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Full Length Article

Contribution of Water Use Efficiency of Summer Legumes for the Production of Rainfed Wheat

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ABSTRACT

Knowledge about water in soil profile and the efficiency with which crop use this water is essential for replacing conventional summer fallow with the objective to optimize legume-wheat rotation system in rainfed areas. A 2-year field experiments were carried out to assess the effects of rotational systems on crop yield, N_2-fixation and water use efficiency (WUE) in two different locations of rainfed Pothwar. Two legumes crops (*mung bean, Vigna radiata* & mash bean, *V. mungo*) along with reference sorghum *Sorghum bicolor* were rotated with wheat (*Triticum aestivum*). The WUE values on N_2-fixation basis was 25% and 16% higher in mash and mung bean with P fertilization over legumes with out P. WUE on grain basis 2.09 kg ha^{-1} mm^{-1}, was 16% higher than mung bean with P fertilization. Over all 29% increase in grain WUE of legumes was observed in succeeding year. Soil water contents were 31% higher under mash bean fertilized with P than sorghum. Soil water distribution across soil profile showed that maximum quantity of water was found at 60-90 cm depth. Total soil profile water contents were 25 cm 100 cm^{-1}, under legumes and lower, 23 cm 100 cm^{-1}, under non-legume sorghum at harvest. Grain WUE of wheat was found 11-44% higher in the plots, which were previously under legumes crops as compared to non-legume sorghum. The P fertilization to legumes increased grain WUE of wheat by 22% compared to that of control. © Friends Science Publishers

Key Words: Legumes; Mung bean; Mash bean; WUE; Rainfed wheat

INTRODUCTION

Wheat (*Triticum aestivum*) is a major crop of Pothwar. Pothwar plateau consists mainly of Rawalpindi, Chakwal, Attock and Jhelum district of northern Punjab, Pakistan consisting of an area of more than one million hectare (Hayat, 2005). Being a rainfed tract, it contributes significantly to agricultural and livestock production of Pakistan (Supple *et al*., 1988; Mohammad, 1989). About 70% of the 1 million ha of the cultivated pothwar are cropped to cereals principally wheat (*Triticum aestivum*). Groundnut (*Arachis hypogaea*) and chickpea (*Cicer arietinum*) are widely grown in the southern, drier part of the Pothwar. Mung bean, mash bean and soybean are grown in the wetter, more northerly parts (Ali *et al*., 2002). Water is the most limiting factor for crop production in Pothwar. Soils are left fallow during summer and only ploughed with aimed to capture and store moisture *in situ*. Fallow period is approximately five months for wheat from harvest in April-May to planting in October-November of the same year. Fallow is applied to conserve water worldwide (Bonfil *et al.,* 1999; Ülker & Çiftçi, 2007). However, researchers have different opinion regarding the effects of fallow in water conservation especially in arid and semi-arid regions (Godwin, 1990). Most of conserved water is lost during summer fallow (Farahani *et al*., 1998) and growing only wheat can deplete the soil nutrients. To avoid these losses, legumes being cover crops consume less water can be utilized during fallow (Ülker & Çiftçi, 2007) and traditionally used to replace conventional summer fallow in arid regions. Wheat yield and quality increased much better if legumes are grown before wheat than wheat fallow wheat (Gan *et al*., 2003).

Available water is the determinant of oil seed and legumes yield (Cutforth *et al*., 2007; Knights *et al*., 2007) (Angadi *et al*., 2008). Researchers under rainfed conditions examine the characteristics of water use by oilseed and legumes crops (Miller *et al*., 2001; Nielsen *et al*., 2005; Campbell *et al*., 2007; Gan *et al.,* 2007), but more detailed information on water distribution within the various depths of the soil profile is needed. Knowledge of soil water at various soil depths and how it has been used by previous crops is imperative to design an appropriate rotation system for more efficient water use (Gan *et al*., 2009). In this paper and the previous one (Hayat *et al*., 2008a & b), we reported legumes-wheat rotational benefits. Usually the farmers in Pothwar area leave their fields fallow during summer and only ploughed the fields with the objectives to conserve soil moisture for wheat production during winter seasons. In this study, instead of leaving the soil fallow, we cropped

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legumes along with reference sorghum for their N_2-fixation and WUE and their effects on yield and WUE of succeeding wheat.

MATERIALS AND METHODS

Rotational field experiments were conducted during two growing seasons (2002-2003 & 2003-2004) at two locations in Pothwar, northern Punjab Province: location 1, average annual rainfall 380 mm, the Research Farm of PMAS Arid Agriculture University, Rawalpindi (UAAR) and location 2, average annual rainfall 308 mm, the farmer's field at Chakwal district. Meteorological data were collected at Regional Agro-Meteorological Centers (RAMC, UAAR station & SWCRI Chakwal) and is presented in Fig. 1a and b. The legumes crop i.e., mung bean (Var. NM-92) and mash bean (Var. Mash-3) was sown with seed rate 20 and 18 kg ha^{-1}. The legumes were grown with and without Phosphorus fertilizer. Sorghum (Var. YSS-98) was also sown as non-legume crop with seed rate 25 kg ha^{-1} and 100 kg N ha^{-1}. Phosphorus was applied as single super phosphate and nitrogen was applied to sorghum only in the form of urea. The net plot size was 5 m×5 m. Treatments were (T_1) Mungbean, (T_2) Mashbean, (T_3) Mungbean + P @ 80 kg ha^{-1}, (T_4) Mashbean + P @ 80 kg ha^{-1}, (T_5) Sorghum + N @ 100 kg ha^{-1}. Each treatment had four replications in Randomized Complete Block Design. Grain yield and N_2-fiation data of legumes is given in Table I. During winter, of 2002-2003 and 2003-2004, the whole fields were under wheat (Var. Wafaq, 2001). The soils of the experimental sites were sandy loam. For soil moisture contents by gravimetric methods, soil samples were taken with king tube from 0-30, 30-60, 60-90 and 90-120 cm depths at crops (legumes & wheat) sowing and harvesting. Soil moisture contents (percent) were determined using gravimetric method and percent values were converted to mm basis using soil bulk density measured for that growing season. The mean bulk densities for the two experimental years at UAAR and Chakwal fields were 1.40, 1.50, 1.60, 1.65 and 1.55, 1.60, 1.68 and 1.70 Mg m^{-3} for the 0-03, 30-60, 60-90 and 90-120 cm depth, respectively. Total water contents (mm) to a depth of 120 cm were calculated by adding the values for each of the four sections.

Water use efficiency of grain yield and N_2-fixation: Water use efficiency of N_2-fixed by legumes and grain yield (legumes & wheat) was calculated according to the procedure followed by Gregory (1991) and Herridge *et al.* (1995).

$$WUE = e/(f - g + h)$$

Where, e representing grain yield (kg ha^{-1}) or N_2-fixed (kg ha^{-1}), f and g are soil water contents (mm) to 1.20 m depth measured at planting and at harvest, respectively and h is growing season rainfall. The data collected for various characteristics were subjected to statistical analysis using Randomized Complete Block Design. Two years data were combined for broad based and reliable results. A software package MStat C was used to calculate ANOVA Tables. Treatments means were separated by using DMRT at $p<0.05$.

RESULTS AND DISCUSSION

Soil water distribution in the profile under legumes: Soil water contents were significantly increased (29%) by legumes to non-legume sorghum (Fig. 2). Soil water distribution across profile showed that maximum quantity of water was available below 61 cm depth and more water was depleted from surface soil. It was also observed that maximum water was available below 60 cm depth. Data of Fig. 2 confirmed the superiority of legumes. Distribution of soil water contents showed that plants depleted more water from surface 60 cm depth and availability of water was maximum at 60-90 cm depth. Data on total profile (0-120 cm) water contents (Fig. 3) indicated that during summer, 2002 at UAAR site, total water contents under mung and mash bean without P were 260 mm and these crops retained 29% more water in soil profile compared with non-legume sorghum. The influence of phosphorus fertilization was negligible. After summer, 2003 at UAAR site, maximum water >300 mm was observed under mash bean without P and on average legumes retained 12% more water than non-legume sorghum. Shoot dry matter definitely affects the soil water retention. Non legume sorghum utilize moisture form upper, as well as deeper layer of soil due to their deep root system (Srivastva *et al.*, 1985) and have leave less moisture in soil profile for the following crops. Results suggested that this plant available soil water accumulated at summer harvest will be contributed in yield responses of following winter wheat. Similarly, on average water contents were between 270-286 mm and 243 mm under beans and non-legume sorghum, respectively at Chakwal site in summer, 2002. It was also mentioned here that total water contents under summer crops at harvest was used to calculate WUE of N_2 fixation and grain yield of mung and mash bean. The results are similar to those of Miller *et al.* (2002 & 2003), who reported higher post harvest soil water contents under pulse crops than for wheat. They also observed the soil differences by indicating that pulse crops might conserve more soil water for subsequent crop on clay than loam soils.

WUE of grain yield of legumes: Water Use Efficiency of mash bean without P application was 113 and 37% greater than that of mung bean at UAAR site during summer, 2002 and 2003, respectively (Table II). The WUE of mung bean and mash bean were 1.65 and 2.09 kg ha^{-1} mm^{-1} with P fertilization, respectively. Water Use Efficiency of mash bean without P application was 22% higher than that of mung bean at Chakwal site, during summer, 2002. The average WUE of two years shows that WUE based on grain yield during summer, 2003 1.79 kg ha^{-1} mm^{-1}, were 30% greater as compared to previous year, 2002. The addition of P to chickpea (*C. arietinum*) increased yield and WUE

Fig. 1a: Rainfall (mm) and pan-evaporation (mm) regime during the years 2002-2003 at two sites

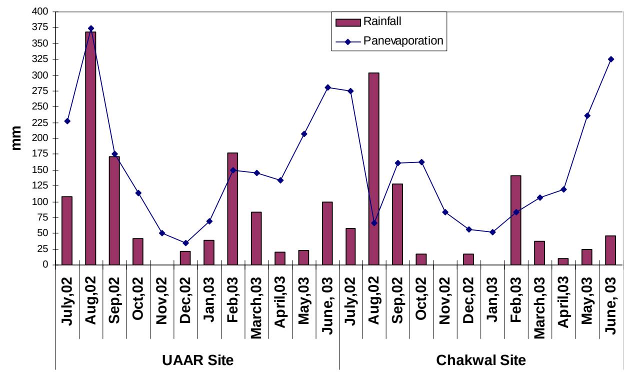


Fig. 1b: Rainfall (mm) and pan-evaporation (mm) regime during the years 2003-2004 at two sites

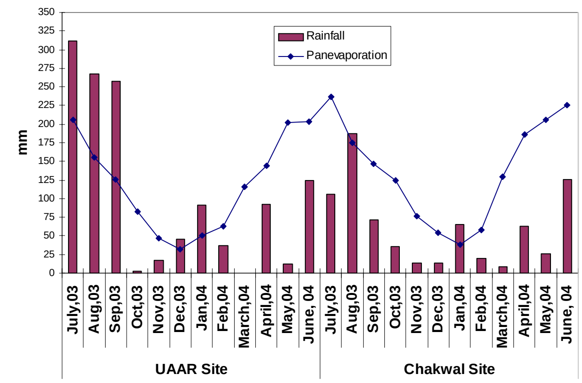
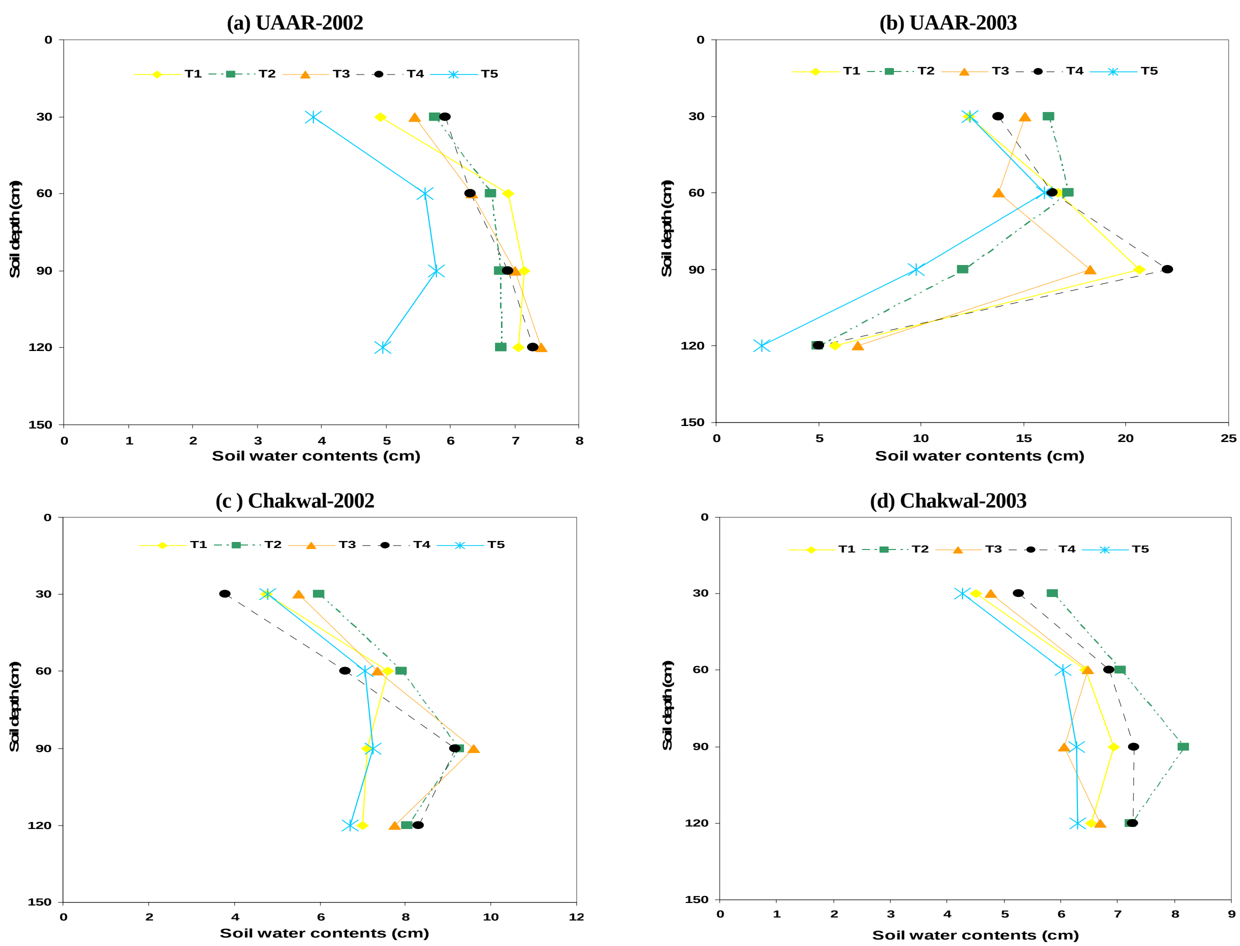


Fig. 2: Distribution of soil water with depth, (a) UAAR-2002, (b) UAAR-2003, (c) Chakwal-2002, (d) Chakwal-2003, each point is the mean of four replicates, data are after harvesting of summer crops

♦Mung bean, ■ Mash bean, ▲Mung bean + P, ●Mash bean + P, × Sorghum



from 8.5 to 12.2 kg ha^{-1} mm^{-1} with the application of 0 and 100 kg P ha^{-1} (Singh & Bhushan, 1980). Herridge *et al.* (1995) observed that WUE of Chickpea grain yield were different at different location and were not affected by fertilizer N. However, soil inherent fertility has a direct positive impact on crop yield and WUE (Viets, 1962). Davis and Quick (1998) suggested that to optimize WUE, nutrient management must be according to the requirement of crops

Table I: Grain yield and N_2-fixation of legumes

Treatments	Locations	Grain t ha^{-1}	N_2-fixed kg ha^{-1}	Grain t ha^{-1}	N_2-fixed kg ha^{-1}
		2002		2003	
Mung bean	UAAR	0.49	18.85	0.99	46.58
Mash bean	UAAR	1.05	13.33	1.30	68.31
Mung bean + 80 kg P ha^{-1}	UAAR	0.42	16.58	1.32	57.93
Mash bean + 80 kg P ha^{-1}	UAAR	0.77	12.9	1.66	79.72
LSD $_{0.05}$		0.2861	N.S	0.4047	N.S
Mung bean	Chakwal	0.72	18.53	0.81	29.63
Mash bean	Chakwal	0.80	22.53	0.86	32.25
Mung bean + 80 kg P ha^{-1}	Chakwal	0.81	19.71	0.87	35.43
Mash bean + 80 kg P ha^{-1}	Chakwal	0.85	26.07	0.88	38.26
LSD $_{0.05}$		0.08761	N.S	N.S	N.S

Table II: WUE of grain yield and N_2-fixation of legumes

Treatments	Locations	Soil H_2O (mm) Sowing	Soil H_2O (mm) Harvest	Total H_2O Used[a] mm	WUE (kg ha^{-1} mm^{-1}) Grain[b]	WUE (kg ha^{-1} mm^{-1}) N_2-fixation[c]	Soil H_2O (mm) Sowing	Soil H_2O (mm) Harvest	Total H_2O Used[a] mm	WUE (kg ha^{-1} mm^{-1}) Grain[b]	WUE (kg ha^{-1} mm^{-1}) N_2-fixation[c]
				2002					2003		
Mung bean	UAAR	184.5	260.30	613.50	0.80	0.030	239.65	278.39	801.86	1.23	0.058
Mash bean	UAAR	184.5	259.75	614.05	1.71	0.021	239.65	312.54	767.71	1.69	0.089
Mung bean + 80 kg P ha^{-1}	UAAR	184.5	262.27	611.53	0.69	0.027	239.65	279.19	801.06	1.65	0.072
Mash bean + 80 kg P ha^{-1}	UAAR	184.5	264.32	609.48	1.15	0.021	239.65	284.62	795.63	2.09	0.100
LSD (0.05)					0.4636	N.S				0.5058	0.0160
Mung bean	Chakwal	288.12	264.48	529.24	1.36	0.035	305.54	244.24	462.10	1.75	0.064
Mash bean	Chakwal	288.12	311.82	481.90	1.66	0.046	305.54	283.33	423.01	2.03	0.076
Mung bean + 80 kg P ha^{-1}	Chakwal	288.12	301.86	491.86	1.65	0.040	305.54	250.58	455.76	1.91	0.078
Mash bean + 80 kg P ha^{-1}	Chakwal	288.12	278.62	515.10	1.65	0.053	305.54	266.98	439.36	2.00	0.087
LSD (0.05)					0.1752	N.S				0.2771	N.S

[a]Calculated as sowing soil H_2O used-harvest soil H_2O + in-crop rainfall (UAAR 2002, 689.3 mm; UAAR 2003, 840.6 mm; Chakwal 2002, 505.6 mm; Chakwal 2003, 400.8 mm)
[b]Expressed as kg grain ha^{-1} mm^{-1} H_2O use; grain yield data in Table I
[c]Expressed as kg N_2 fixed ha^{-1} mm^{-1} H_2O used; N_2-fixation data in Table I

Table III: Residual effect of legumes and reference sorghum on yield and WUE of wheat

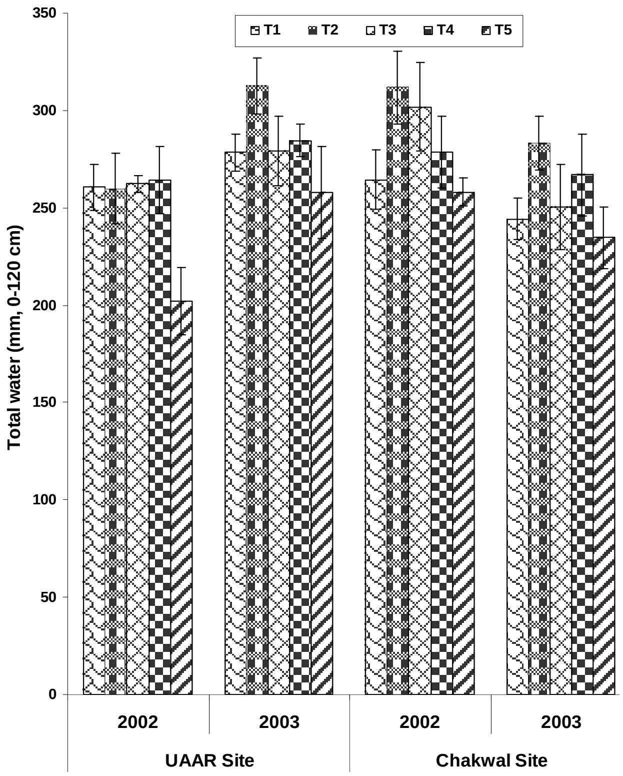
Treatments/Previous Crops	Locations	Soil H_2O (mm) Sowing	Soil H_2O (mm) Harvest	Total H_2O Used[a] mm	WUE (kg ha^{-1} mm^{-1}) Grain Yield t ha^{-1}	WUE (kg ha^{-1} mm^{-1}) WUE	Soil H_2O (mm) Sowing	Soil H_2O (mm) Harvest	Total H_2O Used[a] mm	WUE (kg ha^{-1} mm^{-1}) Grain Yield t ha^{-1}	WUE (kg ha^{-1} mm^{-1}) WUE
				2002-2003					2003-2004		
Mung bean	UAAR	260.50	173.97	469.53	2.16	4.60	278.39	199.62	364.47	3.43	9.41
Mash bean	UAAR	259.75	206.98	435.77	2.52	5.78	312.54	299.18	299.06	3.56	11.90
Mung bean+80 kg P ha^{-1}	UAAR	262.27	174.40	470.87	2.58	5.48	279.19	211.49	353.40	3.64	10.29
Mash bean+80 kg P ha^{-1}	UAAR	264.32	201.33	445.99	2.27	5.09	284.62	207.74	362.58	3.76	10.37
Sorghum+100 kg N ha^{-1}	UAAR	202.25	175.64	409.61	2.13	5.20	257.87	170.60	372.97	3.07	8.23
LSD (0.05)		*	*	41.82			*	*	*		
Mung bean	Chakwal	264.48	254.16	232.82	1.55	6.66	244.24	169.38	293.06	2.92	9.96
Mash bean	Chakwal	311.82	284.93	249.39	1.73	6.94	283.33	158.93	342.60	3.25	9.48
Mung bean+80 kg P ha^{-1}	Chakwal	301.86	285.75	238.61	1.78	7.46	250.58	192.22	276.56	3.13	11.32
Mash bean+80 kg P ha^{-1}	Chakwal	278.63	270.07	231.06	1.66	7.18	266.98	159.93	325.25	4.06	12.48
Sorghum+100 kg N ha^{-1}	Chakwal	258.15	242.96	237.69	1.28	5.38	234.79	160.75	292.24	2.87	9.82
LSD (0.05)		*	*	*		*	*	*	*		*

[a]Calculated as sowing soil H_2O used-harvest soil H_2O + in-crop rainfall (UAAR 2002-2003, 383 mm; UAAR 2003-2004, 285.7 mm; Chakwal 2002-2003, 222.5 mm; Chakwal 2003-2004, 218.2 mm)
[b]Expressed as kg grain ha^{-1} mm^{-1} H_2O use

(cultivar) and variation occurs in measured WUE under different climate, crops and soil management practices. It is possible to increase WUE by 25-40% through soil management practice and WUE can be enhanced by adopting more intensive cropping systems for dry areas (Jerry *et al.*, 2001).

WUE of N_2-fixation of legumes: Water Use Efficiency of N_2-fixation of mung bean without P application was 43% higher than that of mash bean at UAAR site during summer, 2002 (Table II). However, WUE of N_2-fixation of mash bean was 53% higher than that of mung bean without P during summer, 2003. The WUE of N_2-fixation of mung bean and mash bean were 0.07 and 0.10 kg N_2-fixed ha^{-1} mm^{-1} with P fertilization. Water Use Efficiency of mash bean without P application was 67% higher than that of mung bean at Chakwal site during summer, 2002. However, in the following year reported WUE of mash bean was to be half of that in 2002. The WUE of mung bean and mash bean were 0.08 and 0.09 kg N_2-fixed ha^{-1} mm^{-1} with P fertilization (Table II). WUE of N_2-fixation was 20% higher

Fig. 3: Total water after summer harvest to a depth of 1.2 m



at Chakwal site as compared to UAAR site and WUE of N_2-fixation during 2nd year legumes crops was 167% higher than previous year values. These higher values associated with higher percent P_{fix} (Hayat *et al.,* 2008b) during summer, 2003. The concept of WUE of legume N_2-fixatoin was firstly introduced by Herridge *et al.* (1995) It has relevance to WUE of grain and biomass yields and is used to evaluate and compare the efficiency of cropping usually in respect of applied treatments (Gregory, 1991). WUE of chickpea N_2-fixation vary between 0.14 and 0.24 kg ha^{-1} mm^{-1}, with the higher values associated with higher percent P_{fix} (Herridge *et al.,* 1995).

Residual effect of legumes and reference sorghum on yield and WUE of wheat: The results on WUE of wheat grain yield (Table III) demonstrated that during 1st year at UAAR site, WUE of wheat, 5.78 kg ha^{-1} mm^{-1} was maximum in treatments, which were previously under mash bean followed by, 5.48 kg ha^{-1} mm^{-1} in plots previously under mung bean fertilized with P. WUE of wheat grain was 11% higher in plots previously under mash bean to that of non-legume sorghum. The following year, WUE of wheat, 11.90 kg ha^{-1} mm^{-1}, was 45% higher in the plots that were previously under mash beans as compared to non-legume sorghum. The above findings are in line with those of Shafiq *et al.* (1998), who found while comparing soil water dynamics, crop yields and WUE that WUE in mung-bean-wheat was higher than the fallow-wheat cropping system. Similarly at Chakwal site, wheat grain WUE was 27-38% higher in plots, which were previously under mung bean with P, when compared with sorghum. Over all higher WUE of wheat was recorded during, 2003-2004 compared to 2002-2003. The P fertilization to previous legumes crops improved the production and water use efficiency of subsequent wheat under rainfed conditions and helped the plant to fight against the drought. The residue of legume (such as leaves etc) fallen on the surface of soil at maturity worked as residue mulch that probably resulted in better utilization of rainfall. Such crop residues would likely to have improved the soil organic fertility that resulted in better moisture utilization and crop nutrient availability (Muhammad *et al.,* 2003). Research has shown that wheat grown after a legume had a higher WUE than grown after wheat. The efficient storage of water in the soil profile coupled with efficient use of *in-situ* rainfall is important factors in production. Legumes worked as a covered crop and reduce surface evaporation (Hamblin *et al.,* 1987) and wheat yield WUE was increased by using legumes in rotation. The legume-wheat rotation system has proven to give high yield and WUE as compared to fallow-wheat rotation system and high WUE in the legumes treatments were due to the additional N_2-fixed thus improving soil fertility (Cayci *et al*., 2009). The size of legume canopy increased under fertile soil and large crop canopy reduces soil evaporation loses by shading the surface soil and increase the available water for transpiration, resulting in an increase in WUE (Richards *et al*., 2002; Sadras, 2003). Ülker and Çiftçi (2007) recommended wheat-lentil rotation, as growing lentil in fallow years enhanced permeability and water holding capacity of soil, optimized N fertility and increased farmer's additional income. Gan *et al.* (2009) also observed that pulse crop improve WUE in semi-arid environment.

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