × 45 cm in paired rows

Results and Discussion

Yield attributes and yield studies

Diameter of curd

Data pertaining that different fertigation levels significantly influenced the diameter of curd of broccoli. Application of fertigation at 100% RDF attained the maximum average diameter of curd (20.23 cm) as compared to rest of fertigation levels. This is followed by 75% RDF fertigation level the average diameter of curd (18.92 cm). The findings are comparable to those reported by Chand *et al*. (2017) [3]. The microbial consortium of MPKV Consortium registered the maximum diameter of curd (23.56 cm) among all the microbial consortium. The lower curd diameter as determined by the control. The results are in conformity with the findings Pawde *et al*. (2019) [7], Kumar *et al*. (2017) [6] and Singh *et al*. (2014) [10].

Weight of curd plant^{-1}

Application of fertigation at 100% RDF exhibited the maximum and significantly highest average weight of curd; (1907 g) as compared to rest of fertigation levels. Because the average weight of curd plant^{-1} was positively connected to the amount of fertigation used, the crop satisfied the nutrient demand throughout the crop growth period at 100% RDF fertigation, which improved vegetative growth, curd diameter and girth, resulting in an increase in curd weight. It was at par with 75% RDF, average weight of curd (1900 g). Similar findings have been reported by Tumbare (2013) [14], Chand and Singh (2017) [3]. Microbial consortium of MPKV Consortium among all the consortium, had the greatest average curd weight (2009 g). Whereas, the control observed minimum average curd weight plant^{-1}. Nutrient application with extended splits increases curd diameter which ultimately increases curd weight plant^{-1}. These findings are consistent with those reported by Pawde *et al*. (2019) [7], Kumar *et al*. (2017) [6] and Singh *et al*. (2014) [10].

Yield

The application of 100% RDF fertigation resulted in the highest values of curd yields across all harvesting intervals that is 19.47 q ha^{-1} (first harvest), 20.88 q ha^{-1} (second), 22.21 q ha^{-1} (third) and 20.39 q ha^{-1} (fourth), culminating in the maximum total curd yield of 82.95 q ha^{-1}. This was at par with the 75% RDF fertigation level, which yielded first harvest (19.11 q ha^{-1}), second harvest (19.63 q ha^{-1}), third harvest (20.60 q ha^{-1}), fourth harvest (19.51 q ha^{-1}) and 79.05 q ha^{-1}. In contrast, the lowest yield components and total production were recorded under the 50% RDF fertigation treatment. These findings align with reports by Chand and Singh (2017) [3], Sharma *et al*. (2017) [9], Biradar *et al*. (2018) [2], Sohail *et al*. (2018) [12] and Tumbare *et al*. (2013) [14]. The MPKV Consortium resulted in the highest curd yields across all harvest intervals: first harvest (21.62 q ha^{-1}), second (21.96 q ha^{-1}), third (26.59 q ha) and fourth (20.87 q ha^{-1}), culminating in the highest total curd yield of 91.03 q ha^{-1}.while VNMKV Biomix application was found at par with MPKV Consortia with yield of 79.31 q ha^{-1} this results are in consistent with Pawde *et al*. (2019) [7], Kumar *et al*. (2017) [6] and Singh (2014) [10].

Irrigation Studies

Consumptive Use

Fertigation under the 100% RDF fertigation level had the consumptive use (252.68 mm). The fertigation level of 50% RDF resulted in the same amount of consumptive consumption (252.68 mm). During the crop growth period, all of the microbial consortium averaged 252.68 mm consumptive consumption.

Water Use Efficiency

The water use efficiency was influenced significantly due to different fertigation levels. Scheduling of fertigation at 100% RDF fertigation levels registered highest water use efficiency (32.82 kg ha^{-1} mm^{-1}) than rest of fertigation levels. It was at par with 75% RDF fertigation level registered water use efficiency (31.28 kg ha^{-1} mm^{-1}). Similar findings were also reported by Debbarma *et al*. (2021) [4]. The application of different microbial consortia led to significant variation in water use efficiency in broccoli cultivation. Among the treatments, the MPKV Consortium comprising Azotobacter, PSB, KSB and Trichoderma exhibited the highest water use efficiency (36.02 kg ha^{-1} mm^{-1}), surpassing all other microbial treatments.

Table 1: Yield attributing characters and total yield of broccoli as influenced by different treatments

Tr. No.	Treatment	Yield attributing characters		
		Diameter of curd (cm)	Weight of curd plant^{-1} (g)	Total Yield (q ha^{-1})
I.	**Fertigation Levels**			
F_1	50% RDF	16.10	1737	64.06
F_2	75% RDF	18.92	1900	79.05
F_3	100% RDF	20.23	1907	82.95
	S.E.(m) ±	0.78	14.89	1.09
	C.D at 5%	3.04	58.48	4.30
II.	**Microbial Consortia**			
C_0	Control	14.75	1702	65.09
C_1	MPKV Consortium	23.56	2009	91.03
C_2	VNMKV Biomix	20.25	1913	79.31
C_3	Arka Microbial Consortium	18.62	1814	71.31
C_4	IFFCO NPK Liquid Biofertilizer Consortium	17.68	1802	69.48
	S.E.(m) ±	1.43	32.94	3.03
	C.D at 5%	3.66	96.17	11.72
III.	**Interaction**			
	A × B	N.S.	Sig.	Sig.
	General mean	19.26	1848	75.35

Table 2: Curd yield of broccoli as influenced by different treatments

Tr. No.	Treatment	Curd yield (q ha^{-1})				
		First harvest	Second harvest	Third harvest	Fourth harvest	Total yield
I.	**Fertigation Levels**					
F_1	50% RDF	16.03	17.67	16.82	13.53	64.06
F_2	75% RDF	19.11	19.63	20.60	19.51	79.05
F_3	100% RDF	19.47	20.88	22.21	20.39	82.95
	S.E.(m) ±	0.68	0.34	0.79	0.41	1.09
	C.D at 5%	2.66	1.33	3.11	1.62	4.30
II.	**Microbial Consortia**					
C_0	Control	15.60	17.22	16.69	15.58	65.09
C_1	MPKV Consortium	21.62	21.96	26.59	20.87	91.03
C_2	VNMKV Biomix	19.17	20.87	20.2	19.03	79.31
C_3	Arka Microbial Consortium	17.46	19.20	18.14	17.04	71.31
C_4	IFFCO NPK Liquid Biofertilizer Consortium	17.17	18.07	17.71	16.53	69.48
	S.E.(m) ±	0.84	0.41	1.16	0.64	3.03
	C.D at 5%	2.45	1.18	3.39	1.88	11.72
III.	**Interaction**					
	A × B	Sig.	Sig.	Sig.	Sig.	Sig.
	General mean	18.03	19.46	19.87	17.81	75.35

Table 2: Consumptive use and water use efficiency in broccoli as influenced by different treatments

Tr. No.	Treatment	Etc (mm)	*Consumptive use (mm)	Yield (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})
I.	**Fertigation Levels**				
F_1	50% RDF	252.68	252.68	6406	25.34
F_2	75% RDF	252.68	252.68	7905	31.28
F_3	100% RDF	252.68	252.68	8295	32.82
	S.E.(m) ±	-	-	-	0.43
	C.D at 5%	-	-	-	1.70
II.	**Microbial Consortia**				
C_0	Control	252.68	252.68	6509	25.75
C_1	MPKV Consortium	252.68	252.68	9103	36.02
C_2	VNMKV Biomix	252.68	252.68	7931	31.38
C_3	Arka Microbial Consortium	252.68	252.68	7185	28.43
C_4	IFFCO NPK Liquid Biofertilizer Consortium	252.68	252.68	6948	27.49
	S.E.(m) ±	-	-	-	1.55
	C.D at 5%	-	-	-	4.69
III.	**Interaction**				
	A × B	-	-	-	Sig.
	General mean	-	-	-	29.81

Conclusion

The combination of 100% RDF fertigation and MPKV Consortium resulted in the highest yield This could be due to application of required quantity of nutrients directly in the vicinity of root zone. Also, all macro and micro nutrient are easily available to plant. The plant grows without any deficiency with high leaf area. Which increase in luxurious crop development throughout the growing season by increasing the

water usage efficiency of applied water. It creates a conducive environment for promoting physiological processes like as photosynthesis, which resulted in increased curd width and average weight of curd plant^{-1}, resulting in increased curd yield along with extended activities of microorganisms helps to make unavailable nutrients in available form, which met the crop's nutrient requirements, Above mentioned treatment was found to be at par with 75% RDF along with MPKV Consortia which is comparatively equally beneficial under drip irrigation systems. This highlights the potential of combined fertigation and biofertigation in optimizing water usage. On the basis of results obtained after one year of experimentation it is concluded that, application of fertilizer at 75% recommended dose (97.5:15:22.5 N:P_2O_5:K_2O kg ha^{-1}) coupled with biofertilizer MPKV Consortium through fertigation found suitable to broccoli for maximum growth, yield attributes, curd yield, quality and monetary returns.

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