Journal of AgriSearch 4(2):92-97
An Open Access International Peer Reviewed Quarterly
ISSN : 2348-8808 (Print), 2348-8867 (Online)
http://dx.doi.org/10.21921/jas.v4i2.7778

Beneficial Microorganism and Phosphorus Application Influence Growth, Biomass and Harvest Index in Irrigated and Dryland Wheat under Calcareous Soils in Semiarid Condition

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ARTICLE INFO

Received on	:	12.05.2017
Accepted on	:	29.05.2017
Published online	:	01.06.2017

ABSTRACT

Field experiment was conducted to investigate the impact of phosphorus (P) and BM on growth, biomass and harvest index in irrigated and dryland wheat (*Triticum aestivum* L., cv. Siren-2010) under calcareous soils in Northwestern Pakistan. The experiment was conducted under full and limited or dryland irrigated conditions at the Research farm of The University of Agriculture Peshawar during winter. The experiment was laid out in randomized complete block design. The results revealed that growth, biomass and harvest index was significantly higher for full than limited condition and for treated plots (rest) than control. The interaction of BM x P x IC revealed that under full irrigated condition the increase in both P and BM levels (90 kg P ha-^{1} and 30 L ha-^{1}, respectively) and under limited irrigated condition the intermediate levels of both P and BM (60 kg P ha-^{1} and 20 L ha-^{1}, respectively) increased growth, biomass and harvest index in wheat under calcareous soils in semiarid condition.

Keywords: Beneficial microorganism, phosphorus, irrigation, wheat, growth, biomass, harvest index.

INTRODUCTION

Wheat (*Tritium aestivum* L.) is key staple food crop among cereals in Indian sub continent (Singh *et al.*, 2017). Globally, Pakistan is an important wheat producer. In Pakistan among cereals wheat occupies about 37% of the cropped area and consumes about 45% of the total fertilizers utilized in the country and 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} (MINFA, 2012). Wheat average yield in the province of Khyber Pakthukhwa was 1550 kg ha-1in the same growing season which looks very compared with the national average yield (MINFA, 2012).

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. 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 (Amanullah *et al.*, 2010). The soils of Khyber Pakhtunkhwa have low organic matter content and less available P. 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. 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. 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 (BM) 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. Many kinds of soil bacteria (Bacillus, Pseudomonas, Rhizobium and Enterobacter) and fungi (Aspergilllus 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, fumaeric acids, and succinic acids. These acids reduce the PH and bring the dissolution of bound forms of phosphate (Walpola and Yoon, 2012). As P is the major limiting factor for crop production in Khyber Pakhtunkhwa therefore combine application of BM and P to these soils could increase P availability and crop productivity. However, there is no research to investigate the interactive effects of BM x P under irrigated and moisture stress conditions. This research work was therefore designed to study the interactive effects of BM x P on growth, biomass and harvest index of wheat under full and limited irrigated conditions.

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MATERIALS AND METHODS

Field experiment was conducted to investigate effects of beneficial micro-organisms (BM) applied at (10, 20, and 30 L ha-^{1}) as Bioaab and P levels (30, 60 and 90 kg P_2O_5 ha-^{1}) as triple super phosphate (46 % P_2O_5) on dry matter partitiioning of wheat under full (five irrigations) and limited (two irrigations, moisture stress) irrigated conditions at the Agricultural Research Farm of The University of Agricultural Peshawar, during winter 2012-13. 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 February2013.

Location Information

The experimental farm is located at 34.018N latitude, 71.358E 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 is clay loam, low in organic matter (0.87%), phosphorus (6.57 mg kg-^{1}), potassium (121 mg kg-^{1}) and alkaline (pH 8.2) and is calcareous in nature.

Factors and Their Levels Studied

Control: No BM and no P was applied

A. Beneficial Micro-organisms (Bioaab L ha-^{1}): BM_1 = 10, BM_2 = 20, BM_3 = 30

B. Phosphorus Levels (kg P_2O_5 ha-^{1}): P_1 = 30, P_2 = 60, P_3 = 90

The experiment was conducted under full irrigated condition which received a total of five irrigations [1st for seedbed preparation, 2nd 10 days after sowing for beneficial microorganism and 2nd dose of N application (26thNovember), 3rd 60 days after sowing (15th January), 4th after anthesis (30th March) and 5th at grain fill duration (13th April)] and under limited irrigated condition received only two irrigations [1stirrigation for seedbed preparation before sowing and 2nd irrigation at 10 days after sowing for BM and 2nd dose of N application (26thNovember)]. The experiment was laid out in randomized complete block design using three replications under both full and limited irrigated conditions. Each replication consisted of 10 treatments including three BM levels x three P levels (9 treatments) + one control treatment (no BM 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 in two equal splits i.e. half each at sowing and first irrigation (10 days after sowing). The BM (Bioaab) used was obtained from Cheinar Agro Trade Butkhela, Malakand, Khyber Pakhtunkhwa.

Data recording and Statistical Analysis

Days to anthesis was recorded when about 75% spikes emerged in each subplot, while days to physiological maturity was recorded from the date of sowing till date when all the plants gets physiologically matured in each subplot. Complete loss of the green color of the glumes was used as sign of physiological maturity. Data on plant height (cm) at physiological maturity was recorded with the help of meter rod by selecting ten plants randomly within each subplot and then average height was calculated. Number of leaves tiller–^{1} at anthesis were recorded by taking ten plants from each subplot and mean was worked out. Leaf area (cm^{-2}) was calculated by taking five representative plants from each treatment at anthesis. The leaf area was calculated by the following formula.

Leaf area = Leaf length x Leaf width x Factor (0.67)

Data on biomass yield was recorded by harvesting four central rows in each subplot, the material was sun dried for several days and weighed, and then converted into biomass yield kg ha^{-1} and Grain yield (kgha^{-1}). Harvest index for each treatment was calculated. Data were statistically analyzed combined over irrigation condition (Steel *et al.,* 1997) and means were compared using LSD test ($p < 0.05$). The detail analysis of variance along with probability is given the data at anthesis and PM in table 1 and table 2, respectively.

RESULTS AND DISCUSSION

Days to anthesis

Days to anthesis (DTA) of wheat were significantly affected by the irrigation condition (IC), phosphorus (P) and beneficial microorganism (BM) levels (Table 1). The rest (the average of all treated plots) took significantly less number of DTA (128 d) than control (131 d). The minimum DTA (127 d) was recorded for the full irrigated field as compared with the limited

Table 1: Days to anthesis of wheat as affected by phosphorous (P) and beneficial microorganism (BM) under full and limited irrigated conditions (IC)

Irrigation	P (kg ha^{-1})	BM (Lit ha $^{-1}$)			IC x P
		10	20	30	
Full	30	129	127	129	128
	60	129	125	128	127
	90	128	124	125	126
Limited	30	132	129	130	130
	60	130	128	128	129
	90	130	126	126	127
Full		129	125	127	127b
Limited		130	128	128	129 a
	30	131	128	130	129 a
	60	129	127	128	128 ab
	90	129	125	125	127 b
Mean		130 a	127 b	128 b	
Planned means comparison					**p-value**
Control		131 a			0.0000
Rest		128 b			

Means of the same category followed by different letters are significantly different from each other using

LS Difference ($P \leqslant 0.05$): BM: 1.18; P: 1.18; BM x P= NS, IC x BM= NS, IC x P = NS and IC x BM x P= NS.

Where: NS stands for non-significant using LSD test ($P \leqslant 0.05$).

irrigated field (129 d). Among the P levels, delayed DTA (129 d) was recorded for the plots treated with the lowest P level (30 kg ha^{-1}), followed by 128 days with 60 kg P ha^{-1}, while the earlier DTA (127 d) was recorded for the plots that received 90 kg P ha^{-1}. Among the BM levels, delayed DTA (130 d) was recorded for the plots treated with the lowest BM level (10 L ha^{-1}), followed by 128 days with 30 L ha^{-1}, while the earlier DTA (127 d) was recorded for the plots that received 20 L BM ha^{-1}. Early DTA was observed for the full irrigated condition (five irrigations), while late anthesis was found in the limited irrigated condition (two irrigations). During flowering initiation and inflorescence development water shortage cause delay in anthesis. Early DTA was observed for the plots that received 90 kg P ha^{-1}, while delayed anthesis was observed in the control plots (P not applied).

Means of the same category followed by different letters are significantly different from each other using

LS Difference ($P \leqslant 0.05$): BM: 1.18; P: 1.18; BM x P= NS, IC x BM= NS, IC x P = NS and IC x BM x P= NS.

Where: NS stands for non-significant using LSD test ($P \leqslant 0.05$).

Days to physiological maturity

Days to physiological maturity (DTPM) of wheat was significantly affected by IC, P and BM levels, while all the interactions had no significant effect on DTPM (Table 2). Delayed DTPM (158 d) was recorded under full irrigated condition while early maturity was observed under limited irrigation condition (157d).) Among the P levels, the delayed DTPM (159 d) was recorded for the plots treated with the lowest P level (30 kg ha^{-1}), followed by 157 days with 60 kg P ha-1, while the earliest DTPM (155 d) was recorded for the plots that received 90 kg P ha^{-1}. These results agree the statement of Khalil *et al.* (2010) observed that application of large amounts of P enhance maturity in wheat. Among the BM levels, delayed DTPM (159 d) was recorded for the plots treated with the lowest BM level (10 L ha^{-1}), followed by 157 days with 20 L ha$^{-1,}$ while the earliest DTPM (156 d) was recorded for the plots that received 30 L BM ha^{-1}. Application of bio-fertilizer has been reported to enhance the microbial diversity of soil, increase availability of P and so crops also enhance phenological development and yield.

Table 2: Days to physiological maturity of wheat as affected by phosphorous (P) and beneficial microorganism (BM) under full and limited irrigated conditions (IC)

Irrigation	P (kg ha^{-1})	BM (Lit ha^{-1}) 10	20	30	IC x P
Full	30	161	160	159	160
	60	158	157	157	157
	90	157	156	155	156
Limited	30	160	159	157	159
	60	159	155	157	157
	90	158	153	154	155
Full		158	158	157	158a
Limited		159	156	156	157b
	30	160	160	158	159a
	60	159	156	157	157b
	90	157	154	154	155c
Mean		159a	157b	156c	
Planned means comparison					**p-value**
Control	160a				0.0000
Rest	157b				

Means of the same category followed by different letters are significantly different from each other using LSD test ($P \leqslant 0.05$).
LS Difference ($P \leqslant 0.05$). BM : 0.72; P: 0.72; BM x P, IC x BM, IC x P and IC x BM x P= NS.
Where: NS stands for non-significant data using LSD test ($P \leqslant 0.05$).

Plant height

Plant height (PH) of wheat was significantly affected by IC, P and BM levels, while all the interactions were non-significant (Table 3). The tallest plants (96.6 cm) were obtained for the full irrigated field as compared with the limited irrigated field (88.1cm) and control (87.2cm). This may be due to the improved plant growth with enough accessibility of plans to nutrients and water having no moisture stress. Among the P levels, the taller plants (94.5 cm) was recorded for the plots treated with the highest P level (90 kg ha^{-1}), followed by 92.9 cm with 60 kg P ha^{-1}, while the shorter plant height (89.7 cm) was noted for the plots that received 30 kg P ha^{-1}. Among the BM levels, the plants were taller (94.1cm) with the highest BM level (30 L ha^{-1}) while the shorter plants (90.2 cm) were recorded for the plots that received 10 L BM ha-1. The possible

Table 3: Plant height (cm) of wheat as affected by phosphorous (P) and beneficial microorganism (BM) under full and limited irrigated conditions (IC)

Irrigation	P (kg ha^{-1})	BM (Lit ha^{-1}) 10	20	30	IC x P
Full	30	91.0	94.5	95.8	93.8
	60	94.8	97.8	98.5	97.0
	90	97.2	99.5	100.4	99.0
Limited	30	83.7	85.3	87.7	85.6
	60	86.3	89.3	90.7	88.8
	90	87.9	90.4	91.7	90.0
Full		94.4	97.2	98.2	96.6a
Limited		86.0	88.3	90.0	88.1b
	30	87.4	89.9	91.8	89.7c
	60	90.6	93.5	94.6	92.9b
	90	92.6	94.9	96.1	94.5a
Mean		90.2c	92.8b	94.1a	
Planned means comparison					**p-value**
Control	87.2b				0.0000
Rest	92.6a				

Means of the same category followed by different letters are significantly different from each other using LSD test ($P \leqslant 0.05$). LS Difference ($P \leqslant 0.05$) BM : 0.95; P: 0.95; BM x P, IC x BM, IC x P and IC x BM x P= ns.
Where: ns stands for non-significant data using LSD test ($P \leqslant 0.05$).

reason for increase in plant height due to BM application was that bio-fertilizer are involved in destruction of harmful microorganisms and increase P availability to crops that improve different physiological and chemical processes in the crop which enhance the vegetative growth and plant heights. An increase in plant height has been reported due to inoculation of phosphate-solubilizing microorganism and phosphorus.

Number of leaves tiller^{-1}

Number of leaves tiller^{-1}(NLPT) of wheat was significantly affected by IC, P and BM levels. The interactions i.e. BM x P and I x BM x P had significant effect (Table 4). The rest had significantly higher NLPT (5.3) than control (4.2). The highest NLPT (5.5) was obtained from the full irrigated field as compared with the limited irrigated field (5.0). Among the P levels, the highest NLPT (5.9) was recorded for the plots treated with the highest P level (90 kg ha^{-1}) while the lowest NLPT (4.7) was obtained with 30 kg P ha^{-1}. The increase in leaf count as well as leaf weight due to adequate fertilizer nutrition is explainable in terms of possible increase in nutrient mining capacity of plant as a result of better root development and increased translocation of carbohydrates from source to growing points in well fertilized plots (Singh and Agrawal, 2001).Among the BM levels, the highest NLPT (5.8) was recorded with 30 L BM ha^{-1} while the lowest NLPT (4.7) was obtained from the plots that received 10 L BM ha^{-1}. The interaction between BM x P indicated that at all P levels the increase in BM levels increased NLPT. The IC x BM x P interaction revealed that the increase in both P and BM levels increased NLPT under full as well as limited irrigated condition. However, the increase was more under full irrigated condition than limited irrigated condition. The less number of NLPT under limited irrigated condition was due to moisture stress.

Table 4: Number of leaves tiller^{-1}of wheat as affected by phosphorous (P) and beneficial microorganism (BM) under full and limited irrigated conditions (IC)

Irrigation	P (kg ha^{-1})	BM (Lit ha^{-1})			IC x P
		10	20	30	
Full	30	4.6	4.7	5.5	4.9
	60	5.0	5.4	5.6	5.3
	90	5.1	6.3	7.1	6.2
Limited	30	4.1	4.2	5.0	4.4
	60	4.4	5.2	5.3	5.0
	90	4.7	5.8	6.4	5.6
Full		4.9	5.5	6.1	5.5a
Limited		4.4	5.1	5.6	5.0b
	30	4.3	4.5	5.3	4.7c
	60	4.7	5.3	5.4	5.2b
	90	4.9	6.1	6.8	5.9c
Mean		4.7c	5.3b	5.8a	
Planned means comparison					**p-value**
Control	4.2b				0.0000
Rest	5.3a				

Means of the same category followed by different letters are significantly different from each other using LSD test (P ≤ 0.05). BM=0.27; P=0.27; BM x P**, IC x BM= NS, IC x P= NS; IC x BM 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 ≤ 0.05).

Leaf area tiller^{-1}

Leaf area tiller^{-1} (LAPT) of wheat was significantly affected by IC, P and BM levels. The interaction I x BM had significant effect while all other interactions had no significant effect LAPT (Table 5). The rest plots had significantly higher LAPT (111.2 cm^{-2}) than control (95.3 cm^{-2}). The highest LAPT (115.6 cm^{-2}) was obtained from the full irrigated field as compared with the limited irrigated field (105.7 cm^{-2}). Among the P levels, the highest LAPT (114.9 cm^{-2}) was recorded for the plots treated with the highest P level (90 kg ha^{-1}) while the lowest leaf area tiller^{-1} (105.0 cm^{-2}) was obtained from the plots that received 30 kg P ha^{-1}. Among the BM levels, the highest LAPT (115.0 cm^{-2}) was recorded with the highest BM level (30 L ha^{-1}) while the lowest LAPT (105.4 cm^{-2}) was obtained from those received 10 L BM ha^{-1}. The interaction between IC x BM indicated that the irrigated field produced higher LAPT than the limited irrigated condition at all BM levels. However, the higher LAPT was noted under both conditions when the highest level of BM was used. LAPT boosted up with every extra supplementation of P.

Table 5: Leaf area tiller^{-1} (cm^{-2}) of wheat as affected by phosphorous (P) and beneficial microorganism (BM) under full and limited irrigated conditions (IC

Irrigation		BM (Lit ha^{-1})			IC x P
		10	20	30	
Full	30	103.8	111.2	115.2	110.1
	60	112.1	117.2	120.9	116.7
	90	114.2	120.0	125.4	119.9
Limited	30	94.1	100.9	105.1	100.0
	60	103.5	108.5	109.5	107.2
	90	104.4	111.1	114.0	109.9
Full		110.1	116.1	120.5	115.6a
Limited		100.7	106.8	109.5	105.7b
	30	99.0	106.0	110.1	105.0c
	60	107.8	112.9	115.2	112.0b
	90	109.3	115.6	119.7	114.9a
Mean		105.4c	111.5b	115.0a	
Planned means comparison					**p-value**
Control		95.3b			0.0000
Rest		111.2a			

Means of the same category followed by different letters are significantly different from each other using LSD test (P ≤ 0.05).
BM : 1.65; P1.65; IC x BM:*; BM x P, IC x P and IC x BM x P= NS.
Where: ns stands for non-significant data, while * indicates significant at 5% level of probability, respectively using LSD test (P ≤ 0.05).

Biomass yield

Biomass yield (BY) of wheat was significantly affected by IC, P and BM levels. The interactions IC x BM and IC x P had significant effect on BY (Table 6). The rest plots had significantly higher BY (8795 kg ha^{-1}) than control (7780 kg ha^{-1}). The highest BY (9368 kg ha^{-1}) was obtained from the full irrigated condition as compared with the limited irrigated condition 8152 (kg ha^{-1}). The results from this study (data not published) revealed that the full irrigated plots accumulated more total DM m^{-2} and partitioned more DM into leaf, stem and spike at both anthesis and PM than limited irrigated condition. The less DM m^{-2} accumulation and partitioning under limited irrigated conditions probably may be due to lower photosynthetic rate because of low water availability. The results of this experiment (Amanullah *et al*., 2014) revealed that number of spikes m^{-2} grains per spike in wheat increased under full irrigated condition and lowered under limited irrigated condition. The increase in number of spikes m^{-2} and grains per spike probably may be the major cause to increase wheat biomass under full irrigated condition. Among the P levels, the highest BY (9013 kg ha^{-1}) was recorded for the plots treated with the highest P level (90 kg ha^{-1} while the lowest BY (8409 kg ha^{-1}) was obtained from the plots receiving 30 kg P ha^{-1}. The increase in biomass yield with increase in P probably may be due P being the components of ATP contributed to a higher photosynthetic rate, abundant vegetative growth including taller plants, more NLPT and LAPT (Lu and Barber, 1995). Among the BM levels, the highest BY (9169 kg ha^{-1}) was recorded for the plots treated with the highest BM level (30 L ha^{-1}), while the lowest BY (8207 kg ha^{-1}) was obtained from the plots that received 10 L BM ha^{-1}. This might be due to maximum release of nutrients from soil organic matter especially P and higher photosynthetic rate. The results from this study revealed that application of BM at the two higher levels (20 and 30 L ha^{-1}) accumulated more total DM accumulation m^{-2} at both anthesis and PM (data not published), produced taller plants, had more NLPT and LAT thus resulted in higher BY. Zhang *et al.* (1996) also reported that the application of P fertilizer with PSB (Pseudomonas striata) + FYM increased tillering, root development and plant dry weight. BM application increases the availability of plant nutrients especially P availability that results in better plant growth and higher production (Walpola and Yoon, 2012). The interaction between IC x BM indicated that irrigated plots at all BM levels produced higher BY than limited irrigated condition. The interaction between IC x P indicated that increase in P level up to the highest level (90 kg P ha^{-1}) increased biomass yield under full irrigated condition, but under limited irrigated condition, the BY was increased up to 60 kg P ha^{-1} but further increase in P level decreased BY.

Harvest Index

Harvest index (HI) was not affected by IC, while both P and BM levels had significant effect on HI (Table 7). The interactions BM x P and IC x P x BM had significant effect on HI. The rest plots had significantly higher HI (38.5%) than control (30.6%). The highest HI (38.4%) was obtained from the full irrigated condition as compared with the limited irrigated

Table 6: Biological yield (kg ha^{-1}) of wheat as affected by phosphorous (P) and beneficial microorganism (BM) under full and limited irrigated conditions (IC)

Irrigation	P (kg ha^{-1})	BM (Lit ha^{-1}) 10	20	30	IC x P
Full	30	8374	8953	9411	8913
	60	8816	9488	9849	9384
	90	9120	9862	10438	9806
Limited	30	7452	7990	8274	7905
	60	7679	8885	8429	8331
	90	7805	8237	8615	8219
Full		8770	9434	9899	9368a
Limited		7645	8370	8439	8152b
	30	7913	8471	8843	8409b
	60	8247	9187	9139	8858a
	90	8462	9049	9526	9013a
Mean		8207c	8902b	9169a	
Planned means comparison					**p-value**
Control		7780b			0.0000
Rest		8795a			

Means of the same category followed by different letters are significantly different from each other using LSD test ($P \leq 0.05$).
BM : 213; P 213; IC x BM:*; BM x P= NS, IC x P= *and IC x BM x P= NS.
Where: NS stands for non-significant data, while * indicates significant at 5% level of probability, respectively using LSD test ($P \leq 0.05$).

Table 7: Harvest index (%) of wheat as affected by phosphorous (P) and beneficial microorganism (BM) under full and limited irrigated conditions (IC)

Irrigation	P (kg ha^{-1})	BM (Lit ha^{-1}) 10	20	30	IC x P
Full	30	33.4	33.6	40.1	35.7
	60	35.2	39.3	41.1	38.6
	90	39.6	41.4	42.1	41.0
Limited	30	29.6	33.5	38.6	33.9
	60	33.6	44.0	41.2	39.6
	90	34.3	39.1	43.3	38.9
Full		36.1	38.1	41.1	38.4a
Limited		32.5	38.9	41.0	37.5b
	30	31.5	33.6	39.3	34.8b
	60	34.4	41.7	41.2	39.1a
	90	36.9	40.2	42.7	40.0a
Mean		34.3c	38.5b	41.1a	
Planned means comparison					**p-value**
Control		30.6b			0.0000
Rest		38.5a			

Means of the same category followed by different letters are significantly different from each other using LSD test ($P \leq 0.05$).
BM : 1.17 ; P 1.17; IC x BM: NS.; BM x P= NS, IC x P= *and IC x BM x P= *.
Where: NS stands for non-significant data, while ** and * indicates significant at 1 and 5% level of probability, respectively using LSD test ($P \leq 0.05$).

condition (37.5%). The higher number of grains spike^{-1} (Misbah, 2009) and improved crop growth, yield components and economic yield (Kabir *et al.,* 2009) under irrigated condition resulted in higher harvest index over limited irrigated condition. Among the P levels, the highest HI (40.0) was obtained with the highest P level (90 kg ha^{-1}), while the lowest HI (34.8%) was obtained with 30 kg P ha^{-1}. The higher HI with increase in P level was attributed to higher yield components and grain yield (Memon*et al*.,, 2011; Rahim *et al.,* 2010). Among the BM levels, the highest HI (41.1%) was recorded for the plots treated with the highest BM level (30 L ha^{-1}), while the lowest HI (34.8%) was obtained from the plots that received 10 L BM ha^{-1}. Dobblaere *et al.* (2002) assessed the inoculation effect of BM on growth of spring wheat and observed that inoculated wheat plants had better growth, more number of grains spike^{-1} and grain yield. The interaction between BM x P indicated that at the two P levels (30 and 90 kg P ha^{-1}) increase in BM level increased HI, but at 60 kg P ha^{-1} the HI was increased when BM level was increased up to 20 L BM ha^{-1}and further increase in BM decreased the HI. The interaction among IC x BM x P indicated that under full irrigated condition at all the P levels increase in BM level increased HI, while under limited irrigated conditions at the two P levels (30 and 90 kg P ha^{-1}) increase in BM level increased HI, but at 60 kg P ha^{-1} the HI was increased when BM level was increased up to 20 L BM ha-1and further increase in BM level decreased HI (Chaturvedi, 2006). The application of the highest P level improved yield and yield components thereby increased harvest index in wheat Saber et al. (2010). Application of the highest BM level improved yield and yield components (Amanullah *et al.,* 2014) and thereby increased harvest index in wheat) reported that grains per spike in wheat increased with increase in P level.

CONCLUSION

Under full irrigated condition the increase in both P and BM levels (90 kg P ha^{-1} and 30 L ha^{-1}, respectively) and under limited irrigated condition the intermediate levels of both P and BM (60 kg P ha^{-1} and 20 L ha^{-1}, respectively) was found more beneficial in terms of better growth, higher biomass yield and harvest index of wheat grown on calcareous soils under semiarid condition. Thus the combined application of both P + BM should be demonstrated to growers for getting maximum crop productivity.

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Citation:

Amanullah,, Khan Siddique, Iqbal Asif and Ali Akhtar. 2017. Beneficial Microorganism and Phosphorus Application Influence Growth, Biomass and Harvest Index in Irrigated and Dryland Wheat under Calcareous Soils in Semiarid Condition. *Journal of AgriSearch* **4** (2): 92-97