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in

Lamaddalena N. (ed.), Bogliotti C. (ed.), Todorovic M. (ed.), Scardigno A. (ed.).
Water saving in Mediterranean agriculture and future research needs [Vol. 1]

Bari : CIHEAM
Options Méditerranéennes : Série B. Etudes et Recherches; n. 56 Vol.I

2007
pages 213-221

PLANT - SOIL WATER DYNAMICS OF ALTERNATE FURROW AND REGULATED DEFICIT IRRIGATION FOR TWO LEGUME CROPS IN THE FERGANA VALLEY, UZBEKISTAN

H. Webber *, C. Madramootoo *, M. Bourgault **, M. Horst *, G. Stulina *** and D. Smith ****

* Brace Centre for Water Resources Management, McGill University, 21,111 Lakeshore Road, Ste Anne de Bellevue, Quebec, Canada, H9X 3V9

** Department of Plant Science, McGill University, 21,111 Lakeshore Road, Ste Anne de Bellevue, Quebec, Canada, H9X 3V9

*** Central Asian Scientific Research Institute of Irrigation (SANIIRI) Karasu-4, Tashkent 700187, Uzbekistan

SUMMARY - Water scarcity, severe environmental degradation and increasing competition for water resources as the population grows are causing water managers in Central Asia to re-evaluate irrigation water use. In this area, the goal of any intervention must include water conservation without overall reduced crop productivity. The objective of this study was to evaluate the water use efficiency (WUE) and impact on components of the plant-soil water system of two water saving irrigation technologies used in food legume production in the Fergana Valley of Uzbekistan. Common bean and green gram, grown as second crops after winter wheat harvest, were irrigated using alternate furrow irrigation and regulated deficit irrigation. The WUE was quantified for commercial yield, above ground biomass and root biomass per unit of water consumed by the plant. WUE increased in green gram when deficit irrigation or alternate furrow irrigation were practiced, whereas it remained constant in bean for all treatment combinations. The use of both deficit irrigation and alternate furrow irrigation resulted in water savings and reduced crop evaporative consumption. The reduction was greater (46%) in green gram than common bean (23%) when the technologies were used together. Severely stressed bean was able to extract more water at 60 cm than non-stressed plants, whereas severely stressed green gram used less water at all depths. Collectively, these results indicate alternate furrow irrigation and deficit irrigation can increase WUE in the Fergana Valley, allowing application of less irrigation water, when used with appropriate crops.

Key words: Alternate furrow irrigation, deficit irrigation, *Phaseolus vulgaris*, *Vigna radiata*, water use efficiency, Fergana Valley of Uzbekistan.

RESUME – *La pénurie d'eau, la dégradation de l'environnement et la compétition croissante pour les ressources hydriques avec la croissance de la population forcent les gestionnaires en Asie Centrale à ré-évaluer la consommation d'eau d'irrigation. Dans ce domaine, le but des interventions doit inclure la conservation de l'eau sans sacrifier la productivité agricole globale. L'objectif de cette recherche était d'évaluer l'efficacité de l'utilisation en eau (EUE) et ses impacts sur les composés du système plante-sol de deux technologies d'irrigation utilisées dans la production de légumineuses dans la vallée de Fergana, en Ouzbékistan. Le haricot commun et le haricot mung, cultivés après la récolte de blé d'hiver, ont été irrigués avec l'irrigation alternante et l'irrigation déficitaire. L'EUE a été quantifiée pour le rendement commercial, la biomasse et la biomasse racinaire par unité d'eau consommée par les plantes. L'EUE a augmenté pour le haricot mung avec l'irrigation alternante et déficitaire, mais est restée constante pour le haricot commun dans tous les traitements. L'utilisation d'une combinaison d'irrigation alternante et déficitaire a mené à des économies d'eau et a réduit l'évaporation des cultures. Cette réduction a été plus grande chez le haricot mung (46%) que chez le haricot commun (23%) quand ces technologies ont été utilisées ensemble. Le haricot commun sévèrement stressé a démontré une capacité à extraire plus d'eau à une profondeur de 60 cm comparé au traitement non-stressé, alors que le haricot mung a utilisé moins d'eau à toutes les profondeurs. Ces résultats démontrent que l'irrigation alternante et déficitaire peut augmenter l'EUE dans la vallée de Fergana, en réduisant l'application d'eau d'irrigation lorsque des cultures appropriées sont utilisées.*

Mots-clés: *Irrigation alternante, irrigation déficitaire, Phaseolus vulagris, Vigna radiata (L.) Wilczek, efficacité de l'utilisation en eau, Vallée de Fergana, Ouzbékistan*

INTRODUCTION

As in most arid and semi-arid regions, drought and water scarcity influence many aspects of life in Uzbekistan. Irrigation is required for almost all crop production, and agriculture forms the backbone of the country's economy. While it was part of the Soviet Union, intensive land and infrastructure development during the 1960's resulted in the rapid doubling of its irrigated area and Uzbekistan gained the status of the world's 4^{th} largest cotton producer with 8 million acres of irrigated land. This same time period saw water withdrawals from the Syr Darya and Amu Darya rivers increase from 60.6 km^3 to 105.0 km^3, and the population of the five countries in the Aral Sea basin increase from 14.1 to 41.5 million (UN/SPECA, 2001). The result of this development was greatly reduced flows in the basin's rivers and the drying of the Aral Sea. This is considered one of the most serious anthropogenic environmental disasters in history. Since the early 1980's, when water withdrawals for irrigation left virtually no water for the Sea, progress has been made to address the region's water scarcity (Micklin, 2000). However, the pressure on water resources is expected to increase as the population grows and water management is transferred to farmers in a state controlled system requiring them to produce cotton and wheat to gain access to resources. The improvement of on-farm irrigation systems and the introduction of low cost, water saving irrigation technologies are identified as key and attainable components for reducing agriculture's water demand (Horst *et. al.*, 2005). Furthermore, growing legumes as a second crop, after winter wheat, offers farmers a way to increase their income and improve both their food security and land productivity, while still fulfilling their commitment to produce cotton and wheat.

Regulated deficit irrigation (RDI) and alternate furrow irrigation (AFI) are two water saving technologies that are relatively inexpensive and easy to implement. Both strategies involve manipulating the soil water to induce the crop's inherent response to drought conditions, usually in order to improve their water use efficiency (Davies *et. al.*, 2002). In RDI, the soil water is allowed to be depleted beyond a threshold value at which the crop experiences water stress. Water savings generally result with the use of RDI and are attributed to reductions in stomatal conductance, which occurs as a result of the plant roots encountering drying soil. This is thought to be mediated by abscisic acid (ABA) and the alkalization of the xylem flow (Loveys *et al.*, 2004). While the stomata control both the rates of transpiration and CO_2 entry into the cell, some evidence suggests that, initially, the reduction in stomatal conductance is greater than the concurrent reduction in carbon assimilation. Whether this always results in increased WUE remains unclear as evidence exists to show it has both increased and decreased WUE (Garside *et al.*, 1992; Kang *et al.*, 2000b; Lawn, 1982; Webber et al, 2006). Partial root drying (PRD), practiced as alternate furrow irrigation in surface irrigation systems, is a variation of RDI that generally improves the WUE of crops (Davies et al., 2000; Wakrim et al., 2005). In many cases, the strategy circumvents the yield losses frequently associated with RDI, as in grape (Loveys *et al.*, 2000), soybean (Graterol *et al.*, 1993) and pot and field grown maize (Kang *et al.*, 2000a). PRD involves exposing part of the root system to drying soil while maintaining other sections in well watered soil, and is most effective when the two sections of roots are alternately exposed to wet and dry soil (Kang, 1998). The method is thought to operate in the same manner as RDI, with the benefit of keeping the plant well hydrated through roots still in moist soil.

The methodology suggested in the Food and Agriculture Organization of the United Nations, Paper 56 (Allen *et al.,* 1998) on computing the rate of evapotranspiration (ET_{actual}) when water conditions are limited involves multiplying the maximum value of evapotranspiration, ET_{max}, achieved under optimal conditions by the water stress coefficient, k_s

$$ET_{actual} = k_s ET_{\max} \tag{1}$$

The water stress coefficient varies between 1, when the crop does not experience water stress, and 0, when the soil is at the permanent wilting point. In their model, a crop is expected to experience water stress when the actual root zone depletion of total available soil water, D_r, exceeds a threshold value, the readily available water, *RAW*, equal to:

$$RAW = pTAW \tag{2}$$

Where:

TAW: total amount of water available in the root zone (mm) equal to the difference between field capacity and the permanent wilting point, and *p* is the fraction of *TAW* that a crop can extract from the root zone without suffering water stress.

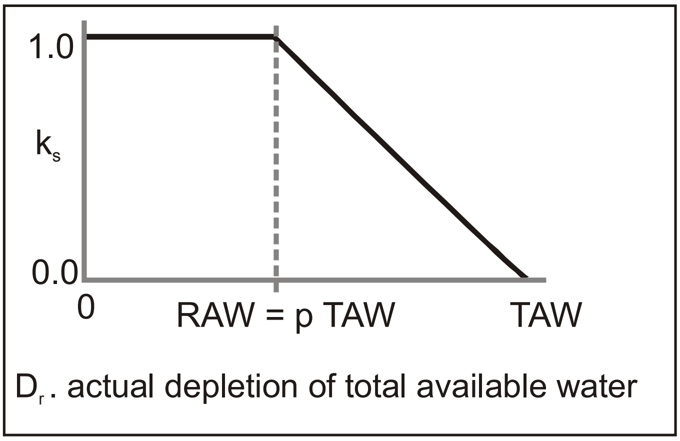

Fig. 1. The water stress coefficient, k_s, used with the FAO Penman-Moneith equation to estimate ET under water limiting conditions varies from 1 to 0 as a function of the soil water content. Modified from Allen *et al.*, (1998)

When the depletion exceeds the readily available water ($D_r > RAW$), k_s will decrease linearly from 1 (Fig 1). In the case that the actual depletion has not yet exceeded the readily available water ($D_r > RAW$), $k_s = 1$ and the crop is not expected to experience water stress. This condition holds for crops that have previously experienced water stress and are subsequently irrigated, irrespective of the length or severity of the preceding soil water deficit. This method does not explicitly account for conditions of variable soil drying, as is the case of PRD.

In an attempt to contribute to our understanding of irrigated food crop production systems when water is limited, this study looks at how various components of the plant – soil water balance are affected by the use of deficit and/or alternate furrow irrigation. The specific research objectives were to (i) quantify the effects of alternate furrow irrigation and RDI on the WUE (for each of commercial seed yield, above ground biomass, and root biomass per unit of water transpired, WUE_{seed}, $WUE_{biomass}$ and WUE_{root}, respectively) of common bean and green gram (ii) evaluate the effect of using regulated deficit and alternate furrow irrigation on patterns of water extraction from the soil profile and (iii) compare ET predicted from the product of the stress coefficient and the Penman-Monteith equation to ET determined from the soil water balance.

MATERIALS AND METHODS

Site description, crop varieties and experimental design

A field experiment was conducted in the Fergana Valley of Uzbekistan (40°23´N, 71°45´E) during the summers of 2003 and 2004. The fields (one in 2003 and another in 2004) were organized following a randomized complete block split-plot design, with four blocks, where the treatments were comprised of factorial combinations of regulated deficit irrigation level, as the main plot factor (recommended, mild stress and severe stress), and furrow irrigation strategy (alternate and the conventional every furrow irrigation) and crop (bean and green gram) comprised the sub-treatments. Each plot measured 15 m by 15 m and contained on average 23 furrows of 12 m length. The furrow spacing was 60 cm.

Despite the close proximity of the fields (only 200 m apart), the soil properties and groundwater contributions differed between the years (*Table 1*). In 2003, a granular layer at depths greater than

1 m prevented groundwater from the water table (depth of 2.2 m) from rising into the plant root zone. The average field slope was 0.002 m m^{-1}, though considerable variability existed among plots due to the short furrow length. In 2004, the average slope was 0.003 m m^{-1}. In that year, there was more variability in soil properties across the field. The average ground water table depth was 1.3 m and varied along the length of the field. In both years, the soil salinity is considered low to moderate, with an EC_e value of 5, but containing considerable calcium content.

Local varieties of common bean (*Phaseolus vulgaris*) and green gram (*Vigna radiata*) were sown, following winter wheat, in mid- July. Cotton was grown on both fields in the year preceding the experiment, so that the subsequent production of a legume constitutes a double cropping system. In 2003, local practices were followed for seeding resulting in planting densities of 70,000 and 105,000 plants/ha for green gram and common bean, respectively. In 2004, the plant density was increased to 333,000 plants/ha for both crops, to be comparable with densities found in similar studies (Haqqani and Pandey, 1994).

Irrigation scheduling and management

In both years, a pre-irrigation of approximately 800 m^3 ha^{-1} was applied to every furrow in each plot, at 2 days before seeding. A second irrigation of 600 m^3 ha^{-1} was applied, also to every furrow, to encourage a full and even plant stand at the time of emergence. Subsequent irrigation scheduling was determined using daily water balances. Each water balance calculated excess or deficit water in the crop root zone relative to field capacity. Inputs to the system considered were applied irrigation water, precipitation and groundwater contribution. Water outputs were due only to crop evapotranspiration (ET), as deep percolation and run-off were assumed to be negligible. Rainfall was minimal in both years. Crop ET was calculated with the FAO Penman-Monteith equation (Allen et al., 1998) using weather data collected at the experimental site and crop coefficients for standard and stress conditions, as appropriate (Allen et al*.,* 1998). Soil moisture measurements, made two days before and after each irrigation and every five days between irrigations, were used to check the water balance, particularly the effect of the water stress coefficient.

Irrigations were applied when the root zone water deficit equaled the maximum allowable depletion of the available soil water. For the FAO recommended irrigation schedule, no stress condition, when 45% of the available water was depleted, the plots were irrigated. The depletion factors for the moderate stress treatments were 60% for common bean and 65% for green gram. For the treatments receiving the largest water stress, the depletion factors were 70% for common bean and 80% for green gram (Allen et al., 1998).

Plots were irrigated using either conventional- or alternate-furrow irrigation. In conventional-furrow irrigation water is introduced into every furrow in the plot. In alternate-furrow irrigation water is introduced into only every second furrow. The furrow receiving water is alternated between successive irrigations.

In 2003 separate water balances and schedules were used for the conventional and alternate furrow treatments within the same crop and depletion factor. In 2004, the methodology was changed to ensure significant water savings for the alternate furrow irrigation treatments. Irrigations for the alternate furrow treatments were applied on the same day as the corresponding conventional furrow treatment, with only 75% of the water.

RESULTS AND DISCUSSION

Water use efficiency

Crop effects

The water use efficiencies have been previously reported in Webber et al. (2006). WUE_{seed} and $WUE_{biomass}$ (*Table 1*) were approximately twice as large for green gram (0.53 and 2.23 kg m^{-3}, respectively) as bean (0.35 and 1.04 kg m^{-3}, respectively), in 2004. The same pattern was observed in 2003; WUE_{seed} for common bean was 0.20 kg m^{-3} and 0.38 kg m^{-3} for green gram. The differences between years were probably due to the different planting densities and, possibly, soil conditions. The opposite trend was observed for WUE_{roots} (*Table 1*). WUE_{roots} for common bean was greater across all treatment combinations, with an average value of 0.19 kg m^{-3} compared to 0.16 kg m^{-3} for green gram. Green gram invested proportionally more of its photosynthetic resources into yield and biomass production per unit of water transpiration, whereas bean invested more heavily in root production.

Irrigation schedule effect

When RDI was practiced the response of the two crops was very different. For common bean, in both 2003 and 2004, when subjected to water stress, WUE_{seed} remained constant at 0.26 and 0.35 kg m^{-3}, respectively. Likewise, $WUE_{biomass}$ was constant across all stress levels. While WUE_{seed} and $WUE_{biomass}$ did not change when subjected to soil drying, their ratio, the harvest index (HI), decreased at the severe stress level. WUE_{roots} increased to 0.23 kg m^{-3} at the most severe stress level, from 0.16 kg m^{-3} for the well watered treatment. This indicates the bean sensed the water deficit in the soil and responded by investing more photosynthetic resources in root production per unit of water use in an attempt to extract more water. However, this strategy was not able to translate into increased values of WUE_{seed} or HI. Green gram responded to water stress by increasing its WUE_{seed} by 50% in 2003 and 89% in 2004 when RDI was practiced. $WUE_{biomass}$ also increased by 78% (2003) and 30% (2004). Like common bean, green gram responded to the severe water stress by increasing its WUE_{roots} by 38%. However, while bean increased its root biomass under severe stress; green gram actually reduced its root biomass (Bourgault et al., unpublished manuscript). The increase in WUE_{roots} for green gram is therefore explained by the greatly reduced water use at the high stress level. This suggests the two crops use very different mechanisms to respond to soil drying; bean produced more roots whereas green gram reduced its rate of water use.

Table 1. Effect of irrigation schedule and strategy on the WUE_{seed}, $WUE_{biomass}$ and WUE_{root} (Modified from Webber et al., 2006)

Year	Crop	Irrigation Schedule	Strategy	WUE* (kg m^{-3})		
				Seed	Biomass	Roots
2003	Common bean	Recommended rate	Every	0.26^{F}	0.84^{C}	-
			Alternate	0.30^{EF}	1.34^{C}	-
		Moderate depletion	Every	0.27^{F}	0.95^{C}	-
			Alternate	0.26^{F}	0.90^{C}	-
		Large depletion	Every	0.22^{F}	0.86^{C}	-
			Alternate	0.25^{F}	1.37^{C}	-
	Green gram	Recommended rate	Every	0.36^{DE}	1.31^{C}	-
			Alternate	0.37^{DE}	2.14^{B}	-
		Moderate depletion	Every	0.50^{AB}	3.13^{A}	-
			Alternate	0.57^{A}	3.02^{A}	-
		Large depletion	Every	0.42^{CD}	2.07^{B}	-
			Alternate	0.46^{BC}	2.15^{B}	-
2004	Common bean	Recommended rate	Every	0.33^{EF}	1.03^{E}	0.16^{DE}
			Alternate	0.36^{EF}	1.05^{E}	0.16^{DEF}
		Moderate depletion	Every	0.38^{DE}	0.95^{E}	0.16^{DEF}
			Alternate	0.33^{EF}	0.91^{E}	0.18^{CD}
		Large depletion	Every	0.30^{F}	1.28^{E}	0.19^{C}
			Alternate	0.41^{EF}	1.05^{E}	0.28^{A}
	Green gram	Recommended rate	Every	0.31^{EF}	1.83^{D}	0.13^{F}
			Alternate	0.47^{C}	$1.90C^{D}$	0.14^{EF}
		Moderate depletion	Every	0.40^{CDE}	$2.15C^{D}$	0.14^{EF}
			Alternate	0.50^{C}	2.69^{A}	0.18^{CD}
		Large depletion	Every	0.66^{B}	2.22^{BC}	0.16^{DEF}
			Alternate	0.82^{A}	2.61^{AB}	0.22^{B}

*Values in the same column and same year associated with the same letters are not different ($P <= 0.05$) as determined using t-tests on least square means.

The difference in the two crop's responses is further illustrated by looking at the ratio of WUE_{seed} to $WUE_{biomass}$. At the recommended level, this ratio is higher in bean (0.35) than green gram (0.22). At the severe stress level, the ratio is greater for green gram (0.34) than bean (0.28), with the probability of significance taken as $P < = 0.10$. It seems clear that the two crops react oppositely under severe water stress; in bean, the HI decreases, whereas it increases for green gram. Taken together with its increase in WUE_{roots}, it appears that under stress, bean partitions less of its resources to seed production and more to root production. The strategy to extract more water by developing more root biomass comes at the expense of seed production. On the other hand, green gram invests more in seed production under severe water stress and reduces it water consumption, though the mechanism is not evident from these results.

Irrigation strategy effects

The use of alternate furrow irrigation increased WUE_{seed} by 10% in 2003 ($P < = 0.10$) and by 20% in 2004 compared to the use of conventional furrow irrigation. An interaction between crop and irrigation strategy exists; alternate furrow irrigation had no significant effect on WUE_{seed} in common bean across all levels of water stress, in either year, contrary to the findings of Wakrim et al. (2005). In green gram, WUE_{seed} increased from 0.43 to 0.47 kg m^{-3} (2003 with $P <= 0.10$) and 0.46 to 0.60 kg m^{-3} (2004) when alternate furrow irrigation was practiced. There was no interaction between using alternate furrow irrigation and the level of water stress imposed on the WUE_{seed}. In 2003, $WUE_{biomass}$ was unchanged by alternate furrow irrigation for both crops, whereas it did increase by a small margin for green gram in 2004. WUE_{roots} increased for both crops when the strategy was used at higher levels of water stress.

Consumptive crop water use

The use of both RDI and alternate furrow irrigation reduced crop water consumption, as determined from the water balance, for all treatments. These results from 2004 are shown in Table 2. The pattern of reduction in soil water use, for the stress treatments, was stronger in 2004 than 2003 due to more accurate detection of soil water depletion, making the timing of irrigation events more precise. Further details are given in Webber et al. (2006). This was done by effectively doubling the number of locations that were sampled for soil moisture in 2004. Averaged across both years and all treatments, bean required more water than green gram, though the details this relationship changed between years. The much higher water consumption for bean in 2003 is believed to be due to a plant density that was twice that of green gram.

Table 2. Irrigation water applied, the number of irrigations, crop consumptive estimated with the modified FAO Penman – Moneith equation and the crop consumptive water use determined using the soil water balance in 2004 for conventional furrow (CF) and alternate furrow (AF) irrigation.

Crop	*Depletion factor*	*Total irrigation applied (m^3/ha)*		Number of irrigations required by water balance	FAO modified Penman – Moneith *ET (mm)*		*ET from water balance (m^3/ha)*		*Difference between FAO Penman Moneith ET & measured value (%)*	
		CF	*AF*		*CF*	*AF*	*CF*	*AF*	*CF*	*AF*
Common bean	0.45	3000	2450	5	2400	2300	2100	1850	13	20
	0.60	2600	2200	3	2225	2175	2000	1700	10	22
	0.70	2300	1900	2	2150	2150	1875	1625	13	24
Green gram	0.45	3500	2850	5	2375	2350	2475	2075	-4	12
	0.65	2950	2450	3	2250	2250	2275	1825	-1	19
	0.80	1700	1450	1	1825	1550	1550	1325	15	15

RDI resulted in greater water savings for green gram than bean. For green gram, a soil water depletion of 0.80 versus the recommended 0.45 of the available water resulted in water savings of 37 and 46% when used together with alternate furrow irrigation. In bean water savings were 11% when the depletion factor was 0.70 instead of the recommended 0.45 and 23% when RDI was combined with alternate furrow irrigation. Interestingly, in 2004, the 0.80 depletion level for green gram resulted in greater seed yield than treatments receiving more water, while bean yields decreased at the 0.70 depletion level (Bourgault et al., unpublished manuscript).

Alternate furrow irrigation resulted in reductions in crop consumptive use of water for both crops and with all irrigation schedules (*Table 2*). The average water savings with alternate furrow irrigation were 13% for common bean and 17% for green gram in 2004. These values were the same for all irrigation schedules. Significantly, Bourgault et al. (unpublished manuscript) report that the use of alternate furrow irrigation did not affect common bean yields and increased green gram yields in 2004. In 2003, water savings were not consistent across all schedules; however, with alternate furrow irrigation yields were not affected by the furrow irrigation strategy (Bourgault et al., unpublished manuscript). The lack of consistent water savings in 2003 is attributed to irrigation scheduling based on measured soil moisture in the alternate furrow plots; these always had lower values, and, as a result, reached the depletion level more quickly and were irrigated more often than their corresponding conventional furrow plots.

The FAO Penman Moneith estimate of ET generally over predicted the amount of water consumed by the crop, as determined by the water balance (*Table 2*). For green gram, the calculated values closely predicted water use at the recommended and moderate stress levels for conventional furrow irrigation, with underestimations of 4 and 1%, respectively. However, at the severe stress level and for all alternate furrow irrigation treatments, the calculated values overestimated water use by an average of 15%. The FAO Penman Moneith estimate of ET for bean was 12 % higher for the conventional furrow treatments and 22% for the alternate furrow treatments than the crop consumptive use of water determined using the water balance.

Distribution of water use in the soil profile

In alternate-furrow irrigation treatments, the average soil moistures were generally lower than the corresponding conventional furrow case, as only one of every two furrows received water in an alternate furrow irrigation event. In the irrigation at flowering (a critical time for water application), most of the water savings associated with alternate-furrow irrigation apparently occurred relatively close to the soil surface (Webber et al., unpublished manuscript). With the exception of the severely stressed green gram treatment, in which alternate furrow irrigation used less water at all depths, alternate furrow irrigation did not produce water savings at either 40 or 60 cm in the soil profile (data not shown).

The seasonal water use, under alternate furrow irrigation, followed the same pattern as water use at the irrigation event at flowering. For bean at 0 and 10 cm depth, alternate furrow resulted in a 30% reduction in water use. However, deeper in the profile, alternate furrow irrigation did not save water. Conversely, for green gram, alternate furrow irrigation resulted in an average reduction of 40% for water consumption at all depths in the profile, when compared to conventional furrow treatments (Webber et al., unpublished manuscript).

The distribution of soil water use, as affected by crop and irrigation schedule, is better illustrated by considering the seasonal change in soil water. Different irrigation schedules resulted in different numbers of irrigation events, making a comparison between individual events problematic. The profile of the soil water extraction was highly biased to the soil surface (0 cm) for both crops, though to a greater extent for bean, due to soil evaporation (Fig. 2). Water extraction decreased with increasing depth in the soil profile.

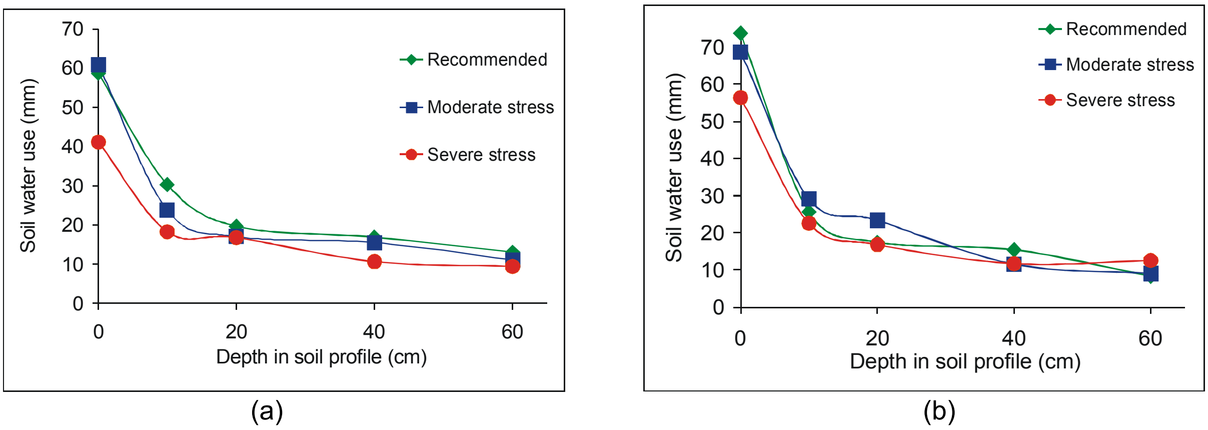

Fig. 2. Measured seasonal change in soil water status in 2004 for (a) green gram and (b) common bean. Note this does not equal the crop consumption over the growing season as soil moisture measurements were made 2 days before and after each irrigation event.

At the soil surface (0 cm) water use by bean was greater than that of green gram in each of the corresponding treatments. At all other depths in the profile, green gram irrigated at the recommended rate consumed the most water. Water use by common bean at 0 through 40 cm was greatest at the recommended and moderate stress irrigation levels. At 60 cm, the situation was reversed; the severe stress irrigation level consumed more water than the recommended level. Green gram did not respond in the same way. The severe stress irrigation level used less water at all depths, including 60 cm, than the moderate or recommended irrigation schedules.

CONCLUSIONS

This research indicates that significant water savings are possible with the adoption of on-farm water saving technologies for irrigation of legumes as a second crop after wheat harvest in the Fergana Valley of Uzbekistan. The benefits to the local population of growing legumes as a second crop using water saving irrigation techniques include a protein rich food, increased land productivity with minimal irrigation or fertilizer input (due to legume nitrogen fixation) and improved land fertility and organic matter if the residue is incorporated into the soil.

The results of this study suggest that both alternate furrow irrigation and deficit irrigation produce water savings by reducing the crop evapotranspiration. However, the degree to which water use was reduced and the mechanisms employed by common bean and green gram are very different. When less water was applied to green gram, WUE doubled as compared to the recommended irrigation amounts. On the other hand, the commercial seed and above ground biomass WUEs of common bean were constant for all combinations of deficit irrigation and alternate furrow irrigation. When RDI was practiced, green gram reduced Evapo-transpiration by 37% where as the reduction in common bean was only 11%. With alternate furrow irrigation, the differences in water use between crops were less pronounced; green gram reduced transpiration by 17% and common bean by 13%, both constant across all irrigation schedules. With severe stress, green gram reduced soil water extraction at all depths in the profile, apparently through stomatal regulation. Common bean responded by increasing root biomass to extract more water from deeper in the profile.

A comparison of the ET estimates calculated using the FAO Penman Moneith equation and those determined experimentally using a daily water balance suggested that the FAO estimates for ET under water stress may not be appropriate for green gram, whereas they more consistently predicted the water use of common bean, considering its less than full ground cover. The discrepancy seems to lay in the method's assumption that following a period of stress, restoring the soil water through irrigation will cause the plant to transpire at its unstressed rate. This phenomenon was observed for common bean under the severely stressed treatment, where bean transpired at a rate higher than the non-stressed treatment after receiving irrigation. Green gram continued to transpire at a reduced rate even after irrigation water was applied. When alternate furrow irrigation was practiced, the FAO methodology overestimated ET for both crops at all stress levels by close to 20%. Before the FAO water stress coefficient can be improved, it will be necessary to better quantify both the responses to irrigation of stressed plants and the effect of alternately maintaining different sections of the roots in drying soil.

Acknowledgements

The authors thank the Canadian International Development Agency (CIDA) for funding this research. Thanks are also due to Prof. V. Dukhovny of the Scientific Information Centre of the Interstate Commission for Water Coordination (SIC ICWC) of Central Asia for hosting the Canadian researchers, as well to all field staff, of the organization for their help and expertise. Finally, thanks are due to the staff of the Brace Centre for their support in technical and managerial aspects of the project.

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