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Alternate furrow irrigation can radically improve water productivity of okra

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ABSTRACT

Alternate furrow irrigation (AFI) is gaining interest as a means of saving water while minimising loss in crop production. Given the potential water savings of AFI, a field experiment was conducted in the Tandojam region of Pakistan by growing okra with AFI and conventional furrow irrigation (CFI) in which every furrow is irrigated. Our results show that total irrigation water applied in the AFI treatment was roughly half (248 ± 2.9 mm) that applied to the CFI treatment (497 ± 1.7 mm). Despite the very significant reduction in irrigation water used with AFI there was a non-significant ($p > 0.05$) reduction (7.3%) in okra yield. As a result, we also obtained a significantly ($p < 0.001$) higher crop water productivity (CWP) of 5.29 ± 0.1 kg m^{-3} with AFI, which was nearly double the 2.78 ± 0.04 kg m^{-3} obtained with CFI. While this reduction in yield and/or potential income may appear small, it could be critical to the welfare of individual farmers, who may as a result hesitate to make changes from CFI to AFI if they are worse off than farmers who do not adopt AFI. This situation exists because current water charges are based on crop and land area rather than the volume of water being accessed for irrigation. Transitioning from the current crop and land area based method of charging for water to a volumetric method may require investment in irrigation system changes and may take time to accomplish. These are important lessons for other countries, and particularly developing countries who are trying to improve the environmental, social and economic performance of their irrigated systems. We recommend that further studies be carried out using AFI to determine whether similar water savings and flow-on benefits can be achieved across a wide range of cropping systems in arid and semi-arid environments.

1. Introduction

Pakistan's economy is dependent on agricultural production. It is estimated that 70–80% of the total area cultivated in Pakistan is irrigated through a network of canals. About 93% of the available fresh water resources are currently utilized in the agricultural sector (Bhangar and Saima, 2008). The increasing population has resulted in demand for more food and fiber, which is met through increasing irrigated agriculture. This translates into increasing pressure on Pakistan's water resources. It is critical therefore that management and utilization of available water resources is improved at all scales; from catchment, to irrigated district, to farm and field scale. Management of water at the macro level is generally expensive, time consuming and difficult. By comparison management of water at the field scale is generally relatively inexpensive, more feasible and practical, and it can be implemented in a short period of time. It is therefore critical to improve water management at the field scale through adoption of more efficient and effective irrigation methods.

About 90% of the irrigated land of the world is irrigated using relatively inefficient surface irrigation methods (Tiercelin and Vidal, 2006). As a result about 20–30 million ha of irrigated lands globally are seriously damaged by the build-up of salts and it is estimated that the area of salt affected soils will increase by about 0.25–0.5 million ha per year (FAO, 2002). Similar trends are observed in Pakistan where traditional surface irrigation methods (basin, border and furrow) are widely used to irrigate crops. These are however inefficient methods of irrigation and are considered one of the main

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Table 1
Measurements of soil properties at four depths at the field experimental site, including soil texture, soil bulk density and soil water content at saturation (0 kPa), field capacity (33.34 kPa) and wilting point (1500 kPa).

S. No.	Soil depth (cm)	Sand %	Silt %	Clay %	Textural class	Dry bulk density ($g\,cm^{-3}$)	Saturation Capacity ($cm^3\,cm^{-3}$)	Field Capacity ($cm^3\,cm^{-3}$)	Wilting point ($cm^3\,cm^{-3}$)
1	0–20	23 ± 0.31	52 ± 0.47	25 ± 0.62	Silt Loam	1.32 ± 0.08	0.41 ± 0.03	0.33 ± 0.02	0.16 ± 0.02
2	20–40	30 ± 0.62	46 ± 0.60	24 ± 1.02	Loam	1.36 ± 0.07	0.38 ± 0.04	0.30 ± 0.04	0.14 ± 0.02
3	40–60	26 ± 0.46	48 ± 0.43	26 ± 0.57	Loam	1.33 ± 0.04	0.39 ± 0.03	0.31 ± 0.04	0.16 ± 0.03
4	60–80	28 ± 0.34	45 ± 0.47	27 ± 0.69	Loam	1.33 ± 0.02	0.40 ± 0.02	0.33 ± 0.03	0.15 ± 0.02

±Denotes confidence interval.

Table 2
A comparison of irrigation water used in alternate furrow irrigation (AFI), conventional furrow irrigation (CFI) and flood irrigation under three different irrigation methods and water savings with CFI and AFI methods.

Irrigation methods	Irrigation water used			AFI water savings (%)	
	m^3 subplot^{-1}	$m^3\,ha^{-1}$	mm	Compared with flood irrigation	Compared with CFI
AFI	50.1 ± 0.36	2480 ± 18	248 ± 2	66	50
CFI	100.4 ± 0.21	4970 ± 10	497 ± 1	–	–
Flood	–	7200[a]	720	–	–

± Denotes confidence interval.
[a] Literature values taken from Mashori (2013).

causes of waterlogging and salinisation (Burt et al., 1997). It is because of these sorts of problems that the use of modern, high-tech and efficient micro irrigation methods (drip, bubbler, sprinkler etc.) are advocated worldwide. However, farmers are often reluctant to adopt these high-tech methods, especially in Pakistan and other developing countries, due to their high cost of installation, operation and maintenance. As a result these methods have not yet been widely adopted by farming communities in developing countries. There is a need therefore for more efficient irrigation methods that are economical, easy to install and operate, and which are readily acceptable to the farming community.

Furrow irrigation, reported to be one of the least efficient methods compared with other irrigation methods (Burt et al., 1997), is still one of the most widely used forms of surface irrigation. It involves water flow through narrow channels (furrows) spaced regularly across the field (with row spacing often between 1.0–2.0 m), instead of flooding water over the whole field. Despite its application efficiency remaining relatively low (Ampas and Baltas, 2009), not enough effort is being made to keep improving its management and efficiency. Because furrow irrigation is a well-known, simple and economical method of irrigation, farmers are likely to be ready adopters of new approaches that are practical improvements of their current practices and that result in improved water use efficiency.

It has been suggested (Kang et al., 2000a; Du et al., 2010; Horst et al., 2005) that the efficiency of conventional furrow irrigation (CFI), referred to by some as every furrow irrigation, can be improved by converting it to alternate furrow irrigation (AFI). The AFI method is essentially the same as CFI, except that instead of irrigating every furrow, irrigation is applied to alternate furrows, while the in-between furrows remain dry. This means each ridge receives water from only one side, and the side receiving irrigation water could be changed with each irrigation if the field is set up to facilitate this change. Irrigating just one side of the ridge means there is significant potential to save irrigation water compared to CFI. There is however, also potential in some cases for a reduction in crop yield (Samadi and Sepaskah, 1984; Crabtree et al., 1985; Mashori, 2013). It has been observed that farmers prefer to stick with traditional flood irrigation methods due to their simplicity, ease of operation and maintenance and low installation/construction cost. If the conventional furrow irrigation method (CFI) is transformed into alternate furrow irrigation (AFI) then it might be readily accepted by farmers. However, before introducing and advocating this method to local farmers for adoption, the method needs to be evaluated under soil and climatic conditions representative of the areas being targeted for its introduction.

The objective of this study is to report on an experiment in which okra (*Abelmoschus esculentus* L.), also known as Lady's finger, was grown using CFI and AFI. Okra is an important vegetable crop grown throughout Pakistan, and the aim of the experiment was to assess the water savings and water productivity improvements that could be achieved with AFI compared with CFI. While we report on benefits of AFI for growing okra in Pakistan, this paper provides lessons for furrow irrigators in general, and particularly for irrigators in developing countries who do not have access to high tech irrigation methods such as pressurised drip irrigation.

2. Materials and methods

An experiment with conventional furrow irrigation (CFI) and alternate furrow irrigation (AFI) methods was conducted at a field site with an experimental plot that was 1260 m^2 (36.5 m × 34.5 m) located in the district Hyderabad, Sindh, Pakistan, at Latitude of 25°25′28″N and Longitude of 68°32′6″E. The elevation at the site is about 26 m above mean sea level (Fig. 1).

The experimental plot was deep ploughed with a moldboard plough and the resulting clods were pulverized with a disc harrow. The whole plot was levelled before demarcation into six subplots, each with a size of 202 m^2. The remaining area (48 m^2) was used for construction of the water supply canals and bunds between the subplots. The selection of subplots for testing the CFI and AFI methods was completely randomized. Furrows were manually constructed using spades. The furrow to furrow and ridge to ridge distance were 0.8 m. The furrow depth was 0.2 m. The total length of each furrow was 18 m, and there were a total of 14 furrows in each subplot. There were therefore 3 subplots and 42 furrows under each treatment. Subplots were irrigated through a field channel passing through the center of the plot.

Seventy two (72) soil samples were collected from 3 randomly selected locations in each subplot at depths of 0–20, 20–40, 40–60 and 60–80 cm for determining soil texture and soil dry bulk density. Soil texture was determined using the hydrometer method (Bouyoucos, 1962). Soil bulk density was determined using the core method (Grossman and Reinsch, 2002). Soil water contents

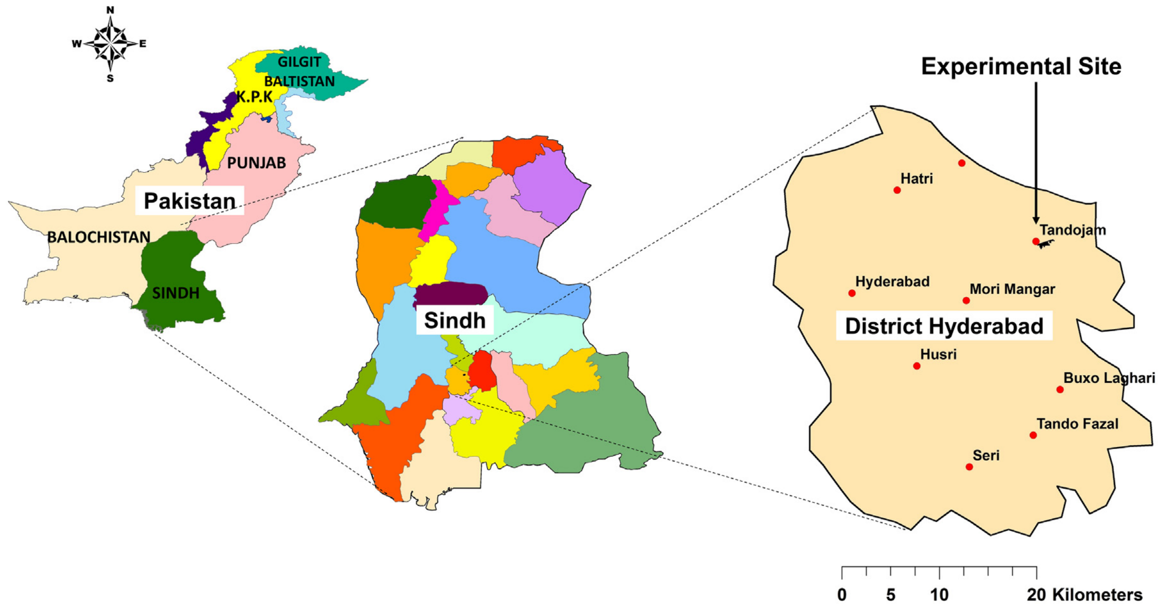

Fig. 1. Schematic showing location of the field experimental site in Pakistan.

at saturation (0 bar), field capacity (33.34 kPa) and wilting point (1500 kPa) were also determined using pressure plate apparatus.

Two to three okra seeds were sown at a depth of 4–5 cm on both sides of the ridge at a rate of 22 kg ha^{-1} (MINFAL, 1997) keeping a 0.2 m plant to plant spacing along the row. The seedlings were inspected once they started to emerge and plants that appeared very weak and unlikely to survive were removed. A total of 2520 plants per treatment (3 subplots) were harvested at maturity. Weeds in all four subplots were removed manually using a hand hoe. Fertilizer was applied to all subplots using recommended quantities (MINFAL, 1997), namely 124 kg Nitrogen ha^{-1}, 247 kg Phosphorous ha^{-1} and 124 kg Potassium ha^{-1}.

Meteorological data including air temperature, pan evaporation, daily and total rainfall for the entire growing season was obtained from a nearby weather station.

The total crop water requirement of an okra crop under furrow irrigation is reported to be around 500 mm per crop growth cycle (MINFAL, 1997). This was split into 8 separate irrigations (62 mm per irrigation) with an interval of 6–8 days between irrigations. Groundwater with an EC of 0.45 dS m^{-1} was diverted from a nearby tubewell for irrigation. The capacity of the tubewell was 0.5 cusec (14.158 L s^{-1}), however during irrigation to furrows, only half of the water flow was diverted while the rest flowed to irrigate the neighboring agricultural land. The irrigation was applied subplot-wise to furrows until the water in the furrows reached the blocked end of the furrows. The water supply was switched off when the water level in the furrows reached 3/4 of the furrow depth. The quantity of water applied to the subplots was measured using cut-throat flume (throat width = 15 cm). Before field installation, it was calibrated using a known discharge. The flume was placed on a levelled surface in such a way that free flow occurred. It was aligned straight with the field channel and levelled longitudinally and laterally. The depth of water applied to each subplot was determined using the following relationship:

$$D = Q \times t/A \tag{1}$$

where Q is discharge ($m^3\,s^{-1}$), t is time (s), A is area of the subplot (m^2) and D is depth of water (m).

The crop was sown on June 03, 2013. The first picking of the okra pods (fruit) started 46 days after sowing with the last picking carried out on August 31, 2013. The harvested okra fruit was weighed and recorded.

Table 3a
ANOVA of irrigation water used by CFI and AFI methods.

Source of Variation	df	SS	MS	F_{cal}	$F_{tab@0.1\%}$
Between groups	1	3795.1	3795.1	14596.7	74.1
With groups	4	1.04	0.26		
Total	5	3796.1			

The water saving with AFI compared to CFI was calculated as:

$$\text{Water Saving}\,(\%) = \frac{W_C - W_A}{W_C} \times 100 \tag{2}$$

where W_C is total water used (mm) with the CFI method and W_A is total water used (mm) with the AFI method.

The okra fruit yield for each subplot was weighed and recorded once the pods had been harvested. The increase/decrease in yield (%) compared to the AFI method was computed as:

$$\text{Increase in yield}\,(\%) = \frac{(Y_A - Y_C)}{Y_C} \times 100 \tag{3}$$

where Y_A and Y_C are yields (kg ha^{-1}) obtained with the AFI and CFI methods, respectively.

The crop water productivity (CWP), expressed as kg m^{-3} of water, of AFI and CFI was determined using the relationship (Talha and Aziz, 1979):

$$CWP = \frac{Y}{W_t} \tag{4}$$

where Y is total production of the crop obtained from all 3 subplots under each treatment (kg $treatment^{-1}$) and W_t is the total water applied (m^3 $treatment^{-1}$). The total water included both rainfall and irrigation.

The economic analysis comparing CFI and AFI was carried out by accounting for all costs involved in growing, harvesting and selling the okra crop. The actual costs on a per hectare basis for growing okra in the Tandojam region of Pakistan at the time this study was carried out included tillage, \$150; furrow construction, \$150; okra seed, \$20; fertilizer and pesticide, \$300; labour for weeding, \$60; labour for picking pods, \$400; irrigation water, \$25; and transportation to market, \$100. The total cost of \$1205 ha^{-1} for okra

Table 3b
ANOVA of the crop yield obtained with CFI and AFI methods.

Source of Variation	df	SS	MS	F_{cal}	$F_{tab@5\%}$
Between groups	1	661.5	661.5	5.75	7.70
With groups	4	460.0	115.0		
Total	5	1121.5			

Table 3c
ANOVA of the crop water productivity of CFI and AFI methods.

Source of Variation	df	SS	MS	F_{cal}	$F_{tab@0.1\%}$
Between groups	1	8.9	8.9	445.6	74.1
With groups	4	0.80	0.20		
Total	5	9.01			

production is the same for both the CFI and AFI treatments. This is because water charges are based on land area and crop grown, and not on the volumetric amount of water accessed for irrigation. The okra yield determined the amount of product that could be used by the farmer for household consumption or sold at the market. The net return was obtained by deducting the input cost from the value of the total marketable product.

3. Results and discussion

Table 1 shows the textural class and bulk density of the soil at the experimental field site at four different depths. The profile shows that the soil was medium textured with sand, silt and clay ranging from 23 to 30%, 45–52% and 25–27%, respectively. The spatial and depth-wise variation of sand, silt and clay soil fractions was non-significant. The soil bulk density of the profile ranged from 1.32 g cm^{-3} to 1.36 g cm^{-3}, with an average value of 1.34 ± 0.01 g cm^{-3}. There were no significant spatial and depth-wise trends in the soil bulk density.

There was 1.5 mm of rainfall at the field site during the entire crop growth period (June to August). The average monthly temperatures for the months of June, July and August were 39.5 °C, 38.2 °C and 36.8 °C, respectively. The corresponding average daily evaporation rates were 9.11 mm, 8.43 mm and 6.75 mm, respectively.

The total volume of irrigation water applied to each of the AFI subplots was 50.1 m^3 (248 mm) while 100.7 m^3 (497 mm) was applied to each of the CFI subplots (Table 2). This shows that the subplots under AFI used roughly half the amount of water compared to the subplots under CFI. This decrease in AFI water was a result of irrigating only alternate furrows, which would have also decreased evaporation and deep drainage losses. Our results align with the 46–50% water savings obtained using AFI compared with CFI as reported by Crabtree et al. (1985), Graterol et al. (1989), Khalid et al. (1999), Kang et al. (2000b) and Slatni et al. (2011).

We have also compared our experimental results with data provided by Mashori (2013) who reported that the typical crop water requirement of okra is 720 mm when grown during the summer season with flood irrigation. Our results show that water savings when irrigating okra with AFI and CFI can be as high as 66% and 31% compared to flood irrigation. The statistical analysis (ANOVA) of the irrigation water use achieved in our experiment is presented in Table 3a. It shows that the difference in irrigation water use between the CFI and AFI methods for growing okra was highly significant ($p < 0.001$).

The total okra crop yield obtained with AFI and CFI is given in Table 4. It shows that the okra yield under AFI was 265 kg $subplot^{-1}$, which is equivalent to 13,118 kg ha^{-1}. Similarly, total okra crop yield under CFI was 286 kg $subplot^{-1}$, equivalent to 14158 kg ha^{-1}. Okra yield in Pakistan using flood irrigation has been reported as 9900 kg ha^{-1} (Rahman et al., 2012). Yield obtained with AFI and CFI in our experiment was roughly 33% and 43% higher than that obtained by Rahman et al. (2012) with flood irrigation. When compared to CFI, the yield obtained with AFI was about 7% less. The statistical analysis (ANOVA) of the okra crop yield obtained in our experiment is presented in Table 3b. It shows that the difference in okra crop yield obtained with CFI and AFI was non-significant ($p > 0.05$). A slight reduction in crop yield with AFI compared to CFI was also reported by Bakker et al. (1995), Sepaskhah and Ghasemi (2008), and Rafiee and Shakarami (2010). Crabtree et al. (1985) also found a yield reduction in sorghum and soybeans when using AFI. This is also supported by Stone and Nofziger (1993) who found that AFI may result in lower yields because too little water is applied, particularly when evaporative rates are very high.

Under the AFI method, the okra plant root system was partially wetted which could result in reduced stomatal conductance and a reduction in plant transpiration. Photosynthesis and dry matter accumulation can however be less affected by this partial stomatal closure (Kang et al., 2000a). Also, the roots on the irrigated side of the furrow (wet soil) will continue to take up water to try and meet the required water demand of the plant (Ahmadi et al., 2010). Zhang et al. (1987) reported that plants with two halves of their root system under alternate drying and wetting cycles resulted in reduced stomatal opening but without significant increase in leaf water deficit. This could be part of the reason why there was a non-significant reduction in crop yield with AFI compared with CFI. Kang et al. (2000a) also observed a high grain yield for corn when subjected to a 50% reduction in the amount of irrigation applied. Panigrahi et al. (2011) reported alternate partial root-zone irrigation as a productive and potential water saving technique for okra cultivation in sandy loam soils. Sepaskhah and Ahmadi (2010) also recommended partial root zone drying (similar to AFI) for better fruit quality and increased crop water productivity in areas with limited water resources.

Table 5 shows the crop water productivity (CWP) of AFI, CFI and flood irrigation methods for growing okra. The highest CWP of

Table 5
Crop water productivity, defined as kg of yield per cubic meter of water applied, obtained with alternate furrow irrigation (AFI), conventional furrow irrigation (CFI) and flood irrigation.

Irrigation Method	Crop water productivity (kg m^{-3})
AFI	5.29 ± 0.10
CFI	2.78 ± 0.04
Flood	1.37[a]

[a] Calculated from literature data with crop water requirement = 7200 m^3 ha^{-1} (Mashori, 2013) and crop yield = 9900 kg ha^{-1} (Rahman et al., 2012).

Table 4
Okra yield and percentage increase/decrease in yield with AFI compared with CFI and flood irrigation methods.

Irrigation method	Crop yield (kg $area^{-1}$)		Yield increase/decrease (%)	
	Per sub-plot	Per hectare	Compared to Flood irrigation method	Compared to CFI method
AFI	265 ± 6.80	13118 ± 337	33	-7
CFI	286 ± 5.50	14158 ± 272	43	––
Flood	––	9900[a]	––	––

[a] Literature values taken from Rahman et al. (2012).

Table 6
Economic analysis demonstrating the difference in benefits obtained between the CFI and AFI treatments. The production costs are the same for both the CFI and AFI treatments because water charges are based on land area and crop grown, and not on the volumetric amount of water accessed for irrigation.

	CFI	AFI
Total cost of okra production ($\$$ ha^{-1})	1205	1205
Cost of water ($\$$ ha^{-1})	25	25
Water applied (m^3 ha^{-1})	4970 ± 10	2480 ± 18
Okra production (kg ha^{-1})	14,158	13,118
Crop water productivity (kg m^{-3})	2.84 ± 0.1	5.29 ± 0.1
Okra selling price ($\$$ kg^{-1})	0.40	0.40
Total return ($\$$ ha^{-1})	5663	5247
Net return ($\$$ ha^{-1})	4458	4042

5.29 kg m^{-3} was obtained with AFI followed by CFI with 2.78 kg m^{-3} and then flood irrigation, which had the lowest CWP. The statistical analysis (ANOVA) of CWP is given in Table 3c. It shows that the variation in CWP for both treatments was highly significant ($p < 0.001$), which highlights the effect the method of irrigation has on CWP. Ibrahim and Emara (2010) reported that the AFI method had higher CWP compared with the CFI method. Stone et al. (1982) and Slatni et al. (2011) reported that AFI resulted in a slight decrease in crop yield but an increased water productivity. Rafiee and Shakarami (2010) also reported that AFI enables more efficient use of irrigation water but with a lower crop yield associated with some water stress compared to CFI.

Table 6 provides a summary of the economic analysis of CFI and AFI. It shows that the input cost per hectare for growing okra using CFI and AFI is the same ($1205/ha), because water charges are based on the crop grown and the area of crop that is irrigated and not on the volume of water accessed for irrigation. The per hectare crop production for AFI and CFI is however different because of the different amounts of water available to the crop, with the net return being $4458 for CFI and $4042 for AFI. This shows that the farmer who accessed roughly 50% less water using AFI than the farmer who used CFI, will have about 1040 kg ha^{-1} (or 7%) less edible product if they keep it to use, or will be $416 dollars (or 9%) worse off if they sell their total crop. While 7% less yield or 9% less income may not seem like much to some people, it could be critical to the welfare of individual farmers who might not have access to other off farm resources. And they will certainly question why they should change if they see a decrease in yield or income for adopting improved water use efficiency practices compared with those who retain their much less efficient irrigation practices.

Pakistan is a water stressed country and the Government is urging farmers to improve their water use efficiency by adopting more efficient irrigation practices. Based on the results of this study this will be difficult to achieve when famers who adopt new more efficient irrigation practices like AFI that save large amounts of water, are worse off than farmers who continue using CFI and do not invest in improving their irrigation water use efficiency.

Given that AFI can reduce water use by as much as 50% compared with CFI, widespread adoption of AFI has the potential to produce massive public benefits as the water saved by using AFI could be used to improve environmental flows and/or to expand irrigation downstream. Encouraging adoption of water use efficient irrigation practices like AFI will, however, require changes to the way farmers pay for irrigation water. The best way to achieve this is to move from crop and land area based water charges to volumetric based water charges (Nyberg and Rozelle, 1999). Paying for each litre of water accessed for irrigation will serve as a real incentive for farmers to adopt the most efficient irrigation practices possible, and moving from CFI to AFI is not a difficult or costly thing to do. Making the change requires instead a mind shift so that water and irrigation management decisions deliver the benefits that AFI is capable of.

Easter and Liu (2005) demonstrated that introduction of volumetric pricing in the Yangtze Basin Water Resource Project in China reduced irrigation costs as farmers used less water per hectare. Losses associated with delivery of water also decreased. It is clear that the volumetric method of charging for water is effective, but transitioning from the current crop and land area based method to a volumetric method may require investment in irrigation system changes and may take some time to accomplish (Hassan and Chaudhry, 1998). These are important lessons for other countries, and particularly developing countries, who are trying to improve the environmental, social and economic performance of their irrigated systems.

4. Conclusions and recommendations

Results of our field study on alternate furrow irrigation (AFI) for okra production demonstrates that this method can (i) deliver water savings in excess of 50% compared with conventional furrow irrigation (CFI), (ii) radically improve okra water productivity, and (iii) be used as a practical management tool to save water so that it can be put to other uses. These other uses could include improved groundwater levels, improved environmental flows and hence improved river and estuary health and/or to expand irrigation downstream. Potential economic implications to individual farmers may however result in hesitation to make changes from CFI to AFI if they are worse off from a yield and/or financial point of view than farmers who do not adopt AFI. This situation exists because current water charges are based on crop and land area rather than the volume of water being accessed for irrigation. Transitioning from the current crop and land area based method to a volumetric method may require government investment in irrigation system changes and may take time to accomplish. We recommend that further studies be carried out using AFI to determine whether similar water savings and flow on benefits can be achieved across a wide range of cropping systems in arid and semi-arid environments.

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