Increasing Water-Use Efficiency in Sloping Areas of Tajikistan and Uzbekistan.

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ABSTRACT

Low water-use efficiency and soil erosion are the main constraints to improved agricultural production in the sloping areas of Tajikistan and Uzbekistan. The soil degradation could be arrested by introducing water-saving and soil conservation technologies such as *strip cropping, supplemental irrigation, mulching*, and *contour irrigation*. During 2000-2002, these technologies were studied at different agroecological conditions of the region. Strip cropping and mulching was tested in semi-humid zone at Faizabad site,

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Tajikistan. The objective of this research was to assess the of influence of strip cropping on combating of soil erosion. Using sloping areas for growing of wheat has resulted in increased soil erosion by 50% compared to natural grasses. Supplemental irrigation and different mulches were practised to grow trees on terraces in semi-arid zone at Fakhrabad site, Tajikistan.

Under these conditions, supplemental irrigation and mulching with plant residues increased soil moisture contents and survival rate of the trees during the dry season. Applying furrow irrigation to winter wheat on sloping areas in the semi-arid conditions resulted in soil fertility reduction. At the same time, contour and *joyak* (zigzag furrows) irrigation tested at Boikozon site, Uzbekistan, almost completely controlled soil erosion at the sloping area, increased winter wheat yield by 2.0-3.6 t ha^{-1} and water use efficiency by 30% comparing to the traditional practice. These three experimental sites are agroecologically representative of large sloping areas of the region.

INTRODUCTION

Sloping land areas are widespread in Tajikistan, Kyrgyzstan, and Uzbekistan, and less so in Kazakhstan and Turkmenistan. These areas have better water supply compared to lowlands. At the same time, the soils are more vulnerable and liable to degradation caused by poor rainfed farming and irrigation practices. Depending on the amount of precipitation, the area is divided into sub-humid and semi-arid zones. Precipitation, exceeding 600 mm in the sub-humid zone, causes significant surface runoff and soil erosion. Water erosion is most prevalent and causes the greatest soil loss; however wind erosion is serious in several areas.

Strip cropping in combination with crop rotation was tested in these conditions to protect soil. In the semi-arid zone, precipitation is in the range of 300-500 mm. Periodic water shortage is the limiting factor for rainfed farming in the zone and requires effective soil moisture maintaining practices such as terracing, narrow strips, mulching, and supplementary water supply. Traditional furrow irrigation in the semi-arid zone is entailed with significant surface runoff and widespread soil erosion. Surface runoff from sloping areas under irrigation reaches 5,000 m^3 ha^{-1} and soil erosion exceeds 5 ton ha^{-1}. The farming system in sloping areas is poorly developed due to low mechanization and lack of fertilizer.

Another constraint is low efficiency of irrigation water use caused by non-uniform soil moisture distribution along the slopes. Testing of contour and joyak (zigzag) furrows in the semi-arid zone revealed water saving technologies in these areas could improve water productivity and reduce soil erosion. Advances in water conservation and water-use efficiency can promote reduced erosion and increasing agricultural production at the sloping areas.

METHODOLOGY

The Study Areas

The Faizabad site is located in the rainfed area of Tajikistan's foothill zone, with an altitude of about 1200 m above the sea level. Landscape is mainly hilly and slope gradients vary from 8 to 40%. Climate is acute continental, with high summer temperatures and uneven distribution of precipitation throughout the year. Annual average temperature is 12.1 ^oC, with lowest temperature occurring in January (0.3 ^oC) and highest in July (25.5 ^oC). Annual precipitation is in the range of 750-850 mm, mainly occurring in the winter and spring.

The soil was moderately eroded, brown carbonate, heavy loam, with total contents of nitrogen 0.08-0.21%; $CaCO_3$, 15-18%; and field capacity, 22%. Originally, brown soils have a 30-35 cm thin layer with organic matter content between 3-5%; however, due to soil erosion, organic matter content in this region is in the range of 1.0-1.6%. Soil bulk density is 1.09 g cm^{-3} in the 0-10 cm layer and 1.41 g cm^{-3} in the 10-40 cm layer.

The Fakhrabad site is located in Rasulev Farm of Gozimalik district in Tajikistan at 950 m above the sea level. The hillside has a slope of 12-25%. Soil is a moderately eroded dark sierozem, heavy silt loam, with organic matter content below 0.9%, and soil bulk density around 1.30-1.45 g cm^{-3}. In Tajikistan, dark Sierozems occupy 750,000 ha of land, almost 90% of them being eroded.

This is a semi-arid rainfed zone with average annual precipitation around 500 mm. Most of the precipitation falls during winter and spring with low intensity. This results in soil moisture shortage in the summer. Average monthly temperature in January is 1.5^o C and in July 23-26^o C. Duration of the vegetation period is up to 210 days. The sum of effective temperatures reaches 4000^o C, which is sufficient to grow early varieties of grapevines, apples, apricots, melons, and cereals.

Boykozon farm is located in Tashkent province of Uzbekistan at 525 m above the sea level. The area is predominantly hilly. The climate is extremely continental with average annual temperature of 14.3^o C. Mean annual precipitation is about 500 mm. The soil is typical sierozem, mainly moderate and heavy loam, with low and medium nutrient content; field moisture capacity is 20-22%. Organic matter content is 1.1-1.5% in the topsoil. The soil infiltration rate is 0.2-0.6 mm min^{-1}.

Installation and Sampling

Strip Cropping

A study on effect of strip cropping on surface runoff, soil erosion, and fertility was carried out at the Faizabad experimental site in 2000-2002. Treatments were as follows:

- Winter wheat (sown in blocks),
- Chickpea (top) - sainfoin (bottom) strips,
- Alfalfa (top)-wheat (bottom) strips,
- Alfalfa,
- Fallow, and,
- Winter wheat (top) and alfalfa (bottom) strips. Treatments were replicated three times on 200 m^3 (20 x 10 m) plot area with 14-21% slope. Flow and soil erosion measurements were taken during the rainy season, mainly in April and May.

Mulching and Supplemental Irrigation

The experiment was laid out at Fakhrabad site, Tajikistan, in 2001 to grow grapevines, forest and fruit trees on terraces with the following mulching treatments:

- Control,
- Mulching with black plastic film,
- White thick film,
- White thin film,
- White thin film and N,
- Plant residues.

The following species were planted on the terraces: cherry and plum saplings with winter wheat as an inter-crop; grapevines in two rows; walnut saplings; and pine trees. Mulching was applied over the saplings on a 50 x 50- cm area. Supplemental irrigation for walnut and pine tree saplings was applied at a rate of 3 liter per sapling twice a month from July to October. The experiment was laid out in three replications. In 2002, an experiment was laid out with the plum and walnut saplings with the following treatments:

- Suplemental irrigation (SI) alone,
- SI and mulching (hay),
- SI, mulching (hay) and manure,
- Control (no mulching, no SI).

Mulching was applied under trees on a 50 x 50-cm area around saplings. Starting from July 2002, supplemental irrigation was practised three times in a month in the afternoon, with 3 liters of water applied each time to the plum and walnut saplings.

Improved Furrow Irrigation Technology

The following irrigation technologies were tested at the sloping site of Boykozon farm in Uzbekistan,

- Joyak (zigzag) furrow irrigation,
- Contour irrigation,
- Traditional irrigation along the slope (control),
- Traditional irrigation with application of 48 kg ha^{-1} polymer K-9. These technologies were tested for application of supplemental irrigation of winter wheat during 2000-2002. Joyaks are zigzag furrows cut across the slope. The furrows' depth was 20-22 cm.

During the 1999-2000 and 2001-2002 seasons, the widths of the horizontal section of the zigzag were: 2.0, 2.5, and 3.0 m. Zigzag furrows of 1.4 and 2.8 m wide were tested in the 2000-2001 season. Contour irrigation was tested during 2001-2002 season only. Soil moisture was monitored in the root zone during the crop season to determine the irrigation requirement.

RESULTS

Strip Cropping in Sub-Humid Zone

The strip cropping significantly reduced surface runoff and soil erosion in the slopes (Fig. 1). The highest runoff and soil erosion in the spring was observed from wheat crop grown in blocks. Runoff and soil erosion reached 277 m^3 ha^{-1} and 4,444 kg ha^{-1}, respectively. Application of strips, i.e., chickpea (top) and grasses (bottom), or alfalfa (top) and wheat (bottom), reduced runoff and soil erosion by 25% and 10%, respectively. The strip fallow or wheat (top) and grasses (bottom) reduced surface runoff and soil erosion by 50% and 30%, respectively. Runoff and soil erosion under alfalfa was 36% and 46% less than wheat.

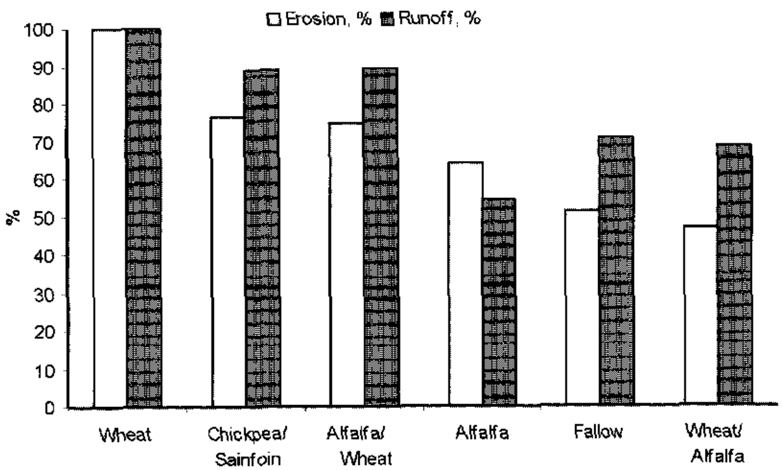

Fig. 1. Runoff and soil erosion under different cropping at the Faizabad site (average for 2000-2002).

The low content of mobile nutrients was another limiting factor for crop yields. Data during 2001 revealed that in early spring there was low nitrogen availability in the 0-50-cm soil layer under wheat sown in blocks (61 kg ha^{-1}) and high under strip sowing (135 kg ha^{-1}). In the comparatively wet 2002, the N content amounted to 55 kg ha^{-1} under alfalfa, 69 kg ha^{-1} under strip cropping, and 166 kg ha^{-1} under fallow, which indicated that under fallow, organic N decomposes and is not used because of the absence of vegetation. At the end of the growing season, there was more mineral N under strip sowing compared to block sowing.

There was low content of P and moderate level of K in the soil. Reduction of mobile P and K content during May was observed in all treatments. During the wet spring of 2002, P and K availability was higher. Under all cropping systems, mobile P reduced by the end of the growing season by about 15%. As to exchangeable K, there was no significant change during the season.

Crop yields were dependent on weather and farming practice. In dry period of 2000, yield of food legumes (chickpea) was low (0.44-0.48 t ha^{-1}). Strip cropping affected the winter wheat yield positively (Table 1).

Table 1. Crop yields in moderately eroded brown carbonate soil as affected by strip cropping.

Treatments	2000	2001	2002	Average
	----------	----------	t ha^{-1} ----------	----------
Winter wheat (block sowing)	0.72	0.84	1.25	1.04
Chickpea/ sainfoin[1]	-	0.73	0.85	0.79
Alfalfa/ winter wheat[2]	-	1.02	1.55	1.28
Alfalfa in first year	2.77	2.88	3.57	3.22
Alfalfa in second year	-	6.43	11.35	8.89
Winter wheat/alfalfa[2]	-	0.92	1.39	1.15

[1] yield of sainfoin; [2] yield of winter wheat

Winter wheat yield was rather low in 2002, even with good rainfall. Planting wheat in strips with alfalfa is improved yield by 11-23%. Higher wheat yield occurred on strips placed down the slope because of more moisture available. Alfalfa yield was good, increasing almost threefold in the second year. Sainfoin was unsuitable forage legume compared to alfalfa. Low content of organic matter and nutrients was the main reason for low crop yields. The results of this study indicated that strip cropping in the sub-humid zone could be efficient method to reduce soil erosion, prevent reduction of soil fertility and increase yield of different crops.

Soil Moisture Content Under Mulches

Under control without mulching, around grapevines saplings, the soil moisture storage on 20 July amounted to 20% of the initial storage on 27 April (Fig. 2). Soil moisture storage was 70%, 30%, 10%, and 5% higher as compared to control when soil was mulched with black plastic film, plant residues, white thick plastic, and white thin plastic, respectively. Mulching with black film and plant residues provided considerable water saving compared to control, which amounted to 700 and 300 m3/ha, respectively. Although soil moisture storage was higher under black film, plant residues proved to be more economical.

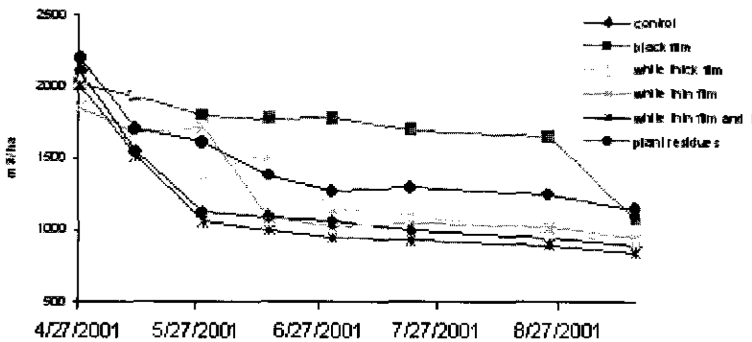

Fig. 2. Soil moisture storages under grapevines as affected by different mulches.

Spring of 2001 season was very dry. Soil moisture storage in the beginning of July fell below 50% of the field capacity. Therefore, to prevent the withering of saplings, supplemental irrigation was applied to walnut and pine tree saplings at the rate of 3 liter per sapling, twice a month from July to October. It improved soil moisture and, as a result, survival rate of saplings was increased (Table 2).

Table 2. Survival rate of walnut saplings as affected by different mulches and supplemental irrigation.

Mulches	Total saplings	July		October	
		Soil moisture	Survival	Soil moisture	Survival
	No.	$m^3 ha^{-1}$	%	$m^3 ha^{-1}$	%
Control	17	1090	43	580	32
Plant residues	30	1180	66	830	60
White thin plastic film	30	1260	71	880	65
Black plastic film	30	1390	86	840	70

Data obtained during July 2001 before supplemental irrigation indicated that soil moisture storage using mulching with plant residues and white and black plastic films were higher by 8, 16 and 27% as compared to the control (no mulching), respectively. As a result, survival rate of walnut saplings increased by 53, 65 and 100% compared to the control, respectively. By the end of vegetative growth in October 2001, soil moisture storage was 43-52% higher with mulching and supplemental irrigation compared to the control. The survival rate of the irrigated walnut saplings with plant residues, white and black plastic films was 88, 103 and 118% higher, respectively, than at the control.

The observations in 2002 indicated that starting from May, the influence of the mulches became obvious, especially in the topsoil. During May-July, the difference in soil moisture storage in the 0-50 cm soil layer was considerable among the three treatments. When mulching was combined with irrigation, soil moisture content at the 0-50 cm and 50-100 cm layers was greater compared to irrigation alone by 569 and 993 m^3 ha^{-1}, respectively. This difference almost disappeared by August. Manure saved additional 40-241 m^3 ha^{-1} of soil moisture in the 0-50 cm soil layer. Irrigation in combination with mulches and manure provided the minimum required soil moisture for growing tree saplings and also increased their survival rate.

Due to poor survival of saplings in dry season of 2001, withered saplings were replanted in March, 2002. During the summer of 2002, all saplings received irrigation except the control. By 1 August, 2002 the survival rate of the saplings of plums, grapevines, walnuts and oleaster received irrigation exceeded 92%.

Joyak and Contour Irrigation Technology

The first two of the three study years were dry for winter wheat production. Precipitation was 380 and 345 mm during 1999-2000 and 2000-2001, respectively. Three irrigations were applied with the rate of 1,200-1,300 m^3 ha^{-1} each. The data revealed that traditional irrigation along the slopes resulted in significant losses of water and fertile soil (Table 3).

Surface runoff was 28% of water applied under traditional irrigation. Water-use efficiency was 20% higher under rainfed conditions compared to traditional furrow irrigation. Application of 2 to 3-m wide joyaks resulted in 14-15% of water saving for irrigation due to reduced surface runoff. Yield of winter wheat increased by 40-45% compared to the control. Moreover, the efficient water-use index increased by 51-55% compared to the control. Soil erosion was reduced by more than five times under joyak irrigation. Results of the 2000-2001 season indicated that the 1.4 m joyak spacing was much less suitable compared to the 2.8 m spacing. During the year 2001-2002, 592 mm of precipitation was recorded. Hence, irrigation was required only in the beginning of June (Table 4).

Table 3. Efficient water use index in winter wheat (1999-2000, 2000-2001 seasons).

Parameter	Rainfed	Control	Joyak furrow irrigation, m 2.0	2.5	3.0	1.4	2.8
Yield, t ha^{-1}	1.94	3.04	5.10	4.80	4.71	3.54	4.65
Precipitation, m^3 ha^{-1}	3800	3800	3800	3800	3800	3450	3450
Irrigation, m^3 ha^{-1}	0	3695	3343	3559	3442	3055	2900
EWU, kg m^{-3}	0.51	0.41	0.71	0.65	0.65	0.54	0.73
Soil erosion, t ha^{-1}	-	5.88	0.72	0.63	0.66	0.33	0.25
LSD5% = 0.6 t ha^{-1}							

[1] These treatments were tested only in 2000-2001, [2] EWU= Efficient Water Use index.

Table 4. Efficient water use index in winter wheat during 2001-2002 season.

Parameter	Rainfed	Control	Joyak furrow irrigation, m 2.0	2.5	3.0	Contour irrigation
Yield, t ha^{-1}	3.23	4.99	5.68	6.07	6.27	6.05
Precipitation, m^3 ha^{-1}	5920	5920	5920	5920	5920	5920
Irrigation, m^3 ha^{-1}	0	1186	1135	1050	1038	1028
EWU1, kg m^{-3}	0.55	0.70	0.81	0.87	0.90	0.87
Soil erosion, t ha^{-1}	-	1.20	0.08	0.04	0.02	0.10
LSD5% = 0.32 t ha^{-1}						

[1]EWU= Efficient Water Use index.

The joyak and contour irrigation technologies increased the yield of winter wheat by almost 20-25%, compared to the control. Efficient water use index was increased by 24-29%. Heavy rainfalls resulted in significant surface runoff in the area. That is why the efficient water- use index was lower under rainfed conditions compared to the control. Remarkably, soil losses due to erosion were reduced from 1.2 t ha^{-1} for the control to 0.02-0.08 t ha^{-1} under joyaks and to 0.10 t ha^{-1} under contour furrows. Thus, irrigation by joyak and contour furrows almost completely controlled the soil erosion.

The joyak irrigation technology greatly reduced the losses of fertile soil layer. The soil moisture profile was uniform over the entire furrow. Irrigation continued without tail water, and water use efficiency was increased. Irrigation during the night also became easier. Absence of mechanisms for making joyaks appears to be major limiting factor for wide adoption of this technology. Two-meter-wide joyaks were found optimal in the dry 1999-2000 season and the 3.0-m joyak in the wet 2001-2002 season. This may be a consequence of making joyaks manually, 20 cm deep, in the 1999-2000 season and with a tractor, 25-27 cm deep, during the following years.

Portable 1.5m-long chutes were designed to improve uniformity of jets into contour furrows in sloping areas. Adjustable outlets allowed optimization of jet discharge to each furrow in accordance with the slope. The maximum discharge of the portable chute was 7.5 liter/sec. With a closed outlet, the portable chutes were used for transit water delivery to lower tiers of the irrigated plot. If necessary, portable chute kits can be assembled of any required length. Water was delivered into the chute every 50 m with flexible hoses.

During the whole trial period no breakdowns or failures of PCh-50 were registered. The following advantages of PCh-50 were noted: *simple design; reliable performance;* and *uniform supply* and *savings* of irrigation water. The portable chutes allowed farmers to easily organize their irrigation schedule. The set installation time was short (30 min) and did not require any special skills. The replacement of parts can be done without special devices.

Economic Assessment

Expenses for purchasing seeds and fertilizers amounted to US$ 75 ha^{-1} using the traditional practice and US$ 133 ha^{-1} using polymer K-9. The cost of polymer K-9 was equal to 36% of the input cost. Expenses related to growing winter wheat using joyak and contour irrigation included the cost of portable chutes and additional labor work to make joyaks.

The data obtained indicated that the share of inputs in the total cost of production ranged from 39% for 2-m wide joyak to 69% for traditional irrigation with the polymer application. Labor cost varied from 6% for polymer use to 31-35% for joyak technology, which was very labor costly. The research revealed that wide dissemination of the joyak technology is dependent on mechanization of the process of making joyaks. Combination of conservation soil tillage practices, supplemental irrigation and joyak technology can promote adoption of this technology by farmers in the region, it does, however, require on-farm testing.

In general, there was no significant increase in the net profit due to contour or joyak furrow irrigation compared to traditional furrow irrigation. In spite of the fact that these technologies increased yield of winter wheat by about 1.0 ha^{-1} and that the irrigation rate was reduced by 14-15%, farmers' net profit increased only by US$ 11-24 ha^{-1}. This is because of the low State procurement price for wheat and free water supply that significantly reduced advantages of joyak and contour irrigation. More than half of the wheat grain produced was bought by the State for half of the market price. Obviously, therefore, the farmers had no apparent benefits from water saving under existing water and agricultural policy. Reduced losses of fertile topsoil caused by erosion under joyak and contour irrigation are likely to have a positive long-term effect. However, farmers had little interest in soil fertility management due to existing land tenure system.

SUMMARY

Following testing in the sloping areas of Tajikistan and Uzbekistan, various water-saving technologies could improve water-use efficiency and reduce soil erosion in sloping areas of Central Asia. The results of the research activities support the following conclusions:

1. Strip cropping of wheat and alfalfa along the slopes could reduce runoff and erosion under sub-humid conditions.
2. Use of plant residues for soil mulching could be an economical preposition to maintain soil moisture storages under young fruit trees in semi-arid rainfed conditions. However, supplemental irrigation may still be needed in summer to improve survival rates of the saplings.
3. Joyak (zigzag) furrow irrigation can improve yield and water-use efficiency and reduce soil erosion in sloping areas, but would require considerable manual operations. At the same time, irrigation by less labor intensive contour furrows with designed portable plastic chutes will provide the water and soil conservation effect.
4. Wide on-farm dissemination of the water-saving technologies in irrigated areas is restrained by some institutional constraints. Existing state procurement system and free water delivery in Uzbekistan are significantly reducing the possibilities of adoption of water-saving technologies. Farmers have limited interest in soil fertility conservation in both rainfed and irrigated areas, especially when they do not have land ownership rights.