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INFLUENCE OF DEFICIT IRRIGATION, SOWING METHODS AND MULCHING ON YIELD COMPONENTS AND YIELD OF WHEAT IN SEMIARID ENVIRONMENT

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Abstract

Water scarcity is one of the leading crop limiting factor in the modern world of farming. Improving water use efficiency is one of the most serious challenge for agricultural scientists and water management experts. To evaluate the influence of sowing methods and mulch on wheat water productivity under deficit irrigation, experiments were conducted over a period of two years (2011-2012 and 2013-2013) at Research Farm of the University of Agriculture Peshawar, Pakistan. The experiments were laid out in randomized complete block design with split- split plot arrangement having three factors and replicated four times. The experiments consisted of three factors such as irrigation deficit (full irrigation, 20, 40 and 60% irrigation), sowing methods (raised bed and flat bed) and mulching (mulched and non-mulched). It was found that sowing methods, mulching and deficit irrigation had significantly affected yield and yield components of wheat. Regarding sowing methods, raised bed cultivation resulted in higher number of grains spike^{1}, thousand grain weight, grain yield, biological yield and harvest index as compared to traditional flat bed sowing. Likewise, application of maize stover as a surface mulch enhanced wheat yield. In case of irrigation deficit, both full irrigation and 20% deficit irrigation resulted increase in thousand grain weight, grain spike^{-1}, biological and grain yield harvest index and water productivity. It can be concluded that raise bed cultivation, mulching and 20% deficit irrigation improved wheat yield and yield components under the semi-arid environmental.

Key words: Sowing methods, Deficit irrigation, Mulches, Wheat yield and yield Components.

Introduction

Growing more food is the ever increasing demand of the day to fulfill the food requirements of ever escalating population of the world. Among food crops, wheat (*Triticum aestivum* L.) is a major source of food all over the world. It is the staple food of Pakistan and provides the major dietary requirements (Ali *et al*., 2012). Wheat was chosen as the trial crops because wheat among cereal crops ranks first worldwide, measured either by cultivated area or production (Jagshoran *et al*., 2004). According to the Pakistan Bureau of Statistics annual report for 2012-2013, the country produced 25285 t of wheat from an area of 9039 ha in the 2013-2014. Wheat has got an evolutionary history parallel to the history of human civilization; as it decides the feast or famine for millions of people even today. Wheat contributes more than 10% of the total agricultural products and 15% of agricultural employment in Pakistan, over 50% share of which comes from small landholding farmers (FAO, 2011). It is highly nutritious as it's per acre amino acid yield is far exceeding that of animal products (Zong *et al.*, 2008).In modern agriculture,; increasing production per unit area, decreasing production cost and maintaining soil fertility on sustainable basis is the great challenge for agricultural scientist across the globe (Ali *et al*., 2011a and Ali *et al*., 2011b). Increase in population growth, poor irrigation system management, decrease in irrigated area due to rapid urbanization and climate change are threatening world sustainable food security. Water is the most limiting factor of crop production and world agriculture is currently utilizing 72% of available fresh water and this available irrigation water is progressively decreasing. To address this problem planners and researchers have diverted their attention towards deficit irrigation which has been widely recognized as a valuable strategy for dry regions (Wajid *et al*., 2002). Deficit irrigation (DI) aims at stabilizing yields and obtaining maximum water use efficiency (Akber *et al*., 2009). The correct application of DI requires understanding the yield response to water and economic impact of yield reduction. In water scarce areas it can be more beneficial for a farmer to increase crop water productivity instead of maximizing the per unit harvest. Water saved through DI can be used for other purposes or for irrigating extra units of land. Deficit irrigation with a water application of 40-70% less than needed for maximum yield resulted in a loss of wheat grain production of only 13% (Pereira *et al*., 2002).

Against the background of low water use efficiency in the traditional flat bed sowing with flood method of irrigation, raised bed cultivation system has been introduced in many developing countries of the world. Besides saving a large amount of water, it also helps to increase the productivity of crops. Meisner *et al*., (2005) found up to a 60% increase in water productivity of wheat in raised bed cultivation compared to that of traditional flat bed. It was observed that sowing of wheat on beds increased wheat grain yield up to 21% as compared to traditional flat bed method of drill sowing (Ahmed *et al*., 2007). A raised bed provides rapid drainage of irrigation water from its surface which helps to avoid water ponding which may cause de-oxygenation in upper rooting zone.

In arid and semi-arid areas evaporation rate may be high. As a result, crops need more water to survive and face stress conditions. In order to reduce evaporation, the effect of the three factors that increase evaporation may be minimized, i.e. reduce the heat for evaporation, decrease the difference in vapor pressure, and lower the water conductivity of the soil. Adding a cover to the soil such as mulch will positively affect the above factors that determine evaporation. Soil moisture conservation is one of the chief advantages of applying mulch. The detrimental effect of deficit water on crop yield could be reduced by adopting moisture conservation methods, such as use of mulches (Sajjid *et al*., 2003). Mulch has also been recognized as an effective method to provide a favorable soil environment by minimizing crusting at the soil surface (Kader *et al*., 2007). Mulch on the surface may increase the infiltration of rainwater and suppress the growth of weeds which compete with crop for water, sunlight, air and nutrients. Therefore, a study was conducted to determine the optimum, efficient and economical amount of irrigation, proper sowing method and mulch for wheat production. The research findings are expected to be useful for wheat farmers, water users and planners to make economical and efficient use of available irrigation water.

Materials and Methods

Experimental site: The experimental site is located at the New Developmental farm of the Khyber Pakhtunkhwa University of Agriculture, Peshawar (34°1'21"N, 71°28'5"E). The climate of the experimental site is hot, semi-arid, sub-tropical and continental with an average annual rainfall of 360 millimetres. Furthermore, the average higher temperature in the summer (from May to September) is 40°C and the average minimum temperature is 25°C. The average minimum temperature in the winter (from December to March) is 4°C and the maximum average temperature is 18.4°C. Normally, average rainfall is higher in the winter than in the summer. Maximum winter rainfall is recorded in the month of March, whereas the maximum summer rainfall is in the month of August.

Soil analysis before the start of experiment: Before start of the experiment, three samples were taken from different places of the field at random from the depth of 0-15 cm. All the samples were mixed together to make a composite sample. This composite sample was then dried in air and sieved through a 2 mm mesh for removal of mainly plant residues, stones or other unnecessary materials. The sand, silt and clay percentage of the composite sample were determined with the help of a textural triangle and are shown in Table 1 along with physicochemical analysis.

Experimental design: The experimental setup consisted of three factors (sowing methods, mulch, and deficit irrigation) arranged in randomized complete block with a split plot arrangement. Deficit irrigation had four levels i.e, full irrigation (DI_0), 20% deficit (DI_{20}), 40% deficit (DI_{40}) and 60% deficit (DI_{60}), while sowing method and mulching each has two levels replicated four times with a sub-plot size of 9 m x 5 m. The sowing methods compared were raised beds cultivation and the traditional flat bed cultivation. Mulching was with or without maize stover. Soil moisture was continuously monitored by gravimetric method and full irrigation was determined on the basis of Management Allow Deficit (MAD) of 50% in the root zone. Wheat was planted in the second week of November using the cultivar Siran. The recommended rate of NPK (120-90-60 kg ha^{-1}) was applied to all treatments equally as a basal dose. Full P and K and half N were applied at the time of sowing and the remaining half dose of N was applied with first irrigation. Urea was used as a source of Nitrogen; Di-ammonium Phosphate (DAP) for Phosphorous and Sulphate of Potash (SOP) for Potash. All agronomic practices were followed uniformly in both years by adopting standard and appropriate procedures used in the country.

Data collection: Agronomic data collected were number of tillers m^{-2}, plant height, number of grains $spike^{-1}$, 1000-grain weight, grain yield and biological yield. Grains $spike^{-1}$ was recorded by counting wheat grains from five spikes in each sub sub-plot that were randomly selected and was average accordingly. Data regarding thousand grains in sub plot were recorded on analytical balance after counting 1000 grains with the help of seed counter. For biological yield, each sub sub-plot of wheat was harvested, grains were sun dried, weighed and then converted to kg ha^{-1}. Grain yield was recorded by harvesting each sub sub-plot; sun dried, weighed and then converted to kg ha^{-1}.

Harvest index and water productivity: Harvest index (HI) and water productivity (WP) were determined by using the following formula;

$$HI = \frac{\text{Economic yield (grain)}}{\text{Biological yield}} \times 100$$

$$WP = \frac{\text{Economic grain yield (kg/ha)}}{\text{Seasonal water consumed (m3/ha)}}$$

Table 1. Basic soil characteristics (physico-chemical properties) before the start of experiment.

Soil physical properties	Unit	Value at the depth of (0-15cm)
Sand	%	24.39
Silt	%	67.20
Clay	%	8.44
Soil texture Class	-	Silt loam
Soil bulk density	-	0.27
Soil chemical properties		
pH	-	7.6
EC	D Sm^{-1}	0.56
Soil P	mg kg^{-1}	2.18
Sol total N	%	0.045
Sol K	mg kg^{-1}	83.25
Organic matter	%	0.73

Rainfall : The monthly rainfalls received during the study period are given in Figure 1. During the wheat growing period (2011-2012 and 201-213), the seasonal rainfalls were 54 and 405 mm respectively, where the seasonal normal rainfall is 232 mm. It can be seen from the figure 1 that below and above normal rainfalls occurred during wheat growing seasons as compared to the long term seasonal average of 253 mm.

Statistical analysis: Data recorded were analyzed statistically and combined over years using analysis of variance techniques appropriate for randomized complete block design. Means were compared using Least Square Difference (LSD) test at 0.05 level of probability, when the F-values were significant (Steel & Torrie, 1980).

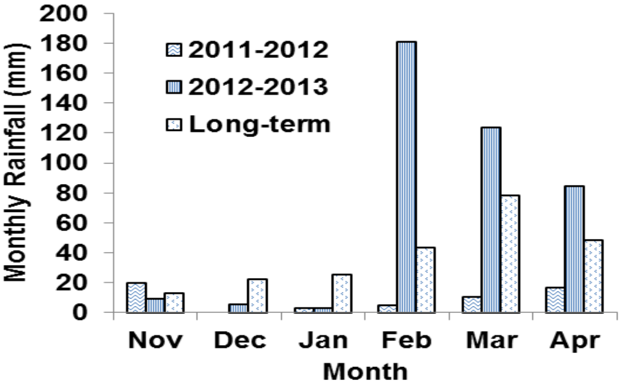


Fig. 1. Monthly Rainfall at the experimental site.

Results and discussion

Yield components

Number of tillers m^{-2}: Statistical analysis of the data revealed that sowing methods, mulching and deficit irrigation had significant effects on number of tillers m^{-2} of wheat (Table 2). Means indicated that raised bed sowing produced higher tillers m^{-2} (428) as compared to flat bed sowing (397). Raised bed resulted 7.8% more tillers m^{-2} than flat bed sowing. Wheat grown on raised beds had a higher number of tillers due to optimal moisture availability in the root zone under raised beds (Meisner *et al*., 2005). However, Mascagni *et al.,* (1995) concluded that wheat crop grown under raised beds produced minimum number of tillers as compared to the flat bed. The higher tillers m^{-2} (422) was recorded in plots where mulch was used. Mulch plots showed 4.7% more tillers m^{-2} than no-mulch plots. A higher number of tillers were produced in mulch plots contrast to no-mulch plots. Infact mulch conserves moisture in the soil and ultimately stimulates the plant growth by providing a layer on soil surface which may increase number of tillers up to 26% (Ahmed *et al.,* 2007). However, in this study the increase in number of tillers m^{-2} in mulch plots were relatively low.

The number of tillers m^{-2} decreased with increase in deficit irrigation level from DI_{20} to DI_{60}. No statistical significant difference in number of tillers m^{-2} observed between DI_o and DI_{20}. In general, deficit irrigations (DI_{40} and DI_{60}) resulted 5.2 to 8.2% reduction in number of tillers m^{-2}, respectively as compared to full irrigation (DI_{100}). The interaction effect of sowing method, mulching and deficit irrigation was found non-significant.

Plant height: Plant height is one of the most important growth parameters and mainly depends on soil moisture and nutrients availability. Data regarding plant height of wheat is shown in Table 2. Among the irrigation treatment, plant height was higher in plots irrigated with full irrigation (DI_0) while deficit irrigation resulted in short stature plants. Data revealed that only deficit irrigation had significant effect on plant height. Full irrigation resulted about 6.2% increase in plant height as compared to 60% deficit. This might be due to the better moisture available for N mobilization that promoted vegetative growth and produced taller plants (Kakar *et al.,* 2003 and Barhma *et al.,* 2007). The interaction effect of mulching and deficit irrigation was found significant.

Number of grains spike^{-1}: Statistical analysis of data exhibited that sowing methods, mulching and deficit irrigation had a significant effect on number of grains spike^{-1} (Table 3). Raised bed produced higher grains spike^{-1} (42) compared to flat bed sowing (40). These results are in conformity with (Mascagni *et al*., 1995) who reported that raised beds planting increase number of grains per spike. Similarly, maximum number of grains per spike (42) was found in mulched applied plots and minimum (40) in no mulched plots.

Higher number of grains spike^{-1} (44) was obtained from plots received full irrigation, while a lower number of grains spike^{-1} (38) was recorded in plots irrigated at 60% deficit irrigation treatment. The number of grains spike^{-1} decreased 13.6% as deficit irrigation level increased from DI_0 to DI_{60}. The most possible reason for this may be that the number of grains spike^{-1} is more sensitive to water stress and decrease in soil water potential increase total soil water potential, which may reduce photosynthesis and plant growth (Amini *et al.,* 2013). These results are in agreement with Mehmood *et al.,* (2013) who concluded that the number of wheat grains spike^{-1} were more water sensitive.

1000-grain weight (g): The 1000-grain weight of wheat was significantly affected by sowing method, mulching and deficit irrigation (Table 3). Wheat sown on raised beds produced 3.4% higher 1000-grain weight (43.1g) compared to flatbed (41.7g). The reason for higher 1000-grain weight in raised beds may be due to higher soil moisture conservation and better light penetration, which leads to produce more, assimilates for grain filling (Akber *et al.,* 2009).

The higher (4.6%) 1000-grain weight (43.3 g) was observed in mulched plots as compared to no-mulch plots (41.4 g). Application of crop residues as mulch may increase the soil organic matter on decomposition which increases nutrient availability resulting in better plant growth and development (Fakher *et al*., 2012).

Higher 1000-grain weight (44.8 g) was recorded with full irrigation, follow by DI_{20} (43.8g) and the lowest 1000-grain weight (39.5 g) was observed at 60% deficit irrigation. Higher deficit irrigation (DI_{60}) resulted 11.8% less 1000-grain weight as compared to full irrigation. Higher 1000-grain weight with full irrigation might be due to translocation of more photosynthates towards higher 1000-grain weight (Waraich *et al*., 2010). In other words plants having limited water supply produced lighter grains which might be due to less availability of nutrients from soil solution (Sarwar *et al*., 2010).

Table 2. Number of tillers and plant height of wheat as affected by different irrigation treatments, sowing methods and mulching.

Factors	Treatments	Number of tillers m^{-2}			Plant height (cm)		
		2011-12	2012-13	Average	2011-12	2012-13	Average
Sowing method (SM)	Raised Bed (RB)	415	441	428 a	95.7	95.8	95.8
	Flat Bed (FB)	372	422	397 b	95.3	95.5	95.4
	$LSD_{0.05}$ for SM = 9.1			*	LSD for SM = 0.85		ns
Mulch (M)	Mulch (M_1)	404	440	422 a	96.2	95.8	96.0
	No-Mulch(M_o)	383	423	403 b	94.8	95.6	95.2
	$LSD_{0.05}$ for M = 9.1			*	LSD0.05 for M = 0.85		ns
Deficit irrigation (DI)	DI_o	412	443	427 a	98.5	97.8	98.2a
	DI_{20}	400	451	425 a	97.0	96.9	96.9b
	DI_{40}	387	423	405 b	95.3	95.1	95.2c
	DI_{60}	375	408	392 c	91.3	92.9	92.1d
	$LSD_{0.05}$ for DI=2.9			*	LSD for DI = 1.2		
Interactions	I X M	Ns	ns	ns	*	*	*

* Significant at $p \leq 5$ %, ns = Non-significant

Table 3. number of grains spike[-1] and thousand grain weight of wheat as affected by different irrigation treatments, sowing methods and mulching.

Factors	Treatments	Number of grains $spike^{-1}$			1000 Grains weight (g)		
		2011-12	2012-13	Average	2011-12	2012-13	Average
Sowing method (SM)	Raised Bed (RB)	43	41	42 a	42.1	44.1	43.1 a
	Flat Bed (FB)	42	39	40 b	41.5	42.8	41.7 b
	LSD for SM = 0.89			*	LSD for SM = 1.03		*
Mulch (M)	Mulch (M_1)	44	40	42 a	42.4	44.3	43.4 a
	No-Mulch(M_o)	41	39	40 b	40.3	42.6	41.4 b
	LSD for M = 0.89			*	LSD for M = 1.03		*
Deficit irrigation (DI)	DI_o	45	41	44 a	44.1	45.5	44.8 a
	DI_{20}	44	42	43 a	43.0	44.6	43.8 a
	DI_{40}	41	39	40 b	40.0	42.9	41.4 b
	DI_{60}	40	36	38 c	38.2	40.8	39.5 c
	LSD for DI= 1.4			*	LSD for DI = 1.4		

* Significant at $p \leq 5$ % , ns = Non-significant

Table 4. Biological and grain yield of wheat as affected by different irrigation treatments, sowing methods and mulching.

Factors	Treatments	Biological yield (tons ha^{-1})			Grain yield (tons ha^{-1})		
		2011-12	2012-13	Average	2011-12	2012-13	Average
Sowing method (SM)	Raised Bed (RB)	12.02	12.08	12.05 a	5.1	5.3	5.2 a
	Flat Bed (FB)	11.05	11.50	11.27 b	4.4	4.7	4.6 b
	LSD for SM = 0.16			*	LSD for SM = 0.12		*
Mulch (M)	Mulch (M_1)	11.94	11.93	11.93 a	4.9	5.1	5.0 a
	No-Mulch(M_o)	11.13	11.64	11.39 b	4.6	4.8	4.7 b
	LSD for M = 0.16			*	LSD for M = 0.12		*
Deficit irrigation (DI)	DI_o	11.98	12.64	12.31 a	5.2	5.4	5.3 a
	DI_{20}	12.22	12.31	12.26 a	5.1	5.3	5.2 a
	DI_{40}	11.46	11.58	11.52 b	4.7	4.8	4.8 b
	DI_{60}	10.46	10.63	10.54 c	4.1	4.4	4.2 c
	LSD for DI=0.23			*	LSD for DI = 0.17		*
Interactions	SM X M	*	*	*	ns	ns	Ns

* Significant at $p \leq 5$ %, ns = Non-significant

Table 5. Harvest index and water productivity of wheat as affected by different irrigation treatments, sowing methods and mulching.

Factors	Treatments	Harvest Index (%)			Water Productivity (kg m^{-3})		
		2011-12	2012-13	Average	2011-12	2012-13	Average
Sowing method	Raised Bed	42.7	43.7	43.2 a	1.93	1.70	1.81 a
	Flat Bed	40.4	40.6	40.5 b	1.67	1.50	1.59 b
	LSD for SM = 1.3			*	LSD for SM = 0.04		*
Mulch	Mulch	41.4	42.9	42.2	1.86	1.65	1.75 a
	No-Mulch	41.7	41.4	41.5	1.75	1.55	1.65 b
	LSD for M = 1.3			ns	LSD for M = 0.04		*
Deficit irrigation (DI)	DI_o	43.6	42.6	43.1 a	1.85	1.73	1.79 a
	DI_{20}	41.7	43.3	42.5 a	1.85	1.71	1.78 a
	DI_{40}	41.3	41.8	41.5 ab	1.79	1.55	1.67 b
	DI_{60}	39.5	41.0	40.3 b	1.72	1.40	1.56 c
	LSD for DI=1.8			*	LSD for DI = 0.06		*

* Significant at $p \leq 5$ %, ns = Non-significant, LSD= Least significant difference

Biological yield (kg ha^{-1}): Biological yields of wheat were significantly affected by sowing methods, mulch and deficit irrigation are presented in Table 4. The sowing of wheat on raised bed produced 6.5% higher biological yield (12.05 tons ha^{-1}) as compared to flat bed (11.27 tons ha^{-1}). This effect is a combined contribution of yield components as plant height, number of grains spike-1 and 1000 grains weight (Galavi *et al*., 2012).

Surface application of crop residue as mulch produced higher biological yield (11.93 tons ha^{-1}) as compared to no mulch plots (11.39 tons ha^{-1}). The reason could be the better nitrogen mobilization at tillering stage which enhanced plant height and resulted in higher biological yield (Khan *et al*., 2011).

Biological yield increased from 10.54 to 12.31 tons ha^{-1} with increase in irrigation from 60% deficit to full irrigation (Figs. 2 and 3). Overall 14.4% more biological yield was obtained from plots that received full irrigation (DI_o) compared to 60% deficit. The reason for increase in biological yield under full irrigation may be due to better seed germination; higher plant height, more spikes m^{-2}, heavier grains and number of tillers m^2.

Grain yield (kg ha^{-1}): Grain yield was considerably influenced by sowing methods, mulching and deficit irrigation (Table 4). It is evident from the mean value that raised bed sowing (Fig. 4) produced 13.0% higher grain yield (5.2 tons ha^{-1}) as compared to flatbed (4.6 tons ha^{-1}), which was lower than reported by Ahmad *et al*., 2007. The reason for higher wheat grain yield may be increased number of grains spike^{-1}, higher 1000-grain weight, and the less dynamic fluctuation of soil water (Zhongming and Fahong, 2005 and Kilic, 2010). Application of maize crop residues as mulch significantly increased wheat yield by producing higher grains compared to no-mulch plots. Mulch plots produced 6.4% higher grain yield (5.0 tons ha^{-1}) than no mulch plots (4.7 tons ha^{-1}). The maize stover had a higher nutrient content than most straws with about 6% crude protein which initially conserve soil moisture by reducing evaporation from crop field and on decomposition it increases soil fertility and results in better crop yield (Bakht *et al*., 2009, Shah *et al*., 2013 and Wariach *et al*., 2010). No statistical difference in grain yield was observed between DI_{20} and full irrigation (DI_o). However, 40 and 60% deficit irrigation caused 9.4 and 20.8% yield reduction, as compared to full irrigation, similar findings were reported by Akber *et al*., 009. Less than 2% grain yield reduction was found between full irrigation and 20% deficit irrigation treatments (Figs. 4 and 5). Increase in irrigation level resulted in better grain yield because of improved crop growth and interception of more photosynthetic radiation over non irrigated plants. The reason for low wheat yields under deficit irrigation might be due to water stress that causes reverse osmosis (Ali *et al*., 2007).

Harvest index (%): Data regarding harvest index of wheat as affected by sowing methods, and irrigation levels are presented in Table 5. Sowing of wheat on raised bed had higher harvest index (43.2%) as compared to flat bed (42.5%). The most possible explanation of these results could be the better soil moisture conservation and nutrients availability for plants sown on raised beds and better light penetration (Zhongming and Fahong., 2005 and Karrou *et al*., 2012). Harvest index increased with full irrigation (DI_o) as compared to deficit irrigation (DI_{60}) from 40.3 to 43.1%. These results are in agreement with Brahma *et al*., (2007) and Ngwako *et al*., (2013) who reported that the increase in deficit irrigation level decreased wheat harvest index (%).

Water productivity (Kg m^{-3}): Data analyses regarding wheat water productivity are presented in Table 5. Water productivity was significantly affected by sowing methods, mulching and deficit irrigation. Raised beds produced 13.8% higher water productivity (1.81 kg m^{-3}) as compared to flat bed (1.59 kg m^{-3}), which was lower than reported by Meinser *et al*., 2005. The obvious reason for higher water productivity under raised beds may be its better drainage that prevented crop from excessive moisture conditions and efficient utilization of available water (Kilic *et al*., 2010). These results are in agreement with Wajjid *et al*., (2002) and Karrou *et al*., (2012) who reported that higher water productivity by adopting raised bed technology for wheat.

Similarly, higher water productivity (1.75 kg m^{-3}) was obtained in mulch plots as compared to no-mulch plots (1.65kg m^{-3}). Mulching enhances economic crop yield by increasing available nutrients and soil moisture that resulted in higher water productivity (Sing *et al*., 2013). These results are in line with those of Amini *et al*., (2013) who reported that mulching significantly increased water productivity.

Higher water productivity (1.79 kg m^{-3}) was recorded with full irrigation. 7-13% water productivity reduced when 40% and 60% deficit irrigation was applied. Figures 6 and 7 shows that there was no significance difference in water productivity between full irrigation and 20% deficit because the grain yield only slightly decreased with application of 20% deficit, after that significant decline was observed (Fereres *et al*., 2007). These results are in agreement with Galavi *et al*., (2012) and Ehsanullah *et al.*, (2013) who reported that water productivity decreased with increase in deficit irrigation level.

Conclusion

Deficit irrigation, sowing methods and mulch significantly affected number of tiller per m^2, thousand grain weight, grain spike^{-1}, biological and grain yield, harvest index and water productivity. Wheat yield, its components and water productivity reduced with deficit irrigation beyond 20% deficit. Wheat cultivation on raised bed enhanced water productivity, crop yield and its components as compared to the traditional flatbed sowing of wheat crop. In case of mulch application, grain yield production was higher than the non-mulched treatments. It is concluded that in semi-arid conditions, wheat can be cultivated on raised beds and mulching with 20% deficit in irrigation water without compromising the grain yield and its components and be used for irrigation of extra land.

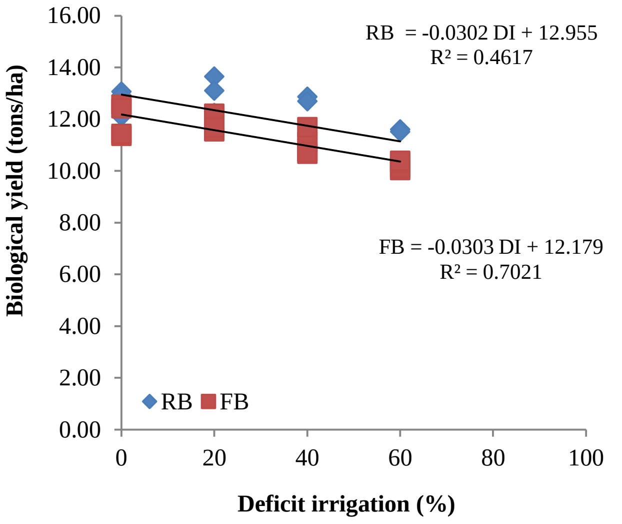


Fig. 2. Effect of deficit irrigation on wheat biological yield under Raised Bed (RB) and Flat Bed (FB).

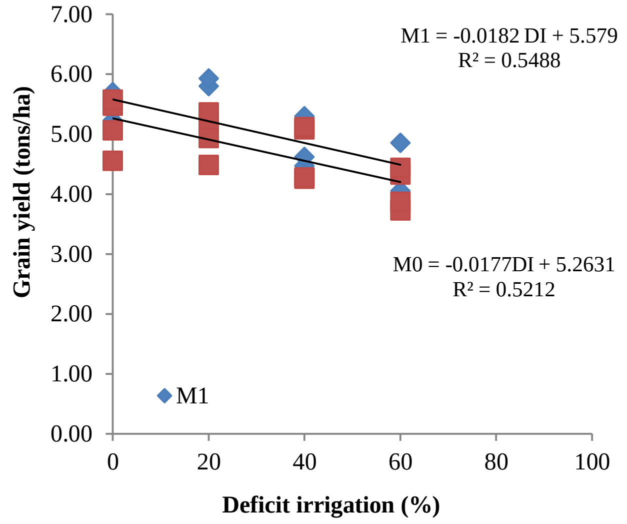


Fig. 5. Effect of deficit irrigation on wheat grain yield under mulching (M1) and no mulch (M0).

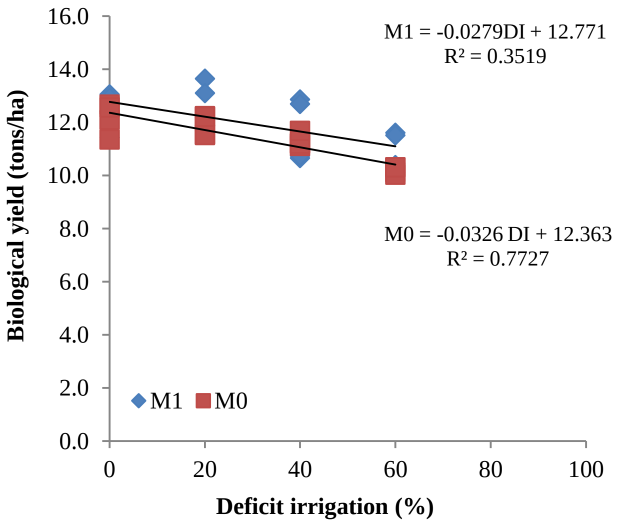


Fig. 3. Effect of deficit irrigation on wheat biological yield under mulching (M1) and no mulching (M0).

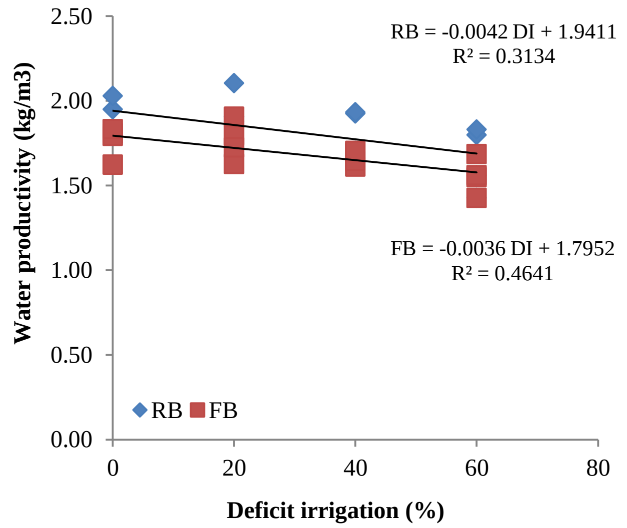
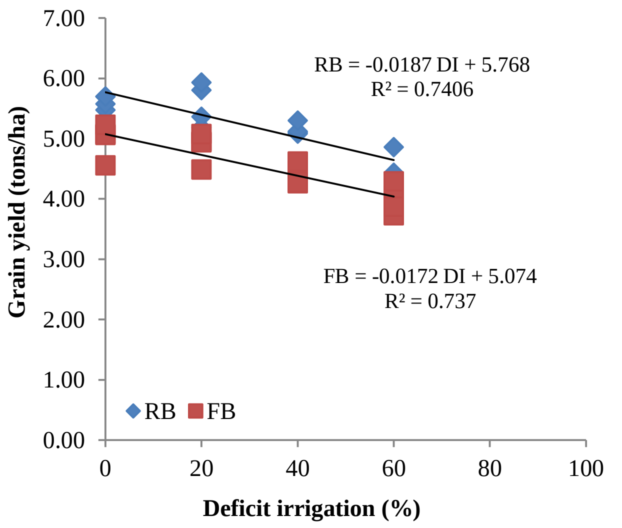


Fig. 6. Effect of deficit irrigation on wheat water productivity under Raised Bed (RB) and Flat Bed (FB).



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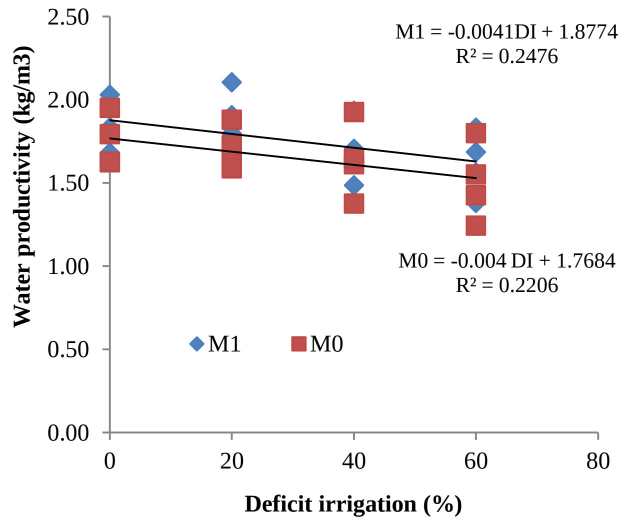

Fig. 7. Effect of deficit irrigation on wheat water productivity under mulching (M1) and no mulch (M0).

Acknowledgements

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