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Optimal Cropping Pattern and Water Productivity: A Case of Punjab Canal

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Abstract: The objective of this study is to obtain optimal cropping pattern to maximize water productivity through reallocation of given resources. A case study of Punjab canal was presented and developed LP models for all categories of farms. The results revealed that sugarcane water productivity was increased as high as 20% on large farms and it was increased by 12% on tail farms. The wheat +citrus and berseem + citrus rotations showed a robust water productivity increase on all farms. Thus, results indicate that water productivity can be maximized through improved irrigation, agronomy and optimizing cropping pattern.

Key words: Water productivity, cropping pattern, net farm income, economic value of water

INTRODUCTION

Pakistan is endowed with rich land, water and mineral resources but unfortunately resource use efficiency is low especially of land and water. The yield and productivity of crops per unit of land and water is low due to irrational use and mismanagement of these two vital resources. The soils are being deteriorated by twin menace of water logging and salinity. The soils are poor in organic matter and are continuously depleting for want of balanced use of fertilizer. Soils are further deteriorated by the wind and water erosions. The conveyance efficiency of water is 45% only (Annonymous, 2006). The inequity and in-efficacy at the farm level is yet another issue. The total surface water availability is 139 Million Acres Feet (MAF) but consumptive use varies from 30-46 MAF and the rest is lost to the system or escaped to the sea. The fertilizer off-take is only 2.5 million nutrient tons against the agronomic requirements of about 5 million metric tons. The agricultural credit is made available to the tune of Rs 160 billion against the annual requirements of Rs 200 billion. Groundwater extraction (through 900,000 tube-wells) is substantial (53 MAF) and in some areas this vital resource is overly mined. The traction power at the farm level is low and approximately one tractor is available for 100 hectares (Annonymous, 2006).

In the national cropping pattern, wheat is the predominant crop of all the provinces in Rabi season. It is grown on 36% of the cropped area in Pakistan. Among the cash crops, cotton is grown on an area of 13% (Punjab 15% and Sindh 13%) in the Kharif season. Sugarcane is grown on 3% of the cropped area. The other dominant crops are the animal fodders grown on an area of 16% in Punjab, 9% in Sindh, 4% in NWFP and 2% in Baluchistan. Rice is the second largest crop in Sindh and is grown on 11% of the cropped area. In NWFP, maize is the second largest crop grown on 28% of cropped area against the national average of 4%. Jawar and Bajra are the next dominant crops in Baluchistan grown on 17% of the area followed by 8% in Sindh with national average of about 4%. Pulses are also important crops of Punjab and NWFP grown on 6% of the area. Barley also occupies 6% area in Baluchistan as an important crop. The major crop rotations are wheat-cotton, wheat-rice and sugarcane. The area under major crops (wheat, rice, maize, sugarcane and cotton) has been almost the same for the past one decade and the major strides have been in production through increase in productivity per unit area (Annonymous, 2006).

The production instability and food security are inter-related. Most of the rain-fed agriculture of the country is experiencing erratic cereal production. The production instability index (coefficient of variation) is 29% in the country (Annonymous, 2006). Most variation is attributed to crop yields. The productivity per unit of resource especially water is low. The declining resource productivity is due to increased water logging and salinity, nutrient depletion, hard pans, deforestation and de-vegetation and increased pest complex.

Looming water scarcity and competition for the same water from non-agricultural sectors necessitates improving crop water productivity to ensure adequate food for the nation with the equivalent or less water than is presently available to agriculture. This can be obtained because available information shows that there is a wide gap between actual and attainable crop water

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productivity, especially in the arid and semi arid environments. Quantifying crop water output reveals gaps in information regarding the preeminent ways to increase crop water productivity. Most of these gaps relate to our lack of ability to quantify all flow mechanism in the domain of interest, their connections with the plants, agricultural inputs and the environment in the process of producing profitable yields. Cropping systems need to be inherently flexible to take advantage of economic opportunities and/or adapt to environmental realities. A dynamic cropping systems concept-characterized by a management approach whereby crop sequencing decisions are made on an annual basis has been proposed to improve the adaptability of cropping practices to externalities (Liebig *et al.*, 2007).

Research has shown that good soil and crop management practices can considerably increase the efficiency with which water available from precipitation and irrigation be used. Improved water productivity can be gained if crops are well established and adequately fertilized, weeds are controlled and appropriate crop rotations are used (Pala and Studer, 1999).

Improved fertility improves water use efficiency (Cooper, 1991) and can, therefore, improve and stabilize production in rainfed areas and enable crops to exploit favorable rainfall in good years. Given the inherent low fertility of many dry area soils, judicious use of fertilizer is particularly important. Extensive work in Syria (Pala *et al.*, 1996), demonstrated the benefits of appropriate fertilization on water-use efficiency and therefore on production and yield stability especially of wheat and barley, in WANA.

The existing resource allocation is sub-optimal; therefore there is a need to maximize the resource use efficiency by adopting optimal cropping pattern. Water management is a must impending water scarcity. The United Nation is stressing the need to gradually produce more output and/or value per unit of water (Nimah *et al.*, 2003). The frontier of agriculture in the next decade or so is to increase revenue per unit of water used. The intent of this research is to improve water productivity through adopting optimal cropping pattern.

MATERIALS AND METHODS

Of a total 120 sample farms surveyed in spring, 2007, 30 farmers from each small, large, head, tail farm were selected, respectively. A representative farm budget for each category was developed. On the basis of representative farm budgets, four optimization models solved through Linear Programming (LP) utilizing General Algebraic Modeling System to obtain optimal cropping pattern to maximize net revenue per unit of water use.

A representative farm of each farm (large, small, head and tail) was taken to develop LP model to evaluate various crop production scenarios through water increase and decrease in water availability. For the sake of brevity LP matrixes were not reported here. In order to estimate the economic value of irrigation, the Change In Net Income (CINI) was used as follows:

The Change in Net Income (CINI) method: In practical applications, irrigation water is often valued with the CINI method. The willingness to pay for an increment of water is the net producer income associated with that increment. A process very similar to that used for residual imputation can represent this approach. It was designed to accommodate the case of a multi-product firm in addition to the individual crop model discussed earlier.

A more general multi-crop/multi-input production function can be written as:

$$f\,(Y_1,\ldots\ldots Y_m;\ X_1,\ldots\ldots X_n) = 0 \qquad (1)$$

Where,

Y = Vector of outputs of feasible crops.

X = Vector of production inputs.

The net income (denoted Z) from producing a given set of crops can be represented by:

$$Z = \acute{O}_{i=1\ldots m}(Y_i P_{yi}) - \acute{O}_{j=1\ldots n}(X_j\, P_{xj}) \qquad (2)$$

The CINI is:

$$\Delta Z = Z_1 - Z_0 \qquad (3)$$

Where the subscripts 0 and 1 refer to the without project and with project situations, respectively.

Note that if land is the only residual claimant in the net income expression Eq. 3, (as it would be if the without project situation involved rain-fed cropping), then Eq. 3 reduces to the residual imputation formula (Chaudhry and Young, 1989). In other words, Z_0 represents the opportunity cost of the residual claimant, land in the without situation.

The change in net income method can be adapted to mathematical programming models (LP model) of farm situations to approximate a functional relationship between net benefits and irrigation water use (Burt, 1992; Bowen and Young, 1985; Chaudhry and Young, 1989). The programming model of a representative farm situation is formulated to maximize net return to the residual claimant (the water resource in this case) subject to constraints on water availability. The model is solved for

Table 1: Characteristics of various farms at Mitha Luck Distributory, Sargodha

Farm characteristics (acres)	Small	Large	Head	Tail
Area owned	6.25	32.5	15.25	12.50
Rented in	0.50	0.0	0.00	1.50
Rented out	0.00	2.5	0.00	0.00
Area shared in	0.00	0.0	0.00	0.00
Area sold out	0.00	0.0	0.00	0.00
Operational area	6.75	30.0	15.25	14.00
Cropped area	9.10	34.8	20.59	14.84
Cropping intensity (%)	135.00	116.0	135.00	106.00

Table 2: Cropping pattern of various farm categories at Mitha Luck Distributory, Sargodha

	Small	Large	Head	Tail
Crops	---------------------	Acres	---------------------	
Cotton	0.36	1.39	0.82	0.59
Rice	0.27	1.04	0.62	0.45
Sugarcane	0.91	3.48	2.06	1.48
Maize	0.18	0.70	0.41	0.30
Kharif vegetables	0.09	0.35	0.21	0.15
Kharif fodder	1.09	4.18	2.47	1.78
Rabi crops	0.00	0.00	0.00	0.00
Wheat	2.82	10.79	6.38	4.60
Wheat+Citrus	0.82	3.13	1.85	1.34
Rabi vegetables	0.09	0.35	0.21	0.15
Berseem+Citrus	0.55	2.09	1.24	0.89
Citrus	1.37	5.22	3.09	2.23
Rabi fodder	0.55	2.09	1.24	0.89
Total	9.11	34.80	20.59	14.84

each of a number of increments of water supply and the net return to each increment of water derived from the incremental change in the objective function. The derivation of the marginal value product of water is shown through LP-model.

Nearly 4 LP models for Mitha Luck distributory, Sargodha were developed. The models respectively representing small, large, head and tail farms at the distributory. The average size of small holding was 6.5 acres and that of large was 32 acres, while head farm size was 15 acres and that tail 13 acres. The cropping intensities at small, large, head and tail were 135, 116, 135 and 106%, respectively. The existing cropping pattern showed that wheat was the predominant crops at all farms followed by citrus, Kharif and Rabi fodders. However, most of farmers showed mixed cropping pattern citrus + wheat and citrus + berseem (Table 1 and 2).

RESULTS AND DISCUSSION

The net revenue of each crop was higher on large and head farms. All the models were calibrated while comparing with existing situation. The net farm revenue was over three times more on large farm and 30% higher on head farm as compared small and tail farms, respectively (Table 3).

The LP model results showed (Table 4) that the economic returns of small, large, head and tail increased 36, 26, 25 and 33% as compared to existing farm revenue, respectively. This indicates that net farm revenue can be increased profitably by reallocation and rationalizing existing resources.

Table 3: Net crop revenue of various farm categories at Mitha Luck Distributory, Sargodha

	Small	Large	Head	Tail
Gross revenue	-------------------	Rs. Acre^{-1}	---------------	
Cotton	2362	9020	5336	3847
Rice	1859	7099	4200	3027
Sugarcane	23884	91211	53960	38896
Maize	640	2443	1445	1042
Kharif vegetables	493	1882	1113	803
Wheat	13616	51998	30762	22174
Wheat + Citrus	21159	80806	47804	34458
Rabi Vegetables	646	2468	1460	1052
Berseem + Citrus	8201	31320	18529	13356
Citrus	48497	185206	109567	78978
Net farm revenue	121357	463452	274176	197633

Table 4: Net economic returns at Mitha Luck Distributory, Sargodha

Farm categories	Existing Rs. Farm^{-1}	Optimal Rs. Farm^{-1}	Existing (%)
Small	121357	164830	35.8
Large	463452	584772	26.2
Head	274176	341843	24.7
Tail	197633	263258	33.2

Table 5: The existing and optimal cropping pattern of small farm at the Mitha Luck Distributory, Sargodha

Crops	Existing	Optimal	Existing (%)
	------------	Acres --------------	
Cotton	0.36	0.00	-100.0
Rice	0.27	0.00	-100.0
Sugarcane	0.91	1.14	25.1
Maize	0.18	0.00	-100.0
Kharif vegetables	0.09	0.00	-100.0
Kharif fodder	1.09	1.09	-0.3
Rabi crops	0.00	0.00	0.0
Wheat	2.82	1.78	-37.0
Wheat+Citrus	0.82	1.57	91.4
Rabi vegetables	0.09	0.00	-100.0
Berseem+Citrus	0.55	0.97	77.4
Citrus	1.37	2.01	47.1
Rabi fodder	0.55	0.55	0.6
Total	9.11	9.11	

Comparison of cropping pattern of small and large farms: The results in Table 5 and 6 showed that rice, cotton Kharif vegetable were removed in the optimal solution, but sugarcane area increased. In Rabi season wheat area declined and Rabi vegetables were removed but area under wheat + citrus and Rabi fodder + citrus was increased on small farms. However, the total cropped area remained the same. In case of large farm in Table 6 the area under cotton declined by 53%, sugarcane area increased by 18%, rice, maize and Kharif vegetables were removed. The area under wheat declined by 25%, but the area under wheat + citrus increased by 57%. The area under Rabi vegetable declined by 63%, however area under Berseem + citrus increased by 63%. The area under citrus increased by 37%.

The comparison of the existing and optimal cropping pattern at large and small farms showed that cotton area was declined on large farms and maize and rice were removed from the optimal solution. The model results showed that area under sugarcane, citrus+wheat, berseem + citrus; and citrus increased substantially but area under wheat declined at the both small farm and large farm (Table 6 and 7). The overall cropped area remained the same on both farms. The value of the objective function was increased by 35% on small farms and 26% on the large farms. The sugarcane, wheat + citrus, berseem + citrus and citrus revenue showed a significant increase at both the farms (small and large). Thus the model results at both farm showed that farmers must follow optimal cropping pattern to increase their farm revenue. There was a tremendous scope to shift resource allocation to more revenue generating high value crops and choose crop mix where the net revenue for resource uses especially irrigation water was highest.

The analysis of the result revealed that farmer's optimal cropping pattern was citrus, wheat + citrus, sugarcane and berseem + citrus at both small and large farm. The wheat and Rabi fodder mixing with citrus provided more revenue and saved water. The water saved was perhaps reflected in increase in sugarcane area.

Table 6: Existing and optimal cropping pattern of large farm at the Mitha Luck Distributory, Sargodha

Cropping pattern	Existing	Optimal	Existing (%)
	------------- Acres ----------		
Cotton	1.39	0.650	-53.3
Rice	1.04	0.000	-100.0
Sugarcane	3.48	4.120	18.4
Maize	0.69	0.000	-100.0
Kharif vegetables	0.35	0.000	-100.0
Kharif fodder	4.18	4.176	0.0
Rabi crops	0.00	0.000	0.0
Wheat	10.78	8.140	-24.5
Wheat+Citrus	3.13	4.940	57.7
Rabi vegetables	0.35	0.120	-65.5
Berseem+Citrus	2.09	3.400	62.8
Citrus	5.22	7.160	37.2
Rabi fodder	2.09	2.088	0.0
	34.80	34.800	100.0

Water productivity of small and large farms: The analysis further revealed that by adopting optimal cropping pattern, the water productivity (net revenue M^{-3}) was increased substantially. The net revenue M^{-3} for sugarcane was increased by 20 and 16% on small and large farm, respectively. The corresponding increase for citrus was 27%. In case of wheat + citrus and beseem + citrus rotation, the net revenue/M^3 increased 27 and 39% on small and large farm, respectively. The increase in cotton was even increase by 200% on large farm. However, wheat water productivity declined by 41 and 33% correspondingly on both farms. The declining productivity was compensated by increase in revenue M^{-3} of wheat + citrus rotation because of increase wheat area. Nevertheless, wheat + citrus and berseem + citrus mix were not preferred choice of agronomists and horticulturalist. It is commonly believed that wheat is an exhaustive crop and would affect growth curve of citrus. It was further argued that citrus requires water in the month of May when farmers were harvesting wheat. This causes falling of citrus fruit in the month of June. The mixing of both crops with citrus creates a problem of pest and disease control of citrus fruit. Therefore, farmers have to decide between competing crop enterprises. Either they should keep citrus being high value fruit as major enterprise and avoid mix cropping pattern However, in the circumstances of water scarcity, farmer has compelling reason to choose mixed cropping pattern. Thus, farmer in the study area followed a crop rotation of wheat + citrus and berseem+citrus in order to cope up with water scarcity. The results were consistent with Celik and Paksoy (1998) who showed that relative profitability affects the crop choice. Nimah *et al.* (2003) also found similar results in Lebanon (Table 7).

Head and tail farms analysis: The position on the water course has important bearing on the productivity of crops per drop. The head farms have more access to irrigation water as compared to tail farms. In the Mitha Luck Distributory tail farmers were receiving less water. The

Table 7: Water productivity of small and large farms at Mitha Luck Distributory, Sargodha

		Small			Large		
Crops	M^3 $Acre^{-1}$	Existing	Optimal	Difference (%)	Existing	Optimal	Difference (%)
		------------ (Rs. M^{-3}) ---------			------------ (Rs. M^{-3}) --------		
Cotton	2092	1.13	*	*	4.31	2.01	214.00
Rice	5676	0.33	*	*	1.25	0.00	
Sugarcane	6077	3.93	4.92	20.00	15.01	17.77	16.00
Maize	2013	0.32	*	*	1.21	0.00	
Wheat	1791	7.60	4.79	-41.00	29.03	21.91	-33.00
Wheat+Citrus	8091	2.62	5.01	48.00	9.99	15.75	27.00
Berseem+Citrus	10430	0.79	1.40	44.00	3.00	4.89	39.00
Citrus	6300	7.70	11.32	32.00	29.40	40.32	27.00

*: Not estimated

distribution of water at head and tail raised an issue of equity. In the present study, the average head farm size was 15 acres whereas the farm size of the tail ender was 13 acres. The LP models were run for both categories of farms. The optimal cropping pattern showed variance with existing cropping pattern. The area under cotton, maize, Kharif vegetables, wheat and Rabi vegetables was declined but area under rice, sugarcane, wheat+citrus and Rabi fodder+citrus showed tremendous increase at the head farms. The value of the objective function was increased by 25% under optimal solution of farm revenue from crops. In case of tail farms, the area under cotton, rice, Kharif vegetable, wheat and Rabi vegetables declined drastically but area under sugarcane, wheat+citrus, Rabi fodder+citrus and citrus showed major increase. The overall optimal solution at the tail farm showed a 33% increase in the net return.

The analysis of head and tail farm showed tremendous scope of resource re-allocation. The head and tail farm can increase their farm income through shifting of cropping pattern to high value crops and reduce area under highly water consumptive crops such as sugarcane. The results were obtained in Table 8 and 9.

Table 8: Existing and optimal cropping pattern of head farm at the Mitha Luck Distributory, Sargodha

Cropping pattern	Existing	Optimal	Existing (%)
	------------ Acres	----------	
Cotton	0.82	0.52	-36.9
Rice	0.62	0.70	13.3
Sugarcane	2.06	2.16	4.9
Maize	0.41	0.00	-100.0
Kharif vegetables	0.21	0.00	-100.0
Kharif fodder	2.47	2.47	0.0
Rabi crops	0.00	0.00	0.0
Wheat	6.38	4.24	-33.6
Wheat+Citrus	1.85	2.20	18.7
Rabi vegetables	0.21	0.00	-100.0
Rabi Fodder+Citrus	1.24	2.47	100.0
Citrus	3.09	4.59	48.6
Rabi fodder	1.24	1.24	0.0
Total	20.59	20.59	0.0

Table 9: Existing and optimal cropping pattern of tail farm at the Mitha Luck Distributory, Sargodha

Crops	Existing	Optimal	Existing (%)
	--------------Acres	----------	
Cotton	0.59	0.00	-100.0
Rice	0.45	0.00	-100.0
Sugarcane	1.48	2.12	42.9
Maize	0.30	0.00	-100.0
Kharif vegetables	0.15	0.00	-100.0
Kharif fodder	1.78	1.78	0.0
Rabi crops	0.00	0.00	0.0
Wheat	4.60	3.12	-32.2
Wheat+Citrus	1.34	2.24	67.7
Rabi vegetables	0.15	0.00	-100.0
Rabi fodder+Citrus	0.89	1.54	73.0
Citrus	2.23	3.15	41.5
Rabi fodder	0.89	0.89	0.0
Total	14.84	14.84	0.0

Water productivity of head and tail: The estimates of water productivity (Table 10) revealed that water productivity of sugarcane increased only 5% but in case rice increased by 12% on head farms; both are competing crops for season and water. However, rice is not the recommended crop of the area. The water productivity of sugarcane on tail farm increased by 30%. In case of citrus the net revenue M^{-3} was increased by 29%. The wheat water productivity was declined by 49 and 47% on head and tail farms, respectively. The wheat productivity of water was less by 28% on tail farms as compared to head farms. The result was consistent with Tyagi *et al.* (2004). However wheat+citrus and berseem+citrus rotations showed tremendous increase of 16-40% and 50 to 42% correspondingly on head and tail farms.

Sensitivity analysis of irrigation water: The right hand side of the LP matrix showing water availability was subjected to water decrease by 10, 20, 30, 40 and 50%. The model results indicated that at small farms, the value of the objective function decreased by 2, 9.6 and 30.8% at 10, 20 and 30% by water discounting, respectively. The water discounting beyond 30% showed negative relation. In case of large farms, the objective function value declined 1.1, 6.6, 23.8 and 76% at 10, 20, 30 and 40% discounting of irrigation water, however, at 50% the farm return became negative. In case of head farms the value of the objective function declined by 6.2, 11.1, 27.4 and 79.6% at 10, 20, 30 and 40% water discounting. The corresponding decrease

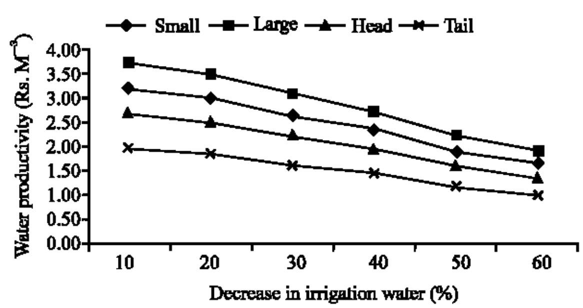

Fig. 1: Water productivity with water discount of various farm categories at Mithaluck Distributory, Sargodha

in the tail farms 12, 31 and 84%. The water discounting at 30% and beyond showed a drastic decline in the net farm revenue. The Fig. 1 showed the declining water productivity of small, large, head and tail farms at the Distributory.

The major shift in net revenue was brought about by change in area; the less efficient crops were removed from the cropping patter and only those crops which generated higher revenue were sustained in the model. The analysis led us to believe that with the existing

Table 10: Water productivity of head and tail farms at Mitha Luck Distributory, Sargodha

		Head			Tail		
		Existing	Optimal		Existing	Optimal	
Crops	M^3 Acre^{-1}	(Rs. M^{-3})		Difference (%)	(Rs. M^{-3})		Difference (%)
Cotton	2092	2.55	1.61	-42.00	1.84	0.00	*
Rice	5676	0.74	0.84	12.00	0.53	0.00	*
Sugarcane	6077	8.88	9.32	5.00	6.40	9.14	30.00
Maize	2013	0.72	0.00		0.52	0.00	*
Wheat	1791	17.18	11.41	-49.00	12.38	8.40	-47.00
Wheat+Citrus	8091	5.91	7.02	16.00	4.26	7.14	40.00
Berseem+Citrus	10430	1.78	3.55	50.00	1.28	2.21	42.00
Citrus	6300	17.39	25.85	33.00	12.54	17.74	29.00

*: Not estimated

Table 11: Economic value of irrigation water of different crops of various categories of farms at Mitha Luck Distributory

	Small farms	Large farms	Head farms	Tail farms
Crops	(Rs. M^{-3})			
Cotton	2.32	3.49	2.71	1.87
Maize	1.13	1.17	0.51	0.98
Rice	1.30	1.17	0.76	1.39
Sugarcane	0.91	1.95	0.50	0.80
Wheat	1.51	0.90	0.70	1.06
Citrus	1.65	1.41	1.13	1.09

resource endowment, farm ex-inefficiency can be minimized through optimal combination of crop mix which generate more net revenue per drop of water. The farmers can bring less water consumptive but high value crops in the cropping pattern. The wheat+citrus and berseem+citrus amply demonstrate this assertion. However, there are additional high value crops such off- season vegetables and cut flowers which further augment farm revenue and improve resource use efficiency. The resource use efficiency of water can be improved from 30-40% if cropping pattern is optimized to achieve such objectives. Therefore, outreach efforts must be geared towards irrigation agronomy and rational resource allocation at the farm level.

The often promoted solution to combat water scarcity is the improvement of irrigation efficiency, i.e., reducing water losses between the point of water diversion and the root zone soil moisture storage. This is, however, not a proper solution everywhere, because percolating water from fields that are irrigated is not necessarily bad (it is not always good either). When farmers are using groundwater or drainage water for irrigation, recycling of water resources will increase irrigation efficiencies that are substantially greater than the nominal field scale values.

In support of the present findings, Dam and Malik (2003) pointed out that the ballpark figure for field scale irrigation efficiencies is 45% and several studies have indicated that the irrigation efficiencies for deltas or river basins as a total system with recycling of percolation water can be as high as 80 to 100%. This implies that improvements in efficiency will be next to impossible and is basically false hope. Hence, irrigation efficiency related management is not straightforward to implement and a paradigm shift is required to describe the utilization of the water resources in irrigation systems in a simple manner. Agricultural production has traditionally been expressed in kg crop ha^{-1} of land, assuming that land resources are the limiting factor. In some cases land is indeed the limiting factor, but with the current water crisis, sufficiently available fresh water resources are becoming the binding constraint for food production and limited water should be use more productively. It is therefore logic to express the agricultural performance in terms of kg crop produced per M^{-3} water used.

The findings of the study were also consistent with Bastiaanssen (2000) who showed the results of a literature review of wheat and corn and he came to the conclusion that WP per unit depletion for wheat ranges between 0.4 to 1.6 kg M^{-3} and that for corn the range was 0.3 to 2.7 kg M^{-3}. This implies that there is a factor 4-9 between the lowest and highest levels and that an enormous scope for improving WP exists. An increase of WP by for instance 40% implies that the same food production can be maintained with 40% less crop water consumption. This is a great opportunity for the irrigation sector that needs to get more attention by water resources planners, agronomists and irrigation engineers. It needs to be emphasized that the saving should be related to E_t (wet saving) and not to water supply (dry saving). If we are able to increase the water productivity in irrigated agriculture, water can be allocated for other users in the river basin.

The analysis further led us to conclude that farmers has the capacity to pay water charges even extreme scarcity water i.e., even if the water is reduced by 60% as shown in the sensitivity analysis above. The current water rate for Rabi and Kharif crop is Rs. 50 and Rs. 85 acre^{-1}, respectively. In case of citrus the water Rs. 250 acre^{-1}. The water charges at the existing flat rate are: wheat as Rs. 0.02 M^{-3}, sugarcane as Rs. 0.013 M^{-3} and citrus as Rs. 0.04 M^{-3}. The estimated economic value of water is much higher for these crops (Table 11). Therefore, farmers have the capacity to pay higher water charges and they are willing to pay higher water provided they are assured the supply of water in time. The water charges can safely be increased by 20% to cover the operation and maintenance cost of the canals and Distributory.

CONCLUSIONS AND RECOMMENDATIONS

The increasing scarcity of water in the arid and semi arid regions is now a well-known problem. The need to produce more food with less water poses vast challenges to reassign existing supplies, encourage more efficient use and promote natural resources protection. On-farm water-use efficient techniques coupled with improved irrigation management options, better crop mix and suitable cultural practices, genetic make-up and timely socio-economic interventions would help achieving this goal.

In water-deficit areas, water is more limiting to production than land hence maximizing water productivity, should have higher priority over maximizing yield in the strategies of water management. The conservative guidelines for determining crop irrigation requirements, which are designed to maximize yield, need to be revisited for obtaining maximum water productivity. Moreover, planning water and land use should be based on the comparative advantages and competitiveness of the arid and semi areas, but within the framework of maximizing the return from the limited available water resources.

The resource use efficiency on Pakistani farms is abysmally low. The literature demonstrates that the water productivity can be increased by optimizing the existing cropping pattern. The intent of this paper was to show that water productivity can be increased through optimal cropping pattern on a case study of Punjab Canal. Four LP models representing small, large, head and tail farm developed for simulation.

The results revealed that sugarcane water productivity was increased by 20% on large farm and 12% on tail farms. The productivity of wheat + citrus and berseem + citrus was increased as high as 40%. The productivity of water of many crops on tail farms was lower as compared to head farm. Moreover farmers have the capacity to pay water charges even under extreme water stress conditions. Thus water rates can safely be increased by 20% to cover the O and M cost of canal maintenance.

Thus, it is possible to substantially increase water productivity through adopting improved irrigation systems, applying sound irrigation management, growing improved crop cultivars and appropriate cropping patterns and cultural practices. Cropping systems need to be inherently flexible to take advantage of economic opportunities and/or adapt to environmental realities. It is however, important that these interventions be integrated with full participation of the farmer to develop viable strategies and efficient and sustainable production systems.

If agricultural production and livelihoods in the Indus Basin are to be sustained, even at current levels, greater priority must be given to improving water productivity and enhancing the efficiency of water delivery. The strategies for determining crop irrigation requirements to maximize water productivity are needed in water deficit areas. There is a need to improve irrigation agronomy at the farm level.

The importance of higher Water Productivity (WP) in irrigated systems in order to meet the food demands can hardly be over emphasized. Traditional agronomical and hydrological knowledge need to be pooled together for addressing the following major problems with regard to WP:

- What are the benchmark WP values under practical conditions for various crops and what are the spatial variations occurring within and among irrigation schemes?
- How can we improve WP at the different spatial scales so that agricultural production can be maintained and fresh water resources come available for competing sectors or for expanding the irrigated area?

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