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Hard Red Winter Wheat Production on Conservation Bench Terraces

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ABSTRACT

Conservation bench terraces were cropped to winter wheat (*Triticum aestivum* L.) in both annual and summer fallow cropping systems. Leveled benches did not support annual cropping of winter wheat. In 2 of 4 years, available water in the surface 30 cm of soil at planting time had to average at least 3.3 cm for successful wheat establishment, and yields were 21% less than the fallowed contributing areas.

Summer fallowing benches increased the amount of available soil water 1.7 times at planting and resulted in 18% greater wheat grain yields compared to yields on the fallowed contributing areas. Leveling, with or without runoff contribution, significantly increased available soil water and winter wheat yields. Lengths of contributing area did not significantly influence depth of runoff in the benches. During the course of this study, there was never enough runoff to completely inundate the leveled benches.

Regression analysis of grain yield and water data predicted a maximum yield of 2,800 kg/ha with 69 cm of available water. This amount was available in only one year of the study with summer fallow and zero years with continuous cropping. Since the level benches were never inundated and the water supply for maximum yield was seldom attained, conservation bench terraces with ratios of contributing area to level-bench area of 3:1 were effective for controlling erosion in the semiarid region of the west-central Great Plains.

Additional Index Words: **soil water storage, runoff, land forming, *Triticum aestivum* L.**

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CONSERVATION bench terraces were initially developed and tested in 1955 at Bushland, Tex. (13).[3] They were designed to control erosion and increase water storage and efficient use of stored water. The concept employs a leveled bench constructed on the contour with a terrace ridge built on the lower side of the bench to retain runoff from the contributing area. Degree of slope and soil type determine the width of the bench.

Research on the use of bench terraces has been conducted at Mandan, N. Dak. (7, 10), Akron, Colo. (11), Gillette, Wyo. (12), Hays, Kans. (3), and Sidney, Mont. (1). Results have shown that the terrace systems increase crop yields by utilizing the runoff and/or snowmelt that was intercepted and stored in the level bench. At Bushland, Tex. (8, 9), conservation bench terraces were found to be more profitable than the conventional graded-ridge terraces.

Since water is the most limiting resource for optimum crop production in the Great Plains region, the widespread practice of summer fallowing that produces a crop every other year was developed to assure production of adapted dryland crops (6). However, conservation bench terraces have afforded a means of increasing water supplies to grow crops annually on the leveled bench. Continuous grain sorghum has been successfully grown on level benches at Hays, Kans., Bushland, Tex., and Akron, Colo. (3, 8, 11). Alfalfa (*Medicago sativa* L.) and wheatgrass (*Agropyron* spp.) production was increased in bench terraces at both Mandan, N. Dak., and Gillette, Wyo. (7, 12). Bench terraces at Sidney, Mont., and Mandan, N. Dak., increased spring wheat yield but had little effect on corn grain yields at Mandan, N. Dak., due to changes in soil properties associated with land forming.

Construction costs of conservation bench terraces are three to four times higher than for conventional ridge terraces because the land is leveled and a greater volume of earth is moved (4). With increased water supplies from the stored runoff, annual production of spring-planted crops is possible (1, 7, 10). This practice utilizes the stored water more effectively, and greater returns on the investment are obtainable over a shorter period of time. However, in most areas of the Great Plains, farmers summer fallow rather than annually crop their bench terraces to winter wheat to assure establishment and save time and money. This paper reports the results of research on both annual and summer-fallowed winter wheat on conservation bench terraces in the west-central part of the Great Plains region near Akron, Colo.

METHODS

The layout of the conservation bench terrace system at Akron, Colo., was described in detail by Mickelson in 1968 (11). Benches were constructed 30.5 m in width on 1% sloping Rago silt loam (a fine, montmorillonitic, mesic Pachic Argiustoll) soils. The benched area was subdivided into eight bench plots each 30.5 m in length with earthern berms 30.5 cm in height on each end. The contributing area above each bench in a set of four was varied in length by 30.5-m increments, from 0 to 91.4 m, to obtain ratios of contributing area to level-bench area of 0:1, 1:1, 2:1, and 3:1. The entire bench area was annually cropped to small grains from 1967 through 1970. The contributing area was established in a crop–fallow rotation with one-half of it in winter wheat and one-half in fallow. Therefore, one set of four benches had fallowed contributing areas while the other set of four benches had cropped contributing areas each year throughout the lifetime of the experiment. Principle objectives were to evaluate the effect of length of fallowed and cropped contributing areas on runoff and water–yield relationships.

Oats (*Avena* spp.) was planted in spring of 1966 on the entire bench area and on the contributing area that was summer-fallowed the previous year. Following the oat harvest of 1966, winter wheat was planted on the benches and the fallowed contributing areas in September of 1967, 1968, 1969, and 1970. The leveled benches were mold-board plowed each year shortly following harvest and kept weed-free during 6 to 8 weeks before winter wheat planting. Plowing this time of year may have contributed to drying out of soil and poor establishment of fall-planted winter wheat, particularly during periods of low rainfall. The contributing areas were stubble-mulch tilled with V-blades once or twice

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[3] Numbers in parenthesis refer to appended literature citations.

Table 1—Mean annual depth of runoff from winter wheat and fallow contributing areas of 30.5, 61.0, and 91.4 m in length and in the level bench.

Years	Contributing areas	Depth of runoff, cm — Slope length, m: 30.5	61.0	91.4	Mean	Water loss† %
		Depth from contributing areas				
1967–1970‡	Fallow	5.0 b*	2.0 a	1.6 a	2.3	6.4
	Wheat	4.2 b	2.8 a	2.5 a	2.9	8.0
1971–1978§	Fallow	3.4 b	1.6 a	1.3 a	1.8	4.9
	Wheat	3.2 b	2.2 a	2.0 a	2.3	6.3
		Depth in level benches				
1967–1970‡	Fallow	5.0 a	4.0 b	4.8 b	4.6	–
	Wheat	4.2 a	5.6 a	7.4 a	5.8	–
1971–1978§	Fallow	3.4 a	3.2 a	4.0 a	3.5	–
	Wheat	3.2 a	4.4 ab	6.1 b	4.6	–

* Means within rows not followed by same letter are significantly different at 0.05 level according to *F* test.
† Percent of annual precipitation on the contributing areas that was lost in runoff.
‡ Years of annual cropping in the bench.
§ Years of crop–fallow in the bench.

in the fall after wheat harvest and two to four times the following year with either a V-blade or a rod weeder to control weeds. The winter wheat was planted at 34 kg/ha with a deep-furrow drill in 35.6-cm rows. Wheat on the contributing area was sown on the contour.

In the fall of 1967 and 1969 when winter wheat establishment failed in the benches because of dry soil conditions, oats was planted the following spring to maintain annual cropping of small grains in the bench.

Summer fallowing of the benches was started in the spring of 1970 when the set of four benches with wheat contributing areas was fallowed rather than planted to oats. The set of fallowed benches cropped to winter wheat had fallow contributing areas so the crop would benefit from the greater volumes of runoff expected from contributing areas in fallow. Having one-half of the bench area in fallow with cropped contributing areas and the other one-half of bench area in winter wheat with fallow contributing areas, yield and water data were obtained every year.

The winter wheat was not fertilized during the first 5 years of the project. Beginning in 1972 and each year thereafter except for 1973, when field conditions were too wet, one-half of the wheat crop was fertilized with 33.6 kg N/ha in the spring after winter dormancy. In 1977 and 1978 the fertilized portion of the area was divided with 33.6 kg of N applied on one-half of the fallow area in July or August before wheat planting, and 33.6 kg of N applied on the other one-half in spring as before. The amounts applied were those recommended from earlier fertility research on these soils

Table 2—Soil water storage at end of fallow as influenced by runoff and length of fallow period.

Variable	Runoff, cm†	Soil water storage, cm	Storage efficiency, %‡
14-month fallow (1971–1978)			
Benches with contributing area	4.5	13.5	33.2
Benches without contributing area	0.0	12.2	30.0
Contributing area	−1.8	10.5	25.8
2-month fallow (1967–1970)			
Benches with contributing area	1.5	4.6	54.1

† From 40.7 and 8.5 cm of precipitation on 14- and 2-month fallows, respectively.
‡ Percentage of the fallow period precipitation that was stored in a 180-cm profile.

(2). All nitrogen was broadcast as NH_4NO_3 on the soil surface. The remaining wheat crop was never fertilized.

Soil water was determined gravimetrically from samples taken at 30-cm increments to a depth of 180 cm at planting and harvest times. Four sample sites were located 7.7 m from plot borders in the level benches and every 30.5 m upslope through the middle of fertilized and unfertilized portions of the contributing areas. Harvest areas for grain yield corresponded with sites used to measure available soil water.

Runoff from each contributing area was measured with 46-cm, H-type flumes and FW-1 recorders. Growing season precipitation was measured by a weighing recording rain gauge located in the experimental area.

RESULTS

Precipitation and Runoff

Annual precipitation for the 12-year period (1967–1978) averaged 36.0 cm, about 5.5 cm below the long-term mean. Eighty percent of the annual precipitation and all the runoff occurred during the 6-month period beginning 1 April. The period of most active growth for winter wheat and 55% of the total annual runoff occurred from April through June.

Mean annual runoff is summarized in Table 1 for both the fallow and winter wheat contributing areas. The runoff is reported in terms of depth from each contributing area and depth impounded in the respective benches. Mean depth of runoff from the contributing areas is the total volume divided by the total area, while the runoff in the benches was either one, two, or three times the runoff from the contributing depending upon its length.

Annual runoff from the wheat contributing areas averaged 2.59 cm, 27% greater than that from the fallow contributing areas. Drying of surface soil associated with periodic tillage and maintenance of wheat residues on the soil surface during fallow increased water intake and storage and retarded runoff. In growing wheat, the soil surface compacted with time by raindrop impact; this tended to reduce intake and accelerate runoff. The differences were not significant in the years from 1967 to 1970 but were significant in years of crop–fallow in the benches (1971 to 1978). The wheat contributing areas lost 6.3 to 8.0% of the precipitation as runoff, while the fallowed contributing areas lost 4.9 to 6.4%.

Depth of surface runoff from the contributing areas decreased with increasing length of slope. The difference in depth of runoff between the 30.5-m slope and either the 61.0- or 91.4-m slopes was significant for both the wheat and fallow contributing areas. The runoff was not significantly different between the 61.0- and 91.4-m slopes. The rate of decrease diminished with increasing length of slope. The relationship conforms best to a power law equation. For six data points, this equation was $Y = 107.38\ X^{-0.97}$ for an r^2 value of 0.881 for the fallow contributing areas and $Y = 17.63\ X^{-0.46}$ for an r^2 value of 0.738 on the wheat contributing areas. As the size of a contributing area of uniform slope and cover increases, so does the area for infiltration of the precipitation falling on it.

Depth of runoff in level benches increased with increasing length of slope for wheat contributing areas, but not for fallow contributing areas (Table 1). The difference, however, was significant only for wheat on fallowed benches. Benches under annual cropping received 4.6 cm from fallow and 5.8 cm from wheat contributing areas. When benches were in crop–fallow rotation, the wheat in benches received 3.5 cm annually from fallow contributing areas while the fallow benches received 4.6 cm in runoff from the wheat contributing areas. Wheat in benches could have benefited more from runoff had the contributing areas also been in wheat. Regression analysis of rainfall's effect on runoff was made for a total of 50 runoff events. The regression equations for rainfall–runoff relationship for the fallow and winter wheat contributing areas is as follows:

fallow contributing areas:

$$Y = 0.46\,X - 0.78;\ r = 0.843^{**},\text{ and}$$

wheat contributing areas:

$$Y = 0.55\,X - 0.93;\ r = 0.860^{**},$$

where Y = runoff in cm, and X = rainfall in cm. For either contributing area the threshold rainfall was 1.68 cm before runoff occurred. However, runoff per increment of rainfall after the first 1.68 cm of rain was greater from the wheat-contributing areas than from fallow-contributing areas. More than 70% of the variation in runoff was attributed to rainfall.

Soil Water Storage

Soil water storage is the net change in water content occurring within a specified depth of soil and time period. The amount of water stored in the soil profile is related to length of fallow period and time of year that the storage takes place. The time period for storage in a 180-cm profile is only 6 to 8 weeks for continuous winter wheat from harvest in early July until planting in early September. During the period 1967–1970, water stored in annually cropped level benches averaged 4.6 cm from 8.5 cm of rainfall and 1.5 cm of runoff during July and August (2-month fallow) when evaporation losses were high (Table 2). About 55% of this storage occurred in the top 61 cm of the profile. Soil water storage for the wheat–fallow cropping system during the 14-month fallow period was almost 3 times that for the 2-month fallow period but fallow efficiency dropped from 54 to 33%.

During the 14-month fallow period for winter wheat, soil water storage in benches receiving runoff was 13.5 cm, which was 1.3 cm more than the level bench without the contributing area (Table 2). The increase in soil water storage was attributed to the 4.5 cm of runoff that occurred from the wheat contributing areas during the 14-month fallow period. Water stored in bench soils without contributing areas was 16% greater than water stored in the fallowed slopes.

The distribution of stored water in the soil profile by wheat planting time is illustrated in Fig. 1. Approximately 70% of the total water storage in leveled benches occurred in the top 91 cm. Storage in benches with contributing areas was 0.2 cm more per 30 cm throughout the 180-cm depth than that in benches without contributing areas. On contributing areas, 80% of the total water storage occurred in the top 91 cm of soil profile, and storage was significantly less at lower depths and nonexistent at the 1.8-m depth on the sloping contributing areas after 14 months of fallow. Leveling not only increased total soil water storage, but promoted deeper water penetration.

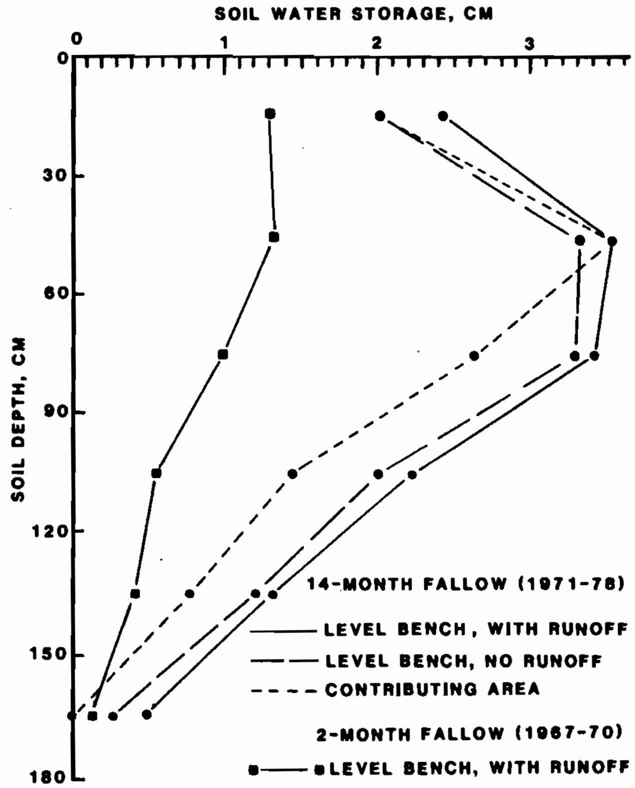

Fig. 1—Eight- and four-year averages for distribution of soil water storage as influenced by leveling and runoff from the contributing area.

Growing Season Water Supplies

Available soil water at seeding time in a 180-cm soil profile on annually cropped benches was not influenced by runoff because the potential for runoff to occur is diminished in July and August (Table 3). On fallowed benches, the increased soil water content was attributed more to runoff prevention rather than runoff contribution. In 5 of the 8 years, the bench that received no runoff had the highest soil water content at seeding. Runoff from contributing areas was infiltrating into the bench at the base of the watershed and the sampling technique employed did not reflect this. With continuous wheat, the benches averaged 12.5 cm available soil water at seeding time, 33% less than that on the contributing area after 14 months of fallow. The available soil water in the benches was not adequate to establish a crop every year under annual cropping. The amount of soil water in the surface 30 cm determined whether or not a crop was successfully established. In 2 of 4 years the surface 30 cm varied from 0.1 to 3.0 cm for an average of 1.3 cm available soil water. In years of successful crop establishment, the surface 30 cm varied from 2.4 to 4.1 cm and averaged 3.3 cm available soil water. When winter wheat was not established, the benches remained fallow until the following spring when available soil water in the top 30 cm averaged 3.3 cm which

Table 3—Available soil water at planting for winter wheat and spring oats produced on leveled benches and contributing areas.

		Available soil water in 180 cm at planting, cm				
		Contri-buting	Ratio of contributing-to-level bench area			
Year	Bench crop	area†	0:1	1:1	2:1	3:1
1968	Oats	21.6 a*	19.0 a	18.6 a	16.5 a	17.0 a
1970	Oats	11.9 a	12.1 a	10.6 a	12.6 a	12.3 a
2-year mean		16.7 a	15.6 a	14.6 a	14.6 a	14.7 a
1967	"Continuous" wheat	17.8 b	10.6 a	9.1 a	10.2 a	10.4 a
1969	"Continuous" wheat	19.4 a	16.7 a	14.7 a	13.1 a	15.0 a
2-year mean		18.6 b	13.6 a	11.9 a	11.7 a	12.7 a
1971	Fallowed wheat	17.9 a	26.0 b	22.8 b	23.9 b	23.7 b
1972	Fallowed wheat	15.0 ab	16.1 b	11.5 ab	9.2 a	12.0 ab
1973	Fallowed wheat	12.1 a	21.5 b	18.7 b	21.7 b	22.3 b
1974	Fallowed wheat	23.3 a	27.1 b	27.9 b	25.6 b	26.9 b
1975	Fallowed wheat	12.4 a	23.4 b	22.4 b	22.8 b	21.4 b
1976	Fallowed wheat	15.8 a	17.2 a	19.4 a	18.1 a	18.3 a
1977	Fallowed wheat	10.8 a	25.0 c	22.1 bc	22.7 bc	21.5 b
1978	Fallowed wheat	17.5 a	22.2 b	20.8 ab	19.7 ab	19.1 ab
8-year mean		15.6 a	22.3 b	20.7 b	20.5 b	20.7 b

* Means within years not followed by same letter are significantly different at 0.05 level according to *F* test.
† Always cropped to winter wheat after fallow.

was adequate for satisfactory establishment of an oat crop.

In 1971, the leveled benches were started in a wheat–fallow rotation which extended the period for soil water recharge to 14 months rather than the 2 months for annual winter wheat. After 14 months of fallow, the level benches averaged 21.0 cm available soil water, 35% more than that on the contributing area for the same period and almost 70% more than had been obtained on the level benches under annual cropping.

Total available growing season water was about the same for wheat in an annual cropping system and fallowed wheat in the level benches (Table 4). In an annual cropping system, level benches did not significantly increase total available water compared to that in the contributing area. When the benches were fallowed, the total available water averaged 21.6% or 9.2 cm more than that in the contributing areas.

Benches with contributing areas received from 2.5 to 3.2 cm of runoff annually which represented about 6% of the total water supply available for plant consumption. Length of contributing area significantly affected runoff only in 1967 and 1973 (Table 4).

The presence or absence of a contributing area did not have a significant effect on total available water for annual cropping in level benches. Significantly more total available water was found in the bench areas than the contributing areas when both were fallowed. With annual cropping, benching did not increase total available water except when significant runoff occurred in 1967.

Table 4—Total growing season water available for winter wheat and spring oats produced on leveled benches and contributing areas.

		Total available growing season water, cm†				
		Contri-buting	Ratio of contributing to level bench area			
Year	Bench crop	area§	0:1	1:1	2:1	3:1
1968	Oats	38.6 a*	36.0 a	35.7 a	33.5 a	34.0 a
1970	Oats	44.0 a	45.1 a	46.7 a	46.8 a	46.5 a
2-year mean		41.3 a	40.6 a	41.2 a	40.2 a	40.3 a
1967	"Continuous" wheat	61.1 a	60.6 a	68.9 b	71.4 c	75.0 d
1969	"Continuous" wheat	41.3 a	39.4 a	39.3 a	36.9 a	39.0 a
2-year mean		51.2 a	50.0 a	54.1 a	54.2 a	57.0 a
1971	Fallowed wheat	47.6 a	55.7 b	54.0 b	53.6 b	53.4 b
1972	Fallowed wheat	39.2 a	41.4 ab	42.6 ab	42.4 ab	47.0 b
1973	Fallowed wheat	45.2 a	60.8 b	65.2 c	70.3 d	73.2 d
1974	Fallowed wheat	47.5 a	51.3 b	52.1 b	49.8 b	51.1 b
1975	Fallowed wheat	46.8 a	59.3 b	60.6 b	60.3 b	58.6 b
1976	Fallowed wheat	36.4 a	38.0 a	41.0 b	39.0 a	39.1 a
1977	Fallowed wheat	38.7 a	55.5 b	56.4 b	56.8 b	56.3 b
1978	Fallowed wheat	38.2 a	43.0 b	41.6 ab	40.5 ab	39.9 ab
8-year mean		42.4 a	50.6 b	51.7 b	51.6 b	52.3 b

* Means within years not followed by same letter are significantly different at 0.05 level according to *F* test.
† Available soil water at planting plus growing season precipitation and plus or minus runoff.
§ Always cropped to winter wheat after fallow.

Crop Yields

Grain yields are summarized in Table 5. Annual wheat grain yields averaged 16.6 and 4.0% less than the average yields on fallowed benches and contributing areas, respectively. When oats were grown in years following winter wheat failure, two-year small grain production was 1.1 to 1.3 times greater than on summer fallow. Nevertheless, the annual yields of either crop were substantially less than the average regional yields on fallowed lands.

Bench leveling increased grain yield of wheat when summer fallowed. Benches without a contributing area produced 18.6% more grain than did the contributing areas, while benches with contributing areas increased yields 22.3%. Grain yield increases in benches were attributed more to improved soil water storage rather than runoff since the volume of runoff in benches was not significantly different in all but 2 years.

Length of contributing area did not significantly increase depth of runoff in the benches; therefore, wheat

Table 5—Grain yields of winter wheat and oats in an annual cropping system and for fallowed winter wheat in level benches and contributing areas.

		Grain yield, kg/ha†				
	Bench	Contri-buting	Ratio of contributing to level bench area			
Year	crop	area‡	0:1	1:1	2:1	3:1
1968	Oats	1,917 b*	926 a	1,049 a	773 a	920 a
1970	Oats	2,468 b	535 a	789 a	464 a	510 a
2-year mean		2,193 b	731 a	919 a	619 a	715 a
1967	Wheat	2,376 c	1,873 ab	1,768 a	1,950 ab	2,058 b
1969	Wheat	2,507 a	1,995 a	1,890 a	1,963 a	2,084 a
2-year mean		2,442 c	1,934 ab	1,829 a	1,957 ab	2,071 b
1971	Wheat§	1,660 a	2,774 b	1,980 a	2,658 b	2,122 a
1972	Wheat	1,967 a	1,511 ab	1,754 ab	1,290 b	1,693 ab
1973	Wheat	1,473 a	2,138 b	2,377 bc	2,700 c	2,522 bc
1974	Wheat	2,188 a	1,914 a	2,625 b	2,208 a	2,241 a
1975	Wheat	2,558 a	3,241 a	3,287 a	3,546 a	3,273 a
1976	Wheat	2,057 a	1,959 a	2,294 a	2,099 a	2,371 a
1977	Wheat	1,414 a	2,654 b	2,657 b	2,958 b	2,696 b
1978	Wheat	2,074 ab	2,064 b	1,738 ab	1,436 a	1,946 ab
8-year mean		1,924 a	2,282 a	2,339 a	2,362 a	2,358 a

* Means within years not followed by same letter are significantly different at the 0.05 level according to *F* test.
† Grain yield reported at 12.5% moisture content.
‡ Always cropped to winter wheat after fallow.
§ Wheat on fallowed level benches.

production was essentially the same on benches regardless of ratio of contributing-to-bench area.

Crop–Water Relationships

Relationship between total available growing season water and winter wheat grain yields on level benches is shown in Fig. 2. A second-degree polynomial equation was fitted to the data, and 48% of the variation in wheat grain yield was associated with total growing season water available. Nonuniform distribution of runoff water within the leveled benches was a factor in reducing the correlation coefficient. Annual runoff on benches cropped to wheat averaged 3.2 to 4.0 cm. Runoff from any given storm event was never enough to completely inundate a 30.5-m wide bench. Consequently, the upper part or cut side of the bench received more water than the lower or fill side of the bench. The runoff flowed laterally in either direction from the flume along the wheat rows, but was never great enough to flow across the rows over an entire bench.

The yield curve in Fig. 2 predicted that maximum yield of wheat in the benches would occur at about 69 cm of total available water. This amount of available water was obtained only in 1973 when runoff onto the benches averaged 9.1 cm and rainfall was almost twice the normal amount for May alone. The mean total available water in the benches tended to increase with increased ratio of contributing-to-benches area, though not significantly. In 4 of the 12 years, the increases were significant. The greatest, average, available growing season water, 52.3 cm, was obtained from the 3:1 ratio, but it was considerably below the 69-cm amount predicted for maximum yield. Thus, the spacing of conservation bench terraces on 1% slopes could conceivably be greater for fallowed winter wheat than the 3:1 ratio used in this experiment.

The amount of available soil water at planting time on the cut side was consistently higher than on the fill side of the bench (Table 6). These differences were significantly greater with summer fallow than with annual cropping. Grain yields also were consistently higher on the cut side of the bench with the exception of 1973 and 1975 when the rainfall in May was nearly twice the normal amounts, and runoff, limited to the cut side of the bench, may have been excessive enough to retard plant development and reduce yields. An October 1969 snowstorm left significant deposits

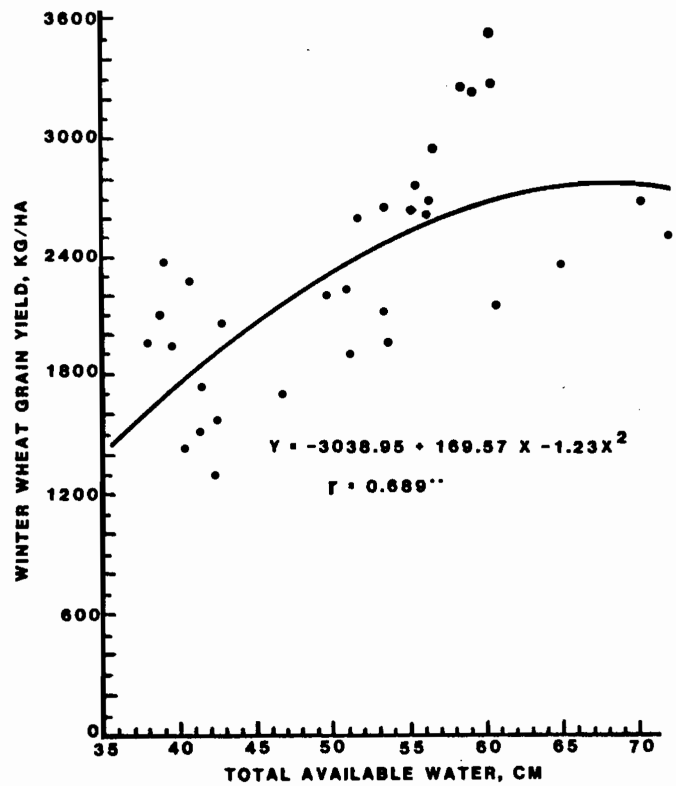

Fig. 2—Regression of winter wheat grain yield on total water available during the growing season.

Table 6—Effect of water distribution in level benches on available soil water (ASM) in 180 cm at planting time and grain yield of winter wheat and oats.

Year	Bench crop‡	ASM at planting, cm		Grain yiled, kg/ha†	
		Fill	Cut	Fill	Cut
1968	Oats	17.0 a*	18.5 a	769 a	1,065 a
1970	Oats	11.7 a	12.0 a	614 a	535 a
2-year mean		14.4 a	15.3 a	692 a	800 a
1967	Wheat	9.5 a	10.6 a	1,761 a	2,063 a
1969	Wheat	13.7 a	16.1 a	1,668 a	2,298 a
2-year mean		11.6 a	13.3 a	1,714 a	2,180 a
1971	Wheat§	21.4 a	26.8 b	2,226 a	2,479 a
1972	Wheat	11.0 a	13.4 a	1,439 a	1,685 a
1973	Wheat	18.9 a	23.2 a	2,524 a	2,327 a
1974	Wheat	26.8 a	27.0 a	1,968 a	2,527 b
1975	Wheat	21.1 a	23.9 b	3,675 a	2,998 a
1976	Wheat	16.9 a	19.6 a	2,038 a	2,324 a
1977	Wheat	20.8 a	24.8 b	2,728 a	2,754 a
1978	Wheat	17.5 a	23.4 b	1,381 a	2,211 b
8-year mean		19.3 a	22.8 b	2,250 a	2,413 a

* Means within years not followed by same letter are significantly different at the 0.05 level according to F test.
† Grain yield reported at 12.5% moisture content.
‡ Always cropped to winter wheat after fallow.
§ Wheat planted on fallowed level benches.

Table 7—Oats and winter wheat water-use efficiencies in an annual cropping system and for fallowed winter wheat in leveled benches and contributing areas.

Year	Bench crop	Water-use efficiency,† kg ha⁻¹·cm⁻¹				
		Contributing area	Ratio of contributing to level bench area			
			0:1	1:1	2:1	3:1
1968	Oats	54.3 b*	29.0 a	34.4 a	25.9 a	31.3 a
1970	Oats	63.1 b	14.8 a	18.5 a	11.4 a	12.8 a
2-year mean		58.7 b	21.9 a	26.5 a	18.7 a	22.1 a
1967	Wheat	50.4 b	50.3 b	38.1 a	34.7 a	38.4 a
1969	Wheat	64.1 a	56.1 a	56.9 a	62.4 a	59.8 a
2-year mean		57.3 a	53.2 a	47.5 a	48.6 a	49.1 a
1971	Wheat§	40.9 a	62.9 b	47.0 ab	58.1 b	47.9 ab
1972	Wheat	64.9 a	58.0 a	65.0 a	45.3 a	46.4 a
1973	Wheat	34.8 a	43.2 a	40.7 a	42.2 a	37.2 a
1974	Wheat	50.0 a	40.4 a	52.7 a	46.1 a	46.5 a
1975	Wheat	56.5 a	65.1 a	65.0 a	72.3 a	64.4 a
1976	Wheat	66.2 a	65.4 a	62.1 a	62.1 a	71.5 a
1977	Wheat	39.1 a	54.7 b	51.4 b	57.2 b	52.3 b
1978	Wheat	54.2 b	47.8 ab	41.5 ab	35.0 a	47.7 ab
8-year mean		50.8 a	54.7 a	53.2 a	52.3 a	51.7 a

* Means within years not followed by same letter are significantly different at the 0.05 level according to F test.
† Water-use efficiency is the kg grain produced per cm of water used during entire growing season of crop.
‡ Winter wheat was grown on contributing area all years.
§ Wheat on fallowed level benches.

Table 8—Effect of N on wheat straw and grain yields when applied on fallow before wheat planting in September and at the onset of spring growth following winter dormancy.

Product	Nitrogen treatment†	Winter wheat yield, kg/ha 1972	1974	1975	1976	1977	1978	Mean
Straw	0 N	1,867	5,379	4,198	3,119	–	–	3,641
	Spring N	1,849	5,119	4,770	3,313	–	–	3,763
Grain	0 N	1,472	2,024	2,690	1,929	–	–	2,029
	Spring N	1,461	1,965	2,987	1,920	–	–	2,083
Straw	0 N	–	–	–	–	4,242	3,219	3,730
	Fallow N	–	–	–	–	4,419	3,159	3,789
	Spring N	–	–	–	–	4,177	3,356	3,767
Grain	0 N	–	–	–	–	2,208	1,718	1,963
	Fallow N	–	–	–	–	2,220	1,499	1,860
	Spring N	–	–	–	–	2,196	1,669	1,932

† Nitrogen applied at 33.6 kg/ha.

in the cut area which remained throughout the winter. The snow-melt resulted in wet seedbed conditions for oat planting and poor oat stands.

Water-use efficiencies for both spring oats and winter wheat were used to evaluate the effectiveness of conservation bench terraces on the crops' available water. Grain yield was divided by the total water use to give kilograms hectare^{-1} centimeter^{-1} (Table 7). Water use was the difference in available soil water in a 180-cm profile at planting and harvest times plus precipitation and runoff during the growing season.

Water-use efficiency of oats in a wheat–oat rotation on the level benches was less than winter wheat and was not affected by runoff. Poor seedbed conditions due to soil wetness at planting time in the spring of 1970 resulted in poor establishment and low water-use efficiencies for the crop of oats. Water-use efficiencies for winter wheat in an oat–wheat rotation averaged 6% less than for winter wheat on fallow in the leveled benches and 7 to 17% less than that for wheat on fallowed contributing areas. Bench leveling increased water-use efficiency of winter wheat by 1.8 to 7.7% over that on the contributing area when benches were fallowed.

Nitrogen–Water Relationship

Application of N fertilizer on fallow before planting or in the spring after fall establishment did not consistently increase yields (Table 8). Mean yield increases or decreases due to spring application of N were best correlated with growing season precipitation. Regression analysis of these data showed that 67% of the mean yield increases or decreases were attributed to growing season rainfall and that grain yield response to N was not positive with <25 cm of growing season rainfall. Runoff was not significant enough to be an influencing factor. Grain yield increases were obtained only in 1975 and 1977 when growing season rainfall totaled >30 cm. Nitrogen tended to increase straw yields more so than grain yields. The protein content in wheat grain was increased by N from 14.2 to 14.7% in level benches and 15.0 to 15.7% in contributing areas. Benefits of N did not meet the costs of application on fallowed winter wheat in either leveled benches or contributing areas. Greb and Brengle (2, 5) also reported no significant wheat yield increases from N when grown on fallowed silt loam (hardland) soils. However, they reported yield increases due to N on sandy soils or when wheat was grown continuously on "hardland" soils. Phosphorus and potash are in adequate supply in these soils. Nitrogen fertilizer on continuous winter wheat in leveled benches was not tested.

[4] Oral communication with the local SCS District Conservationists.

CONCLUSION

Conservation bench terraces improved both the distribution and quantity of water stored in the soil for crop use. However, conservation bench terraces did not support annual winter wheat because stored soil water was not adequate for germination and establishment. Summer fallowing the level benches increased available soil water 69% at seeding time and increased wheat yields 20% over that on fallowed contributing areas. Yield increases from benches frequently occurred even when runoff contribution was insignificant. Spacing of bench terraces on 1% sloping silt loam soils may be greater than the ratio of 3:1 contributing to level-bench area in semiarid areas where fallow–winter wheat is practiced. The Soil Conservation Service, USDA, in eastern Colorado is designing and supervising construction of bench terraces with ratios of as high as 7:1 with effective results.[4] This does not necessarily apply to other cropping systems or to steeper slopes that may require closer spacing of narrower benches.

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