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Level Pan System for Spreading and Storing Watershed Runoff[1]

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ABSTRACT

Level pans were constructed in broad natural waterways to intercept runoff from contributing watersheds for storage and crop use. Stored soil moisture at seeding time in the level pans was as much in a 7-month period over winter as that stored in unleveled fallow plots during a 19- to 21-month period. Watershed runoff during the growing season provided 3 inches of moisture annually to level pans. The increased moisture supplies in the level pans permitted annual cropping with a 2-fold or better increase in yields over unleveled dryland areas in either fallow or continuous cropping. Water-use efficiency of grain and forage sorghums (*Sorghum vulgare* 'RS-610 and 'FS-22') increased with increasing moisture supplies.

Low and unfavorable distribution of precipitation, extended drought periods, high winds and excessive evaporation losses are hazards of dryland agriculture in the West Central High Plains. Average annual precipitation at the experiment station near Akron, Colorado is 16.6 inches with 10 inches of the total occurring in May through August. Approximately 30 to 35% of the annual precipitation is available for plant growth.

Various land surface modifications have been investigated to improve efficient use of available precipitation. At Spur, Texas, a syrup pan terrace system was used on ½ to 1% sloping land for spreading runoff. This system stored 16% more water than fell on the area with a 2- to 3-fold increase in crop yield over an 8-year period (4). Burnett and Fisher reported a 59% increase in yield of cotton lint (*Gossypium hirsutum*) from leveled land receiving supplemental runoff and 24% increase without supplemental runoff (2). Contour level benches were constructed at Bushland, Texas to store potential runoff from a contributing area immediately above (5, 7). After 4 years, yields of continuous grain sorghum in the benches averaged 300 lb more per acre than that in a wheat-sorghum-fallow (*Triticum aestirum-Sorghum vulgare*) rotation on the contributing area. Runoff stored in a reservoir was used by Cosper and Thomas for spreading on grassland (3). The supplemental water with fertilizer increased yields from 10 to 63%.

At Akron, Colorado a level pan system was designed and constructed in broad natural waterways to intercept runoff from contributing watersheds for storage and crop use. The water spreading system is schematically illustrated in Fig. 1. The objectives were to evaluate the feasibility of utilizing watershed runoff on dryland level areas for annual crop production, the response of different crops to intermittent flooding, and some water management problems involved in the spreading system.

This paper briefly describes the system and 3 to 4 years' results on grain and forage sorghum (*Sorghum vulgare* 'RS-610' and 'FS-22') response to the increased moisture supplies.

EXPERIMENTAL PROCEDURE

Construction on a series of 5 level pans was completed in 1959. Figure 2 shows the orientation and sizes of pans and their respective contributing watersheds. The pan size depended on the width and slopes of the natural waterway which varied from 500 to 1,000 feet in width and from nearly level to 3% slopes.

Pans were leveled to zero grade with track or wheel-type tractors and carry-all earthmoving equipment. Approximately 7,800 cubic yards of soil were moved. Maximum cuts varied from 1.0 to 2.2 feet, however the area subjected to these excessive cuts represented < 5% of the total area leveled.

Soils of the leveled areas consisted of Goshen loam near the center of the drainage channels and Weld, Rago, and Platner loams and silt loams along the edges of the waterway. These soils are friable when moist and hard when dry. They are deep at the center and become shallower toward the edges of the waterway. These soils constitute the more highly productive soils in the area and lend themselves to greater diversification of crops when water is available (6).

Flumes with FW-1 water stage recorders were installed to measure runoff into and out of each pan. Earthen dikes were constructed to impound 4 to 6 inches of water in each pan before overflowing through a spillway to a pan at lower elevation. Provisions were made in the spillway to completely drain the pans if water became surplus to crop needs.

Results on moisture supplies and grain sorghum response in the level pans were compared with that on unleveled plots in fallow and continuous cropping in another experimental study on grain sorghum row spacing and rotation (Partial research results from experiment by B. W. Greb, Soil Scientist, Central Great Plains Field Station, Akron, Colo.). These plots were located on part of the contributing watershed to pan 1. Plots were 50 ft by 140 ft on 1% slopes. Results on forage sorghum in pan 4 were compared with that from level plots which were part of a study on water use efficiency of forage sorghum as affected by initial soil moisture supplies and fertility (Partial research results from an experiment by R. W. Shawcroft, Soil Scientist, Central Great Plains Field Station, Akron, Colo.). Plots were 14 ft by 15 ft and diked to receive only the precipitation that fell on them during the growing season.

RS-610 grain and FS-22 forage sorghum in pans 1 and 4, respectively, were surface planted in 40- or 42-inch rows around the first week in June. Ammonium nitrate (33.5% N) was applied annually at a rate of 40 to 50 lb of available N per acre on all leveled areas. Sorghum on unleveled fallow and continuous cropping areas was not fertilized. Unpublished results of earlier fertility research at this station have indicated that sorghum has not responded to N under dryland conditions. In certain years when moisture supplies are favorable, sorghum may respond to fertilization on sandy soils (1).

Sorghum was harvested for forage during the first week in September and for grain around the first of November. Soil

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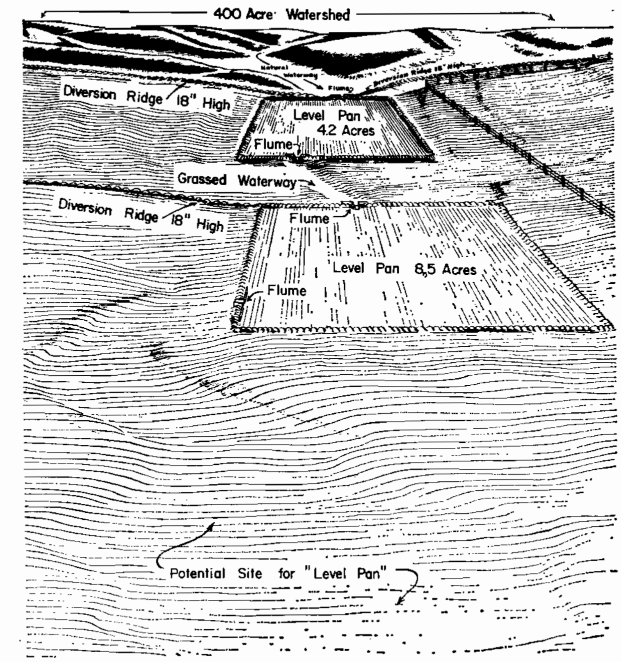

Fig. 1—Schematic representation of level pans system for intercepting, spreading and storing runoff from a contributing watershed.

moisture was assessed by gravimetric sampling to a depth of 5 feet on all areas at seeding and harvest times. Precipitation was measured in a weighing recording rain gauge centrally located among all pans.

RESULTS AND DISCUSSION

Stored Soil Moisture

Available soil moisture represents the amount of water in the soil that can be absorbed by roots of plants, that is, the approximate difference in moisture held in a soil at field capacity and permanent wilting. For these soils, field capacity and wilting point averaged 2.4 and 1.3 inches of moisture per foot, respectively.

Distribution of available soil moisture at seeding time in different areas is shown in Fig. 3. Amounts and depth of moisture in level pans receiving runoff during 7 to 9 months of storage was almost equivalent to that on fallow after 19 to 21 months. Moisture storage in level pans was twice as effective as that for unleveled and leveled check areas of continuous cropping. The difference in moisture storage between annually cropped unlevel and level check areas was attributed to a period of storage 3 months longer for the level check. Dikes around level check plots were not maintained to retain all precipitation that fell on them during the storage period.

Total available moisture in a 5-foot profile for the different areas is summarized in Tables 1 and 2 for grain and forage sorghum, respectively. The total amount of moisture stored at seeding time depended on the amount of precipitation during the storage period. Part of the storage in the level pans in 1960 and 1962 was attributed to either snowmelt or rainfall runoff received before seeding time.

The amounts and types of residue remaining after harvest of different crops had some effects on quantities of water

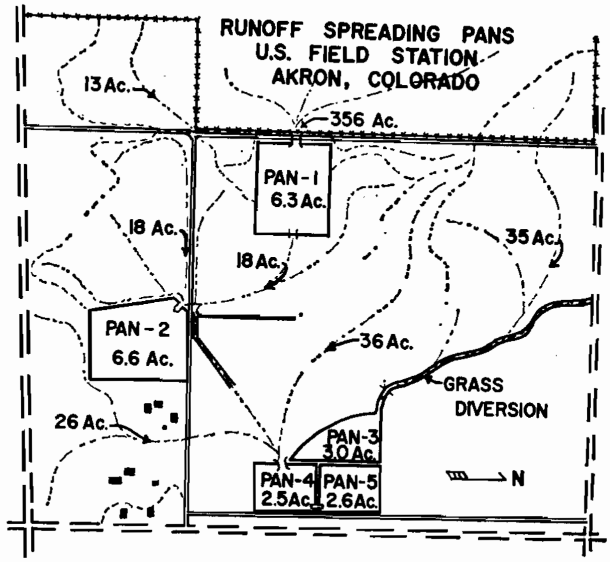

Fig. 2—Plan view of the pan layout showing acreages and watershed divides of contributing areas above individual pans.

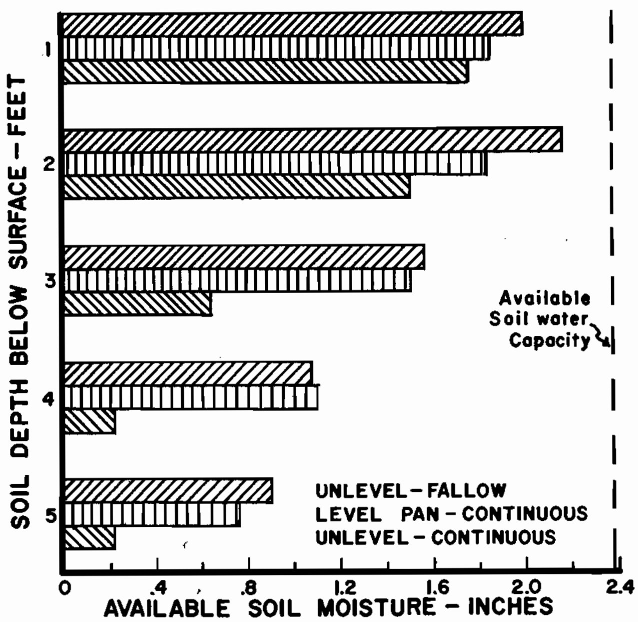

Fig. 3—Available soil moisture distribution to a depth of 5 feet at seeding time in years 1960-1963 in level pans receiving runoff and unleveled areas in fallow and annual cropping.

stored. Sorghum grain was harvested by clipping only the heads which left 24- to 30-inch standing stubble. The entire plant was utilized in harvesting forage sorghum for fodder or ensilage. The grain sorghum stubble in the leveled pan trapped snow and reduced evaporation which, over a 7-month period, increased moisture supplies 1.1 inches more than that in the leveled pan of forage sorghum after a 9-month storage period. Snow trapped by residue on unleveled areas was partially lost in runoff.

Rainfall and Runoff Supplies

Rainfall and runoff during the growing season are given in Tables 1 and 2 for each crop year of grain and forage sorghum,

Table 1—Total available moisture during the growing season, grain sorghum yields, and water use efficiency from pan 1 receiving runoff, and unlevel areas receiving no runoff for years 1960 through 1963

Year	Available soil moisture*	Growing season rainfall	Runoff Lost or received	Grain sorghum yield†	Water use efficiency‡
	inches	inches	inches	lb/acre	lb/inch
	Sorghum after sorghum in unlevel areas with runoff losses				
1960	4.3	5.5	0.0	000	00
1961	4.5	8.8	−0.8§	540	46
1962	4.6	6.9	−0.4	360	33
1963	2.7	12.4	−0.6	300	22
Mean	4.0	8.4	−0.5	300	26
	Sorghum after fallow in unlevel areas with runoff losses				
1960	7.2	5.5	0.0	820	66
1961	8.3	8.8	−0.8	1,840	107
1962	8.5	6.9	−0.4	1,400	95
1963	6.7	12.4	−0.6	1,370	83
Mean	7.7	8.4	−0.5	1,360	88
	Sorghum after soghum in level pan receiving runoff				
1960	8.7	5.5	0.0	1,740	167
1961	7.5	8.8	3.7¶	2,780	163
1962	8.8	6.9	2.1	2,450	163
1963	5.3	12.4	6.2	4,050	232
Mean	7.6	8.4	3.0	2,760	184

* Available soil moisture to a depth of 5 feet at seeding time.
† Grain yields were adjusted to moisture content of 12.5%.
‡ Water use efficiency is in pounds of grain produced per inch of water used.
§ Runoff from unlevel areas was assumed the same as that measured from sorghum of similar slopes in another experimental area.
¶ Flumewas not installed in 1961. Runoff into the level pan was estimated by assuming a 0.5% annual loss from the contributing watershed.

respectively. Average rainfall during the 5-month growing season for grain sorghum was 1.2 inches below normal while rainfall during the 3-month growing season for forage sorghum was near normal. The above normal rainfall during the summer of 1963 plus the runoff into the pans was alone sufficient to mature the crop. In some pans an increase in soil moisture between planting and harvest was calculated for a growing crop in 1963.

Normally, most of the runoff occurs during the growing season. However, in 1962 over 50% of the annual runoff occurred before seeding time. In certain years such as 1960, some runoff resulted from snowmelt. This source of runoff represents < 5% of the total annual runoff.

No runoff occurred during the growing season of 1960 which was the second driest in 56 years with 10.9 inches of annual precipitation. About 0.6 inch of runoff occurred annually in 1961, 1962, and 1963. This runoff increased moisture supplies by 3 to 4 inches in the level pans during the growing season.

Level pans increased total moisture supplies 3.5 to 7.0 inches annually, most of which originated from runoff. The pans contained all water supplies each year except 1963 when some overflow was observed from pan 1. Pan 4 during the same year lost 2.1 inches in overflow to another leveled pan.

Moisture-Yield Relationships

Grain and forage sorghum yields are given in Tables 1 and 2, respectively. Water use efficiency is also given in pounds of dry matter produced per inch of water use. Water use refers to the difference in available soil moisture in 5 feet between seeding and harvest times plus precipitation and runoff during the same period.

Biannual yields of grain sorghum from unleveled plots in fallow averaged 1,360 lb/acre. This yield on an annual basis

Table 2—Total available moisture during the growing season forage sorghum yields, and water use efficiency from pan 4 receiving runoff and level plots receiving no runoff for years 1961 through 1963

Year	Available soil moisture*	Growing season rainfall	Runoff received	Forage sorghum yields†	Water use efficiency‡
	inches	inches	inches	lb/acre	lb/inch
	Continuous sorghum in level areas without runoff				
1961	5.5	5.7	0.0§	3260	360
1962	5.2	6.3	0.0	3960	427
1963	3.4	8.5	0.0	4680	487
Mean	4.7	6.8	0.0	3960	400
	Continuous sorghum in level pan receiving runoff				
1961	6.2	5.7	1.8¶	7880	714
1962	7.5	6.3	2.6	12760	925
1963	5.7	8.5	5.0	6360	518
Mean	6.5	6.8	3.1	9000	728

* Available soil moisture to a depth of 5 feet at seeding time.
† Forage yields baxed on oven-dry weights.
‡ Water use efficiency is pounds of oven-dry forage produced per inch of water used.
§ Level plots were diked to eliminate runoff.
¶ Flumes were not installed in 1961. Runoff was estimated by assuming a 0.5% annual runoff loss from the contributing area.

would be 680 lb/acre which was twice the yield of continuous sorghum on unleveled areas, but only 25% of the yield obtained in level pans. Forage production in the level pan averaged 9,000 lb/acre or more than 2 times the yield on leveled areas receiving no runoff.

Yields in general were related to moisture supplies. For grain sorghum the highest correlation was with total available moisture (initial soil moisture + rainfall + runoff). The relationship showed a 270-lb increase for each additional inch of moisture received during the growing season. The calculated r-value of 0.92 was significant at the 1% level. Yield correlations with initial soil moisture and runoff gave r-values of 0.69 and 0.48, respectively.

Although not evaluated, part of the grain yield increase in the level pan may have been attributed to fertilizer. An estimate of this response was made from the moisture and yield data in Table 1. Where no fertilizer was applied on unleveled areas, the extra moisture supplies on fallow increased yields at a rate of 286 lb/inch over that on continuous sorghum. When considering the average yields and moisture supplies on unleveled areas in fallow and continuous sorghum, the extra moisture available in the pan increased grain yields at a rate of 366 lb/inch. Assuming an uniform yield increase with moisture supplies, the fertilizer in the pan was responsible for approximately 80 lb or 22% of the total yield increase.

Forage yields in Table 2 were related to moisture supplies. Initial soil moisture gave the highest correlation with a r-value of 0.76. Yields increased 1,960 lb/inch of stored moisture at seeding time. The data were too limited and variable for this relationship to be significant. The extreme variation in 1963 was due to a forage sorghum variety which was shorter and matured earlier than those used in previous years. Also the moisture supplies in 1963 were in excess of the crop needs.

Forage yields were less related to total available moisture and runoff than grain yields. Correlation coefficients of 0.59 and 0.31, respectively, were obtained.

Of greater importance were the effects of moisture supplies no water use efficiency. Figure 4 shows the relationship of available moisture on water use efficiencies of forage and grain sorghum. Highest correlations were obtained with available soil moisture at seeding time for forage sorghum and total available moisture during the growing season for grain sorghum. One reason for the water use efficiencies of the two crops to be related to different sources of moisture supplies is the maturity or harvest dates. Ample moisture at seeding time will mature forage sorghums to the boot or flowering stage of plant growth when harvested as fodder or ensilage. In certain years rainfall or runoff occurring before forage harvest was surplus to crop needs so that the total available moisture usually was not exhausted. Grain sorghums, on the other hand, require at least two more months to maturity. By this time, in most years, the moisture supplies were completely exhausted. There was exception to this in 1963 when rainfall was abundant late in the growing season.

Water use efficiency for grain sorghum was increased 14.6 lb/inch of moisture made available. The correlation was significant at the 1% level. For forage sorghums, the water use efficiency was increased 110 lb/inch of moisture stored at seeding, but for reasons mentioned above was not significant.

Management Problems

The water supply in the level pans was derived solely from precipitation falling on the pan area and runoff diverted from the attendant watershed. In certain years, for example 1960, the precipitation did not supply any watershed runoff to the pan area. In the present system all watershed runoff was diverted to the level pans. The water was either impounded to a maximum of 6 inches in the pan before overflowing or intentionally drained at lower end through a spillway. Since there is no control over the amounts and frequencies of runoff, excessive moisture at seeding time could delay seedbed preparation, planting and crop maturity with reduction in yields. This was observed in 1962 when planting was delayed 7 to 10 days because of excessive moisture on the normal seeding date. Future plans of research on the system will involve the possibility of stockpiling the runoff above the pans for later use or methods of diversion around, rather than through, the level pan when extra water is not desired.

Water supplies during the growing season have not been excessive to cause drowning out of crops for the years reported herein. In years of above-normal rainfall, drowning could occur in the present system unless techniques for runoff management are improved. Impounded runoff in the pans usually infiltrate the soils within 1 to 2 days following the storm provided a lapse time of 1 week or so has occurred before the next runoff event. Deep seepage losses have not been observed. Investigations are currently underway to determine possible losses below the root zone depth following major runoff events.

Although runoff was sometimes heavily laden with sediments, deposition has not been serious. Uniform distribution of water within the pans has been more of a problem, particularly the first year or two following construction. It was necessary to reshape the level pans to even out the high spots and settled portions of the fill areas. After 2 years, land smoothing should not be necessary. It may be desirable to establish a slight grade (< 0.5%) to improve water spreading to lower ends of pans. Irrigation techniques for water application and distribution could be applied in the level pan system.

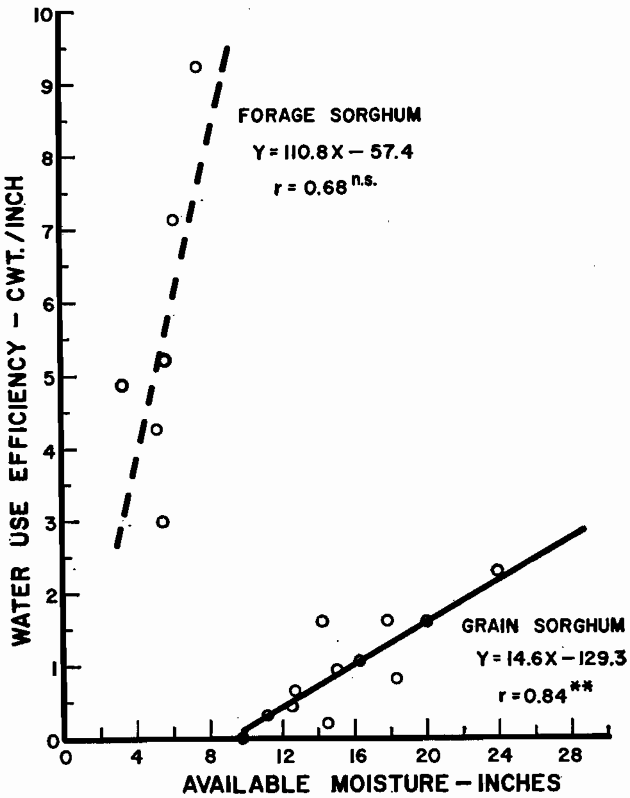

Fig. 4—Relationship of water use efficiency of forage for years 1961–1963 and grain sorghum for years 1960–1963, respectively, to the sum of stored moisture at seeding time, and rainfall and runoff during the growing season.

Yield variability due to cuts and fills were evident the first few years of cropping. Fertilizer trials were incorporated in pan 1 in 1960. Since this was an abnormally dry year when no runoff occurred, response to the fertilizer was not apparent. Crop variability was reduced each year by annual application of N. This reduction was based on observation and yield measurement. Coefficient of variation in yields attributable to fertility was reduced from 49% in 1960 to 28% in 1963. Unpublished results of research on fertility of exposed subsoils at this location have indicated that with ample moisture supplies the fertility could be replenished to near its original level in 1 year with adequate amounts of N and P.

Costs of constructing a level pan system would depend on type of equipment used and volume of soil moved, the latter depending on size and shape of area and distance of haul. Leveling by a contractor varied from $90 to $100/acre which in some cases included dike construction around the leveled area. At current market prices, increased gross return was $30 to $40 annually from grain sorghum and $42 annually from forage sorghum sold as ensilage. This increased annual return could offset the construction costs in a period of 4 to 6 years of near normal precipitation.

Approximately 5% of the land area would be suitable for pan leveling in the West Central High Plains area. The moisture supplies made available and subsequent yield increases obtained in the spreading system can insure against complete crop failures during drought periods. A number of crops, particularly those of higher cash value, not normally grown in the area, might do very well if adequate moisture were available. If so the system could allow greater diversification in dryland agriculture on limited areas where untimely distribution of rainfall and extended drought periods are common.

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