Beneficial Microbes and Phosphorus Management Influence Dry Matter Partitioning and Accumulation in Wheat (*Triticum aestivum* L.) with and without Moisture Stress Condition

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Abstract

Field experiment was conducted to investigate the impact of beneficial microorganism (BMO) and phosphorus (P) application on dry matter (DM) accumulation and partitioning in spring wheat (*Triticum aestivum* L., cv. Siren) under full irrigated (no moisture stress) and limited irrigated (dryland or moisture stress) conditions. The experiment was conducted at the Agronomy Research Farm, The University of Agriculture Peshawar during winter 2012-13. The experiment under both moisture conditions was laid out in randomized complete block design using three replications. The results revealed that DM accumulation and partitioning into leaf, stem and spike was significantly higher in wheat under irrigated than dryland wheat. The treated plots (rest) had higher total DM accumulation and partitioned more DM into leaf, stem and spike than control at both anthesis and physiological maturity (PM). Application of P and BMO at the highest rates (90 kg P ha⁻¹ and 30 L ha⁻¹, respectively) had accumulated more total DM and had partitioned more DM into leaf, stem and spike at the two growth stages. We found that under irrigated condition, increase in both P and BMO levels (90 kg P ha⁻¹ and 30 L ha⁻¹, respectively) and under dryland condition the intermediate levels of both P and BMO (60 kg P ha⁻¹ and 20 L ha⁻¹, respectively) had produced higher total DM and partitioned more DM into various parts at both anthesis and PM. The percent DM partitioning into leaf was more (36%) than stem and spike (each 32%) at anthesis stage; while at PM, more DM was partitioned into spike (59%) than stem (21%) and leaf (20%). Increase in DM partitioning into spike under both irrigated and dryland wheat with proper P and BMO management showed positive relationship with grain yield that resulted in higher growers income in the study area.

Keywords: Beneficial microorganism; Phosphorus; Irrigation condition; Wheat; Dry matter partitioning; Growth stages

Introduction

Wheat (*Triticum aestivum* L.) is Pakistan key staple food crop among cereals which occupies about 37% of the cropped area and consumes about 45% of the total fertilizers utilized in the country. In Pakistan wheat is cultivated in both irrigated and dryland conditions and contributes 14.4% share in agriculture and 3% in gross domestic products. The total area of wheat in Pakistan during 2011-2012 was 8.649 million ha having 23.473 million tons production with average yield of 2714 kg ha⁻¹ [1]. Wheat average yield in the province of Khyber Pakhtunkhwa was 1550 kg ha⁻¹ in the same growing season which looks very compared with the national average yield [1]. The major factors for low productivity of wheat in Khyber Pakhtunkhwa are imbalanced application of fertilizers and water shortages especially under un-irrigated (dryland) condition. Increased production from the dryland areas is important if Pakistan is going to meet the needs of the country for food and other products. It is estimated that 12% of the total wheat production is harvested from rainfed areas, which can be increased several fold with proper management of production factors as the current management by the farmers is at a very basic level of technology [2]. Dryland agriculture is an important component of the national economy of Pakistan which currently contributes around 15 billion rupees annually.

The lack of optimum moisture and low soil fertility are the inherent problems in rainfed areas of Khyber Pakhtunkhwa [2]. The soils of Khyber Pakhtunkhwa have low organic matter content and less available P [2]. These soils contain high calcium carbonate with pH ranging from 7 to 9. This high calcium activity coupled with high pH favors the formation of relatively insoluble dicalcium phosphate,

hydroxyl apatite, carbonate apatite, and octo calcium phosphate. Soils with high fixation capacity have higher demand for P-fertilizer [3]. Phosphorus deficiency is invariably a common crop growth and yield-limiting factor in unfertilized soils, especially in soils high in calcium carbonate which reduces P solubility [4]. Under these conditions only little of the applied P is available for crop plants which results in lower crop productivity. Under these soils application of beneficial microorganism (BMO) could increase P availability and thereby crop productivity. A diverse group of soil microflora was reported to be involved in solubilizing insoluble P complexes enabling plants to easily absorb P [5]. Many kinds of soil bacteria (bacillus, pseudomonas, rhizobium and enterobacter) and fungi (aspergillus and penicillium) have the skill to change insoluble form of P in the soil into soluble form through releasing organic acids such as formic acids, propionic acids, acetic acids, fumaric acids, and succinic acids. These acids reduce the pH and bring the dissolution of bound forms of phosphate [6]. As P is the major limiting factor for crop production in Khyber Pakhtunkhwa therefore combine application of BMO and P to these soils could increase P availability and crop productivity. However,

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there is no research to investigate the interactive effects of BMO x P under irrigated and moisture stress conditions. This research work was therefore designed to study the interactive effects of BMO x P on dry matter partitioning of spring wheat under full irrigated (no moisture stress) and limited irrigated (moisture stress or dryland) conditions.

Materials and Method

Experimentation

Field experiment was conducted to investigate the effect of beneficial micro-organisms (BMO) [10 L ha⁻¹ (50% less than the recommended rate), 20 L ha⁻¹ (recommended rate), and 30 L ha⁻¹ (50% higher than the recommended rate)] and phosphorus levels (0, 30, 60 and 90 kg P ha⁻¹) on dry matter partitioning and accumulation in spring wheat (*Triticum aestivum* L., cv. Siren-2010). The experiment was conducted under full irrigated condition (having no moisture stress) and limited irrigation (having moisture stress or dryland) conditions at the Agronomy Research Farm of The University of Agricultural Peshawar, during winter 2012-13. The experiment under full irrigated condition received a total of five irrigations [1st for seedbed preparation, 2nd 10 days after sowing for beneficial microorganism and 2nd dose of N application (26th November), 3rd 60 days after sowing (15th January), 4th after anthesis (30th March) and 5th at grain fill duration (13th April)]. The experiment under limited irrigated condition (moisture stress, dryland condition) received only two irrigations [1st irrigation for seedbed preparation before sowing and 2nd irrigation at 10 days after sowing for BM and 2nd dose of N application (26th November)]. The BMO was applied in the form of "Bioaab" obtained from the Cheinar Agro Trade Batkhela (Malakand), Khyber Pakhtunkhwa, while phosphorus was used in the form of triple super phosphate (46% P₂O₅). The BMO 'Bioaab' was prepared by mixing one liter of Bioaab+one kgmolasses+10 or 20 or 30 liters of water and sprayed in their respective plots in standing water at 10 days after sowing.

Experimental design and plot size

The experiment was laid out in randomized complete block design using three replications under both full irrigated (no moisture stress) and limited irrigated (moisture stress) conditions. Each replication consisted of 10 treatments including three BMO levels x three P levels (9 treatments) +one control treatment (no BMO and P applied). A sub-plot size of 4 m by 2.40 m, having 8 rows, 4 m long and 30 cm apart was used. A uniform dose of 120 kg N ha⁻¹ as urea was applied to all treatments in two equal splits, i.e., half each at sowing and first irrigation (10 days after sowing).

Site description

The experimental farm is located at 34.018°N latitude, 71.358°E longitude at an altitude of 350 m above sea level in Peshawar valley. Peshawar is located about 1600 km north of the Indian Ocean and has a continental type of climate. Soil of the farm is clay loam, low in organic matter (0.87%), phosphorus (6.57 mg kg⁻¹), potassium (121 mg kg⁻¹), is alkaline (pH 8.2) and calcareous in nature [7]. The area has a continental type of climate and is generally semiarid with mean annual rainfall ranging between 300 and 500 mm, of which 60-70 %, called the *monsoon rains*, occurs during summer (July-September) and the remaining 30-40% occurs in winter [7].

Weather data of experimental period

The average rainfall data of wheat growing season (2012-13)

indicates that there was no rainfall during the whole months of January and May. The rainfall was less in November 2012 (0.4 mm), April 2013 (7.2 mm) and March 2013 (9.5 mm). The rainfall was little higher in December 2012 (34 mm), while maximum rainfall (166 mm) occurred in February 2013.

Data recording and handling

Data were recorded on dry matter (DM) partitioning into leaf, stem, spike and total DM accumulation (gm⁻²) at the time of anthesis and physiological maturity (PM).

Statistical analysis

Data were statistically analyzed combined over irrigation condition [8] and means were compared using LSD test ($p \leq 0.05$).

Experimental Results

Leaf dry matter at anthesis

Leaf dry matter (LDM) at anthesis of wheat was significantly affected by irrigation condition (IC), phosphorus (P) and beneficial microorganism (BMO), the interactions BMO x P, IC x P and IC x P x BMO had significant effect on LDM, while the interaction IC x BMO had no significant effect on LDM (Table 1). The rest of the treated plots had significantly higher LDM (251.8 gm⁻²) than control (210.7 gm⁻²). The highest LDM (259.4 gm⁻²) was obtained from the full irrigated field as compared with the limited irrigated field (243.0 gm⁻²). Among the P levels, the highest LDM (262.7 gm⁻²) was recorded for the plots treated with the highest P level (90 kg ha⁻¹), followed by 252.2 gm⁻² (60 kg P ha⁻¹).

Irrigation	P (kg ha ⁻¹)	BMO (Lit ha ⁻¹)			IC x P
		10	20	30	
Irrigated	30	227.7	266.0	252.0	248.6
	60	239.3	272.3	268.7	260.1
	90	244.0	286.7	278.3	269.7
Dryland	30	206.7	248.0	232.3	229.0
	60	220.7	259.0	253.0	244.2
	90	230.7	271.7	265.0	255.8
Irrigated		237.0	275.0	266.3	259.4a
Dryland		219.3	259.6	250.1	243.0b
	30	217.2	257.0	242.2	238.8c
	60	230.0	265.7	260.8	252.2b
	90	237.3	279.2	271.7	262.7a
Mean		228.2c	267.3a	258.2b	
Planned means comparison					p-value
Control		210.7b			0.0000
Rest		251.8a			

Means of the same category followed by different letters are significantly different from each other using LSD test ($P \leq 0.05$).

Least Significant Difference ($p \leq 0.05$)		
BMO	=	1.5
P	=	1.5
BMO x P	=	**
IC x BMO	=	ns
IC x P	=	**
IC x BMO x P	=	**

Where: ns stands for non-significant data, while ** and * indicates significant at 1 and 5% level of probability, respectively using LSD test ($P \leq 0.05$).

Table 1: Dry matter partitioning into leaf (g m⁻²) at anthesis of wheat (*Triticum aestivum* L.) as affected by phosphorus (P) and beneficial microorganism (BMO) under irrigated and dryland conditions (IC).

¹), while the lowest LDM (238.8 gm⁻²) was obtained from the plots that received 30 kg P ha⁻¹. Among the BMO levels, the highest LDM (267.3 gm⁻²) was recorded for the plots treated with 20 L BMO ha⁻¹, followed by 258.2 gm⁻² (30 L ha⁻¹), while the lowest LDM (228.2 gm⁻²) was noted for the plots that received 10 L BMO ha⁻¹. The interaction between BMO x P indicated that at all P levels the LDM was increased when BMO level was increased up to 20 L BMO ha⁻¹ and further increase in BMO level decreased LDM. The interaction between IC x P indicated that increase in P level increased LDM under both full and limited irrigation conditions. The interaction among IC x BMO x P indicated that the intermediate BMO level (20 L ha⁻¹) produced the highest LDM at all P levels in both full irrigated and limited irrigation conditions.

Stem dry matter at anthesis

Stem dry matter (STDM) of wheat at anthesis stage was significantly affected by IC, P and BMO levels. The interactions BMO x P and IC x P had no significant effect, while IC x BMO and IC x P x BMO had significant effect on STDM (Table 2). The rest of the plots had higher STDM (227.0 gm⁻²) than control (199.7 gm⁻²). The highest STDM (237.0 gm⁻²) was obtained from the full irrigated field as compared with the limited irrigated field (214.1 gm⁻²). Among the P levels, the highest STDM (233.1 gm⁻²) was recorded for the plots treated with the highest P level (90 kg ha⁻¹), followed by 226.1 gm⁻² (60 kg P ha⁻¹), while the lowest STDM (217.6 gm⁻²) was noted with 30 kg P ha⁻¹. Among the BMO levels, the highest STDM (234.4 gm⁻²) was recorded for the plots treated with 20 L BMO ha⁻¹, followed by 225.9 gm⁻² (30 L ha⁻¹), while the lowest STDM (216.4 gm⁻²) was obtained from the plots that received 10 L BMO ha⁻¹. The interaction between IC x BMO revealed that irrigated plots at all BMO levels produced higher STDM than limited irrigation

condition. The interaction among IC x BMO x P indicated that the intermediate BMO level (20 L ha⁻¹) produced highest STDM at all P levels in both full irrigated and limited irrigation conditions.

Spike dry matter at anthesis

Spike dry matter (SPDM) at anthesis was significantly affected by IC, P and BMO levels, and all the interactions i.e. BMO x P, IC x BMO, IC x P and IC x BMO x P had significant effects on SPDM (Table 3). The rest of the treated plots had higher SPDM (218.9 gm⁻²) than control (197.0 gm⁻²). The highest SPDM (227.3 gm⁻²) was obtained from the full irrigated field as compared with the limited irrigated field (212.0 gm⁻²). Among the P levels, the highest SPDM (226.8 gm⁻²) was recorded for the plots treated with the highest P level (90 kg ha⁻¹), followed by 220.2 gm⁻² (60 kg P ha⁻¹), while the lowest SDM (112.1 gm⁻²) was obtained from the plots that received 30 kg P ha⁻¹. Among the BMO levels, the highest SPDM (228.5 gm⁻²) was recorded for the plots treated with 20 L BMO ha⁻¹, followed by 220.5 gm⁻² (30 L ha⁻¹), while the lowest SDM (210.0 gm⁻²) was obtained from the plots that received 10 L BMO ha⁻¹. The interaction between BMO x P indicated that at all P levels the SPDM was increased when BMO level was increased up to 20 L BMO ha⁻¹ and further increase in BMO level decreased SPDM. The interaction between IC x BMO revealed that irrigated plots at all BMO levels produced higher SDM than limited irrigation condition. The interaction between IC x P indicated that increase in P level up to the highest level (90 kg P ha⁻¹) increased SPDM under both full and limited irrigation conditions. The interaction among IC x BMO x P indicated that the intermediate BMO level 20 L ha⁻¹ produced highest SPDM at all P levels in both full irrigated and limited irrigation conditions.

Irrigation	P (kg ha ⁻¹)	BMO (Lit ha ⁻¹)			IC x P
		10	20	30	
Irrigated	30	220.7	239.0	225.3	228.3
	60	226.7	252.7	235.3	238.2
	90	228.7	260.3	244.7	244.6
Dryland	30	199.0	211.7	209.7	206.8
	60	207.7	215.7	218.7	214.0
	90	215.7	227.3	222.0	221.7
Irrigated		225.3	250.7	235.1	237.0a
Dryland		207.4	218.2	216.8	214.1b
	30	209.8	225.3	217.5	217.6c
	60	217.2	234.2	227.0	226.1b
	90	222.2	243.8	233.3	233.1a
Mean		216.4c	234.4a	225.9b	
Planned means comparison					
Control		199.7b			
Rest		227.0a			

Means of the same category followed by different letters are significantly different from each other using LSD test ($P \leq 0.05$).

Least Significant Difference ($p \leq 0.05$)		
BMO	=	1.9
P	=	1.9
BMO x P	=	ns
IC x BMO	=	**
IC x P	=	ns
IC x BMO x P	=	**

Where: ns stands for non-significant data, while ** indicates significant at 1% level of probability using LSD test ($P \leq 0.05$).

Table 2: Dry matter partitioning into stem (g m⁻²) at anthesis of wheat (*Triticum aestivum* L.) as affected by phosphorous (P) and beneficial microorganism (BMO) under irrigated and dryland conditions (IC).

Irrigation	P (kg ha ⁻¹)	BMO (Lit ha ⁻¹)			IC x P
		10	20	30	
Irrigated	30	209.3	228.0	222.3	219.9
	60	219.0	235.0	230.0	228.0
	90	224.0	243.7	234.7	234.1
Dryland	30	193.7	213.7	205.3	204.2
	60	203.0	221.0	213.0	212.3
	90	211.0	229.7	217.7	219.4
Irrigated		217.4	235.6	229.0	227.3a
Dryland		202.6	221.4	212.0	212.0b
	30	201.5	220.8	213.8	212.1c
	60	211.0	228.0	221.5	220.2b
	90	217.5	236.7	226.2	226.8a
Mean		210.0c	228.5a	220.5b	
Planned means comparison					
Control		197.0b			
Rest		218.9a			

Means of the same category followed by different letters are significantly different from each other using LSD test ($P \leq 0.05$).

Least Significant Difference ($p \leq 0.05$)		
BMO	=	1.35
P	=	1.35
BMO x P	=	**
IC x BMO	=	**
IC x P	=	**
IC x BMO x P	=	**

Where: ns stands for non-significant data, while ** indicates significant at 1% level of probability using LSD test ($P \leq 0.05$).

Table 3: Dry matter partitioning into spike (g m⁻²) at anthesis of wheat (*Triticum aestivum* L.) as affected by phosphorous (P) and beneficial microorganism (BMO) under irrigated and dryland conditions (IC).

Total dry matter at anthesis

Total dry matter (TDM) of wheat at anthesis was significantly affected IC, P and BMO levels, and all interactions (Table 4). The rest (treated plots) had significantly higher TDM (697.7 gm^{-2}) than control (607.3 gm^{-2}). The highest TDM (723.8 gm^{-2}) was recorded for the full irrigation condition as compared with the limited irrigation condition (669.1 gm^{-2}). Among the P levels, the highest TDM (722.6 gm^{-2}) was recorded for the plots treated with the highest P level (90 kg ha^{-1}), followed by 698.4 gm^{-2} (60 kg P ha^{-1}), while the lowest TDM (668.4 gm^{-2}) was obtained from the plots that received 30 kg P ha^{-1} . Among the BMO levels, the highest TDM (730.2 gm^{-2}) was recorded for the plots treated with 20 L BMO ha^{-1} , followed by 704.7 gm^{-2} (30 L ha^{-1}), while the lowest TDM (654.6 gm^{-2}) was obtained from the plots that received 10 L BMO ha^{-1} . The interaction between BMO x P indicated that at all P levels the TDM increased when BMO level was increased up to 20 L ha^{-1} and further increase in BMO level decreased TDM. The interaction between IC x BMO revealed that irrigated plots at all BMO levels produced higher TDM than limited irrigation condition. The interaction between IC x P indicated that increase in P level up to the highest level (90 kg P ha^{-1}) increased TDM under both full and limited irrigation conditions. The interaction among IC x BMO x P indicated that the intermediate BMO level (20 L ha^{-1}) in combination with 90 kg P ha^{-1} produced higher TDM under full and limited irrigation conditions, but the increase in TDM was more under full than limited irrigation condition.

Leaf dry matter at physiological maturity

Leaf dry matter LDM (gm^{-2}) at physiological maturity (PM)

Irrigation	P (kg ha ⁻¹)	BMO (Lit ha ⁻¹)			IC x P
		10	20	30	
Irrigated	30	657.7	733.0	699.7	696.8
	60	685.0	760.0	734.0	726.3
	90	696.7	790.7	757.7	748.3
Dryland	30	599.3	673.3	647.3	640.0
	60	631.3	695.7	684.7	670.6
	90	657.3	728.7	704.7	696.9
Irrigated		679.8	761.2	730.4	723.8a
Dryland		629.3	699.2	678.9	669.1b
	30	628.5	703.2	673.5	668.4c
	60	658.2	727.8	709.3	698.4b
	90	677.0	759.7	731.2	722.6a
Mean		654.6c	730.2a	704.7b	
Planned means comparison					
Control		607.3b			
Rest		697.7a			

Means of the same category followed by different letters are significantly different from each other using LSD test ($P \leq 0.05$).

Least Significant Difference ($p \leq 0.05$)		
BMO	=	2.86
P	=	2.86
BMO x P	=	**
IC x BMO	=	**
IC x P	=	**
IC x BMO x P	=	**

Where: ns stands for non-significant data, while ** indicates significant at 1% level of probability using LSD test ($P \leq 0.05$).

Table 4: Total dry matter accumulation (g m^{-2}) at anthesis of wheat (*Triticum aestivum* L.) as affected by phosphorous (P) and beneficial microorganism (BMO) under irrigated and dryland conditions (IC).

of wheat was significantly affected by IC, P and BMO levels. The interactions BMO x P and IC x P had significant effect, while IC x BMO and IC x BMO x P had no significant effect on LDM (Table 5). The rest (treated plots) had higher LDM (198.5 gm^{-2}) than control (180.5 gm^{-2}). The highest LDM (204.7 gm^{-2}) was obtained for the full irrigation condition as compared with the limited irrigation condition (191.1 gm^{-2}). Among the P levels, the highest LDM (204.5 gm^{-2}) was recorded for the plots treated with the highest P level (90 kg ha^{-1}), followed by 199.7 gm^{-2} (60 kg P ha^{-1}), while the lowest LDM (189.4 gm^{-2}) was obtained from the plots that received 30 kg P ha^{-1} . Among the BMO levels, the highest LDM (204.6 gm^{-2}) was recorded for the plots treated with 30 L BMO ha^{-1} , followed by 199.3 gm^{-2} (20 L ha^{-1}), while the lowest LDM (189.7 gm^{-2}) was obtained from the plots that received 10 L BMO ha^{-1} . The interaction between BMO x P indicated that increase in BMO and P levels increased LDM of wheat. The interaction between IC x P indicated that increase in P level increased LDM under both full and limited irrigation conditions, however, the increase was more for full than limited irrigation condition.

Stem dry matter at physiological maturity

The STDM of wheat at PM was significantly affected IC, P and BMO levels. The interactions BMO x P, IC x P and IC x P x BMO had no significant effect, while the interaction IC x BMO had significant effect on STDM (Table 6). The rest plots had higher STDM (214.0 gm^{-2}) than control (187.3 gm^{-2}). The highest STDM (223.6 gm^{-2}) was obtained from the full irrigation condition as compared with the limited irrigation condition (202.1 gm^{-2}). Among the P levels, the highest STDM (218.8 gm^{-2}) was recorded for the plots treated with the highest

Irrigation	P (kg ha ⁻¹)	BMO (Lit ha ⁻¹)			IC x P
		10	20	30	
Irrigated	30	190.3	197.7	201.7	196.6
	60	198.7	206.7	211.0	205.4
	90	203.7	213.7	218.7	212.0
Dryland	30	175.0	184.0	187.7	182.2
	60	183.7	195.7	202.7	194.0
	90	187.0	198.0	206.0	197.0
Irrigated		197.6	206.0	210.4	204.7a
Dryland		181.9	192.6	198.8	191.1b
	30	182.7	190.8	194.7	189.4c
	60	191.2	201.2	206.8	199.7b
	90	195.3	205.8	212.3	204.5a
Mean		189.7c	199.3b	204.6a	
Planned means comparison					
Control		180.5b			
Rest		198.5a			

Means of the same category followed by different letters are significantly different from each other using LSD test ($P \leq 0.05$).

Least Significant Difference ($p \leq 0.05$)		
BMO	=	1.91
P	=	1.91
BMO x P	=	**
IC x BMO	=	ns
IC x P	=	*
IC x BMO x P	=	ns

Where: ns stands for non-significant data, while ** and * indicates significant at 1 and 5% level of probability, respectively using LSD test ($P \leq 0.05$).

Table 5: Dry matter partitioning into leaf (g m^{-2}) at physiological maturity of wheat (*Triticum aestivum* L.) as affected by phosphorous (P) and beneficial microorganism (BMO) under irrigated and dryland conditions (IC).

Irrigation	P (kg ha ⁻¹)	BMO (Lit ha ⁻¹)			IC x P
		10	20	30	
Irrigated	30	208.7	219.3	225.3	217.8
	60	217.3	225.7	231.7	224.9
	90	216.3	230.3	237.3	228.0
Dryland	30	181.3	197.0	204.3	194.2
	60	195.0	204.3	208.3	202.6
	90	201.0	210.0	218.0	209.7
Irrigated		214.1	225.1	231.4	223.6a
Dryland		192.4	203.8	210.2	202.1b
	30	195.0	208.2	214.8	206.0c
	60	206.2	215.0	220.0	213.7b
	90	208.7	220.2	227.7	218.8a
Mean		203.3c	214.4b	220.8a	
Planned means comparison					
Control		187.3b			
Rest		214.0a			

Means of the same category followed by different letters are significantly different from each other using LSD test ($P \leq 0.05$).

Least Significant Difference ($p \leq 0.05$)		
BMO	=	2.7
P	=	2.7
BMO x P	=	ns
IC x BMO	=	*
IC x P	=	ns
IC x BMO x P	=	ns

Where: ns stands for non-significant data, while ** indicates significant at 1% level of probability using LSD test ($P \leq 0.05$).

Table 6: Dry matter partitioning into stem (g m^{-2}) at physiological maturity of wheat (*Triticum aestivum* L.) as affected by phosphorous (P) and beneficial microorganism (BMO) under irrigated and dryland conditions (IC).

P level (90 kg ha^{-1}), followed by 213.7 gm^{-2} (60 kg P ha^{-1}), while the lowest STDM (206.0 gm^{-2}) was obtained from the plots that received 30 kg P ha^{-1} . Among the BMO levels, the highest STDM (220.8 gm^{-2}) was recorded for the plots treated with 30 L BMO ha^{-1} , followed by 214.4 gm^{-2} (20 L ha^{-1}), while the lowest STDM (203.3 gm^{-2}) was obtained from the plots that received 10 L BMO ha^{-1} . The interaction between IC x BMO revealed that irrigated plots at all BMO levels produced higher STDM than limited irrigation condition, however, the increase under both irrigation conditions was more when MB level was increased.

Spike dry matter at physiological maturity

The SPDM at PM of wheat was significantly affected by IC, P and BMO levels. The interactions BMO x P, IC x P and IC x P x BMO had no significant effect, while the interaction of IC x BMO had significant effect on SPDM (Table 7). The treated plots had significantly higher SPDM (597.8 gm^{-2}) than control (553.2 gm^{-2}). The highest SPDM (612.6 gm^{-2}) was obtained from the full irrigation condition as compared with the limited irrigation condition (578.6 gm^{-2}). Among the P levels, the highest SPDM (607.6 gm^{-2}) was recorded for the plots treated with the highest P level (90 kg ha^{-1}), followed by 596.3 gm^{-2} (60 kg P ha^{-1}), while the lowest SPDM (582.9 gm^{-2}) was obtained from the plots that received 30 kg P ha^{-1} . Among the BMO levels, the highest SPDM (605.9 gm^{-2}) was recorded for the plots treated with 30 L BMO ha^{-1} , followed by 597.7 gm^{-2} (20 L ha^{-1}), while the lowest SPDM (583.2 gm^{-2}) was obtained from the plots that received 10 L BMO ha^{-1} . The interaction between IC x BMO revealed increase in BMO level increase SPDM under both irrigation conditions, however, the irrigated plots at all BMO levels produced higher SPDM than limited irrigation condition.

Irrigation	P (kg ha ⁻¹)	BMO (Lit ha ⁻¹)			IC x P
		10	20	30	
Irrigated	30	590.0	603.0	610.0	601.0
	60	601.0	614.0	625.7	613.6
	90	612.7	625.3	632.0	623.3
Dryland	30	549.7	569.0	576.0	564.9
	60	566.7	580.0	590.3	579.0
	90	579.0	595.0	601.7	591.9
Irrigated		601.2	614.1	622.6	612.6a
Dryland		565.1	581.3	589.3	578.6b
	30	569.8	586.0	593.0	582.9c
	60	583.8	597.0	608.0	596.3b
	90	595.8	610.2	616.8	607.6a
Mean		583.2c	597.7b	605.9a	
Planned means comparison					
Control		553.2b			
Rest		597.8a			

Means of the same category followed by different letters are significantly different from each other using LSD test ($P \leq 0.05$).

Least Significant Difference ($p \leq 0.05$)		
BMO	=	2.03
P	=	2.03
BMO x P	=	ns
IC x BMO	=	**
IC x P	=	ns
IC x BMO x P	=	ns

Where: ns stands for non-significant data, while ** indicates significant at 1% level of probability using LSD test ($P \leq 0.05$).

Table 7: Dry matter partitioning into spike (g m^{-2}) at physiological maturity of wheat (*Triticum aestivum* L.) as affected by phosphorous (P) and beneficial microorganism (BMO) under irrigated and dryland conditions (IC).

Total dry matter at physiological maturity

The TDM of wheat at PM was significantly affected by IC, P and BMO levels (Table 8). The interactions between BMO x P and IC x BMO had significant effect, while the interactions IC x P and IC x P x BMO had no significant effect on TDM. The rest (treated plots) had significantly higher TDM (1010.3 gm^{-2}) than control (921.0 gm^{-2}). The highest TDM (1040.9 gm^{-2}) was obtained from the full irrigation condition as compared with the limited irrigation condition (971.8 gm^{-2}). Among the P levels, the highest TDM (1030.9 gm^{-2}) was recorded for the plots treated with the highest P level (90 kg ha^{-1}), followed by 1009.7 gm^{-2} (60 kg P ha^{-1}), while the lowest TDM (978.3 gm^{-2}) was obtained from the plots that received 30 kg P ha^{-1} . Among the BMO levels, the highest TDM (1031.4 gm^{-2}) was recorded for the plots treated with 30 L BMO ha^{-1} , followed by 1011.4 gm^{-2} (20 L ha^{-1}), while the lowest TDM (976.2 gm^{-2}) was obtained from the plots that received 10 L BMO ha^{-1} . The interaction between BMO x P indicated that increase in both BMO and P levels increased TDM in wheat.

Discussion

The results revealed that the treat plots (rest) accumulated more total dry matter (DM) and partitioned more DM into leaf, stem and spike at both anthesis and physiological maturity (PM). Total DM accumulation and partitioning is very important because it had positive relationship with absolute growth rate, crop growth rate, net assimilation rate and water use efficiency [8]. Our results from the same study suggested that the rest (treated plots) produced taller plants, more leaves per plant and higher single leaf area (data not

Irrigation	P (kg ha ⁻¹)	BMO (Lit ha ⁻¹)			IC x P
		10	20	30	
Irrigated	30	989.0	1020.0	1037.0	1015.3
	60	1017.0	1046.3	1068.3	1043.9
	90	1032.7	1069.3	1088.0	1063.3
Dryland	30	906.0	950.0	968.0	941.3
	60	945.3	980.0	1001.3	975.6
	90	967.0	1003.0	1025.7	998.6
Irrigated		1012.9	1045.2	1064.4	1040.9a
Dryland		939.4	977.7	998.3	971.8b
	30	947.5	985.0	1002.5	978.3c
	60	981.2	1013.2	1034.8	1009.7b
	90	999.8	1036.2	1056.8	1030.9a
Mean		976.2c	1011.4b	1031.4a	
Planned means comparison					
Control	921.0b				
Rest	1010.3a				

Means of the same category followed by different letters are significantly different from each other using LSD test ($P \leq 0.05$).

Least Significant Difference ($p \leq 0.05$)		
BMO	=	3.57
P	=	3.57
BMO x P	=	**
IC x BMO	=	**
IC x P	=	ns
IC x BMO x P	=	ns

Where: ns stands for non-significant data, while ** indicates significant at 1% level of probability using LSD test ($P \leq 0.05$)

Table 8: Total dry matter accumulation (g m⁻²) at physiological maturity of wheat (*Triticum aestivum* L.) as affected by phosphorous (P) and beneficial microorganism (BMO) under irrigated and dryland conditions (IC).

published), and higher yield and yield components [9] than control plots. The improved growth and higher yield under treated plots than control plots indicating the importance of P x BMO application under calcareous soils in semiarid condition. The results further revealed that the full irrigated plots accumulated more total DM and portioned more DM into leaf, stem and spike at both anthesis and PM. The less DM accumulation and partitioning under limited irrigation conditions probably may be due to lower photosynthetic rate because low water availability. According to Sinaki et al., photosynthesis and DM accumulation reduced under moisture stress condition [10]. The results of this experiment [9] revealed that number of spikes m⁻² grains per spike in wheat increased under full irrigation condition and lower number of both parameters was recorded under limited irrigation condition. The increase in number of spikes m⁻² and grains per spike under full irrigation condition probably may be the major cause to increase total DM accumulation and partitioning into various parts. Radmehr et al. observed more number of spikes m⁻² under irrigated than un-irrigation condition [11]. Misbah reported higher number of grains spike⁻¹ under irrigation condition because of the availability of water at critical growth stages improve growth and development of wheat than moisture stress condition [12]. Kabir et al. reported that full irrigation improved economic yield because of improved crop growth, yield components and also it enabled crop to intercept maximum photosynthetic radiation over limited irrigated plants [13]. The results also revealed that the increase in P level accumulated more total DM and portioned more DM into leaf, stem and spike at both anthesis and PM. A large amount of DM was accumulated in response to the application of the highest rate of (90 kg P ha⁻¹). The increase in total

DM accumulation with increase in P probably may be due P being the components of ATP might have contributed to a higher photosynthetic rate, abundant vegetative growth and assimilates formation and partitioning [14]. The results of this experiment revealed that number of spikes m⁻² and grains per spike in wheat increased when P was applied at the highest rate 90 kg P ha⁻¹ [9]. The increase in number of spikes m⁻² and grains per spike with increase in P level probably may be the major cause for increasing total DM accumulation and its partitioning into various plant parts. Memon et al. and Rahim et al. reported that grains per spike in wheat increased with increase in P level [15,16]. The lack of optimum moisture and low soil fertility are the inherent problems in rainfed areas of Khyber Pakhtunkhwa [2]. Phosphorus and N deficient plants usually have more dry matter partitioning to roots than shoots, probably as a result of higher export rates of photosynthates to roots [17]. The results also revealed that application of BMO at the two higher levels (20 and 30 L ha⁻¹) accumulated more total DM and partitioned more DM into leaf, stem and spike at both anthesis and PM. Our results from this study suggested that the increase in BMO level increased spikes m⁻² and grains per spike that resulted in higher total DM accumulation and partitioning into different parts of wheat [9]. Because BMO application increases the availability of plant nutrients especially P availability that results in better plant growth and higher production [5,6,18]. Dobbelaere et al. assessed the inoculation effect of BMO on growth of spring wheat and observed that inoculated wheat plants had better growth, more number of grains spike⁻¹ and grain yield [19]. The average data (Table 9) revealed that at anthesis percent DM partitioning into leaf was more (36%) than stem and spike (each 32%), while at PM more DM was portioned into spike (59%) than stem (21%) and leaf (20%). At anthesis more assimilates were partitioned into leaf because during this stage there was no or less sink present, but at PM the highest assimilates were translocated into the spike. These results are similar to those of Singh et al. who stated that during anthesis stages most of the DM accumulated in stem and leaves [20-25]. But during maturity stage, greater assimilates was translocated to spike for grain formation. Amanullah and Stewart observed differences in DM partitioning into various plant parts of oats at 30, 60 and 90 days after emergence [8].

Conclusion

It was concluded from the experiment that under full irrigated (no moisture stress) condition wheat had more DM accumulation and partitioning into various plant parts than dryland (moisture stress) condition. Increase in both P and BMO levels (90 kg P ha⁻¹ and 30 L ha⁻¹, respectively) had positive effects on total DM accumulation,

Treatment	Anthesis				Physiological maturity			
	Leaf	Stem	Spike	Total	Leaf	Stem	Spike	Total
BMO (L ha⁻¹)								
10	35	33	32	100	19	21	60	100
20	37	32	31	100	20	21	59	100
30	37	32	31	100	20	21	59	100
Phosphorus (kg ha⁻¹)								
30	36	33	32	100	19	21	60	100
60	36	32	32	100	20	21	59	100
90	36	32	31	100	20	21	59	100
Irrigation condition								
Full	36	33	31	100	20	21	59	100
Limited	36	32	32	100	20	21	60	100
Average treatments	36	32	32	100	20	21	59	100

Table 9: Percent dry matter partitioning into leaf, stem and spikes at anthesis and physiological maturity of wheat as affected by beneficial microorganism (BMO), phosphorus (P) under full and limited irrigation conditions.

DM partitioning and yield when there was no moisture stress. Under moisture stress, the intermediate levels of both P and BMO (60 kg P ha⁻¹ and 20 L ha⁻¹, respectively) was found more beneficial in terms of higher DM accumulation, DM partitioning and yield. The percent DM partitioning was greater into leaf at anthesis (leaf> stem=spike) and greater into spike (spike>stem>leaf) at physiological maturity.

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