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Enhancing Crop Water Use Efficiency with Different Spatial Cropping Sequences and Subsequently Harvested Monetary Benefit Per Unit Rainfall Under Rainfed Conditions

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ABSTRACT

A series of field experiments was conducted to study the effect of 10 different spatio-temporal cropping sequences on water use efficiency of different crops, their suitability to locations and subsequently harvested monetary benefit per unit rainfall for the three years (2003-2006) at three different rainfall locations. The different treatments were: CS-1 was fallow-wheat based, CS-2 was maize (grain) based, CS-3, CS-7 and CS-9 were groundnut based, CS-4 was canola based, CS-5 was oats fodder based. CS-6 and CS-8 were sunflower+mungbean (intercropped) based and CS-10 was maize fodder based sequences. The water use efficiency of wheat was enhanced in fallow-wheat sequence by 8.77, 4.96 and 19.56% compared to groundnut-wheat sequence in high, medium and low rainfall locations, respectively. The water use efficiency of sunflower and mungbean decreased in wheat-(sunflower+mungbean intercropped) sequence by 271.97 and 37.47% in comparison to fallow-(sunflower+mungbean intercropped) sequence in high and medium rainfall zones, respectively. Thus water use efficiency of sunflower and mungbean in spring season was 124.85 and 144.54% higher as compared to those in summer season that might be due to favourable temperature and effective rainfall that enhanced partitioning of dry matter towards the grain filling of both the crops. The rainfall in excess of the crop water requirement lowered the water use efficiency at all locations. The economic analysis of the data revealed the highest net benefit of Rs. 34738 and monetary benefit of Rs. 39 per mm of rainfall were harvested as compared to the rest of the cropping sequences in high rainfall zone of Pothwar. Under the medium and low rainfall condition monetary benefit per unit rainfall were substantially higher in the groundnut based cropping sequences (Rs. 21–32 Rs. ha^{-1} mm^{-1}), followed by canola based ones. On the basis of consecutive three years experimentation, it is strongly recommended that the summer fallowing should be replaced with sunflower+mungbean (intercropped) in high rainfall zone and with groundnut in both medium and low rainfall zones of Pothwar Plateau in order to harvest rainfall water efficiently and accruing higher economic returns.

Key Words: Water use efficiency; WUE; Cropping sequences; Monetary benefit mm^{-1} rainfall; Rainfed zones

INTRODUCTION

In the rainfed Pothwar, which constitutes one million hectares, rainfall is the major source of water supply to crops. The rainfall orientation in this zone is regulated by south-east monsoon in summer (May-September) and by western disturbance originating over the Mediterranean Sea in winter (October-April). On the basis of climatic conditions, this zone has been divided into three categories i.e., sun-humid, semi-arid and arid areas. The average rainfall varies considerably from 1000 mm in the north-east to 250 mm in south-west part of the region. More than 70% of annual precipitation falls in the summer months (Khan *et al.,* 1998). In this zone the soil characteristics vary, depending upon the parent materials and age of the land-scape. This zone is part of the great Indo-gangetic synclinorium separated from it and elevated at the end of tertiary period. The surface soils are: loess deposits, residual mental on sandstones and shale bedrocks. In these soils, the major morphogical characteristic is Pleistocene. Soils are generally medium textured, with predominant textural classes of sandy loams, loams and sandy clay loam. The soils of this tract are low in natural fertility, deficient in nitrogen and phosphorous; however potassium level is adequate. Similarly, the soils are also low in organic matter and having pH of 7.5 to 8.5 (Ahmad *et al.,* 1990). The low soil fertility, inefficient water use practices and lack of scientific based rotations for crop water use contribute to the sub-optimal yield of crops (Safdar *et al.,* 2002). The rainfed environment for agriculture is extremely fragile and has limitations for soils, water and crop management. Despite this, the tract has enormous potential to share considerable magnitude of crop production to address the food security issue of the country.

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About 70% of cultivated Pothwar are cropped to cereals, principally wheat (Agricultural statistics of Pakistan, 2007). Summer fallowing is a common and traditional practice and about 80% of the rainfed areas are practicing fallow-wheat cropping (Razzaq *et al.,* 1990; Khan & Rizwan, 2000). The most common sequences of crops are winter-wheat-summer maize in the north and wheat or chickpea with a summer fallow in the drier south (Ahmad *et al.,* 2001; Safdar *et al.,* 2002). The net farms returns, cropping intensity, sustainable yield index and crop water harvests are low with this system (Arif & Malik, 2009).

The benefits of legumes to soil nitrogen fertility and cereals have been reported for various agricultural production systems (Toomsan *et al.,* 1995; Felton *et al.,* 1998; Schulz *et al.,* 1998; Sharar *et al.,* 2000; Ahmad *et al.,* 2001). Legumes grown in less fertile soil could improve the soil health by fixing atmospheric N and may partially supplement the use of inorganic fertilizers (Safdar *et al.,* 2005). Legume crops also support the growth of cereal crops by improving organic matter and physical characteristics of soil (Aslam & Mehmood, 2003). Sunflower by virtue of short duration, wide adoptability, photoperiod insensitivity has stabilized its area in rainfed agriculture (Reddy & Sudhakara, 2003).

Rainfall and available soil moisture are critical factors in determining the water use efficiency, crop water harvests and choice of crop. The prevalent cropping sequences do not make an efficient use of rainfall (Arif, 2009). The soil moisture conserved through the year-long fallow is sparingly enough for sowing of winter crops. If winter rainfalls fail, which often do, which limits the expected crop yield. It is therefore, necessary to bring the cropping sequences in harmony with the rainfall sequences by shifting emphasis from winter to summer crops in rainfed areas (Arif & Malik, 2009). The productivity of rainfed area could be increased by improving the yield potential of a crop as well as, by growing of more crops per unit land instead of leaving it fallow (Aslam & Mehmood, 2003). The improved cropping sequences on long term basis at field level may provide effective means for proper water harvest and its utilization to get sustainable yields of crops.

Water use efficiency acts as the indicator to check the ability of a crop to convert available water to economic yield. Increasing the efficiency of water use by crop continues to escalate as a topic of concern because of water use and improved environmental quality by human population (Safdar *et al.,* 2005). Therefore, the present study was carried out to investigate appropriate cropping sequences for efficient water use and harvested monetary benefit per unit rainfall water under rainfed conditions.

MATERIALS AND METHODS

Field experiments were conducted during six rainy seasons from 2003–2006 at the three locations i.e., Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi (AAUR), Barani Agricultural Research Institute, Chakwal (BARI) and Groundnut Research Station, Attock (GRS) representing high (> 850 mm annum^{-1}), medium (550–700 mm annum^{-1}) and low (< 550 mm annum^{-1}) rainfall conditions, respectively. The detail of the cropping sequences under study is given in Table I.

All the cropping sequences were arranged in a randomized complete block design (RCBD) using three replications. The experiment at each location comprised 30 plots. The size of plot was 10 x 6 m^2 at AAUR and GRS and 15 x 10 m^2 at BARI. CS-1 was fallow-wheat based, CS-2 was maize (grain) based, CS-3, CS-7 and CS-9 were groundnut based, CS-4 was canola based, CS-5 was oats fodder based. CS-6 and CS-8 were sunflower+mungbean (intercropped) based and CS-10 was maize fodder based treatments.

The composite soil samples were collected from each experimental site before crop sowing and were analyzed for their physical and chemical soil characteristics of the experimental sites (Table II). The meteorological data during study period is presented in Table III. The sowing and subsequently harvesting dates of different crops in different growing seasons are presented in Table IV. Fertilizer was broadcast in the form of Urea and DAP at the time of planting. Weeds were kept under control by manual weeding, when needed. The rainfall and temperature (both maximum & minimum) at all the locations were gathered from the Agrometerological Centers located at these locations to elaborate the experimental results. Using the data, water use efficiency (WUE) of each crop grown for grain purpose in different spatial cropping sequences was calculated by using the formula given by Gregory (1991).

$$WUE = \frac{e}{f - g + h}$$

Where "e" is the grain yield kg ha^{-1}, "f and g" are soil water contents (mm) measured at planting and at harvest, respectively and "h" is precipitation during crop growing season. The soil moisture was determined at 0–30 cm soil depth with the help of soil augar from summer, 2003 to Winter, 2005–2006 at the sowing and harvesting time of each crop in each cropping sequence.

The Harvested Monetary Benefit (HMB) of different cropping sequences per unit of rainfall was also worked out for efficient utilization of available rainfall water i.e., how many Rupees can be earned from one mm of rainfall by a specific cropping sequence under a specific rainfall zone of Pothwar Plateau was calculated by applying the methodology described by CIMMYT (1988) and Scott (2001) using the following formula:

$$HMB = \frac{\text{Net Return (Rs. ha}^{-1}\text{)}}{\text{Rainfall (mm)}}$$

The net returns of whole cropping sequence was calculated by summing net returns of all crops present in a cropping pattern during three years of study. Similarly, total rainfall of all seasons in a cropping sequence was summed up to find grand total rainfall in a cropping sequence.

Statistical analysis. The pooled data were subjected to variance analysis accordingly and means were compared by using LSD technique at 5% probability level (Steel & Torrie, 1980).

RESULTS AND DISCUSSION

Water use efficiency (WUE) of different crops in different cropping sequences (kg ha^{-1} mm^{-1}). Water use efficiency is the ratio of grains or biomass produced per unit water used. At AAUR site during summer 2003, sunflower and mungbean intercropping exhibited the highest water use efficiency of 6.88 and 1.10 kg ha^{-1} mm^{-1}, respectively followed by maize (1.82 kg ha^{-1} mm^{-1}) as is evident from Table V. During winter 2003–2004, the highest water use efficiency of 19.32 kg ha^{-1} mm^{-1} was exhibited by wheat, followed by canola (16.04 kg ha^{-1} mm^{-1}). During spring 2004, sunflower and mungbean intercropping showed the highest water use efficiency of 15.47 and 2.69 kg ha^{-1} mm^{-1}, respectively. The groundnut showed similar water use efficiency of 3.47–3.5 kg ha^{-1} mm^{-1} in different groundnut based cropping sequences (fallow-groundnut). Thus water use efficiency of sunflower and mungbean is 124.85 and 144.54% higher in spring as compared to those in Summer, 2003 due to more grain yield of these crops in spring, 2004 (Table IX). This is perhaps due to favourable temperature and effective rainfall in spring season (Table III) that enhanced partitioning of dry matter towards the grain filling of both the crops. During Winter 2004–2005, wheat exhibited the highest water use efficiency of 12.58 in CS-1, followed by CS-2 (11.74), CS-4 (11.30) and the lowest in CS-6 (9.69) because of growing of wheat after maize fodder in CS-6, while in CS-1, CS-2 and CS-4 wheat was grown in fallow plots in which maximum wheat grain yield was obtained (Table IX). Canola showed the lowest water use efficiency (4.11), which was also grown after maize fodder in CS-10. The water use efficiency of wheat is enhanced in fallow-wheat cropping sequence by 20.43% as compared to maize fodder-wheat sequence. In summer 2005, groundnut exhibited approximately equal water use efficiency in CS-3 and CS-7 and CS-9. Thus groundnut indicated higher water use efficiency in summer, 2004 than summer, 2005 because of 78.40% low rainfall in summer, 2004 than summer, 2005 (Table III). The sunflower and mungbean intercropping showed the highest water use efficiency of 4.16 and 0.68, respectively, followed by maize in which water use efficiency of 1.92 was recorded, respectively. The water use efficiency of sunflower decreased in wheat-(sunflower+mungbean intercropped) sequence by 271.97% in comparison to fallow-sunflower+mungbean intercropped) sequence. During winter 2005-2006, wheat exhibited the highest water use efficiency of 24.73 and 22.56 in CS-1 and CS-7, respectively and the lowest water use efficiency of 11.37 and 10.66 was recorded in canola in CS-4 and CS-9, respectively by virtue of different cropping pattern. Hence, the water use efficiency of wheat is increased in fallow-wheat sequence by 8.77% compared to groundnut-wheat sequence. Similarly water use efficiency of canola was increased in fallow-canola pattern by 9.41%, when compared to groundnut-canola sequence. Thus water use efficiency of all the winter crops was higher than all summer and spring crops because of 59.23% higher rainfall occurrence during summer season (Table III). Among winter crops, water use efficiency of wheat was the highest as compared to canola and among summer crops the

Table I. Cropping Sequences (CS) under study

Cropping Sequences	Summer 2003	Winter 2003-2004	Spring/Summer 2004	Winter 2004-2005	Summer 2005	Winter 2005-2006
CS-1	Fallow	Wheat	Fallow	Wheat	Fallow	Wheat
CS-2	Maize	Fallow	Fallow	Wheat	Maize	Fallow
CS-3	Fallow	Fallow	Groundnut	Fallow	Groundnut	Fallow
CS-4	Fallow	Canola	Fallow	Wheat	Fallow	Canola
CS-5	Fallow	Oats Fodder	Maize Fodder	Wheat	Fallow	Oats Fodder
CS-6	Sunflower+Mungbean	Fallow	Maize Fodder	Wheat	Sunflower+Mungbean	Fallow
CS-7	Fallow	Fallow	Groundnut	Fallow	Groundnut	Wheat
CS-8	Fallow	Fallow	Sunflower +Mungbean	Oats Fodder	Maize Fodder	Fallow
CS-9	Fallow	Fallow	Groundnut	Fallow	Groundnut	Canola
CS-10	Fallow	Fallow	Maize Fodder	Canola	Maize Fodder	Oats Fodder

Maize= Agati-2002, Sunflower= Parsun-2002, Mungbean= MN-92, Wheat= Chakwal-97, Oats Fodder= PD-2 LV-65, Groundnut = Chakori. All the crops were sown at recommended seed and fertilizer rates. CS-1 was fallow-wheat based, CS-2 was maize (grain) based, CS-3, CS-7 and CS-9 were groundnut based, CS-4 was canola based, CS-5 was oats fodder based. CS-6 and CS-8 were sunflower + mungbean (intercropped) based and CS-10 was maize fodder based treatments

Table II. Physical and chemical characteristics of the experimental sites (0-15 cm)

Location	Clay (%)	Silt (%)	Sand (%)	Texture	Bulk Density Mg m^{-3}	pH	EC (dS m^{-1})	Total N (%)	Available P (mg kg^{-1})	Available K (mg kg^{-1})
Rawalpindi (AAUR)	15	14	71	Sandy clay loam	1.45	7.7	0.25	0.046	3.50	131.38
Chakwal (BARI)	16.2	6	77.8	Sandy loam	1.2	8.0	0.42	0.041	3.43	129.21
Attock (GRS)	13	9	78	Sandy loam	1.1	7.03	0.23	0.031	3.00	122.73

Table III. The monthly average rainfall (mm) and temperature (°C) regime at three locations during 2003−2006

		AAUR			BARI			GRS		
Year	Months	Rainfall (mm)	Max. temp. (°C)	Min. temp. (°C)	Rainfall (mm)	Max. temp. (°C)	Min. temp. (°C)	Rainfall (mm)	Max. temp (°C)	Min. temp. (°C)
2003	Jul	185	34	28	106	39	20	95	44	18
	Aug	214	31	26	187	36	20	188	43	17
	Sep	93	30	23	71	36	24	64	39	16
	Oct	5	25	20	35	34	10	9	32	9
	Nov	17	20	11	13	30	2	3	22	11
	Dec	45	13	9	13	23	-0.7	0	15	7
2004	Jan	21	17	4	65	16	4	14	12	2
	Feb	37	22	6	19	21	4	23	16	4
	March	0	30	11	9	30	10	55	27	11
	April	92	32	17	62	33	16	8	35	18
	May	24	36	19	25	37	19	23	41	22
	June	132	36	22	126	36	22	44	42	21
	July	161	35	23	46	38	24	89	43	24
	Aug	174	33	21	169	33	23	105	37	19
	Sep	30	34	20	23	35	21	17	38	21
	Oct	67	27	12	34	28	13	60	31	17
	Nov	19	25	6	2	25	8	11	26	10
	Dec	29	20	4	30	19	4	22	19	6
2005	Jan	53	16	2	77	14	2	45	14	2
	Feb	191	16	4	145	15	5	20	16	4
	March	90	29	9	75	26	13	0	27	11
	April	12	29	12	12	29	12	75	34	15
	May	30	35	13	38	32	17	20	32	16
	June	14	45	18	51	42	29	31	34	17
	July	312	36	17	166	33	24	132	35	18
	Aug	267	35	20	93	34	23	112	39	21
	Sep	257	37	19	85	33	22	113	39	21
	Oct	54	35	8	14	31	15	14	34	23
	Nov	26	25	7	44	24	6	12	25	14
	Dec	0	21	1	0	20	-0.4	25	14	4
2006	Jan	63	18	3	42	17	14	30	13	2
	Feb	45	25	9	0	24	7	132	17	5
	March	65	26	11	60	24	10	55	30	8
	April	40	32	15	71	33	14	12	44	22

Sources: Agro meteorological Centers of AAUR, BARI and GRS

sunflower and mungbean intercropping exhibited the highest water use efficiency than maize. Thus sunflower + mungbean intercropping proved to be the best alternative cropping option for maize with respect to water use efficiency in high rainfall zone. The reduction of water use efficiency of crops in winter 2003–2004 and winter 2004–2005 as compared to winter 2005–2006 may be due to more rains received during reported period, which were more than the requirement of the crop. Findings of these experiments are in consistent to those of Upadhyay *et al.* (2000) and Manaf and Fayyaz, (2006), who reported that rainfall in excess of the crop water requirement would lower the water use efficiency. Similar results have also been reported by Frengrui *et al.* (2000), Huang and Shao (2003), Kaneko *et al.* (2004) and Sarkar and Goswami (2007).

At BARI, the sunflower and maize exhibited the same water use efficiency of 2.22 kg ha^{-1} mm^{-1}, followed by mungbean (0.88 kg ha^{-1} mm^{-1}) in summer, 2003. The water use efficiency of all the winter crops was higher than all the summer and spring crops (Table VI). For example, during winter, 2003–2004 the highest water use efficiency of 11.87 kg ha^{-1} mm^{-1} was determined in wheat, followed by canola (10.59 kg ha^{-1} mm^{-1}). During spring 2004, sunflower and mungbean intercropping showed the highest water use efficiency of 6.64 and 2.64 kg ha^{-1} mm^{-1}, respectively. The groundnut showed water use efficiency of 2.97–2.99 kg ha^{-1} mm^{-1} in different groundnut based cropping sequences. During winter 2004–2005, a water use efficiency of 10.45–11.72 kg ha^{-1} mm^{-1} was recorded in wheat with different cropping sequences. The lowest water use efficiency of 4.24 kg ha^{-1} mm^{-1} was found in canola. The highest water use efficiency of 5.13 kg ha^{-1} mm^{-1} was determined in maize, followed by sunflower and mungbean intercropping. The groundnut showed a water use efficiency of 4.09–4.16 kg ha^{-1} mm^{-1} in different rotations during Summer, 2005 and was higher than spring/summer, 2004 under the medium rainfall. A water use efficiency of 28.00–29.14 kg ha^{-1} mm^{-1} was monitored in wheat, while canola showed a range of 13.98 to 15.32 kg ha^{-1} mm^{-1} during winter, 2005–2006 by virtue of different growing sequences. Thus maize or groundnut may replace sunflower and mungbean intercropping at medium rainfall zone in terms of water use efficiency.

Higher water use efficiency of 2.36 kg ha^{-1} mm^{-1} was observed in maize and was followed by mungbean (1.26 kg ha^{-1} mm^{-1}) in summer, 2003 under low rainfall conditions of

Table IV. The sowing and harvesting of different crops in six different growing seasons at three locations during 2003-06

	UAAR		BARI		GRS	
Crop	Sowing date	Harvesting date	Sowing date	Harvesting date	Sowing date	Harvesting date
Maize(grain) Summer 2003	17-7-2003	30-9-2003	13-7-2003	4-10-2003	8-7-2003	20-10-2003
Sunflower Summer 2003	17-7-2003	30-9-2003	13-7-2003	28-9-2003	8-7-2003	26-9-2003
Mungbean Summer 2003	17-7-2003	30-9-2003	13-7-2003	28-9-2003	8-7-2003	26-9-2003
Wheat Winter 2003-2004	31-10-2003	17-4-2004	22-10-2003	15-4-2004	3-11-2003	24-4-2004
Canola Winter 2003-2004	31-10-2003	30-3-2004	22-10-2003	5-4-2003	3-11-2003	4-4-2004
Oats fodder Winter 2003-2004	31-10-2003	5-3-2004	22-10-2003	27-2-2004	3-11-2003	14-3-2004
Groundnut spring 2004	27-4-2004	26-10-2004	4-5-2004	4-11-2004	26-3-2004	26-9-2004
Maize fodder spring 2004	27-3-2004	12-6-2004	13-3-2004	28-5-2004	6-3-2004	21-5-2004
Sunflower spring 2004	12-3-2004	27-6-2004	7-3-2004	22-6-2004	8-7-2003	26-9-2003
Mungbean spring 2004	12-3-2004	27-6-2004	7-3-2004	22-6-2004	8-7-2003	26-9-2003
Wheat Winter 2004-2005	29-10-2004	13-4-2005	6-11-2004	16-4-2005	3-11-2004	18-4-2005
Canola Winter 2004-2005	31-10-2004	17-4-2005	6-11-2004	16-4-2005	3-11-2004	24-4-2005
Oats fodder Winter 2004-2005	31-10-2004	14-3-2005	6-11-2004	20-3-2005	3-11-2004	26-3-2005
Groundnut Summer 2005	15-4-2005	15-10-2005	20-4-2005	16-10-2005	17-4-2005	17-10-2005
Sunflower Summer 2005	13-7-2005	15-10-2005	16-7-2005	16-10-2005	4-8-2005	5-11-2005
Mungbean Summer2005	13-7-2005	15-10-2005	16-7-2005	16-10-2005	4-8-2005	5-11-2005
Maize(grain) Summer 2005	13-7-2005	15-10-2005	16-7-2005	16-10-2005	4-8-2005	10-11-2005
Maize fodder Summer 2005	13-7-2005	30-9-2005	16-7-2005	3-10-2005	4-8-2005	26-10-2005
Wheat Winter 2005-2006	2-11-2005	30-4-2006	4-11-2005	22-4-2006	1-11-2005	21-4-2006
Canola Winter 2005-2006	2-11-2005	19-4-2006	4-11-2005	22-4-2006	1-11-2005	15-4-2006
Oats fodder Winter 2005-2006	2-11-2005	12-3-2006	4-11-2005	15-3-2006	1-11-2005	10-3-2006

Table V. Water use efficiency of crops (kg ha^{-1} mm^{-1}) in ten cropping sequences at AAUR during different years

Cropping sequences	Summer 2003	Winter 2003-2004	Spring/Summer 2004	Winter 2004-2005	Summer 2005	Winter 2005-2006
CS-1	Fallow-	Wheat (19.32)	Fallow-	Wheat (12.58)	Fallow-	Wheat (24.73)
CS-2	Maize (1.82)	Fallow-	Fallow-	Wheat (11.74)	Maize (1.92)	Fallow-
CS-3	Fallow-	Fallow-	Groundnut (3.47)	Fallow-	Groundnut (2.08)	Fallow-
CS-4	Fallow-	Canola (16.04)	Fallow-	Wheat (11.30)	Fallow-	Canola (11.37)
CS-5	Fallow-	Oats Fodder-	Maize Fodder-	Wheat (10.01)	Fallow-	Oats Fodder-
CS-6	Sunflower (6.88) + Mungbean (1.10)	Fallow-	Maize Fodder-	Wheat (9.69)	Sunflower (4.16) + Mungbean (0.68)	Fallow-
CS-7	Fallow-	Fallow-	Groundnut (3.47)	Fallow-	Groundnut (2.07)	Wheat (22.56)
CS-8	Fallow-	Fallow-	Sunflower (15.47) + Mungbean (2.69)	Oats Fodder-	Maize Fodder-	Fallow-
CS-9	Fallow-	Fallow-	Groundnut (3.51)	Fallow-	Groundnut (2.08)	Canola (10.66)
CS-10	Fallow-	Fallow-	Maize Fodder-	Canola (4.11)	Maize Fodder-	Oats Fodder-

Water Use Efficiency of different crops is given in parentheses

Table VI. Water use efficiency of crops (kg ha^{-1} mm^{-1}) in ten cropping sequences at BARI during different years

Cropping sequences	Summer 2003	Winter 2003-2004	Spring /Summer 2004	Winter 2004-2005	Summer 2005	Winter 2005-2006
CS-1	Fallow-	Wheat (11.87)	Fallow-	Wheat (11.49)	Fallow-	Wheat (29.46)
CS-2	Maize (2.22)	Fallow-	Fallow-	Wheat (11.09)	Maize (5.13)	Fallow-
CS-3	Fallow-	Fallow-	Groundnut (2.97)	Fallow-	Groundnut (4.16)	Fallow-
CS-4	Fallow-	Canola (10.59)	Fallow-	Wheat (10.16)	Fallow-	Canola (15.32)
CS-5	Fallow-	Oats Fodder-	Maize Fodder-	Wheat (10.45)	Fallow-	Oats Fodder-
CS-6	Sunflower(2.22) + Mungbean (0.88)	Fallow-	Maize Fodder-	Wheat (11.72)	Sunflower (4.83) + Mungbean (1.38)	Fallow-
CS-7	Fallow-	Fallow-	Groundnut (2.98)	Fallow-	Groundnut (4.15)	Wheat (28.00)
CS-8	Fallow-	Fallow-	Sunflower (6.64) + Mungbean(2.64)	Oats Fodder-	Maize Fodder-	Fallow-
CS-9	Fallow-	Fallow-	Groundnut (2.99)	Fallow-	Groundnut (4.09)	Canola (13.98)
CS-10	Fallow-	Fallow-	Maize Fodder-	Canola (4.24)	Maize Fodder-	Oats Fodder-

Water Use Efficiency of different crops is given in parentheses

Pothwar (Table VII). The mungbean acted as sole crop due to failure of sunflower germination. Therefore, mungbean utilized all available nutrients and moisture of soil and gave good yields, thus it exhibited the higher water use efficiency in summer, 2003 as compared to other locations. Thus mungbean based cropping pattern was found feasible in low rainfall zone of Pothwar tract instead of intercropping it with sunflower. Therefore, sunflower based cropping pattern may not be adopted by the farmers in low rainfall zone of Pothwar tract.

During winter 2003–2004, the highest water use efficiency of 16.97 kg ha^{-1} mm^{-1} was determined in wheat,

Table VII. Water use efficiency of crops (kg ha^{-1} mm^{-1}) in ten cropping sequences at GRS during different years

Cropping sequences	Summer 2003	Winter 2003-2004	Spring/Summer 2004	Winter 2004-2005	Summer 2005	Winter 2005-2006
CS-1	Fallow-	Wheat (16.97)	Fallow-	Wheat (17.71)	Fallow-	Wheat (15.74)
CS-2	Maize (2.36)	Fallow-	Fallow-	Wheat (17.78)	Maize (2.63)	Fallow-
CS-3	Fallow-	Fallow-	Groundnut (3.76)	Fallow-	Groundnut (3.76)	Fallow-
CS-4	Fallow-	Canola (15.99)	Fallow-	Wheat (16.29)	Fallow-	Canola (6.31)
CS-5	Fallow-	Oats Fodder-	Maize Fodder-	Wheat (18.46)	Fallow-	Oats Fodder-
CS-6	Sunflower (-) + Mungbean (1.26)	Fallow-	Maize Fodder-	Wheat (13.77)	Sunflower (-) + Mungbean (1.69)	Fallow-
CS-7	Fallow-	Fallow-	Groundnut (3.65)	Fallow-	Groundnut (3.32)	Wheat (12.66)
CS-8	Fallow-	Fallow-	Sunflower (-) + Mungbean (2.56)	Oats Fodder-	Maize Fodder-	Fallow-
CS-9	Fallow-	Fallow-	Groundnut (3.71)	Fallow-	Groundnut (3.37)	Canola (6.08)
CS-10	Fallow-	Fallow-	Maize Fodder-	Canola (6.67)	Maize Fodder-	Oats Fodder-

Water Use Efficiency of different crops is given in parentheses

Table VIII. Harvested Monetary Benefit (HMB) of different cropping sequences (Rs. ha^{-1}mm^{-1}) at the three experimental sites

	AAUR		BARI		GRS	
Cropping Sequences	Net benefits (Rs. ha^{-1})	HMB (Rs. ha^{-1}mm^{-1})	Net benefits (Rs. ha^{-1})	HMB (Rs. ha^{-1}mm^{-1})	Net benefit (Rs. ha^{-1})	HMB (Rs. ha^{-1}mm^{-1})
CS-1	30283	39a	17992	27b	18016	33a
CS-2	12289	14d	11046	16e	6084	11b
CS-3	15101	17d	14274	21d	9828	18b
CS-4	26182	30b	18442	27b	17016	31a
CS-5	22120	25c	14765	22c	10356	19b
CS-6	34738	39a	14742	22c	1583	3c
CS-7	25297	29b	20765	31a	17824	32a
CS-8	26951	30b	18510	28b	3237	6c
CS-9	22772	26c	19904	30a	16142	29a
CS-10	17380	20d	13009	19d	6357	11b

*Any two means not sharing a letter in common in a column differ significantly at 5% probability level
LSD (0.05) for AAUR = 8.5669 LSD (0.05) for BARI= 4.1375 LSD (0.05)

followed by 15.99 kg ha^{-1} mm^{-1} in canola. During spring 2004, groundnut showed water use efficiency of 3.65–3.71 kg ha^{-1} mm^{-1} in different cropping sequences in which groundnut was a base crop. Thus groundnut based cropping sequences were more efficient in terms of water use efficiency. The mungbean showed water use efficiency of 2.56 kg ha^{-1} mm^{-1}. Again sunflower did not germinate and mungbean was grown as sole crop as in summer, 2003. During winter 2004-2005, wheat exhibited the highest water use efficiency of 16.29 to 18.46 kg ha^{-1} mm^{-1} in different wheat based sequences, which was about three times higher than that of canola (6.67 kg ha^{-1} mm^{-1}). The groundnut showed approximately equal water use efficiency in summer 2005 (3.32–3.76 kg ha^{-1} mm^{-1}) and spring, 2004 at GRS site. The maize exhibited the water use efficiency of 2.63 kg ha^{-1} mm^{-1} followed by mungbean (1.69). During winter 2005–2006, wheat exhibited the highest water use efficiency ranging from 12.66 to 15.74 kg ha^{-1} mm^{-1}, which was approximately two times higher than canola (6.08–6.31 kg ha^{-1} mm^{-1}). Among winter crops, water use efficiency of wheat was 2–3 times higher than canola under low rainfall conditions of Pothwar Plateau. The sunflower and maize based cropping sequences are the poorest in rainfall water harvesting and should not be practiced by the farming community in low rainfall areas of Pothwar tract. Thus, in low rainfall zone the summer fallowing may be replaced by groundnut for efficient rainfall water utilization and enhance water use efficiency.

The locations differed form one another for water use efficiency. The higher water use efficiency was not specific to one location for all the crops. The results showed that the crops have varied suitability for the locations. The high rainfall location is much better the medium and low rainfall zones. This may be due to the differences in soil characteristics and soil texture of the location.

Harvested monetary benefit (HMB) per unit rainfall by different cropping sequences (Rs. ha^{-1} mm^{-1}). The highest net benefit of Rs. 34738, Rs. 30283 was determined in CS-6 and CS-1, respectively, which was followed by groundnut based cropping pattern i.e., CP-7 under high rainfall zone, while they were the lowest for CS-2 (Table VIII). Thus, CS-6 and CS-1 proved to be the best cropping sequences that harvested Rs. 39 per mm of rainfall as compared to the rest of the cropping sequences (Table VIII) over three years of study and followed by CS-4 and CS-8 under high rainfall conditions. The CS-2 showed minimum HMB of 14.00 Rs. ha^{-1} mm^{-1}. Arif and Malik (2009) reported 45.62% higher marginal rate of return (MRR) of sunflower+mungbean (intercropped) based cropping patterns in comparison to groundnut based treatments in high rainfall zone of Pothwar tract. It is evident from economic analysis, if farmers in high rainfall zone of Rawalpindi do not leave their land fallow during summer, then they may replace it with

Table IX. Average grain yield/fodder yield of crops in different cropping patterns at the three locations (kg ha^{-1}) during 2003-2006

Crops	AAUR	BARI	GRS
Wheat Winter 2003-2004 (CS-1)	4166.67	2268.00	1904.00
Wheat Winter 2004-2005 (CS-1)	4848.00	4059.0	3272.67
Wheat Winter 2005-2006 (CS-1)	4487.00	3150.00	4163.33
Maize Summer 2003 (CS-2)	957.09	904.12	849.27
Wheat Winter 2004-2005 (CS-2)	4418.00	3904.00	3190.00
Maize Summer 2005 (CS-2)	1731.14	1876.27	934.97
Groundnut spring 2004 (CS-3)	1458.67	1284.00	1235.33
Groundnut Summer 2005 (CS-3)	1903.83	1917.27	1414.69
Canola Winter 2003-2004 (CS-4)	2212.72	1668.67	1687.67
Wheat Winter 2004-2005 (CS-4)	4380.33	3560.33	2951.92
Canola Winter 2005-2006 (CS-4)	2005.77	1615.47	1664.74
Fodder oats Winter 2003-2004 (CS-5)	43097.67	54500.00	25756.00
Maize fodder spring 2004 (CS-5)	14028.67	3755.33	3308.33
Wheat Winter 2004-2005 (CS-5)	4020.44	3620.67	3370.00
Fodder oats Winter 2005-2006 (CS-5)	52076.67	15943.33	33866.67
Sunflower Summer 2003 (CS-6)	3636.00	890.33	-
Mungbean Summer 2003 (CS-6)	582.00	350.67	447.00
Maize fodder spring 2004 (CS-6)	15606.33	8721.33	5978.67
Wheat Winter 2004-2005 (CS-6)	3930.00	4120.00	2461.67
Sunflower Summer 2005 (CS-6)	3693.04	1739.63	-
Mungbean Summer 2005 (CS-6)	610.35	495.90	594.58
Groundnut spring 2004 (CS-7)	1460.41	1286.28	1237.18
Groundnut Summer 2005 (CS-7)	1905.73	1918.91	1416.64
Wheat Winter 2005-2006 (CS-7)	4037.00	2946.00	3387.00
Sunflower spring 2004 (CS-8)	3692.67	1431.00	-
Mungbean spring 2004 (CS-8)	641.96	568.63	587.32
Fodder oats Winter 2004-2005 (CS-8)	77613.67	65466.67	43453.33
Maize fodder Summer 2005 (CS-8)	29501.67	32783.39	9456.47
Groundnut spring 2004 (CS-9)	1464.98	1290.70	1240.93
Groundnut Summer 2005 (CS-9)	1908.00	1921.86	1423.59
Canola Winter 2005-2006 (CS-9)	1859.01	1498.08	1606.81
Maize fodder spring 2004 (CS-10)	17194.67	10618.00	8868.67
Canola Winter 2004-2005 (CS-10)	1640.00	1487.33	1157.00
Maize fodder Summer 2005 (CS-10)	20093.00	29322.04	8380.94
Fodder oats Winter 2003-2004 (CS-10)	42934.00	13738.33	31594.67

- No seed germination took place

sunflower+mungbean intercropping. Similar results have been reported by the several researchers (Watkins & Tesdale, 1999; William, 2002; Aslam & Mehmood, 2003; Andrew, 2006).

Under the medium rainfall zone, the groundnut based cropping sequences (CS-7 & CS-9) were more efficient in utilizing rainfall than the rest of the cropping sequences, followed by CS-8 (Rs. 28 ha^{-1} mm^{-1}). The CS-1 and CS-4 showed similar monetary benefit of Rs. 27 Rs. ha^{-1} mm^{-1}. The least rainfall water harvested monetary benefit of Rs. 16 ha^{-1} mm^{-1} was found in CS-2 (Table VIII). The economic analysis of the data revealed that the farmers in medium rainfall zone may replace their fallow land preferably with groundnut in terms of net benefits.

In low rainfall zone of Pothwar, CS-1 (fallow-wheat) and groundnut based cropping sequences proved to be the most efficient in terms of harvested monetary expression per unit rainfall water utilization (Rs. 29–33 ha^{-1} mm^{-1}). The CS-8 and CS-6 can not be adopted due to very poor performance in terms of monetary benefit and efficient utilization of rainfall (Table VIII).

Aslam (1995) showed that net benefits per unit rainfall and MRR were the highest in legume based cropping systems than non-legumes based ones. Drinkwater *et al.* (2000) reported that improved cropping patterns with higher cropping intensity preserved more organic matter, reduced run-off and harvested more economic returns. Gadgil *et al.* (2002) reported that introduction of groundnut based cropping patterns in India provided higher benefit cost ratio and appreciable net returns and they cited that cropping patterns are location specific keeping in view its soil and climatic conditions. Reddy and Sudhakara (2003) found the highest sustainable yield index (44.20%) and net returns of Rs. 17756 in case of groundnut based cropping sequences than other non-legume based treatments.

CONCLUSION

The cropping sequences, where summer fallowing was replaced with sunflower+mungbean (intercropped) or with groundnut were more efficient in crop water use efficiency, harvesting and utilization of rain water and more remunerative than those where summer fallowing is practiced. It is recommended that the summer fallowing should be replaced with sunflower+mungbean (intercropped) in high rainfall zone and with groundnut in both medium and low rainfall zones of Pothwar Plateau in order to harvest rainfall water efficiently and accruing higher economic returns. This study will have overall positive effect on rainfed agriculture, where rainfall harvesting is the prerequisite for sustainable crop productivity.

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