A preliminary evaluation of furrow inflow rate and cut-off time on the performance of smallholder raised bed farming systems

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Introduction

Irrigated raised bed farming systems in north-west Pakistan are characterised by short furrow lengths (30 to 100 m), narrow bed widths (65 to 75 cm furrow spacing) and blocked ends. Wide beds (typically 130 cm furrow spacing) have recently been introduced and shown (Akbar et al. 2007) to produce agronomic benefits but are not in common usage. In general, 5 to 10 furrows are concurrently irrigated from small head channels with the time to cut-off determined by flow arrival at the end of the furrow and/or furrow filling. Management is often poor with varying furrow inflow rates, frequent overtopping of beds, problems with wetting front penetration (i.e. subbing) into beds and the potential for substantial deep percolation losses (Akbar et al. 2007). The purpose of this study was to evaluate the irrigation performance of narrow and wide raised bed systems under farmer managed conditions and to identify the potential to improve performance using simple irrigation management strategies.

Material and Methods

Three irrigated raised bed fields (furrows 80 to 90 m in length) located in Mardan, north-west Pakistan were observed during the summer season of 2010. Each site had a similar sandy clay loam alluvial soil classified as a Fine Usteric Camborthid (Hassan et al., 2005) and a slope of 0.002 m m^{-1}. Cotton was grown at one site and maize at the other two sites. The target soil moisture deficit prior to irrigation was 60 mm within the top 60 cm depth at each site. Furrow conditions varied between the sites due to differences in farming practices, crop and growth stage. Hence, there were differences in furrow compaction (due to wheel trafficking), weed infestation and the surface roughness of furrows (due to manual weeding) between the trial sites. Two raised bed sizes (NB = 65cm and WB = 130cm furrow spacing) with four irrigations were observed at each site. The furrow dimensions, furrow inflow rate (Q), distance and time of water advance along the furrow at multiple points and the time to cut-off (T_{co}) were measured in each furrow and event.

The measured field data was used to calculate the infiltration characteristic for each furrow and irrigation event using IPARM (Gillies and Smith, 2005). This data was then used to parameterise the surface irrigation model SIRMODIII (Walker, 2003). Calibration of SIRMODIII was achieved by adjusting the manning's roughness coefficient until the simulated advance time matched the measured advance time. The calibrated model was then used to evaluate the irrigation performance. The performance indicators were application efficiency (E_a) which is the ratio of the water stored in the root zone and the water received at the field inlet; requirement efficiency (E_r) which is the ratio of volume of water stored in the root zone to the pre-irrigation root zone soil moisture deficit; and distribution uniformity (*DU*) which is the average infiltrated depth of water in the lower one quarter of the field divided by the average infiltrated depth of water over the whole field. The calibrated model was subsequently used to evaluate two irrigation management optimisation strategies: (a) T_{co} optimisation using the measured inflow and (b) optimisation of both T_{co} and Q simultaneously. Optimisation was based on $E_r \geq 85\%$ and water arriving at the tail end. The aim for these criteria was to ensure adequate subbing, to use in season rainfall effectively and to avoid any dry sections of the field. Practically applicable inflow rates up to 5 L s^{-1} per furrow were evaluated.

Results and Discussion

The furrow inflow rate under farmer management was 52% higher (on average) in WB than in NB systems (Table 1). However, the advance time to the end of NB fields was only 16% longer (on average) than WB. All furrows in WB were trafficked where as only every second furrow was trafficked in NB systems. Hence, WB furrows were generally observed to be more highly compacted and smoother than NB furrows. There were also higher weed infestations in NB furrows than in the WB furrows which would increase flow resistance and advance times.

The E_a of the farmer managed irrigations ranged from 50 to 92% in NB and from 72 to 99% in WB systems (Table 1). However, E_r was generally higher in NB (83 to 100%) than in WB (77 to 99%). Therefore, subbing problems in WB systems may, in part, be attributed to applying insufficient irrigation water. The effect of bed width on uniformity of application varied with *DU* lower at site 1 in WB compared to NB but higher in WB than in NB at sites 2 and 3.

The relationship between E_a and E_r is site specific and dependent on the soil infiltration, furrow inflow rate and field length. For each site and bed configuration, it is possible to identify a combination of inflow rate and time to cut-off which maximises both E_a and E_r (e.g. Figure 1). For example, using NB at site 3 (Figure 1a), it is possible to achieve an E_a and $E_r > 85\%$ using a Q = 1 L s^{-1} and T_{co} = 80 mins. However, using the WB system at site 1 (Figure 1b), similar performance can be achieved using either Q = 1 L s^{-1} and $T_{co} \sim 140$ mins or Q = 2 L s^{-1} and $T_{co} \sim 80$ mins. However, the water application strategy required to optimise the irrigation performance appears to be site (ie. soil and infiltration characteristic) specific. Improving performance at site 1 would result in water savings of up to 40% on both NB and WB systems (Table 1). However, optimisation of irrigation performance at site 2 would require the application of up to 14% more water to ensure adequate E_r and *DU* in both NB and WB systems. At site 3, up to 37% water could be saved in NB systems through improved water management but in the WB system up to 7% more water is needed to be applied to satisfy E_r.

This work raises the prospect of significantly enhancing water use productivity of raised bed farming systems in north-west Pakistan through improved irrigation management. Importantly, the management strategies identified in this research may be implemented without incurring substantial changes to infrastructure, machinery or labour. However, further work is required to confirm the benefits across a wider range of soil types and irrigated field layouts.

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References

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Figures and Tables

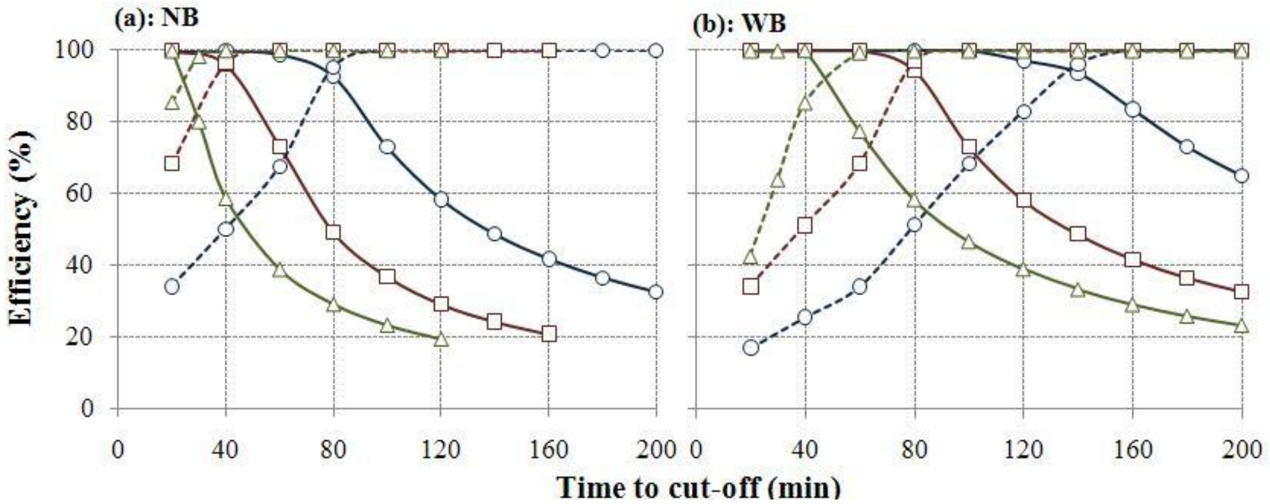

Figure 1: Example for NB and WB (Site 3 = 90 m field length) showing the effect of T_{co} and Q (○ = 1, □ = 2 and Δ= 2.5 L s^{-1}) on E_a (——) and E_r (– – –) during irrigation 1.

Table 1: Impact of irrigation management optimisation (based on $E_r \geq 85\%$ and flow reaching furrow end) on current irrigation performance of three sites with two bed sizes (values in brackets are standard deviations).

Site	Bed Size	*Strategy	Q (L s^{-1})	T_{co} (min)	E_a (%)	E_r (%)	DU (%)	Inflow (m^3/ha)	Water saving# (%)
1	**NB**	Current	3.0 *(0.2)*	39 *(2)*	50 *(6)*	100 *(0)*	90 *(6)*	1206 *(147)*	
		1	3.0 *(0.2)*	32 *(4)*	59 *(12)*	99 *(0)*	80 *(3)*	1029 *(210)*	15
		2	5.0 *(0.0)*	14 *(1)*	90 *(11)*	93 *(2)*	86 *(7)*	725 *(114)*	40
	WB	Current	4.9 *(0.0)*	33 *(2)*	72 *(4)*	99 *(1)*	77 *(2)*	828 *(55)*	
		1	4.9 *(0.0)*	21 *(0)*	99 *(0)*	89 *(1)*	92 *(3)*	542 *(5)*	35
		2	5.0 *(0.0)*	20 *(1)*	100 *(0)*	85 *(1)*	94 *(4)*	514 *(6)*	40
2	**NB**	Current	1.6 *(0.1)*	34 *(3)*	92 *(8)*	83 *(7)*	66 *(7)*	556 *(85)*	
		1	1.6 *(0.1)*	38 *(3)*	86 *(0)*	88 *(1)*	61 *(1)*	620 *(6)*	-11
		2	0.5 *(0.0)*	115 *(7)*	89 *(8)*	87 *(2)*	69 *(21)*	590 *(36)*	-6
	WB	Current	2.7 *(0.1)*	35 *(1)*	99 *(1)*	77 *(0)*	84 *(8)*	465 *(5)*	
		1	2.7 *(0.1)*	38 *(0)*	98 *(1)*	87 *(0)*	82 *(5)*	531 *(5)*	-14
		2	1.5 *(0.0)*	68 *(0)*	99 *(1)*	87 *(0)*	89 *(12)*	521 *(0)*	-12
3	**NB**	Current	2.4 *(0.4)*	37 *(1)*	68 *(9)*	99 *(1)*	73 *(1)*	880 *(113)*	
		1	2.4 *(0.4)*	24 *(2)*	98 *(1)*	91 *(6)*	94 *(1)*	555 *(42)*	37
		2	2.3 *(0.0)*	23 *(2)*	99 *(1)*	90 *(6)*	93 *(2)*	547 *(48)*	38
	WB	Current	3.0 *(0.2)*	34 *(1)*	99 *(1)*	83 *(7)*	75 *(9)*	504 *(48)*	
		1	3.0 *(0.2)*	36 *(2)*	97 *(2)*	87 *(1)*	75 *(8)*	541 *(3)*	-7
		2	2.5 *(0.0)*	41 *(1)*	99 *(1)*	92 *(9)*	84 *(12)*	517 *(6)*	-3

*Current: Farmer managed
1: Time to cut-off optimised
2: Time to cut-off and inflow rate optimised
#Water saved as compared to farmer practice