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EVALUATION OF LOW COST IRRIGATION METHODS FOR ENHANCED ONION PRODUCTIVITY UNDER SEMI-ARID CLIMATE OF PAKISTAN

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Onion is highly sensitive to water stress due to the absence of root hairs and shallow root system. Water stress at any growth stage of onion can result in severe loss of yield and profit. Moreover, fresh water availability for irrigation is continuously declining due to population explosion and global warming. There is a dire need to increase water productivity of irrigation systems. Although drip irrigation is highly efficient, its practical application is limited in developing countries due to high installation costs and lack of technical knowledge among farmers. The present research work was conducted in semiarid climate of Faisalabad, Pakistan to examine low cost irrigation methods for their profitability for onion production even under limited water availability. A field study was conducted using two onion cultivars (Dark red and Robina) with and without mulch under three irrigation methods (furrow, fixed furrow and alternate furrow) during two consecutive winter seasons (2012-13 and 2013-14). Results showed that profitability of onion bulbs produced under alternate furrow irrigation method with mulching was at par with bulbs produced by furrow irrigation without mulching (common method used by farmers). Among onion cultivars "Dark red" was found more consistent in generating a profit under limited water supply than "Robina". From the experimental results it may be concluded that under limited supply alternate furrow irrigation can be successfully used as an effective low cost substitute of normal furrow irrigation. The results showed that profitability of alternate furrow may be enhanced by the application of mulching.
Keywords: *Allium cepa,* benefit cost ratio, bolting, drought, splitting, water stress, water use efficiency.

INTRODUCTION

Onion (*Allium cepa* L.) is second most important horticultural crop in the world after tomato (Black *et al*., 2006). Onion is grown on an area of 44.4 Mha with total production of 85 MT. Annual onion productivity of the world is 19.3 t/ha (FAO, 2013). It is an important vegetable for its flavor (Kopsell and Randle, 1997; Javaid and Rauf, 2015) and medicinal value (Griffiths *et al*., 2002). Statistical data revealed significant differences in mean onion productivity of developed countries like USA (i.e. 54.5 t/ha) and developing countries like Pakistan (13.1 t/ha) (FAO, 2013).Use of inferior management techniques is major reason of low productivity in developing countries (Masood *et al*., 2012). The situation is further exacerbated in semi-arid regions due to high temperature and erratic rainfall (Hudson, 1987).

At present irrigation water availability is becoming a serious issue (Hussain, 2011). More efficient water management practices are needed (Chiplunkar *et al*., 2012; Irfan *et al*., 2014). Scientists reported improved crop water productivity by the use of regulated deficit irrigation (English, 1990; Goodwin and Jerie, 1992; Pereira *et al*., 2002; Fereres and Soriano, 2007) partial root zone drying (Kang *et al*., 1997, 1998, 2000a, 2002b; Kang and Zhang, 2004; Zegbe *et al*., 2004) or alternative furrow irrigation (Mitchell *et al.,* 1993; Mitchell and Yang, 1998). Due to shallow root system (Shock *et al*., 1998), absence of root hairs and lower leaf water potential (Brewster, 2008) onion is considered very sensitive to water stress (Singh and Alderfer, 1966). Onion crop showed significant reduction when subjected to deficit irrigation (Al-Jamal *et al*., 2001; Shock *et al*., 1998). So, in order to maximize water productivity without losing onion profitability there is a need to improve irrigation methods (Playán and Mateos, 2004). Since, irrigation efficiency of system is affected by the different types of water losses (Walker, 1989) therefore, the efficiency of the system can easily be increased by limiting these losses. In literature, alternate furrow irrigation method was reported more efficient as compare to furrow irrigation method (Khan *et al*., 1999; Mitchell *et al.,* 1993; Mitchell and Yang, 1998). Another modification of alternate furrow irrigation method is fixed furrow method. El-Sharkawy *et al*. (2006) evaluated alternate furrow irrigation method and reported it suitable for onion cultivation under Gemmeiza, South Sudan. However, the fixed furrow irrigation method had not been tested. Keeping in view constraints in future water availability and the sensitivity of onion to water stress, the present study was conducted to assess profitability of onion grown with various irrigation treatments.

MATERIALS AND METHODS

Field experiment using two onion varieties (i.e. Dark Red and Robina) was conducted during two consecutive years (2012-13 and 2013-14) in the Vegetable Research Area, University of Agriculture, Faisalabad, Pakistan. Experiment was laid down in randomized complete block design, with 3 factors (irrigation methods, onion varieties, mulching practice) and three replications (Table 1).

Table 1. Details of irrigation treatments.

Treatment Number	(Factor A) Mulching practice	(Factor B) Irrigation Method	(Factor C) Onion Variety
1.	Mulched	Furrow	Dark red
2.	Mulched	Furrow	Robina
3.	Mulched	Alternate Furrow	Dark red
4.	Mulched	Alternate Furrow	Robina
5.	Mulched	Fixed Furrow	Dark red
6.	Mulched	Fixed Furrow	Robina
7.	Non-Mulched	Furrow	Dark red
8.	Non-Mulched	Furrow	Robina
9.	Non-Mulched	Alternate Furrow	Dark red
10.	Non-Mulched	Alternate Furrow	Robina
11.	Non-Mulched	Fixed Furrow	Dark red
12.	Non-Mulched	Fixed Furrow	Robina

During both growing seasons, onion seeds were sown on 1st October. Seedlings were transplanted, on 11th December, 2012 and 6th December, 2013 on both sides of ridges at recommended plant to plant (0.10 m) distance. Total estimated plant population was 262,048 plants per hectare.

In furrow irrigation, water was applied in all furrows while, in fixed furrow method water was applied to the odd furrows (i.e. 1st, 3rd, 5th …) every time leaving even numbered furrows dry. Alternate furrow method differed from the fixed furrow method only in sense for the alternative furrow irrigation, irrigations shifted between even and odd furrows for successive irrigation. A cut throat flume installed at the upper head of water channel was used to measure total quantity of water applied to the field according to the method proposed by Walker (1989). Irrigation depth of 12 inches was applied to onion crop in irrigation (David and Vaughn, 2013). Soil moisture depth was regularly monitored after application of irrigation with the help of soil sampling tube (Augering Kit for PR2 Delta-T Devices Ltd). Next irrigation was applied when soil moisture was depleted from top 8 inches of soil. Onion bulbs were harvested on 11th May, 2013 and 9th May, 2014.

At the end of growing season, total onion bulbs harvested per experimental unit (9.3 m) were counted and weighed. Number of split, bolted and small sized bulbs (<3cm in diameter) were counted and separated from marketable bulbs. Marketable bulb were weighed and expressed in grams.

For economic analysis total expenditure was split into fixed and variable costs. Cost of seed, nursery preparation, land preparation, plant protection and fertilizer was included in the fixed cost because these were the same for all treatments. Weeding, irrigation, mulching, packaging and transportation costs were considered variable costs and were calculated for each treatment individually. Total expenditures were calculated by adding the total fixed and variable costs per hectare. Total revenue per hectare was estimated by selling marketable onions in the local market. Benefit cost ratio (BCR) was calculated by dividing the revenue by the expenditures. Irrigation water use efficiency was calculated by dividing total yield obtained by the total water applied and was expressed in $kg/m^3/ha$.

RESULTS AND DISCUSSION

Bulb Quality and Yield Parameters:

***Survival of onion plants*: ** Since onion is highly sensitive to water stress, therefore, at the end of growing season total number of bulbs per plot was recorded to assess the survival of onion plants. Results showed a significant reduction in plant mortality due to mulching (Table 2). Onion cultivar "Dark red" showed slightly more bulbs per hectare compared to "Robina"; however, in mulched treatments differences remained statistically non-significant except for fixed furrow irrigation method. Among non-mulched irrigation treatments "Dark red" produced maximum bulbs per hectare (257,130 bulbs per hectare) under furrow irrigation method which was at par with those produced by "Robina" (256,630 bulbs per hectare) under furrow irrigation method. Minimum bulbs (217,850 bulbs per hectare) were produced by "Robina" under fixed furrow irrigation. Under furrow method, water was supplied to all furrows at every irrigation cycle thus, maximum bulbs survived at the end of growing season. In alternate and fixed furrow methods where water was supplied to specific furrows (leaving others dry), induced water stress may have resulted in fewer bulbs per hectare as reported by Singh and Alderfer (1966). Contrary to alternate furrow, (where soil moisture in furrows refilled due to shuffling after each cycle) in fixed furrow method specific furrows remained dry throughout the growing season thus caused greater plant mortality rate which ultimately reduced number of bulbs per hectare. Mulching improved water availability by limiting soil evaporation. Alternate furrow method had a similar number of bulbs as were observed in furrow irrigation because mulching slowed the rate of soil moisture depletion (Chalker-Scott, 2007). Since, specific furrows remained dry throughout growing season, even the practice of mulching was of little use in fixed furrow irrigation system.

Table 2. Onion bulb yield as affected by various methods of irrigation, mulching and variety treatments.

Treatments	Total onion bulbs (000 bulbs/ ha)			Marketable yield (t/ha)		
	2013	2014	Average	2013	2014	Average
Mulched: (F): (DR)	255.65 a	254.90 a	255.65 a	15.067 a	14.820 a	15.067 a
Mulched: (F): (R)	252.43 a	251.45 a	252.43 a	16.055 a	15.067 a	15.561 a
Mulched: (AF): (DR)	256.63 a	254.16 a	256.63 a	12.597 b	12.844 b	12.597 b
Mulched: (AF): (R)	253.17 a	250.71 a	253.18 a	12.350 b	12.103 b	12.350 b
Mulched: (FF): (DR)	253.42 a	251.45 a	253.42 a	9.88 cd	10.374 b	10.127 c
Mulched: (FF): (R)	245.52 b	249.72 a	245.52 b	8.892 d	9.386 c	9.139 d
Non-Mulched: (F): (DR)	257.13 a	251.45 a	257.13 a	12.597 b	12.597 b	12.597 b
Non-Mulched: (F): (R)	256.63 a	250.21 a	256.63 a	13.585 b	11.609 b	12.597 b
Non-Mulched: (AF): (DR)	239.34 c	247.99 a	239.34 c	10.374 c	10.127 c	10.374 c
Non-Mulched: (AF): (R)	212.42 f	227.73 bc	212.42 f	7.410 e	8.398 d	7.904 e
Non-Mulched: (FF): (DR)	233.42 d	235.14 b	233.42 d	6.916 e	6.669 e	6.916 f
Non-Mulched: (FF): (R)	217.85 e	225.76 c	217.85 e	6.916 e	6.422 e	6.669 f
LSD value	4.94*	8.39**	4.94**	1.482*	1.482*	0.988*

*significant at p<0.05 and ** significant at p<0.01.

***Total off type bulbs per hectare*:** Off type bulbs includes split, bolted and small sized bulbs and are responsible for reducing the marketable yield of onion crop. Data showed significant differences in bulb quality among various irrigation treatments (Fig. 1). Among all irrigation methods, furrow irrigation showed fewest off type bulbs. Among mulched treatments, a high incidence of off type bulbs was observed in fixed furrow irrigation treatment while, alternate furrow irrigation method had a high number of off type bulbs among non-mulched irrigation treatments. On the basis of the average over two years "Robina" had a high percentage of splitting in fixed furrow mulched treatment and bolting in the alternate furrow non-mulched treatment (Fig. 1). Overall, furrow irrigation had fewer small sized, bolted and split bulbs compared to alternate furrow and fixed furrow irrigation. A high number of small sized bulbs were observed in onion cultivar "Robina" grown under non-mulched fixed furrow irrigation. In comparison to non-mulched irrigation treatments, mulching significantly reduced number of small sized bulbs however, fixed furrow irrigation method with mulching had more bolted bulbs compared to the similar non-mulched treatment (Fig. 1). Increased splitting percentage under alternate furrow and fixed furrow irrigation was probably due to water stress as reported by Shock *et al*. (2007). Onion in the current trial had a significant increase in bolting percentage under short duration water stress as was imposed in alternate furrow irrigation. Transition from vegetative to reproductive stage under stress conditions (Levy and Dean, 1998) might be the possible reason for increased pre-mature bolting under water

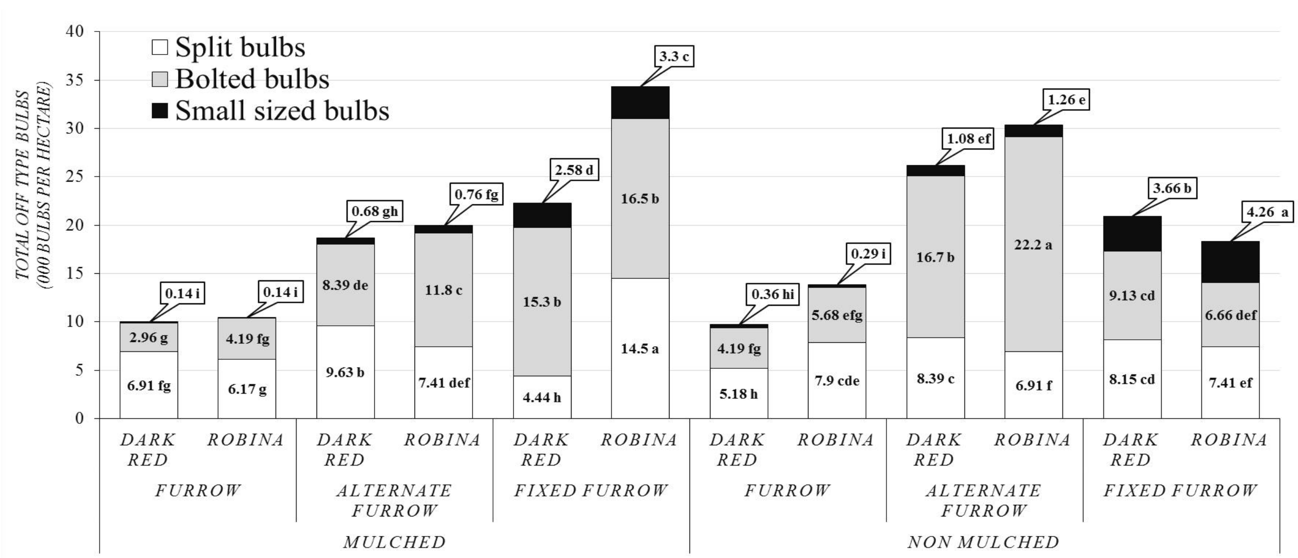

Figure 1. Details of total off type bulbs per hectare.

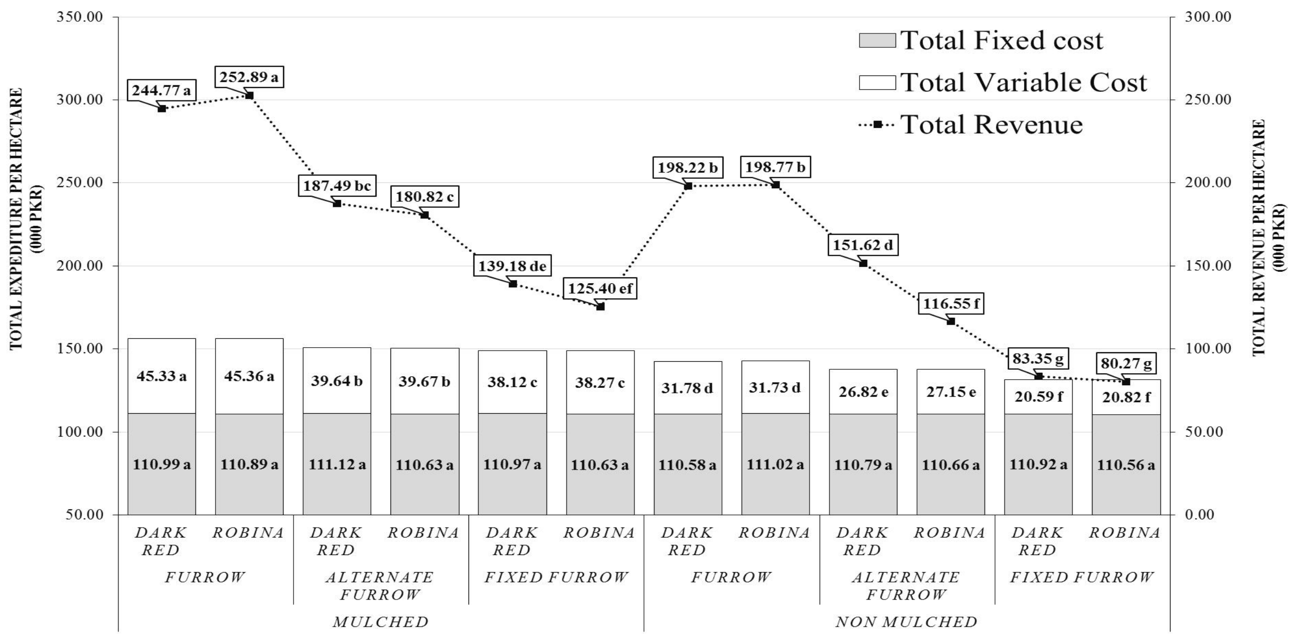

Figure 2. Treatment wise details of total expenditure and revenue.

stress. Alternate and fixed furrow irrigation methods increased small sized bulbs mainly due to limited availability of water consistent with the results of Shock *et al.* (1998) and Kumar *et al.* (2007).

Marketable yield: Marketable yield is of great significance from farmer's view point (Table 2). Furrow irrigation had high marketable yield followed by alternate furrow irrigation and fixed furrow irrigation. Onion cultivar "Robina" had higher yields than "Dark red" under furrow irrigation. However, in alternate furrow and fixed furrow irrigation systems "Dark red" had greater yield than "Robina". These results suggest that "Robina" is more sensitive to water stress compared to "Dark red". Mulching significantly increased marketable yield in all irrigation treatments. Significant reduction in small sized bulbs per hectare was the major reason for improved marketable yield in all mulched treatments, consistent with the results of Shock *et al*. (1999) who reported increased yield with furrow mulching. Overall, onion cultivar "Dark red" was more productive. Since, bulb size is dependent on water availability (Shock *et al*., 1998; Kumar *et al.,* 2007) more marketable yield was observed in furrow irrigation mulched treatment. Interestingly, mulching increased water availability to the plants even under alternate furrow irrigation thus, marketable yield of onion grown with alternate furrow irrigation plus mulching was at par with that observed in furrow irrigation without mulching. Our result that alternate furrow irrigation can be used as a substitute of furrow irrigation is consistent with the findings of other scientists (Mithcell *et al*., 1993; Mitchell and Yang, 1998; Mintesinot *et al*., 2004).

Economic Parameters

Total cost: There were significant differences in total costs among various irrigation treatments (Fig. 2). Mulching, irrigation and weeding were major variable costs. Variable costs of mulched treatments were 9.81, 9.57 and 13.37% greater in furrow, alternate furrow and fixed furrow irrigation methods, respectively compared to the comparable non-mulched treatments. Despite the fact that mulching increased overall variable cost, it significantly reduced irrigation and weeding costs.

Total revenue: Maximum revenue was obtained by "Robina" when grown under furrow irrigation coupled with the practice of mulching (Fig. 2). Among non-mulched treatments furrow irrigation method had the greatest revenue for both varieties while, the least revenue was obtained from fixed furrow irrigation. Interestingly, alternate furrow irrigation with mulching showed statistically similar productivity in 2013 and slightly lower in 2014 than was observed in furrow irrigation without mulching. Total revenue was 23.5, 23.7 and 67% more in furrow, alternate furrow and fixed furrow irrigation method due to application of mulch compared to corresponding non-mulched irrigation treatments.

Benefit cost ratio: There were significant variations in benefit cost ratios (BCR) among the treatments. Furrow irrigation showed maximum BCR followed by alternate furrow irrigation method. Mulching improved the BCR in furrow, alternate furrow and fixed furrow irrigation method by 12.2, 12.7 and 47.6%, respectively, compared to corresponding non-mulched treatments. Fixed furrow irrigation with and without mulching showed low BCR (< 1)

Table 3. Effect of irrigation methods, mulching and variety treatments on profitability of onion crop.

Treatments	Benefit cost ratio			IWUE (kg/m³/ha)		
	2013	2014	Average	2013	2014	Average
Mulched: (F): (DR)	1.54 a	1.60 a	1.56 a	7.86 c	9.51 d	8.68 c
Mulched: (F): (R)	1.63 a	1.61 a	1.61 a	7.42 c	9.72 d	8.57 c
Mulched: (AF): (DR)	1.25 c	1.24 c	1.24 c	11.15 a	14.34 a	12.70 a
Mulched: (AF): (R)	1.23 cd	1.19 cd	1.20 cd	11.03 a	13.90 ab	12.50 a
Mulched: (FF): (DR)	0.93 e	0.94 e	0.93 e	9.67 b	12.77 c	11.20 b
Mulched: (FF): (R)	0.84 e	0.86 e	0.84 e	9.77 b	13.10 bc	11.40 b
Non-Mulched: (F): (DR)	1.40 b	1.39 b	1.39 b	3.01 f	3.30 g	3.16 f
Non-Mulched: (F): (R)	1.52 ab	1.28 bc	1.39 b	2.96 f	3.27 g	3.11 f
Non-Mulched: (AF): (DR)	1.12 d	1.09 d	1.10 d	5.08 d	5.27 ef	5.18 d
Non-Mulched: (AF): (R)	0.81 e	0.89 e	0.84 e	5.21 d	5.71 e	5.46 d
Non-Mulched: (FF): (DR)	0.64 f	0.64 f	0.63 f	3.73 e	4.05 g	3.89 ef
Non-Mulched: (FF): (R)	0.61 f	0.62 f	0.61 f	3.98 e	4.15 fg	4.07 e
LSD value	0.13*	0.13*	0.11*	0.71*	1.15*	0.786*

*significant at $p<0.05$ and ** significant at $p<0.01$.

during both growing seasons and was found inappropriate for profitable onion production. Among onion cultivars, "Dark Red" more consistently generated profit compared to "Robina". Despite the fact that BCR of alternate furrow irrigation mulched treatment (1.24 and 1.20 for "Dark red" and "Robina", respectively) was lower than BCR of furrow irrigation non-mulched treatment but under limited water availability conditions, the potential profit from mulching could be a priority for growers considering the sensitivity of onion to loss from water stress (Table 3). Benefit cost ratio of furrow irrigation without mulching was similar to that reported by Choudhary *et al*. (2008) and Haque *et al*. (2011). However, analysis of alternate and fixed furrow irrigation methods have not yet been reported for onion. Despite the fact that mulching increased the total cost of production, outcome was higher than non-mulched treatments (Fig. 2) thus mulched treatments showed more BCR than non-mulched treatments.

***Irrigation water use efficiency*:** Results revealed significant increase in water use efficiency (IWUE) due to mulching (Table 3). Maximum IWUE was found in alternate furrow mulched treatment followed by fixed furrow and furrow irrigation mulched treatments. However, the profitability of fixed furrow irrigation mulched treatment was too less to be used for profitable onion production. Mulching significantly reduced weeding and irrigation cost and increased soil water availability to the plants which significantly increased marketable yield of onion. Increased water use efficiency due to mulching has already been reported by Díaz-Perez *et al*. (2004) in onion.

***Conclusion*:** Present research work revealed that under limited supply of water alternate furrow irrigation method coupled with mulching can be a substitute of conventional furrow irrigation method for profitable onion production. Onion cultivar "Robina" should be grown under furrow irrigation due to its higher productivity when water supplies are abundant; however, in areas having danger of water shortage cultivation of "Dark red" is advisable.

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