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APPARENT AND REAL WATER PRODUCTIVITY FOR COTTON-WHEAT ZONE OF PUNJAB, PAKISTAN

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Water productivity need to be enhanced in view of diminishing water supplies. A study was conducted to assess the existing water productivity status in cotton-wheat cropping zone in Punjab Province of Pakistan and identifying factors for its improvement. Six watercourses on four distributaries taking off from Lower Bari Doab Canal (LBDC) of river Ravi were selected in tehsil Kabirwala, district Khanewal. The data regarding crop yield, irrigation water, fertilizer and pesticides was recorded from farmers and cross checked with information collected from *Patwaris*. The results indicated that mean yield, apparent water productivity (yield/irrigation water) and real water productivity (yield/water evapotranspired) for wheat was 3210 kg ha^{-1}, 0.43 kg m^{-3} and 1.12 kg m^{-3}, respectively. The corresponding values for cotton were 2675 kg ha^{-1}, 0.22 kg m^{-3} and 0.26 kg m^{-3}, respectively. It was concluded that all the three considered factors (irrigation water, fertilizer and pesticide) improved real water productivity (yield/water evapotranspired). Further pesticide in wheat and fertilizer in cotton was the most effective. However, water productivity studies on the larger scale and inclusion of factors (irrigation method, soil fertility, crop variety, irrigation scheduling etc.) influencing water productivity are recommended for future to improve water productivity.

Keywords: Apparent water productivity, real water productivity, CROPWAT

INTRODUCTION

Wheat and cotton are the major crops of the country utilized to meet the food and fiber requirements of the masses. It is estimated that in Pakistan, these crops are grown on 11.60 million hectares (mha) while in Punjab the estimated area is 8.83 mha, which is 76% of the total cotton-wheat area of Pakistan (Govt. of Pakistan, 2009). Pakistan lies in arid to semi-arid region where average annual rainfall is 254 to 356 mm against a potential demand (of water to get maximum crop production) of 1778 mm (Khan, 2003). This gap between the demands and supplies is met by applying irrigation. Moreover, the country is facing threat of rapidly increasing population with the annual growth rate of 2.05 percent (Pakistan Economic Survey, 2011). It has been observed that water availability for the agriculture is expected to fall from 72% in 1995 to 62% by 2020, globally, and 87% to 73% in developing countries (Khan *et al*., 2006). This decreasing water availability is really an alarming situation for such a developing country which requires sustainable use of water for crop production. This sustainability can be largely ensured through appropriate management of water resources.

It was observed that for the lined watercourses, the irrigation water losses ranged from 35 to 52% and for the unlined these were from 64 to 68% (Arshad *et al*., 2009). Farmers apply water to unleveled bunded units, resulting in long irrigation events, poor water uniformity and over-irrigation (Kahlown and Kemper, 2004). These practices result in very low irrigation application efficiencies, which eventually result in lower land and water productivity. Studies in Pakistan indicate that 13–18 cm of water is applied per irrigation event on the average for a crop, which is considerably higher than the actual consumptive use of approximately 8 cm of water between two irrigation events (Kahlown *et al*., 2001). On-farm irrigation efficiencies in Punjab range between 23 and 70% (Clyma and Ashraf, 1975; Kalwij, 1997). Rapidly increasing demands from domestic, industries and environmental uses may put additional pressure on water resources in many river basins, and therefore, food security is challenged by an ever increasing food demand from a growing population in the coming decades (Rijsberman and Molden, 2001). The agricultural sector faces a challenge to produce more food with less water by increasing water productivity (Kijne *et al*., 2003).

The concept of water productivity as presented by Kijne *et al*. (2003) was a robust measure of capability of agricultural system to convert water into food. This term is also defined by other researchers as the physical mass of production or the economic value of production measured against gross inflow, net inflow, depleted water, or available water (Molden, 1997; Molden and Sakthivadival, 1999). Water productivity is of two types: Apparent Water Productivity

(AWP), which is the crop yield per unit of applied water and Real Water Productivity (RWP) defined by Kassam and Smith (2001) as "crop yield/water consumptively used in evapotranspiration".

Timsina and Connor (2001) stated that average combined yields of rice and wheat systems in the western Indo-Gangetic plains are in the order of 6000-8000 kg ha^{-1} while yields attainable with higher fertilizer and better management inputs were much greater (9000-11000 kg ha^{-1}). In Pakistan, AWP is lower than many other countries of the world. Hussain *et al.* (2003) conducted a study in the Bhakra Canal System of the Kaithal Irrigation Circle in India (BCS-India) and Lower Jehlem Canal System in Chaj sub-basin in Pakistan (LJCS-Pakistan) under fairly similar cropping, agro-climatic, socio-economic and management conditions. The AWP was higher for BCS-India (1.47 kg m^{-3}) than for LJCS-Pakistan (1.11 kg m^{-3}).

These findings have raised an important research question, i.e. why AWPs of wheat vary to such a magnitude under fairly similar agro-climatic, socio-economic and management conditions. This simply implies that water is not being used very efficiently under the existing cropping systems. This necessitates that the existing cropping system should be evaluated to find out the reasons for the low crop yields and water productivities. Therefore, improvement of water and crop productivity has become the priority consideration. The objective of the study was to find out the existing water productivity in the Cotton-Wheat zone of Punjab Province-Pakistan and suggest measures to improve it.

MATERIAL AND METHODS

***Description of study area*:** The study was conducted at Khanewal district situated in Bari Doab (the land between river Chenab and river Sutlej) of Punjab. This study area was selected as representative of the entire cotton-wheat belt, which constitutes Khanewal, Multan, Bahawalpur and Faisalabad districts. It has 30.9667° N latitude, 72.4833° E longitude, 3,259 Sq. km area and 1,650,000 population. It annually contributes 147 and 567 thousand metric tons of cotton and wheat, respectively (Govt. of Pakistan, 2009).

Khanewal district has very extreme climate, i.e. temperature approaches 52°C in summer, and 1°C in winter. The land around Khanewal is very fertile. A diversity of crops is grown such as cotton, wheat and rice, in this area including mango orchards also. The average annual rainfall in the area is 93 mm. The river Chenab flows on North and the river Ravi on North East side of Khanewal district. The irrigation system consists of main canal, branch canal, major distributary/minor distributary, watercourses and field channels. Despite of this groundwater extraction is also there.

***Watercourse data*:** The selected distributaries such as Fazal Shah, Qadir, Allah Hoo and Abdul Hakeem take off from Lower Bari Doab Canal (LBDC). Data was collected from 6 watercourses, namely two watercourses 13680L (WC1) and 7900L (WC2) on Fazal Shah Distributary, one watercourse 6774TL (WC3) on Qadir minor, one watercourse 15580TR (WC4) on Allah Hoo distributary and two watercourses 26995L (WC5) and 28992L (WC6) on Abdul Hakim Distributary. Watercourse WC3 was present on the tail of Qadir minor where the canal water was not present whole the year and the farmers were totally dependent on tubewell water. The detailed features of the watercourse commands are presented in Table 1. Primary data was (crop yield, water, fertilizer, pesticide applied to each crop) collected from *Patwaris* (visiting clerks) of the respective watercourses and On Farm Water Management Department. Suitable number of farmer's (6 on each watercourse) was interviewed in order to cross check the information taken from the Patwaris. Crop yield was the major component of water productivity. However in addition to water, it might be influenced by other growth factors including soil type, soil

Table 1. Salient features of the watercourses selected for the study

Salient features	Sample watercourses					
	WC1	**WC2**	**WC3**	**WC4**	**WC5**	**WC6**
Distributary/minor	Fazal Shah	Fazal Shah	Qadir	Allah Hoo	Abdul Hakeem	Abdul Hakeem
Village/Mouza	Shahadad Kanlai	Battian	Ali Chappa	Allah Hoo	Jalilpur	Jalilpur
GCA of watercourse (ha)	106	71	213	207	23	35
Length of watercourse (m)	4165	4000	3465	6287	970	1776
No. of farmers	35	40	40	40	06	06
CCA of watercourse (ha)	94	66	202	202	22	32
Designed discharge (m^3s^{-1})	0.1	0.055	0.076	0.064	0.010	0.012
Number of tubewells	2	7	40	40	1	6
Average discharge of each tubewell (m^3s^{-1})	0.028	0.028	0.028	0.028	0.028	0.028
Area under wheat (ha)	81	51	172	142	16	26
Area under cotton (ha)	81	41	172	151	16	26

fertility, added fertility, pesticide and others. Therefore, the fertilizer and pesticide applied to the crops was also included in the study. The data was collected through a detailed proforma specially designed for the study.

***Climatic data*:** The daily climatic data was recorded from Regional Meteorological Centre, for the Meteorological Observatory, Multan located on Latitude 30°12' and Longitude 71°26' at a distance of 54 km from study area with elevation 123 m. The climatic data included minimum and maximum temperature (°C), relative humidity, daily sunshine hours, wind speed and rainfall as required by CROPWAT computer model for the calculation of crop water requirements.

***Crop water requirements*:** The crop water requirements (CWR) for wheat and cotton were estimated using CROPWAT computer model, which uses Penman-Monteith equation for calculation of the reference evapotranspiration (Allen *et al*., 1998). The seasonal CWR called as actual evapotranspiration were calculated by multiplying the reference evapotranspiration with crop coefficient (Kc) for wheat and cotton crops (Ullah *et al*., 2001).

The effective rainfall is the portion of total rainfall that is useful for crop production. Effective rainfall in this research work was estimated using USDA Soil Conservation Service method. Effective rainfall values were converted to daily values through linearly interpolation. Due to lack of soil properties data, rainfall losses due to deep percolation and surface runoff were not directly taken into account in the actual soil moisture content of the root zone. The USDA method accounted for some of the losses (surface runoff, depression fillings and interception losses). The irrigation requirements (irrigation water) were calculated by subtracting effective rainfall from CWR.

***Statistical analysis*:** The yield and water productivity for wheat and cotton crops were analyzed statistically using variance technique (Multiple Regression) using Minitab Statistical Computer Software (Version 13). The relationships between yield (Y) and irrigation water (IW); Y and fertilizer (F) and Y and pesticides (P) were established for both wheat and cotton crops. Then the Y, AWP and RWP responses were developed against IW, F, P and also their significant interactions (IW x F, IW x P, F x P, IW^2, F^2, P^2 and IW x F x P).

RESULTS AND DISCUSSION

***Water applied*:** The total water applied to both the crops under study on the six watercourse commands is shown in Tables 2 and 3. The total volume of water is the sum of canal plus groundwater and effective rainfall for the total growing season of the crops. The effective rainfall for wheat and cotton seasons was 1107 and 1232 m^3 ha^{-1}, respectively. The average total water applied for wheat crop was 8340, 8827, 7949, 9176, 4699 and 6761 m^3 ha^{-1} for watercourses WC1, WC2, WC3, WC4, WC5 and WC6, respectively (Table 2). The corresponding values for cotton were 11527,

Table 2. Irrigation water, fertilizer, pesticide, yield, AWP and RWP for wheat crop across the selected watercourses

Watercourse	Irrigation water (m^3 ha^{-1})	Fertilizer (kg ha^{-1})	Pesticides (L ha^{-1})	Yield (kg ha^{-1})	AWP (kg m^{-3})	RWP (kgm^{-3})
WC1	8340	482	3.0	3362	0.40	1.17
WC2	8827	494	3.0	3409	0.39	1.19
WC3	7649	469	2.5	3272	0.43	1.14
WC4	9176	544	4.4	4100	0.45	1.43
WC5	4699	305	2.2	2371	0.50	0.82
WC6	6761	336	2.2	2746	0.41	0.96
Mean	**7575**	**438**	**2.9**	**3210**	**0.43**	**1.12**

Table 3. Irrigation water, fertilizer, pesticide, yield, AWP and RWP for cotton crop across the selected watercourses

Watercourse	Irrigation water (m^3 ha^{-1})	Fertilizer (kg ha^{-1})	Pesticides (L ha^{-1})	Yield (kg ha^{-1})	AWP (kg m^{-3})	RWP (kgm^{-3})
WC1	11527	540	23	2529	0.22	0.25
WC2	12230	534	24	2618	0.21	0.26
WC3	13632	500	27	2724	0.20	0.27
WC4	15792	680	32	3269	0.21	0.32
WC5	9709	494	22	2332	0.24	0.23
WC6	11722	543	24	2579	0.22	0.25
Mean	**12435**	**548**	**25**	**2675**	**0.22**	**0.26**

12230, 13632, 15792, 9709 and 11722 m^3 ha^{-1} (Table 3). The average for wheat and cotton across all the studied watercourses was 7575 and 12435 m^3 ha^{-1}, respectively.

***Fertilizer and pesticide application*:** The total fertilizer applied to both the crops under the study on the six watercourse commands is shown in Tables 2 and 3. The total fertilizer is the sum of number of applications of N, P and K. The average total fertilizer applied for wheat crop was 482, 494, 469, 544, 305 and 336 kg ha^{-1} for watercourse WC1, WC2, WC3, WC4, WC5 and WC6, respectively (Table 2). The corresponding values for cotton were 540, 534, 500, 680, 494 and 543 kg ha^{-1}, respectively (Table 3). The average for wheat and cotton across all the studied watercourses was 438 and 548 kg ha^{-1}, respectively.

The average total pesticides (N, P, K) applied for wheat crop (1 per season) was 3.0, 3.0, 2.5, 4.4, 2.2 and 2.2 L ha^{-1} for watercourse WC1, WC2, WC3, WC4, WC5 and WC6 (Table 2). The corresponding values for cotton (3-4 per season) were 23, 24, 27, 32, 22 and 24 L ha^{-1} (Table 3). The average for wheat and cotton across all the studied watercourses was 2.9 and 25 l ha^{-1}, respectively.

***Crop yields*:** Table 2 shows that the mean wheat yield was obtained as 3210 kg ha^{-1}. The highest wheat yield was observed on watercourse WC4 (4100kg ha^{-1}) while the wheat yield was minimum at watercourse WC5 (2371 kg ha^{-1}). Yields for other watercourses WC1, WC2, WC3 and WC6 ranged from 2746 to 3405 kg ha^{-1}. The crop yield variation across the selected watercourses might be attributed to the number of irrigations that the farmers applied. The irrigations were applied according to their own perception (Aslam, 1998). Other factors could be crop variety, fertilizer application rate and timing etc. It is evident from Table 2 that maximum crop yield (4100 kg ha^{-1}) was for the watercourse (WC4) for which the irrigation water (9176 m^3 ha^{-1}), fertilizer (544 kg ha^{-1}) and pesticide (4.4 L ha^{-1}) were maximum. It shows that all the considered factors contributed in the enhancement of wheat yield. The average wheat yield showed good agreement with the yields reported earlier (Ahmad *et al.*, 2004 (3146kg ha^{-1}), Ilbeyi *et al.*, 2006 (3200 kg ha^{-1}) and Ali *et al.*, 2007 (3298 kg ha^{-1}). The mean wheat yield was higher than that of reported by Zwart and Bastiaanssen (2007) (2500 kg ha^{-1}) and Hussain *et al.* (2004) (1451 kg ha^{-1}). The mean wheat yield was lower than that reported by Hussain *et al.* (2003) (4295 kg ha^{-1}), Chahal *et al*. (2007) (4852 kg ha^{-1}) and Singh *et al*. (2006) (6300 kg ha^{-1}).

The cotton yield across various watercourse commands is given in Table 3. The mean cotton yield was 2675 kg ha^{-1}. The highest cotton yield (3269 kg ha^{-1}) was found on watercourse WC4 while the lowest cotton yield was 2332 kg ha^{-1} at watercourse WC5. Yields for watercourses WC1, WC, WC3 and WC6 ranged from 2529 to 2724 kg ha^{-1}. It is evident from Table 3, that crop yield (3269 kg ha^{-1}) was maximum for the watercourse WC4 for which the irrigation water 9176 m^3 ha^{-1}, fertilizer (680 kg ha^{-1}) and pesticide (32 L ha^{-1}) was used. It showed that up to the measured range, all the considered factors contributed to the increase in cotton yield. The average yield was more than that reported by Jalota *et al.* (2006) (1876 kg ha^{-1}), Jalota *et al*. (2008) (1649 kg ha^{-1}), Rafiq (2007) (2122 kg ha^{-1} with surface irrigation) and Singh *et al.* (2006) (1850 kg ha^{-1}). The mean cotton yield was lower than that reported by Ibragimov *et al*. (2007) (3525 kg ha^{-1}).

***Apparent water productivity*:** The apparent water productivities (AWPs) for various watercourse commands are given in Table 2 and 3 for wheat and cotton crops, respectively. The mean apparent water productivity for wheat over the all six watercourses was 0.43 kg m^{-3}. The maximum apparent water productivity (0.50 kg m^{-3}) was found on watercourse WC5 and minimum (0.39 kg m^{-3}) at watercourse WC2 (Table 2). The highest AWP (0.50 kg m^{-3}) for watercourse WC5 with minimum wheat yield (2371 kg ha^{-1}) and minimum water applied (4699 m^3 ha^{-1}) showed that the water was supplied in lesser amount and the corresponding yield reduction was lesser corresponding to irrigation water applied, therefore, AWP was maximum at this watercourse. As compared to watercourse WC4 where the wheat yield (4100 kg ha^{-1}) was the maximum, AWP (0.45 kg ha^{-1}) was not the highest that might be due to over irrigation at this watercourse. It is clear from Table 2 that AWP (0.50 kg m^{-3}) was the maximum for the watercourse (WC5) where the irrigation water (4699 kg ha^{-1}), fertilizer (305 kg ha^{-1}) and pesticide (2.2 L ha^{-1}) application was minimum. It showed that up to the measured range, the marginal benefit of the considered factors is more prominent in case of AWP meant more part of the factors contributed to AWP. The mean AWP value was within the range as given by Cai and Rosegrant (2003) (0.2-2.4 kg m^{-3}). The following researchers reported higher values than the mean AWP value: Hussain *et al*. (2003) (1.11 for Pakistan and 1.47 kg m^{-3} for India), Ahmad *et al*. (2004) (1.06 kg m^{-3}), Hussain *et al*. (2004) (1.53 kg m^{-3}), Jalota *et al*. (2006) (1.27 kg m^{-3}), Chahal *et al*. (2007) (0.96kg m^{-3}), Ali *et al*. (2007) (1.79 kg m^{-3}) and Singh *et al*. (2006) (1.26 kg m^{-3}).

Apparent water productivity for cotton across the three watercourses is presented in Table 3. The mean value of AWP for cotton was 0.22 kg m^{-3}. The highest AWP of 0.24 kg m^{-3} was found for watercourse WC5. The AWP for watercourse WC3 was minimum (0.20 kg m^{-3}). The highest AWP (0.24 kg m^{-3}) for cotton was also for watercourse WC5, although the cotton yield (2332 kg ha^{-1}) and water supplied (9709 m^3 ha^{-1}) were minimum for this watercourse. It indicated deficit irrigation application which could be one of the factors causing AWP variability across various watercourse commands. From Table 3, it is clear that AWP (0.24 kg m^{-3}) was maximum for the watercourse (WC5) where the irrigation water (9709 kg ha^{-1}), fertilizer (494 kg ha^{-1}) and pesticide (22 L ha^{-1}) were minimum. It shows that upto the measured range, the marginal benefit of the considered factors is more prominent in case of AWP means more part of the factors contributed to AWP. The mean AWP value was a very close agreement as reported by Singh *et al*. (2006) (0.24 kg m^{-3}). Jalota *et al*. (2006) (0.41 kg m^{-3}) reported higher value the mean.

***Evapotranspiration and crop water requirement*:** The total water used as evapotranspiration during the entire wheat crop season was 359 mm and its CWR (evapotraniration – effective rainfall) was 287 mm. The CWR value showed an agreement with the values reported by Ahmad *et al*. (2004) (314 mm) and Kahlown *et al*. (2003) (271-515 mm). The value was out of range than that of reported by PARC (1982) (353-562 mm), Ilbeyi *et al*. (2006) (469 mm), Singh *et al*. (2006) (372 mm) and Chahal *et al*. (2007) (421 mm).

The amount of water used as evapotranspiration during the cotton season was 1200 mm and CWR (evapotraniration – effective rainfall) were found to be 1015 mm. The CWR value was well within range as reported by Doorenbos and Kassam (1979) (700-1300 mm), Kahlown *et al*. (2003) (627-1161 mm). The CWR value was higher than that reported by PARC (1982) (587-797 mm), Jalota *et al*. (2006) (50-700 mm), Karam *et al*. (2006) (540 mm) and Singh *et al*. (2006) (758 mm).

***Real water productivity*:** The real water productivities (RWPs) for wheat crop across various watercourses are given in Table 2. The mean RWP was found to be 1.12 kg m^{-3}. The highest RWP was recorded for watercourse WC4 (1.43 kg m^{-3}) and lowest for watercourse WC5 (0.82 kg m^{-3}). The highest RWP (1.43 kg m^{-3}) value at watercourse WC4 with maximum yield (4100 kg ha^{-1}) and maximum water diverted (9176 m^3 ha^{-1}) showed that the crop attained a fair part of potential CWRs, better fertilizer and pesticide combination (Table 2), It is evident that RWP (1.43 kg m^{-3}) was maximum for that watercourse (WC4) where the irrigation water (9176 m^3 ha^{-1}), fertilizer (544 kg ha^{-1}) and pesticide (4.4 L ha^{-1}) were maximum. Zwart and Bastiaanssen (2004) (0.6-1.7 kg m^{-3}), Ahmad *et al*. (2004) (0.78-2.03 kg m^{-3}), Chahal *et al*. (2007) (1.15 kg m^{-3}) and Ali *et al*. (2007) (1.19 kg m^{-3}) reported values in agreement to the mean RWP value. The mean RWP value was lower than that reported by Hussain *et al*. (2003) (1.37 kg /m^3 for Pakistan and 1.36 kg m^{-3} for India), Ilbeyi *et al*. (2006) (1.63 kg m^{-3}).

The RWP for the cotton crop across various watercourses is given in Table 3. The mean value of RWP was found to be 0.26 kg m^{-3} with the highest RWP of 0.32 kg m^{-3} for the watercourse WC4 and the least value of 0.23 kg m^{-3} for the watercourse WC5. The RWP (0.32 kg m^{-3}) was maximum at watercourse WC4 with highest cotton yield (3269 kg ha^{-1}) and highest water diverted (15792 m^3 ha^{-1}) which showed that water was diverted in proper amount to meet potential crop water requirements. It is evident from Table 3 that RWP (0.32 kg m^{-3}) was maximum for that watercourse (WC4) where the irrigation water (15792 m^3 ha^{-1}), fertilizer (680 kg ha^{-1}) and pesticide (32 L ha^{-1}) was maximum. It shows that the considered factors were contributing still to enhance RWP. The mean RWP value showed good agreement with Rafiq (2007) (0.25 kg m^{-3}). The mean RWP value was lowered than that reported by Jalota *et al*. (2006) (0.3 kg m^{-3}), Ibragimov *et al*. (2007) (0.75 kg m^{-3} for drip and 0.49 kg m^{-3} for furrow irrigation system), Jalota *et al*. (2008) (0.48 kg m^{-3}) and Karam *et al*. (2006) (1.05 kg m^{-3}).

These results showed that the AWP was maximum for the watercourse with minimum crop yield and minimum water diverted for irrigation. The RWP was mimimum for the watercourse with minimum crop yield and minimum water diverted for irrigation that might be due to loss of irrigation water as deep percolation due to which the potential crop water requirements were not fulfilled. This showed that AWP increased by decreasing irrigation water (deficit irrigation) but RWP decreased by reducing irrigation amount. Similar findings were presented by Jalota *et al*. (2006).

***Statistical analysis*:** To understand the relationships between the yield, AWP and RWP and the considered factors (irrigation water, fertilizer and pesticide), statistical analysis was conducted as given below:

***Simple regression analysis*:** The yield trends with irrigation water, pesticide and fertilizer were evaluated for both the crops separately. In general, similar trends in these parameters were observed at each watercourse. While comparing the response of cotton with that of wheat for the studied factors (IW, F and P), it is evident that for the measured range of factors, the response of cotton was linearly increasing as compared to that of wheat which was quadratic. This result was very much similar to that of earlier researchers such as Jalota *et al.* (2006). It is also evident that the pesticide effect on wheat crop and fertilizer effect on cotton crop was most prominent.

Wheat crop:

$$Yw = 2235.6+0.1455\ IW + 0.000031\ IW^2 \quad R^2=0.904 \qquad (4)$$

$$Yw = 1524.6 + 1.2757\ F + 0.0056\ F^2 \quad R^2 = 0.896 \qquad (5)$$

$$Yw = -1909.2 + 2741.6\ P - 310.92\ S^2 \quad R^2 = 0.875 \qquad (6)$$

Cotton crop:

$$Yc = 649.78 + 0.1629\ IW \quad R^2 = 0.935 \qquad (7)$$

$$Yc = 238.837 + 4.44113\ F \quad R^2 = 0.937 \qquad (8)$$

$$Yc = 382.35 + 0.132\ P \quad R^2 = 0.943 \qquad (9)$$

***Multiple regression analysis*:** Multiple Regression technique was also employed for statistical analysis. Regression analysis for yield, AWP and RWP for both the crops is given below.

***Wheat crop*:**

$$Yw = 739+0.115\ IW + 5.53\ F - 334\ P - 0.997\ F \times P +163\ P^2 \quad R^2 = 0.988 \qquad (10)$$

$$AWPw = 0.621 - 0.000044\ IW - 0.000954\ F + 0.149\ P - 0.00756\ F \times P + 0.000004\ F^2 + 0.0390\ P^2 \quad R^2 = 0.928 \qquad (11)$$

$RWPw = 0.216 + 0.000201\ IW - 0.0015\ F + 0.0006\ P - 0.000069\ IW \times P + 0.00108\ F \times P + 0.0196\ P^2$

$R^2 = 0.990$ (12)

***Cotton crop*:**

$Yc = -309 + 0.0410\ IW + 2.52\ F + 61.8\ P - 0.0337\ F \times P$

$R^2 = 0.997$ (13)

$AWPc = 0.219 - 0.000018\ IW + 0.000522\ F - 0.00223\ P - 0.000016\ F \times P + 0.000331\ P^2$

$R^2 = 0.985$ (14)

$RWPc = -0.0111 + 0.000005\ IW + 0.000159\ F + 0.00593\ P - 0.000044\ P^2$

$R^2 = 0.991$ (15)

It was concluded, on the basis of multiple regression analysis, that pesticides effect was prominent as compared to irrigation water and fertilizer and their interactions. In multiple regression analysis the fertilizer and pesticide interaction were prominent as compared to others except for RWP of cotton. Simple regression analysis indicated that up to the measured range the pesticide was more effective in case of wheat crop as compared to its effect on cotton crop. This could be due to the reason that wheat crop require little protection against insect pests as compared to cotton crop and a little pesticide doze had great effect on wheat crop insects and pests than that of cotton crop.

***Conclusions*:** The yield of both the crops was found increased by increasing irrigation water, fertilizer and pesticides upto the measured range. Similar was the case with RWP. But the AWP decreased by increasing irrigation water and increased by increasing fertilizer and pesticides. It was also concluded that the pesticide effect on wheat and fertilizer effect on cotton was the most prominent.

Water productivities for cotton and wheat crops need to be determined on larger scale such as canal command, for their precise assessment and explicability. As productivity is influenced by a variety of crop production factors; additional factors such as crop variety, soil type, irrigation method, irrigation scheduling, etc, need to be considered for comprehensive assessment. Developing methods of separating influence of water from other production factors would help understanding the real role of water in productivity.

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