Increasing Rangeland Forage Production by Water Harvesting

H. A. SCHREIBER AND G. W. FRASIER

Highlight: Effects of additional water, provided from adjacent water-collecting areas, on forage production of blue panicgrass (*Panicum antidotale* Retz.) were assessed. Applying paraffin for water repellency of runoff areas increased water for use on the collecting areas. In this 3-year study, more than 2,000 kg/ha/year forage was harvested with rainfall of less than 130 mm and collecting-area runoff from 14 summer events in 1974 and from 18 summer events each in 1975 and 1976. Forage production from control plots averaged only 200 kg/ha/year the second and third years. Forage yield was increased about 16-fold over that of the control using a waxed-soil runoff area two times the crop growing area. Adjusting yields for the size of the bare runoff areas, the average yield increase for the system was still five times greater than that which would have been obtained from an uninterrupted planting of grass. Water-use efficiencies for this technique were comparable to those for irrigated grass.

The semiarid and arid regions of the United States encompass a large portion of our rangelands and produce much of our red meat. Concern is increasing that, unless we approach maximum utilization of the rangeland forage resources, economic pressures may cause an overall reduction in meat production (Box 1974; Long 1974). One means of maintaining meat productivity is to increase forage production in these areas. Limited natural rainfall may be more effectively used by collecting runoff water from specially prepared areas and concentrating this water on a crop area. This may result in more efficient use of water for increasing forage production. This method, commonly called "runoff farming," was developed over 4,000 years ago and consisted of collecting runoff water from higher areas with characteristically low infiltration rates for application to small fields in valleys (Evenari et al. 1961). Evans et al. (1975), rediscovering the technique, showed the feasibility of collecting water from impermeable highway surfaces for increased forage production. Recently, researchers have investigated various materials and methods for increasing runoff (Cooley et al. 1975). These methods consist primarily of covering the soil surface with a membrane or chemically sealing soil pores. However, most of these water-harvesting methods are relatively expensive for collecting water for crop production. Only a limited number of methods, like land forming and water-repellent soil treatments, have potential for being adapted to runoff-farming applications.

Many native range grasses that evolved under limited moisture conditions are not capable of efficiently utilizing water quantities that might occur with various water-harvesting treatments (Paulsen and Ares 1962; Martin and Cable 1975). One range grass, blue panicgrass (*Panicum antidotale* Retz.), will survive periods of low seasonal rainfall (80 to 250 mm) that often occur in arid lands, but can respond to over 500 mm of water (Wright 1962). This grass can compete on range sites with native perennials but when cultivated, fertilized, and irrigated has yielded over 30,000 kg/ha/year near Tucson, Ariz.

In this paper we report results of a 3-year study conducted to assess the effect of water harvesting on production of blue panicgrass. By coupling more available water with a higher fertility level, the productivity of specialized areas of our rangelands could be significantly increased.

Methods and Materials

A series of small test plots was established on a recently developed sandy loam alluvial terrace (2% slope) created in part from old mine spoils. These plots were located 6.5 km west of Tombstone, Ariz., on the lower part of the Walnut Gulch Watershed. There were no confining layers within 5 m (17 ft) of the surface, and gravel increased with depth. The plots were enclosed with a 6-cm high metal border buried 2 cm below ground. Grass plots (3 × 3 m) were seeded with blue panicgrass on June 24, 1974, at a rate of 4.5 kg/ha. After seeding, the plots were sprinkle irrigated with 8 mm/day for 2 weeks to insure seedling emergence and a stand of grass. All grass plots were fertilized before seeding with triple superphosphate, ammonium nitrate, and agricultural limestone at a rate of 33, 23, and 450 g/m^2 (300, 200, and 4,000 lb/acre), respectively.

A total of 36 plots were installed in a randomized block design with three replications of treatments. The treatments were three lengths of runoff areas and four runoff to crop-growing-area ratios of 0:1, 1:1, 2:1, and 3:1. The 0:1 plots had no runoff-contributing area and were used as the controls. The remaining plots had metal-bordered runoff areas that were 3 m wide and either 3, 6, or 9 m long. The water collected from the runoff area was retained within the cropped area by using a 6 to 18 cm metal border. The three runoff-area treatments were: bare soil (cleared and smoothed), waxed (cleared, smoothed, and waxed), and grassed (cleared and seeded with blue panicgrass like the crop area). On the cleared and smoothed areas, all vegeta-

---

The authors are soil scientist and research hydraulic engineer, respectively, with the Agricultural Research Service, U.S. Department of Agriculture. The former is with the Southwestern Watershed Research Center, Tucson, Arizona, and the latter is with the U.S. Water Conservation Laboratory, Phoenix, Ariz.

The authors thank Raymond Brown, Candido Ballesteros, Loel Cooper, and John Griggs, for assistance of field work and acknowledge with thanks Gary Richardson, Agricultural Research Service biometrician, in Fort Collins, Colorado, for statistical assistance.

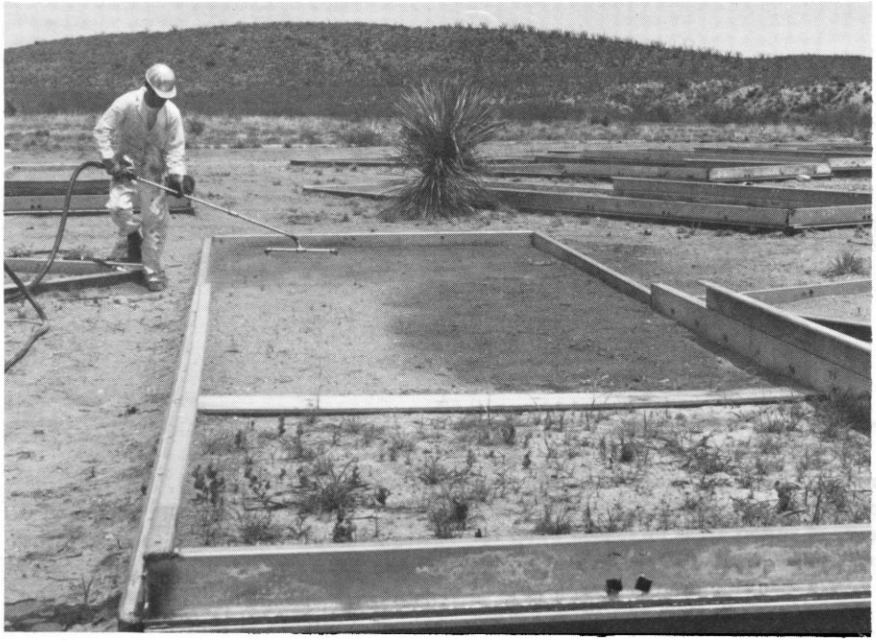

Fig. 1. *Liquid paraffin being applied to runoff area on July 11, 1974. The plot has a 3:1 runoff to cropping area ratio.*

tion was removed and the soil surface smoothed and compacted with a smooth steel-drum lawnroller. For the wax treatment, refined paraffin wax (128–135 AMP) was heated to 100°C and sprayed on cleared and smoothed soil surfaces at a rate of 1.1 kg/yd^2 , as described by Fink et al. (1973) (Fig. 1). One year later, on July 9, 1975, ammonium nitrate, triple superphosphate, potassium chloride, and magnesium sulphate were applied at rates of 30, 33, 11, and 13 g/m^2 (270, 300, 100, and 120 lb/acre), respectively.

Rainfall for the 1974 growing season was normal until early August (Table 1) and provided sufficient water for adequate growth on all plots. However, because of an August drought, all plots were harvested on August 26, 1974, even though flower emergence was not uniform among treatments. Rainfall after the cutting date was minimal, and no further harvests were attempted in 1974, although residual available water provided some additional growth on the plots with the larger runoff-contributing areas. This growth and the early 1975 spring growth froze without producing any harvesting vegetation, which essentially depleted the soil water as evidenced by the absence of growth on any plots before the 1975 summer rainfall. The 1975 and 1976 summer precipitation was more uniformly distributed than that of 1974, and the latter year's rainy seasons were longer. Smith and Schreiber (1974) found that the mean amount of rainfall was 7.6 mm (0.3 inch) with a median of 4.3 mm (0.17 inch) for each of 30 events per growing season. At the study location, although all years had typical rainfall distributions, there were only 14, 18, and 18 events per growing season June 1 to September 30 for the 3 years, respectively.

The 1975 harvest was made in December, after all plots had depleted the available soil water and frost had killed all top growth. Eighteen rainfall events were recorded prior to harvest with a total depth of 123 mm (4.84 inches) in 1976. Unlike either preceding year, two events exceeded 25 mm, but the calculated runoff (discussed later) was lowest in 1976.

In May 1976, a small laboratory rainfall simulator covering a 1-m^2 area was used to estimate runoff efficiencies from the wax runoff areas by spraying water onto the catchment surface at a constant rate from a 150-cm height. The runoff water was collected at the lower edge of the test area by a small tube connected to a vacuum pump, which deposited the runoff water in a plastic precalibrated chamber. The spray rate was determined by placing a pan cover over the test area for a predetermined time and measuring the water collected. The pan was then removed and the water sprayed directly on the catchment. The water was sprinkled at a rate of 4.5 to 5 cm/hour, until a total of 1 cm of water was applied. This corresponded with the quantity and intensity of many of the precipitation events in the Southwest.

Table 1. Monthly rainfall, estimated runoff, and potential water available for plant growth on forage plots during three growing seasons.

			Runoff (mm)		Potential water (mm)[1]					
					Waxed plots			Bare soil plots		
Year	Month	Rainfall[2] (mm)	Waxed plots	Bare soil plots	1:1	2:1	3:1	1:	2:1	3:1
1974	June	3.6	2.6	0.6	6.2	8.8	11.4	4.2	4.8	5.4
	July	103.6	91.6	22.2	195.4	287.2	379.0	125.8	148.0	170.2
	Aug.	22.1	21.1	8.0	43.2	64.3	85.4	30.1	38.1	46.1
	Sept.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	129.3	115.3	40.8	244.8	360.3	475.8	160.1	190.9	221.7
1975	June	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	July	66.2	56.2	18.0	122.4	178.6	234.8	84.2	102.2	120.2
	Aug.	14.5	11.5	3.3	26.0	37.5	49.0	17.8	21.1	24.4
	Sept.	47.8	43.5	16.0	91.3	134.8	178.3	63.8	79.8	95.8
	Total	128.5	111.2	37.2	239.7	350.9	462.1	165.8	203.1	240.4
1976	June	8.9	7.9	2.7	16.8	24.7	32.6	11.6	14.3	17.0
	July	99.0	88.0	30.8	193.0	281.0	369.0	135.8	166.6	197.4
	Aug.	14.9	9.1	2.1	24.0	33.1	42.2	17.0	19.1	21.2
	Total	122.8	110.8	35.6	233.8	338.8	443.8	164.4	200.0	235.6

[1] Potential water = (rainfall) + runoff: crop growing area ratio × runoff).

[2] Since grass plots had no runoff as supplemental water, precipitation equalled water available for grass growth in 1974 and 1975. Runoff could have occurred in 1976, but no estimates could be made.

Results and Discussion

The rainfall simulator was used to evaluate the runoff efficiency of the waxed runoff area in May, 1976. Results indicated that the runoff per event from waxed plots could be expressed as:

$$\text{Runoff (mm)} = \text{Rainfall (mm)} - 1.0. \quad (1)$$

Using the results from Frasier (1975), the runoff of the bare soil plots per event could be expressed as:

$$\text{Runoff (mm)} = [\text{Rainfall (mm)} - 2.2] \times [0.4]. \quad (2)$$

Table 2 presents the calculated quantities of runoff for the waxed and bare-soil plots for each season. There was no apparent runoff from the grass plots, because no rainfall event exceeded the soil infiltration capacity.

The potential water available for plant growth is the rainfall plus the water collected from the runoff area.

This is expressed mathematically as follows:

$$\text{Potential water (mm)} = \text{Rainfall (mm)} + [\text{Runoff: crop-growing ratio} \times \text{runoff (mm)}]. \quad (3)$$

Table 1 shows the monthly potential water available for plant growth from each of the test areas.

The average forage yields for 1974 (Table 2) did not differ statistically among all treatments because of the uncertain effect of the residual soil water remaining after sprinkle irrigation of all plots. The forage yield differences between and within the 1975 and 1976 seasons, when the plant growth was totally dependent upon natural rainfall, were significant (P = .05). Contrasting production in 1976 with that of 1975 indicated that production increased with time as stands became more established. Yields of the best 1975 plots from waxed runoff areas increased slightly, if at all, in 1976. This suggested that these grass stands were already in equilibrium with the climatic and soil factors by the end of 1975. In 1976, yields from plots with larger runoff ratios in the bare and grassed runoff areas increased 2 to 2.5 times over that found in 1975. With an equal amount of rain and less calculated total runoff, this increase might be attributable to the runoff penetrating deeper into the soil profile, or to the age of the stand. Yields were almost five times greater for plots receiving runoff water from waxed areas than those for the control for the 2:1 ratio of runoff: crop area treatment on the complete system unit area basis. Forage yields for plots from the waxed runoff areas sometimes decreased as the ratios of treatment: crop growing area increased from 2:1 to 3:1. Possibly this was a chance result of some undetermined nutritional deficiency or of leaching of the existing nutrients by the increased water.

Table 2. Average forage yield (kg/ha) from plots as affected by the size of the runoff area and soil surface treatments.

Year	Runoff-crop growing area ratio	Runoff areas: Waxed		Bare soil		Grass	
1974	0:1	–	–	–	–	961	(961)
	1:1	954[1]	(1909)[2]	623	(1246)	534	(1068)
	2:1	646	(1932)	588	(1755)	401	(1203)
	3:1	284	(1136)	560	(2338)	273	(1093)
1975	0:1	–	–	–	–	186	(186d)d[3]
	1:1	666	(1333)bc	268	(536)d	216	(433)d
	2:1	973	(2920)a	227	(683)cd	140	(421)d
	3:1	484	(1939)b	237	(949)b	123	(494)d
1976	0:1	–	–	–	–	227	(227)e
	1:1	771	(1543)c	493	(986)cde	292	(583)de
	2:1	998	(2993)a	539	(1616)c	317	(951)cde
	3:1	650	(2602)a	553	(2211)b	327	(1308)cd

[1] Yield expressed for total area including crop-growing area and runoff area.
[2] Yield expressed only for the crop-growing area.
[3] Means within a year followed by similar letters are not significantly different (P = 0.05). Yields of 1974 are shown for comparison with following year. Statistical differences in 1974 water and rainfall cannot be determined because data applied is a combination of unmeasured irrigation.

Dividing the average yield of each plot (Table 2) by the potential available water for each treatment, the average yield of blue panicgrass herbage per millimeter of water was 1 to 3 kg/ha for waxed runoff areas and 1 to 2 kg/ha per millimeter of water for the bare soil runoff areas for 1975. The only source of water was precipitation and runoff during this year. Variation in water-use efficiency among plots for the size and types of the runoff areas could be related to the different depths of soil water storage between treatments and to plant responses to varying degrees of drought. Maximum runoff would result in proportionately less surface evaporation and more evapotranspiration from plants, as compared with crop-growing areas receiving no runoff water. Plant responses to drought might also be a factor if prolonged desiccation caused irreplaceable loss of photosynthetic tissue, thereby resulting in a less capable system to manufacture dry matter.

Our results compared favorably with some other studies of irrigated blue panicgrass. Erie et al. (1965) reported an average seasonal consumptive use of 1,328 mm (52.3 inches) with 630 mm (24.8 inches) of the water being used during July, August, and September. Their yields for a 2-year study were 7,160 kg/ha (6,378 lb/acre) the first year and 3,775 kg/ha (3,362 lb/acre) the second year for an average yield of 5.4 and 2.8 kg/ha per millimeter of water for the 2 years, respectively.[1] The application of additional water by water-harvesting techniques permits a water-use efficiency of the same order of magnitude as that for irrigated blue panicgrass.

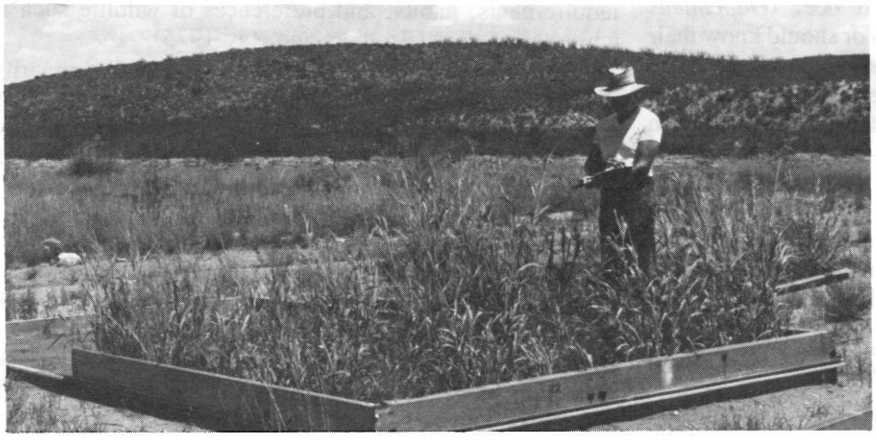

Fig. 2. *Stand of blue panicgrass in a 1:1 runoff to cropping area plot on August 6, 1976. Within 2 weeks, this plot produced more than 1,500 kg/ha of ovendry forage.*

Summary and Conclusions

A 3-year study was conducted to evaluate the possibility of increasing forage production by increasing the available water for plant growth by runoff farming (water-harvesting) techniques. Although the study was conducted on soil not generally suited for optimum growth, our results indicated that average per hectare yield was about five times greater than the control for an area receiving less than 130 mm (5.1 inches) of precipitation during the growing season. These results are significant, since two-thirds of the area

[1] Personal communication with L. J. Erie of unpublished data.

was used only for collecting water and did not contribute any forage. Additional studies are needed to further evaluate different types of runoff treatments and grasses and to develop methods for managing this type of system for optimum forage production.

Literature Cited

Box, T. W. 1974. Increasing red meat from rangeland through improved range management practices. J. Range Manage. 27:333-336.

Cooley, K. R., A. R. Dedrick, and G. W. Frasier. 1975. Water harvesting: state of the art. p. 1-20. *In:* Proceedings of the Watershed Management Symposium, Amer. Soc. Civil Eng. (Irrig. and Drain. Div.), Logan, Utah, Aug. 11-13, 1975.

Erie, L. J., O. F. French, and K. Harris. 1965. Consumptive use of water by crops in Arizona. p. 24-25. Arizona Agr. Exp. Sta. Tech. Bull. 169.

Evans, C. E., D. A. Woolhiser, and F. Rauzi. 1975. Opportunity for harvesting water from and along highways in rangeland areas of Wyoming. p. 293-301. *In:* G. W. Frasier (Ed.) Proceedings of the Water Harvesting Symposium, Phoenix, Ariz., Mar. 26-28, 1974. ARS W-22.

Evenari, M. L., L. Shanan, N. Tadmor, and Y. Aharoni. 1961. Ancient agriculture in the Negev. Science 133:979-996.

Fink, D. H., K. R. Cooley, and G. W. Frasier. 1973. Wax-treated soils for harvesting water. J. Range Manage. 26:376-398.

Frasier, G. W. 1975. Water harvesting for livestock, wildlife, and domestic use. p. 40-49. *In:* G. W. Frasier (Ed.) Proceedings of the Water Harvesting Symposium, Phoenix, Ariz., Mar. 26-28, 1974. ARS W-22.

Long, R. W. 1974. Future of rangelands in the United States. J. Range Manage. 27:253-255.

Martin, S. C., and D. R. Cable. 1975. Highlights of research on the Santa Rita experimental range. p. 51-57. *In:* Arid Shrublands—Proceedings of the Third Workshop of the U.S./Australia Rangelands Panel, Tucson, Ariz., Mar. 26–Apr. 5, 1973.

Smith, R. E., and H. A. Schreiber. 1974. Point processes of seasonal thunderstorm rainfall 2. Rainfall depth probabilities. Water Resour. Res. 10(3):418-423.

Wright, L. N. 1962. Effects of management practices in forage yield and percent protein in blue panicgrass, *Panicum antidotale* Retz. Agron. J. 54:413-416.