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Rangeland Forage Rehabilitation by Water Harvesting

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Highlight

Soil moisture and plant nutrients are two major factors that limit forage productivity in the arid and semiarid regions of the United States. By using water harvesting — runoff farming techniques — we increased forage yields of blue panicgrass (*Panicum antidotale* Retz) three- to fivefold. Analyses of nitrogen balance within the test plots indicated that the grass is efficient in the use of nitrogen and may actually be fixing some nitrogen. The ability of the blue panicgrass to produce high forage yields without encountering nitrogen deficiencies could be a major step in maintaining or increasing the forage production of our rangelands.

In the arid and semiarid regions of the United States, soil moisture and plant nutrients limit forage productivity, and in turn the potential beef production of the land. Schreiber and Frasier (1977), in a study at Montijo Flat near Tombstone, Arizona, showed that by clearing and treating strips of land to increase precipitation runoff, and concentrating this water on adjacent strips of crop land, the average forage yield (based on total land area) of blue panicgrass (*Panicum antidotale* Retz.) could be increased 3 to 5 times above the yield from plots with a solid planting of grass. With the runoff farming techniques, forage yields of more than 900 kg/ha were harvested, while the control plots yielded less than 250 kg/ha. Annual precipitation during the growing season for the studies was less than 250 mm.

In these initial studies, soil fertility was not a variable. Instead, the presumed required fertilizers (N, P, Mg, and K) were applied prior to the start of each growing season. All plots were fertilized before planting in 1974 and again on 9 July 1975. On 13 July 1976, P, Mg, and K fertilizers were applied. It had been decided to withhold application of the N-fertilizer a few weeks to allow for better soil moisture conditions. Observations of the plots in late July 1976, indicated that available nitrogen in the soil was not restricting plant growth, even on treatments producing large forage yields. The vigorous, dark-green plant growth indicated that nitrogen was present and available to the plants. Preliminary calculations indicated that the two previous applications of N-fertilizer and other possible natural N sources (organic matter, leguminous forbs) were not present or available in sufficient quantities to explain the observed plant growth.

Literature Review

Nitrogen fixation by grasses has historically been considered to be nonexistent or minimal. This belief was changed when Dobereiner, Day, and Dart (1972) reported that some tropical C_4 forage grasses were capable of fixing atmospheric nitrogen in amounts of economic importance. Later, Dobereiner and Day (1974) demonstrated that some of these grasses appeared to fix as much as 1 kg N/ha/day during the peak growing season. In 1975, Day, Neves, and Dobereiner showed that Guineagrass (*Panicum maximum* Jacq.) was a C_4-type grass capable of fixing nitrogen. Tjepkma (1975) also reported possible nitrogen fixation by switchgrass (*Panicum virgatum* L.), a temperate species of the *Panicum* genus. Smith et al. (1976) showed that the apparent nitrogen fixation by Guineagrass could be enhanced by low application rates of N fertilizer. In studies using isotope tracers of nitrogen, DePolli et al. (1977) confirmed nitrogen fixation in two C_4-type tropical grasses. While these studies are not directly comparable to our field studies, they do provide indications that nitrogen fixation by blue panicgrass may possibly explain the continued high yield obtained on our plots.

Because of the importance of soil fertility, especially nitrogen, on our rangelands, studies were initiated to determine the nitrogen balance of blue panicgrass when grown with these runoff-farming techniques. This paper reports the results of these studies. The ability of the blue panicgrass to produce high forage yields with minimal nitrogen application could be a major step in maintaining or increasing the forage production of our rangelands.

Methods and Materials

The field studies were conducted on the runoff plots described by Schreiber and Frasier (1977). These were 36 plots (3 × 3 m of grass-growing area) in a 3-replicate randomized block design established on a sandy loam alluvial terrace near Tombstone, Arizona. Each plot and the accompanying runoff-contributing area was enclosed by a 6-cm-high metal border buried 2 cm in the ground. Four runoff to crop-growing area ratios, 0:1, 1:1, 2:1, and 3:1, were used. The nine 0:1 ratio plots were used as controls. The runoff contributing areas for the remaining 27 plots were 3 m wide, and 3, 6, or 9 m long. Three runoff area treatments were initially investigated: (1) bare soil (all vegetation removed and the soil surface smoothed and compacted with a smooth steel-drum lawn roller; (2) waxed (cleared then sprayed with paraffin wax, 53 to 54 C average melting point, heated to 100 C, at a rate of 1.1 kg/m²); and (3) grassed (cleared and seeded with blue panicgrass similar to the crop growing areas). The grassed runoff plots were discontinued after the 1976 growing season.

On 24 June 1974, blue panicgrass was hand-broadcast seeded on all plots and the grassed runoff areas at a rate of 4.5 kg/ha. After planting, the seeded areas were sprinkle irrigated with 8 mm of water/day for 2 weeks, to ensure a stand of grass. Prior to seeding, all grass areas were fertilized by hand broadcasting with 330 kg/ha of triple superphosphate, 230 kg/ha of ammonium nitrate (33% N) and 4500 kg/ha of agricultural limestone. On 9 July 1975, ammonium nitrate (33% N), triple superphosphate, potassium chloride, and magnesium sulfate were broadcast on the plots at a rate of 300, 330, 110, and 130 kg/ha, respectively. A final fertilizer application of triple superphosphate, potassium chloride, and magnesium sulfate at 330, 110, and 130 kg/ha, respectively, was applied on 13 July 1976.

All plots were harvested on 26 August 1974, 16 December 1975, 25 August 1976, 10 February 1977, and 18 October 1977. The 1975 harvest cuttings were inadvertently destroyed after determination of the plot yields. The saved clippings of the other harvests were analyzed for total nitrogen content with a Technicon Auto-Analyzer Model II[1].

Core samples of the roots and rhizomes of the blue panicgrass were taken on all plots on 27 August 1977, by driving a 5-cm-diameter coring cylinder 20 cm into the ground. The roots and rhizomes in the

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[1]Trade names and company names, when included, are for the convenience of the reader, and do not imply preferential endorsement of a particular product or company over others by the U.S. Department of Agriculture. The authors gratefully acknowledge the assistance of Ray Brown and Loel Cooper in the harvest and plant analysis.

cores were washed with distilled water, separated, ground, and analyzed for total nitrogen content, as previously described.

A laboratory greenhouse study to investigate the response of blue panicgrass to various levels of nitrogen fertilization was conducted in the summer of 1977, in Tucson, Arizona. Blue panicgrass was planted in standard greenhouse pots containing 1600 g of soil. Five rates of nitrogen 0, 32, 64, 120, and 256 kg/ha applied as ammonium nitrate were used in a 3-replicate randomized factorial block design. All other plant nutrients were provided at optimal amounts. All pots were watered daily. Forage from the pots was harvested on 1-7 July 1977. One replicate from each treatment was used for estimating the first year nitrogen content of the roots-rhizomes and the root-rhizome to shoot growth ratio. All nitrogen analyses were performed as previously described.

Results and Discussion

The forage yields from the blue panicgrass plots at Montijo Flat are presented in Table 1. The treatment yields for 1974 are not statistically

Table 1. Bluepanic grass yields (kg/ha) from the Montijo Flat forage plots.

Harvest date	Area ratio Catchment : crop	Catchment area treatment Wax	Bare soil	Grass
Aug 1974	0:1	961	961	961
	1:1	1909	1246	1068
	2:1	1932	1755	1203
	3:1	1136	2338	1093
Dec 1975	0:1	186d[1]	186d	186d
	1:1	1333bc	536d	433d
	2:1	2920a	683cd	421d
	3:1	1939b	949b	494d
Aug 1976	0:1	227e	227e	227e
	1:1	1543c	986cde	583de
	2:1	2993a	1616c	951cde
	3:1	2602a	2211b	1308cd
Feb 1977	0:1	21	21	21
	1:1	284	218	60
	2:1	300	360	190
	3:1	326	720	181
Oct 1977	0:1	303	303	—
	1:1	2274	1542	—
	2:1	2124	1564	—
	3:1	1824	3178	—
Total 1974-1977	0:1	1698	1698	1395[2]
	1:1	7343	4528	2144
	2:1	10269	5978	2765
	3:1	7827	9396	3076

[1]Duncan multiple range test (P=0.05) for yields from crop growing area. Means within a year followed by no letters in common are significantly different (Schreiber and Frasier, 1977).
[2]For the period of Aug 1974 - Feb 1977. Grass plots removed after Feb 1977.

different because the residual soil water from the sprinkler irrigations after seeding increased forage production on all plots. For all succeeding years, the plant growth was totally dependent upon the growing season rainfall. In 1976, climatic conditions were favorable for an extended growing season permitting two separate harvests. The 1975 and August 1976 forage yield differences between treatments were statistically significant (Duncan's Multiple Range Test, P = 0.05), (Schreiber and Frasier 1977). Statistical analysis of the February 1977 (second cutting, 1976 season) and October 1977 harvests have not been completed. In 1975 and 1976, forage yields tended to increase as the catchment area to crop growing area increased, except for the wax catchments. Yield on the 3:1 catchment ratio was usually less than for 2:1, probably because the greater quantity of water applied to the grass leached some of the fertilizer from the root zone. The wax-treated runoff area plots yielded more forage than the bare soil runoff area plots which in turn had higher yields than the grassed runoff area plots. These results were expected because the large wax-treated runoff areas produced the most water to the plants. In 1977, similar trends were measured in the yields of the bare soil runoff area plots. Yields from the wax-treated runoff area plots tended to remain constant or even decrease as the runoff area increased. This indicated that available plant water was no longer a limiting factor for forage production.

The nitrogen contents of the harvested forage for the 1974, 1976, and 1977 cuttings are presented in Table 2. To fill in for the destroyed

Table 2. Nitrogen content (%) of blue panicgrass from the Montijo Flat forage plots.

Harvest date	Area ratio Catchment : crop	Catchment area treatment Wax	Bare soil	Grass
Aug 1974	0:1	3.4	3.4	3.4
	1:1	2.8	2.8	2.9
	2:1	2.3	2.9	3.0
	3:1	2.3	2.8	3.3
Dec 1975[2]	0:1	1.8	1.8	1.8
	1:1	1.3	1.4	1.3
	2:1	1.0	1.1	1.4
	3:1	1.1	1.5	1.4
Aug 1976	0:1	2.2	2.2	2.2
	1:1	1.7	1.9	2.1
	2:1	1.4	1.7	1.9
	3:1	1.4	2.0	2.0
Feb 1977	0:1	1.8	1.8	1.8
	1:1	1.3	1.4	1.3
	2:1	1.0	1.1	1.4
	3:1	1.1	1.5	1.4
Oct 1977	0:1	1.7	1.7	—[1]
	1:1	.9	1.4	—
	2:1	.7	.9	—
	3:1	.8	1.1	—

[1]Plots removed after Feb 1977.
[2]Estimated the same as measured in February 1977 harvest.

1975 cuttings, we have assumed a nitrogen content equal to the February, 1977 harvest. This is believed a conservative estimate because the plots received nitrogen fertilizer in the summer of 1975, which should have resulted in a forage nitrogen content higher than we have assumed. Forage nitrogen percentages were 2 to 3 percent in the 1974 cuttings. By 1977, the nitrogen contents were 0.7 to 1.5 percent. The results show that the nitrogen content tends to be lowest on the plots which have produced the most forage.

The total nitrogen removed in the harvested forage for each treatment is presented in Table 3. These results were obtained by multiplying the yield (Table 1) for each harvest period by the corresponding nitrogen content (Table 2). The harvested forage does not represent the total quantity of nitrogen used by the plants during the study. Appreciable quantities of nitrogen can be stored in the roots and rhizomes of the plants.

Estimates of the root-rhizome biomass of blue panicgrass was obtained from the greenhouse pot study. In the greenhouse we measured a ratio of 1.5:1 to 2.0:1 shoots (top growth) to root-rhizome growth (Table 4). Wright (1962a, 1962b) showed that irrigated blue panicgrass had approximately equal amounts (1:1) of above-ground and below-ground plant tissue. We have conservatively assumed a value of 2:1 top growth to root-rhizome for the field plots at Montijo Flat.

The nitrogen content of the root-rhizome plant tissue taken with the core sampler from the 4-year-old plots at Montijo Flat was 1.1 to 1.5 percent N. In the greenhouse study, the root-rhizomes of 1-year-old plants was 1.1 to 1.6 percent nitrogen content when N fertilizer had been added (Table 4). The top growth in the greenhouse plants had a nitrogen content of 0.6 to 0.9 percent. Nitrogen content of roots-rhizomes plants was higher than nitrogen content of shoots in both field and greenhouse measurements. For a conservative estimate of the nitrogen content of the roots-rhizomes in the field plots we chose a value of 1.2 percent.

Table 3. Total nitrogen (kg/ha) in the harvested blue panicgrass from the Montijo Flat forage plots.

Year	Area ratio Catchment : Crop	Catchment area treatment Wax	Bare soil	Grass
Aug 1974	0:1	33	33	33
	1:1	53	35	31
	2:1	44	51	36
	3:1	26	65	36
Dec 1975	0:1	3	3	3
	1:1	17	8	6
	2:1	29	8	6
	3:1	21	14	7
Aug 1976	0:1	5	5	5
	1:1	26	19	12
	2:1	42	27	18
	3:1	36	44	26
Feb 1977	0:1	<1	<1	<1
	1:1	4	3	<
	2:1	3	4	3
	3:1	4	11	3
Oct 1977	0:1	5	5	—
	1:1	20	22	—
	2:1	15	14	—
	3:1	16	35	—
Total 1974-1977	0:1	46	46	41[1]
	1:1	120	87	49
	2:1	133	104	63
	3:1	103	169	72

[1]For the period of Aug 1974-Feb 1977. Grassed plots removed after Feb 1977.

Table 4. Plant tissue yield of harvestible forage and roots plus rhizomes (g/pot) and corresponding nitrogen content (%) of blue panicgrass from greenhouse study.

Added nitrogen levels (kg N/ha)	Plant yield Shoots	Root and rhizome	Growth ratio Shoots : roots	Nitrogen content Shoots	Root and rhizome
0	7.4	4.9	1.5:1	0.6	0.4
32	6.0	3.0	2.0:1	0.6	1.2
64	8.6	4.0	2.2:1	0.8	1.2
120	9.1	5.9	1.5:1	0.9	1.1
256	14.7	7.4	2.0:1	0.8	1.6

A summary of the total nitrogen used by the plants in the 4-year study for each treatment is presented in Table 5. The root-rhizome dry matter produced was estimated to be one-half of the total harvested forage, with an average nitrogen content of 1.2 percent. The results show that the total nitrogen removed by the plants is directly proportional to the total plant growth produced in the 4 years. On the wax and bare soil runoff treatment plots with runoff contributing areas of 1:1 or larger, the total nitrogen used by the plants was 114 to 225 kg/ha.

The major sources of nitrogen available to the plants during the 4-year study were: applied fertilizer, soil organic matter, and precipitation. There are no leguminous plants in the area, and the low annual precipitation has limited the growth of other plants which might have provided to the soil organic matter. A total of 177 kg/ha of available nitrogen was applied to the plots as ammonium nitrate. Analysis of organic matter prior to planting showed approximately 1200 kg/ha of nitrogen was present in the top foot of soil. Most of the organic material consisted of live roots, not dead material. Accordingly, using a conservative estimate of nitrogen release from the organic matter at a rate of 1%/year (Brady, 1974), this would have provided a total of 48 kg/ha of useable nitrogen over the four-year period. Preliminary measurement of nitrogen in the precipitation in the Tombstone, Arizona area indicate that 1 to 5 kg N/ha/year may occur. Sneva (1977) reported rainfall nitrogen amounts of up to 5 kg/ha/year. Assuming a maximum of 5 kg N/ha/year, a total of 20 kg N could have been placed into the soil via precipitation. These three nitrogen sources provided an estimated total 245 kg N/ha.

Table 5. Total dry matter and nitrogen balance (kg/ha) of blue panicgrass at the Montijo Flat forage plots, 1974-1977.

	Area ratio Catchment : crop	Catchment area treatment Wax	Bare soil	Grass[5]
Total harvested forage[1]	0:1	1698	1698	1395
	1:1	7343	4528	2144
	2:1	10269	5978	2765
	3:1	7827	9396	3076
Estimated root-rhizome dry matter[2]	0:1	849	849	697
	1:1	3671	2264	1072
	2:1	5135	2989	1382
	3:1	3914	4698	1538
Total nitrogen in harvested forage[3]	0:1	46	46	41
	1:1	120	87	49
	2:1	133	104	63
	3:1	103	169	72
Estimated total nitrogen in roots-rhizomes[4]	0:1	10	10	8
	1:1	44	27	13
	2:1	62	36	17
	3:1	47	56	18
Total nitrogen used by blue panicgrass plants	0:1	56	56	49
	1:1	164	114	66
	2:1	195	140	80
	3:1	150	225	90

[1]From Table 1.
[2]Ratio of 2:1 top growth to bottom growth.
[3]From Table 3.
[4]Assumed 1.2% nitrogen content of roots-rhizomes.
[5]For the period of 1974-1976. The plots were removed after the 1976 season.

To account for the total nitrogen used by the plants, it would be necessary to have a 100% conversion efficiency of the applied fertilizer and organic matter. Bartholomew and Clark (1965) report use efficiencies of 50 to 70% of the applied fertilizer. Westerman and Tucker (1977) showed that approximately 30 to 90% of the nitrogen applied to desert soils may be lost by denitrification processes. We assumed a minimum conversion efficiency of 70% to arrive at a total of 175 kg N/ha available to the blue panicgrass. Based on the measurements of nitrogen content of the plants and using the most conservative estimates for all other unknowns, our studies indicate that the higher yielding forage plots would require at least 20 to 50 kg N/ha from some as yet undetermined source, possibly by nitrogen fixation, to complete the nitrogen balance.

At present, one of the most difficult unknowns to determine is the quantity of nitrogen which is available from the soil organic matter. Our estimate is believed to be conservative because of the relatively slow release of nitrogen from root tissue, most of which is alive, compared to plowed under organic matter. If, however, the release from organic matter is assumed to be 2%/year, the nitrogen availability was approximately equal to the total nitrogen in the plants. This would indicate that the blue panicgrass is not fixing nitrogen, but is a highly efficient user of nitrogen in maintaining the measured rate of plant growth. Following the last measurements, observed plant growth continues to be excellent.

Summary

When blue panicgrass was grown by runoff farming, water harvesting techniques, more nitrogren was used by the plants than was available from the N-fertilizer and organic matter sources in the soil. Based on other studies in Brazil and Florida with similar types of C_4 forage plants, it is hypothesized that nitrogen fixation may be the source of the nitrogen. Additional studies are necessary to conclusively define the magnitude and source of this nitrogen.

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