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Assessment of Crop Water Productivity of Maize in Sub-Trophical Conditions under Tube Wells Irrigation System

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ABSTRACT
This research study was conducted to find the water productivity, relationship between water productivity and depth of water applied and yield of maize crop. The study was based on two years primary data collected in 2012 and 2013 and the questionnaire was used as a research tool for collection of data required for the study. The effective rain fall was estimated through CROPWAT (computer based programme) using the meteorological data obtained from WAPDA (Water and Power development authority), where the discharges of tubewells were determined by volumetric method. The number of irrigations, time taken by each turn and crop yield was recorded with the help of a questionnaire. Result showed that the average yield of maize was 4295 kg ha^{-1}, while the average water productivity was 0.76 kg m^{-3}. The crop water productivity of maize ranged from 0.05kgm^{-3} to 1.8kgm-3, whereas the yield ranged from 978.26kg/ha to 7500kg/ha .The water productivity of maize decreased from 1.8kg$m^{-3}$to 0.89kgm^{-3} when the depth of applied water increased from 99mm to 543mm. The results further revealed that the inadequate knowledge of farmers regarding depth of water to be applied at proper time and the frequency of irrigation were the main reasons for the low water productivity. It can be recommended that irrigation management with minimum applied depth of water is an important step toward the maximum crop water productivity.
Keywords: Tube wells, Yield, water productivity, Maize, CROPWAT.

INTRODUCTION

Water use in agriculture (Barker *et al*., 2003; Xie *et al*., 1993) is economically far less efficient as compared to manufacturing sector (Xie *et al*., 1993). However, increasing water productivity is the fundamental requirement for the best demand management strategy (Molden *et al*., 2001). Though, maximum water productivity is the essential needs for agriculture development particularly in developing countries, however, growing physical shortage of water, scarcity of economically available water, increasing cost of production and rare supply of the resource are the major issues for the agriculture industry (Kijne *et al*., 2003). This is a common opinion of the researchers that capacity of improving water productivity through water management or efficiency improvement is often over-estimated and re use of water is under-estimated (Seckler *et al*., 2003). However, Molden *et al* (2003) explained that water productivity is scale dependent, therefore, it can be analyzed at any level ranging from field, to basin level, and its evaluation will change with the changing scale of analysis. Viets (1966) was firstly introduce the water use efficiency to denote the ratio of crop production to evapo-transpiration (source: Kijne *et al*., 2002), so, over the past few years, the conception of water productivity in agriculture has been shifted in to the increasing water management as a factor of production in Agriculture.

In sub-continent i-e India and Pakistan has widespread and integrated canal irrigation system in the world. According to the statistics of 2010-2011, out of the total area of 79.61 million hectares in Pakistan, 23.0 million hectares is cultivated, about 29 % of cultivated area provided with irrigation facilities. In Khyber Pakhtunkhwa (KP) out of the total cultivated land of 1.59 million hectares only 0.93 million hectares are irrigated, such as 59 % of the total cultivated land is irrigated. Canal irrigated area is about 81 %, tubewells (6%), dug wells (5%) and other means (4%) (Agricultural statistics of Pakistan, 2010-2011).Pakistan's population is increasing at an annual rate of 2.7% adding about three million people every year. For example, in 1901, there were about 16 million people and in 2007 the total estimated population of the country was more than 156.77 million. This necessitates focus on additional food production and output of farm produce. The rate of growth of the agricultural sector has been slow, for instance cropping intensity in the country was 99% only in 1983-84 and increased to 130% in 2007, the low cropping intensity is reflected in low yield per hectare (Pakistan Economic Survey, 2007-08). During the next decade there will be sharp increase in the food demand due to the increase population. To meet increased demand the production of agriculture has to be enhanced. Due to water scarcity water input per unit irrigated area will have to be lowered in reaction to environmental concern. Water productivity can be increased through increase in crop yield and reduction in irrigation water. Irrigation system needs to be modernized and optimized in order to meet these projections (Playana and Mateos, 2006). Taking in to consideration the importance of maize crop in the arid and semi-arid regions, various research have been undertaken in order to inspect its water productivity. Zwart and Bastiaansen (Zwart *et al* 2004) evaluated water productivity under canal irrigation system, reported values of 1.1-2.7kg/m^3

for the water productivity of maize. Their findings suggest that decreasing irrigation application i.e. deficit irrigation, is the key for improving WP index. The study concluded that a great potential existed for improving the WP. In other terms, an improved WP may possibly be achieved by using less water i.e. a decrease of 20 - 40 percent, as was reported to be 1.5 kg/m in India (Mishra *et al* 2001) and 1.5 kg/m in China (Kang *et al* 2000) .

The above literature shows that the water productivity of Maize crop was assessed under canal irrigation system in different climatic conditions except in dry sub-tropical conditions especially under Tubewell irrigation system. The main objective of the study was to assess the water productivity of maize crop in dry sub-tropical conditions under Tubewell irrigation system and to relate it with the depth of applied water, particularly when the area is separated in to small pockets by mountains and rivers, where canal irrigation system is not possible.

MATERIALS AND METHODS

Description of Study area

The study was conducted in District Buner of the Khyber Pakhtunkhwa (KP). The overall climate of the area can be termed as dry sub-tropical with mostly pleasant weather throughout the year. Winter last for 4 to 5 months with mild harshness and the summers are mildly torrid and Snowfall on mountains peak is common. There are two main rainy seasons; the winter rains in the Rabi season which occurs in November to May. The summer monsoon in the Kharif season provides necessary water for respective crops. Tobacco and wheat are Rabi crops while sugarcane and maize are the main Kharif crops. Because of the absence of river and canal system a considerable number of tube wells are operated in the area. The area was rich in groundwater and recharge sources were rainfall and irrigation return flow. Groundwater quality is good for irrigation and salt concentration is low. Total area of 172431 hectares is cultivable land while only 55457 hectares is presently under cultivation (32%). An area of 5301 hectares (9 %) is fallow land and 40983 hectares comprises of forest. The total irrigated Area of the district is14624 hectares out of which 4919 hectare is irrigated from tubewell (Bureau of statistics Khyber Pakhtunkhwa 2007- 2008).

Data collection

The study was based on two years primary data collected in 2012 and 2013 and the questionnaire was used as a research tool for collection of data required for the study.

Questionnaire

A simple questionnaire was prepared for data collection according to the objectives of the study. The questionnaire was pretested and after modification it was adopted for data collection. A total of twenty nine respondents were interviewed. Farmers were asked about the numbers of irrigation, irrigation application and yield of major crops. They were interviewed in their native language in order to get accurate information.

Flow Discharge

Discharges of 29 tubewell were measured in the selected Area. Volumetric technique was used for measurement of tube well discharges. The discharge of a tube wells were determined from existing Basin. The volume of the Basin was determined and the time taken by filling the Basin was recorded. Tube well discharge was calculated by the following formula.

$$\mathbf{Q} = \frac{\mathbf{V}}{\mathbf{t}} \left(\frac{\mathbf{m3}}{\mathbf{s}}\right)$$

Where

V = Volume of stilling basin; Length (m) x Width (m) x Height (m)
W = Width of stilling basin,(m)
H = Height of the stilling basin
L = length (m)
Q = Discharge (m^3/s)
T = Seconds

Effective Rainfall

The CROPWAT was only used to determine the effective rainfall, which is required in seasonal irrigation water calculation. The effective rainfall was determined on monthly basis.

Depth of Water Applied

The depth of water applied was determined by multiplying discharge with a time taken by irrigation and then was divided by the total area to be irrigated. Command area was measured with the help of measuring tape. Discharges of the tubewell were measured by the volumetric method and time taken by irrigation was observed.

With the following equation depth of applied water was determined.

$$D = \frac{QT}{A} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where,

Q= discharge (m^3/s)
T= irrigation period (sec)
A= Area of the field (m^2)
D= depth (m)

Seasonal Irrigation Water Applied

Applied depth per irrigation was observed from equation (1) and the number of irrigation was recorded for the whole season. The effective rainfall was determined from CROPWAT by using metrological data collected from WAPDA office. Seasonal irrigation water applied was calculated by the following equation.

SWA= (depth applied per irrigation (mm)*No of irrigation+ effective rainfall (mm)

Yield of Maize Crop

Yield of the maize crop was collected from the farmers, using a detailed questioner. The data was collected in mound and then was converted in to kg/ha using the following equation. The data showed in Table 2 was collected by the mentioned procedure.

Kg/ha = mound*50/ha

Crop Water Productivity

The revolutionary work on water productivity (WP) was undertaken by Molden in 1997, who first stated the concept. For him, WP can be resulting by dividing the crop yield by the total water consumed (Irrigation + Rainfall). Crop water productivity is defined as being the yield or Biomass production (Kg) per unit of crop water use (m^3) (Hashim *et al.,* 2012).The sample data for the crops were collected at the end of season. The volumes of water applied to the given crops were collected from the measured discharge for the specific time of irrigations. Crop yield was estimated from farmer's interviews in field (kg/ha). Crop water productivity was determined by using the following relation.

$$\mathbf{CWP} = \frac{\mathbf{(Total\ Yield)kg}}{\mathbf{SWA}} \quad \ldots\ldots\ldots\ldots\ldots \mathbf{(2)}$$

CWA; crop water productivity SWA, is combination of seasonal irrigation water and effective rainfall

RESULTS AND DISCUSSIONS

This chapter contains the detail analysis of the data collected in the field via various methodologies as discussed in above paragraphs. All the data collected on the basis of assigned objectives was analyzed and detail results with supporting discussion is listed below.

Effective rainfall

Effective rainfall is that part of the rainfall which is stored in the root zone and effectively utilized by the crops. Effective rainfall is often an important component of irrigation requirements. Figure 2.1 shows that the effectiveness of the rainfall increases from the month of January and become maximum in the month of July, this is because the crop water requirements are increasing due to the temperature and maturity of the crops, and on peak in July. After this the effectiveness of the rain decreases gradually and becomes minimum in the month of December because the water requirements are low. Table.1 shows climatic data of the study area which can be used to determine the effective rainfall.

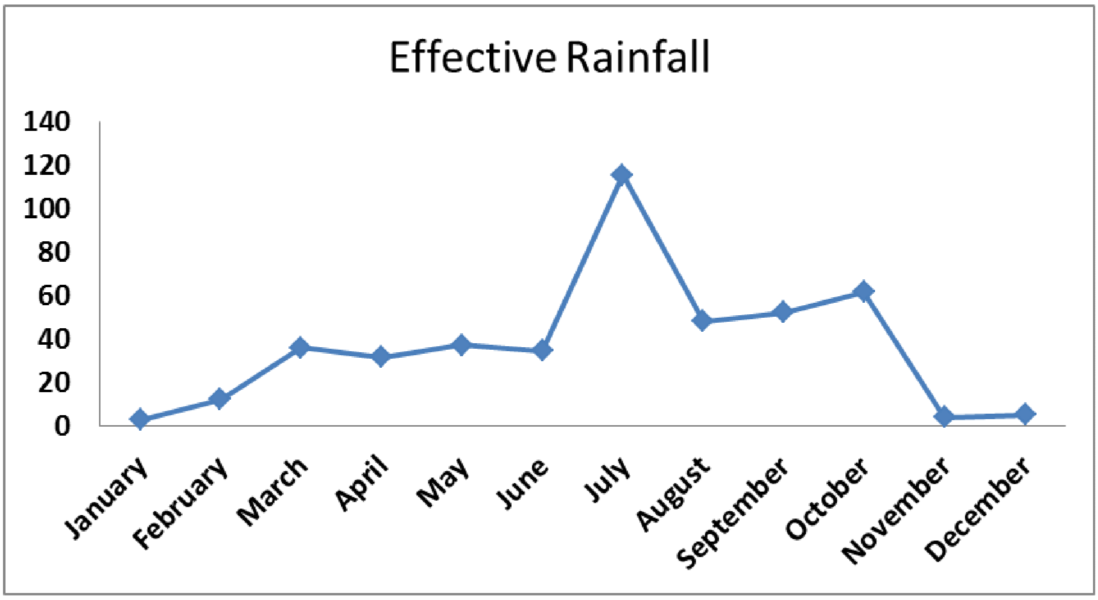

Figure 1: Effective rainfall of 2012-2013

Table.1 Climatic Data of the study area

Sunshine hours		Rain fall(mm)	Wind speed Km/day	Humidity %	maxi(F)	mini(F)
January	4	21	34	56	7	4
February	5	37	41	66	9	6
March	5	75	47	61	15	11
April	6.4	69	33	56	16	13
May	8.1	2.75	26	44	36	16
June	9	73	35	43	37	21
July	8	174	45	60	33	22
August	7.4	90	15	67	33	22
September	8	95	9.9	50	31	20
October	7.5	107	5.89	57	28	13
November	7	23	52	44	23	8
December	5	25	22	43	16	2

Flow Discharge of Tubewells

Figure 3.2 shows discharge of Tubewells in the study Area. The discharge of each Tubewell was calculated by the researcher by the formula discussed in methods and materials. The discharges of the tubewells were distinguished in to minimum and maximum on the basis of installed engine power. The minimum discharge was 0.0085 m^3/s which were calculated from shallow Tubewells while the maximum discharge was 0.019 m^3/s for deep tubewells, average discharge was 0.012975 m^3/s. Discharge of tubewells less than 0.01 m^3/s were considered low discharge, because the engine power of that tubewells were low than the one installed on deep tubewells. Deep tubewells had the capacity to provide enough water to fulfill the pumping need of high power engines, while shallow tubewells provide less water which is enough for the small land holders. The average discharges of the tube wells were enough to fulfill the requirements of the irrigation. These were the private tubewells constructed by the farmers in their own lands and they had the opportunity to irrigate their land.

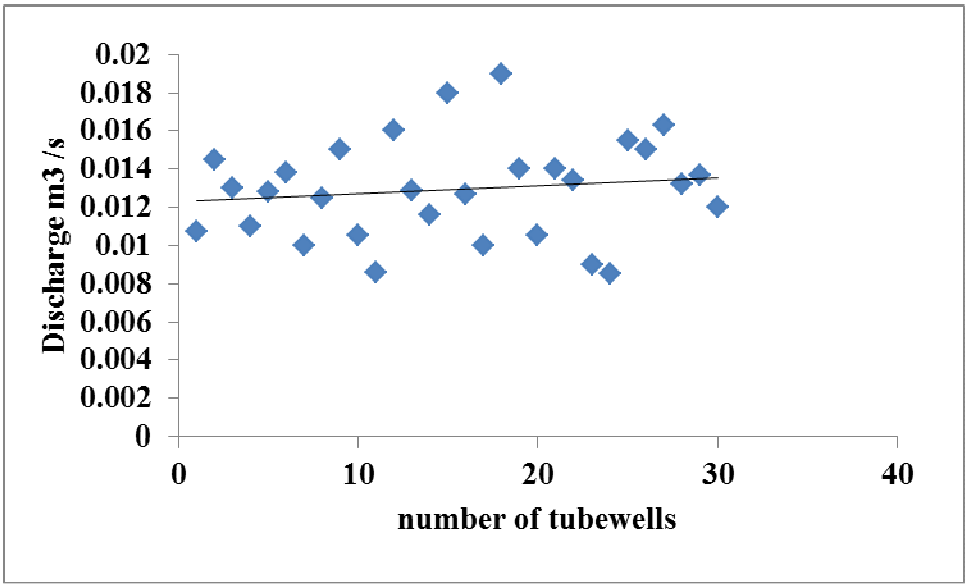

Figure 3.2: Flow discharge of Tubewells

Water productivity of Maize

Water productivity of maize crop is given in Table.2, the water productivity of maize in the study area ranged from 0.05 to 1.8 kg m^{-3} with overall average of 0.76 kg m^{-3}. It is clear from table that the overall average yield of maize crop was 4294.9 kg ha^{-1}, it ranged from 978.26 to 7500 kg ha^{-1} in the study area. The average yield is in close conformity with *Mansour et al 2011*. The average volume of applied water for maize crop in Kharif season was 202.8m^3 ha^{-1}, it ranged from 41.05 to 543 m^3 ha-^{1}.

Table.2 Water productivity of maize in the study area

Area (m2)	Discharge m3/s	Effective rainfall(mm)	Duration of irrigation(sec/jrib)	Number of irrigations	volume of water applied(m3/ha)	Yield (kg/ha)	productivity(kg/m3)
16000	0.0107	249.6	345600	4	261.6	4375	0.167
34000	0.0145	249.6	2601000	4	450	2720.59	0.050
26300	0.013	249.6	1216800	4	198.00	2851.71	0.20
8000	0.011	249.6	57600	6	87.00	7500	1.35
14000	0.0128	249.6	264600	3	167.21	3571.43	1.00
6000	0.0138	249.6	48600	4	41.06	6666.67	1.62
8000	0.01	249.6	115200	2	43.39	6250	1.44
18000	0.0125	249.6	437400	2	221.79	3888.89	0.18
18000	0.015	249.6	729000	3	345	3333.33	0.05
24000	0.0105	249.6	518400	3	234	4166.67	1.20
12000	0.0086	249.6	324000	3	125.27	5000	0.98
8000	0.016	249.6	86400	4	99	7500	1.80
6000	0.0129	249.6	48600	5	105	5833.33	1.33
46000	0.0116	249.6	1904400	8	250.00	978.26	1.00
12000	0.018	249.6	194400	3	150.9	3541.67	0.99
6000	0.0127	249.6	64800	3	105	3750	0.94
10000	0.01	249.6	225000	4	114.96	4000	0.35
8000	0.019	249.6	115200	5	100	3750	0.99
48000	0.014	249.6	6220800	3	543.00	3125	0.09
10000	0.0105	249.6	225000	2	113	4000	1.500
18000	0.014	249.6	874800	4	340.00	2500	0.30
10000	0.0134	249.6	180000	2	120	6000	1.50
20000	0.009	249.6	720000	5	300	5000	0.07
8000	0.0085	249.6	86400	5	80	6250	1.15
10000	0.0155	249.6	270000	6	276.06	3000	0.109
6000	0.015	249.6	64800	4	200	2500	1.050
14000	0.0163	249.6	352800	5	427.50	4642.86	0.11
12000	0.0132	249.6	259200	4	189.19	5000	0.264
14000	0.0137	249.6	441000	2	194.1	2857.14	0.15
Maximum					543	7500	1.800
Minimum					41.1	979	0.050
Average					202.8	4294.9	0.76

Relationship between maize water productivity and depth of irrigation applied.

Figure 3.3 shows relationship between water productivity and depth of water applied. It is clear from the graph that water productivity decreased when the depth of water applied increased. Water productivity of maize decreased from 1.8 to 0.089 kg m^{-3} when depth of water applied increased from 99mm to 543mm.Water productivity was high from 87mm to 234mm depth of applied water. Figure 3.3 clearly shows that when the depth of water applied exceeds 340 mm, it has negative effect on maize productivity. Maize is one of the major crops for the agricultural population of the district. Following an inclination line of maize production from 2004 to 2007, it is clear that Buner produces quality maize with a lower per hectare yield than that of adjacent districts. In 2006-07 it produced with a yield of 1464kg/hac *(Bureau of statistic Khyber Pakhtunkhwa 2006-2007*). The present survey shows that the yield per hectare has been increased by 2.933 times but still yield is lower than the other districts. The lower per hectare produce can be credited in large to the use of more depth of water.

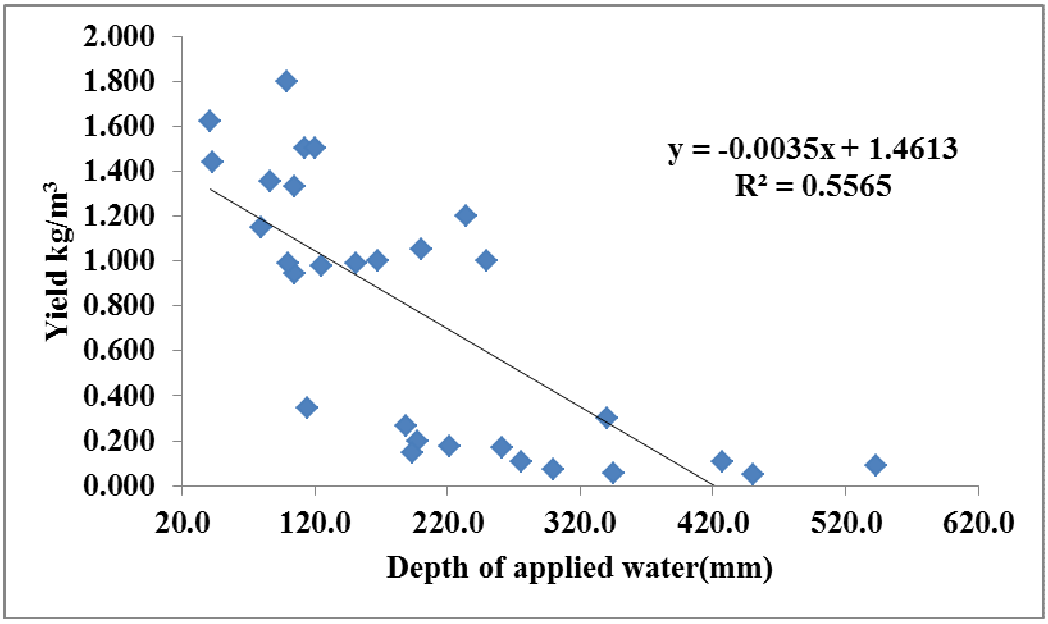

Figure 3.3Relationship between water productivity of Maize and Depth of irrigation water applied

CONCLUSIONS

It was concluded that the water productivity of maize ranged from 0.05 to 1.8kgm^{-3} with overall average of 0.76kgm$^{-3,}$ while the water productivity decreased from 1.8kgm^{-3} to 0.89kgm^{-3}when the depth of applied water increased from 99mm to 543mm. The crop water productivity increase with increase in water applied depth up to an optimal level, beyond which the CWP tend to reduce. The overall average yield of maize crop was 4294.9 kg ha^{-1}, it ranged from 978.26 to 7500 kg ha^{-1}.

These results suggest that trying to increase CWP by using deficit irrigation might be a beneficial strategy under the circumstances of this study as recommended by other researchers. For instance, Zwart and Bastiaanssen (2004) reviewed measured CWP for several crops around the world under canal irrigation system, and concluded that the CWP could be appreciably increased if irrigation was reduced and crop water deficit was deliberately induced. Control irrigation would most likely increase CWP only in situations where crops are being over-irrigated. The same is the case with tubewell irrigation system in the study area, when over irrigation is prevented the crop water productivity will boost up. The adoption of this strategy to reduce over irrigation has implications on farmer's knowledge, because the application of water to the field needs to be accurate and timely. The area is abundant of ground water and the major crops were over irrigated because of the unawareness of the local farmers about depth of irrigation water to be applied to the fields and frequency of irrigation. Irrigation management improvement with minimum applied depth of irrigation water is an important step towards the crop water productivity. Farmers' training and implementation of scientific techniques through participatory approaches in the fields of farmers could be also effective in improving water productivity in this area.

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