Impact of Incremental Surface Soil Depths on Plant Production, Transpiration Ratios, and Nitrogen Mineralization Rates

STEVEN M. LYONS AND GERALD F. GIFFORD

Abstract

From October 1974 to August 1976, a study was conducted to measure how incremental surface soil depths from the pinyon-juniper type affected plant production, plant transpiration rates, and nitrate nitrogen mineralization rates. The treatments were incremental removals of 7.6-cm soil layers to a depth of 30.5 cm. Plant production and transpiration ratios (or water use efficiencies) were measured in greenhouse studies using *Agropyron desertorum* grown in specified incremental 7.6-cm soil layers taken from five study sites throughout Utah. Significant decreases in plant production and increases in transpiration ratios were measured for all sites at incremental depths beyond 7.6-cm. These changes in plant production and transpiration ratios were linearly related to the nitrate nitrogen content of the soils (as determined when the soils were collected for use in the greenhouse). Nitrate mineralization rates were measured for two 6-week periods under field conditions at two sites for each of the 7.6-cm incremental soil layers. Nitrate nitrogen mineralization was linearly correlated with the organic carbon content of the soil. Decreased mineralization rates as measured in the field at both sites were reflected in the significant increases in plant water requirements and decreases in production that were measured in greenhouse studies.

Surface soils may be removed by wind and/or water erosion or through various activities associated with construction and mining. Biotic and hydrologic characteristics of the remaining soil may markedly differ from those of the removed soil and have a significant impact on future rehabilitation efforts.

The amount of water transpired per unit of dry weight production by a given plant species is highly correlated with the fertility of its soil environment, primarily available nitrogen (Briggs and Shantz 1913a, 1913b; Sneva, et al. 1958; Thomas and Osenburg 1959; Viets 1962; Smika et al. 1965; Debreczeni and Debreczeni 1974; Natr and Vee 1974). Vegetation growing on an infertile soil produces less yield for the same amount of water transpired. Debreczeni and Debreczeni (1974) found a 13.1%, 24.0%, and 22.2% decrease in the transpiration ratio (ml water/gm dry matter) when fertilizing with 0.25, 0.50, and 0.75 g of nitrogen, respectively, using oats grown in pots. No decrease was noted when phosphorus or phosphorus-potassium fertilizers were added. Natr and Vee (1974) also found no significant decrease in transpiration rates due to phosphorus. The only nutrient seemingly responsible for changes in transpiration ratios is nitrogen.

Many investigators have done extensive research on factors affecting ammonification, nitrification, and the effects of the processes on vegetal production (Harmsen and Van Schreven 1955; Fitts et al. 1955; Sneva et al. 1958; Bremmer 1965; Legg et al. 1971; Stanford and Smith 1972). Allison and Sterling (1948), Harmsen and Kolenbrander (1965), Standford and Smith (1972), and Stanford and Epstein (1974) found that the limiting step in nitrogen mineralization is the conversion of organic nitrogen to ammonium (NH_4) through the process of decomposition by bacteria. The ammonium is then oxidized to form nitrate (NO_3), which is considered to be available for plant use. The measurement of the nitrogen mineralization rate of a given soil therefore is a measurement of its ammonification rate.

The quantity of soil nitrogen mineralization achieved in a given time depends upon temperature, available water, rate of oxygen replenishment, soil pH, amount and nature of plant residues, and levels of other soil nutrients (Harmsen and Van Schreven 1955). Optimum soil temperatures for nitrification range from 28° C. to 35° C. Harmsen and Kolenbrander (1965) recorded almost complete nitrification at temperatures between 0-35° C. The same researchers also found that even though nitrification ceases at 45° C. ammonification continues. Highest nitrogen mineralization rates occurred between the soil matric suctions of 0.1 to 0.5 bars, or that range which encompasses the soil water content defined as "field capacity" (Miller and Johnson 1964; Stanford and Epstein 1974). Stanford and Epstein (1974) and Reichman et al. (1966) found a linear relationship between nitrogen mineralization and soil water content. As the matric suction increased from 0.2 to 15 bars, the nitrogen mineralization rate decreased. Robinson (1957) concluded that

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Authors are graduate research assistant and professor, Rangeland Hydrology, Watershed Science Unit, College of Natural Resources, Utah State University, Logan, 84322. Mr. Lyons is currently hydrologist with the Bureau of Land Management, Montrose, Colorado.

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"active nitrification of the natural soil nitrogen stops at a soil mosture level just below the permanent wilting percentage (about 15 bars); however, ammonia nitrogen accumulates substantially."

Haque and Walmsley (1972) and Allison and Sterling (1948) found good correlations between nitrogen mineralization and total nitrogen of the soil. Allison and Sterling obtained a correlation coefficient between nitrogen mineralization and total nitrogen of the soil at 0.809 after 42 days of incubation. They also found that the rate of mineralization decreased with time. The variations in results among investigators have probably been due to differences in microorganism populations, quantity of other nutrients present, and soil moisture levels.

The specific objectives of this study were to determine how plant growth characteristics and water use efficiencies are affected by successive 7.6-cm incremental soil layers of a soil profile and secondly to determine field nitrate nitrogen mineralization rates as a function of successive 7.6-cm layers of a soil profile.

Method and Procedure

Site Description

Five study sites were selected throughout Utah, all similar with respect to land management treatments. All sites are within the pinyon-juniper (Pinus spp.-Juniperus spp.) type and all had been chained with debris left in place. The study sites had been seeded several years prior to this study with crested wheatgrass *(Agropyron desertorum)* and Fairway wheatgrass *(A. cristatum).*

Blanding Site

The Blanding site is about 70 km west of Blanding, Utah, in the N.E. ¼ of S.W. ¼ of T38S, R18E, near Coyote Flat. Its elevation is about 1,981 m with a 30-year (1931-1960) average annual precipitation of about 28 cm per year, of which about 13 cm falls between May and September. Soils are derived from sandstone-siltstone and are of the Ardic Argiustolls-Typic Argiustrolls association. The texture is sandy loam and the color is red (Gifford 1973). The pH ranges from 7.7 to 8.1, with a total nitrogen % of 0.13 to 0.21 (Table 1). The area was double-chained in the fall of 1967 and broadcast seeded at a rate of 9.2 kg per hectare.

Brush Creek Site

Brush Creek is about 21 km northeast of Vernal, Utah, in the N.E. ¼ of Section 35 and N.W. ¼ of Section 36 of T2N, R22E, on the Brush Creek Chaining Project. The site elevation is about 1,730 m. Annual precipitation averages 28 cm, with about 50% falling from May to September. The soils are from the Typic Torriorthents (Shallow)-Lithic Calciorthids association. The texture is a sandy loam with a pH of about 7.9 to 8.2 and uniformly low nitrogen content of about 0.4% (Table 1). Age of the chaining project was not determined.

Milford Site

The Milford site is about 72.4 km west of Minersville, Utah, in the S. ½ of Section 7, T30S, R15W. Its elevation is 2,100 m, and the annual precipitation averages about 36 cm, with 15 cm occurring from May to September. The soils are from the Xerollic Calciorthids-Xerollic Paleorthids association and have a silt loam to loam texture (Gifford and Tew 1959). The soil pH is slightly lower than the first two sites, ranging from 7.2 to 7.4. The organic carbon is higher, ranging from 0.7 to 1.7% (Table 1). This site was double-chained in the fall of 1967 and broadcast seeded to crested wheatgrass.

Huntington Site

The Huntington site lies about 12 km up Huntington Canyon, Utah, on top of a small plateau that is about 350 m south of the Huntington Power Plant in Section 36, T17S, R7E. Site elevation is 2,010 m and its average annual precipitation is about 40 cm, with about 18 cm occurring between May and September. The soils are of the Agric Cryoborolls-Pachic Cryoborolls-Cryic Paleborolls association with a sandy loam soil texture. The pH ranges from 7.8 to 8.0, with total nitrogen and organic carbon percentages of about 0.19 and 1.7, respectively.

Dove Creek Site

The Dove Creek site is approximately 17 km southwest of Park Valley, Utah in N.S. ½ of Section 13, T12N, R15W. Its elevation is about 1,675 m. The annual precipitation averages about 28 cm, of which around 11 occur from May through September. The soil is clay loam to loam in texture and and is from the Aridic Calcic

Table 1. Soil analysis of study sites (August 1974).

Site	Soil Depth (cm)	Texture	pH	EC$_c$ (mmhos/cm)	CEC (me/100g)	NO$_3$-N (ppm)	P (ppm)	K (ppm)	N (%)	Org. C (%)	Water-sol Na (me/100g)
Blanding	0 - 7.6	Sandy Loam	7.7	0.3	10.6	0.7	7.7	164	0.21	0.4	<0.1
	7.6 -15.2		7.9	0.4	12.3	0.1	2.3	143	0.18	0.7	<0.1
	15.2 -22.9		8.1	0.3	14.0	0.4	1.7	94	0.15	<0.1	
	22.8 -30.5		8.1	0.3	12.7	0.4	1.7	73	0.13	0.8	<0.1
Brush Creek	0 - 7.6	Sandy Loam	7.9	0.3	7.1	1.0	5.7	171	0.08	0.4	<0.1
	7.6 -15.2		8.0	0.3	6.8	0.1	2.9	104	0.06	0.4	<0.1
	15.2 -22.9		8.1	0.3	6.8	<0.1	2.5	84	0.06	0.4	<0.1
	22.8 -30.5		8.2	0.3	5.4	<0.1	2.3	71	0.06	0.3	<0.1
Milford	0 - 7.6	Sandy Loam to Loam	7.2	0.4	17.3	1.7	11.0	>480	0.14	1.7	0.1
	7.6 -15.2		7.2	0.4	19.9	0.6	5.2	<480	0.10	1.2	0.1
	15.2 -22.9		7.2	0.5	20.7	0.6	4.2	>480	0.11	0.9	0.1
	22.8 -30.5		7.4	0.5	18.2	0.6	3.7	>480	0.07	0.7	0.1
Huntington	0 - 7.6	Sandy Loam	7.8	0.5	9.0	3.5	16.0	371	0.20	1.7	<0.1
	7.6 -15.2		7.8	0.4	12.3	1.2	5.0	297	0.17	1.7	0.1
	15.2 -22.9		7.9	0.4	13.6	0.9	5.5	212	0.19	1.9	0.1
	22.8 -30.5		8.0	0.3	13.2	1.6	4.9	177	0.19	1.7	<0.1
Dove Creek	0 - 7.6	Clay Loam to Loam	7.8	0.3	17.8	4.9	22.0	>480	0.26	2.4	0.1
	7.6 -15.2		7.9	0.3	17.8	1.8	9.7	398	0.15	1.5	0.1
	15.2 -22.9		8.0	0.4	17.8	1.5	5.7	417	0.13	1.4	0.1
	22.8 -30.5		8.0	0.4	16.3	1.3	5.8	342	0.15	1.3	0.1

Arigixerolls-Aridic Petrocalcic Palexerolls association.

Plant Production

During August and September of 1974, random soil samples were collected at four different depths (0-7.6 cm, 7.6-15.2 cm, 15.2-22.9 cm, and 22.9-30.5 cm) over each of the five study site areas. The samples were sieved through a 16-mesh screen to remove rocks and plant root material, and subsamples were analyzed for the parameters given in Table 1. The soil samples were then dried and weighed and put into 1-gallon cardboard pots at a rate of 6.4 kg per pot. Ten replications of each depth for each of the five sites were used, and each pot was planted with four crested wheatgrass *(Agropyron desertorum)* seeds. At the end of a 3-week germination period, each pot was thinned to two plants per pot.

One growth period was defined as 84 days. Incandescent lights were used to ensure 18 days of "daylight"; air temperature was maintained at an average minimum of 20° C, and sufficient amounts of distilled water were added to avoid water stress. At the end of each 84-day growth period, the plants were clipped at 2.5 cm above the soil surface, oven dried, and weighed to determine aboveground production. Measurements were made over two 84-day growth periods, and each growth period was treated separately.

Transpiration Ratios

Water use efficiency or transpiration ratio was defined as the weight (grams) of the total amount of water transpired per gram of above-ground biomass produced. Blanding and Milford were selected as representative sites and used for the transpiration ratio determinations. Six replications were made for each of the four depths at both (Blanding and Milford) sites.

The surface soils were sealed in each pot with two layers of heavy duty aluminum foil and caulking compound. The moisture contents of the pots were maintained below field capacity (1/3 atmosphere) but above the permanent wilting point (15 atmospheres) based on total pot weight. A careful record was maintained on the amount of distilled water added to each pot during an 84-day growth period. The crested wheatgrass plants used in these water efficiency studies had previously been utilized in our production study. The water-use data were combined with the dry matter weights obtained at the end of the 84-day growth period and used to calculate the water use efficiencies or transpiration ratios.

Nitrogen Mineralization Rate

Our procedures were basically the same as those prescribed by Stanford and Smith (1972). The primary differences were: (1) incubation was conducted in the field under natural temperature variations, (2) N-minus nutrient solutions were not added to soils, and (3) the soil samples themselves were analyzed for nitrate nitrogen content, not leachates from soil samples.

Soil samples were collected and processed in the same manner as the soils used in the plant production determinations. The soil was mixed with exfoliated vermiculite at a rate of 1:1/3 by volume. Approximately 15 to 20 g of soil mixture were placed into leach tubes (Fig. 1) through which water could percolate. The soil within the tubes was wetted with distilled water and incubated at 35° C for 2 weeks so that the microbial populations could reach equilibrium with the soil. Mineral nitrogen was removed by leaching with 110 ml of 0.01 m CaC_2 in 5 to 10 ml increments followed by 25 ml of distilled water. The soil cores within the leach tubes were allowed to drain to field capacity. The ends of each tube were stopped with one-hole stoppers to prevent excessive water loss and placed into the ground at each study site so that the top of the soil core was level with the ground surface. At the end of the prescribed 6-week incubation period, the soil was removed from the tubes, air dried in the summer sun and analyzed for nitrate nitrogen.

Vermiculite was added to the soil to prevent soil compaction and encourage a more rapid leaching process (Stanford and Hanway 1955). Glass wool pads at both ends of the 7.6 cm soil core helped hold the soil in place and prevent dispersion of soil when adding leaching fluids. The upper half of each tube was painted white to prevent any "greenhouse effect" within the tube.

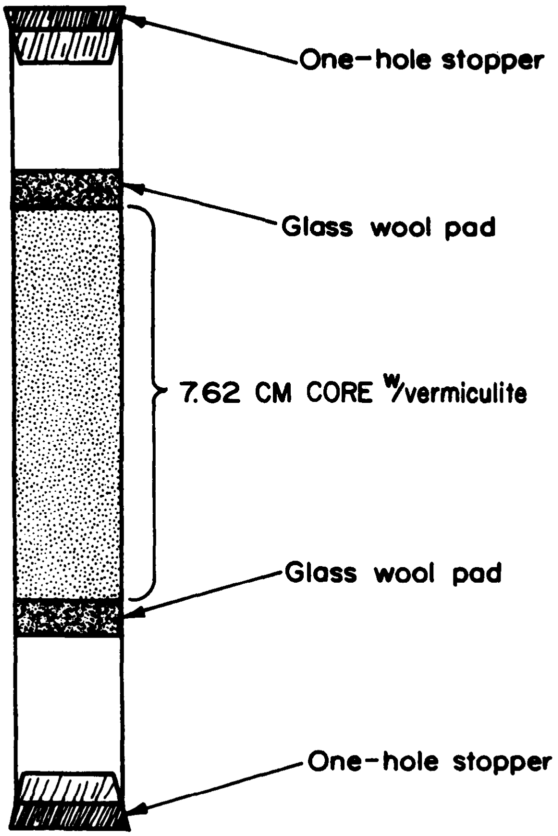

Fig. 1. *Leach tube with soil core.*

Nitrogen mineralization rates were for soils from the Blanding and Milford sites only. A total of 20 replications for each of the four depths for each site were conducted, half of the replications being completed during late summer of 1975 and the rest during early summer of 1976.

Results and Discussion

Plant Production

The analysis of variance for plant production data indicated a significant harvest by date by site treatment-depth interaction. Significant differences between harvest dates had been expected because of nutrient depletion and aging of plant species. Within the three-way interaction, the site by treatment-depth interaction was of particular interest (Fig. 2). This interaction indicated a significant decrease in production for all sites on soils involving the 7.6- to 15.2-cm layers as compared with production on the surface 7.6-cm layer. Production continued to decrease as a function of depth only on soils from the Dove Creek and Milford sites, and then only to a depth of 22.9 cm.

Initial laboratory soil analyses (Table 1) revealed major differences in phosphorus and nitrate nitrogen nutrient contents among the various soil depths at nearly all the study sites. Both nitrogen and phosphorus contents were highly correlated (at the 95% level) with plant production (Fig. 3). However, Natr and Vee (1974) found no significant decrease in growth processes due to deficiencies in phosphorus content. Nitrogen and phosphorus are both mineralized from the unavailable forms found in organic matter to available forms for plant use through associated

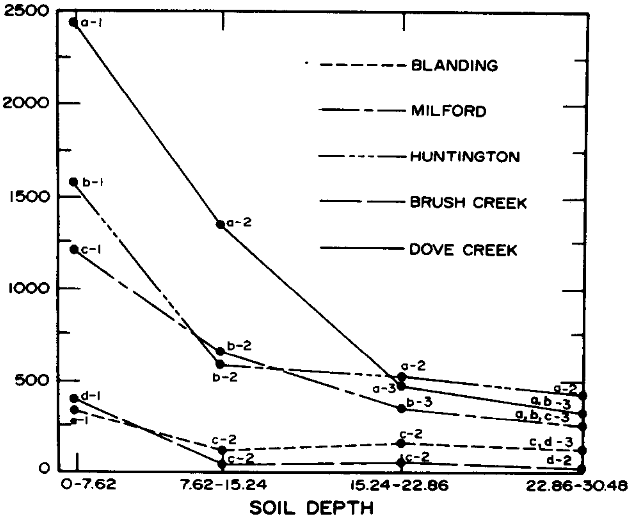

Fig. 2. *Plant production of the four subsoil treatments and surface control. Data pooled over two time periods. Lower case letters indicate significant differences among locations within a depth and numbers indicate significant differences among depths within a location at .05 level of probability.*

processes that occur in given proportions to one another. This accounts for the apparent correlation of both nutrient species. It appears that the variations in available nitrogen among study sites and treatment depths account for the site by treatment-depth interaction.

Transpiration Ratios

Results of this project segment indicated significant differences in transpiration ratios for treatment depths and for study sites. Figure 4 graphically illustrates differences in transpiration ratios with soil depth as pooled over both sites. Pooled over all treatment depths at both sites the average transpiration ratio for the Blanding site was 4,024 and for the Milford site was 3,214. As fertility decreased, the transpiration ratio increased, meaning that more water was being required per gram of plant material produced.

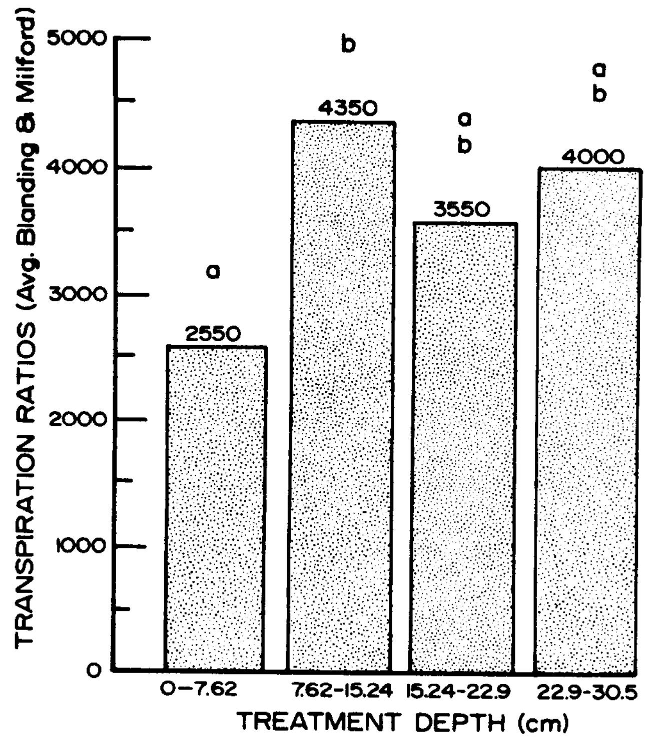

Fig. 4. *Transpiration ratios for the four treatment depths as pooled over both locations. Any bars with the same subscript are not significantly different at the .05 level of probability.*

Transpiration ratios appear to be highly correlated with soil nitrate nitrogen (Fig. 5). Correlation coefficients of -0.89 and -0.94 were obtained for the Blanding nd Milford sites, respectively, both of which are significant at the 95% level.

The reason for the increased consumption of water by

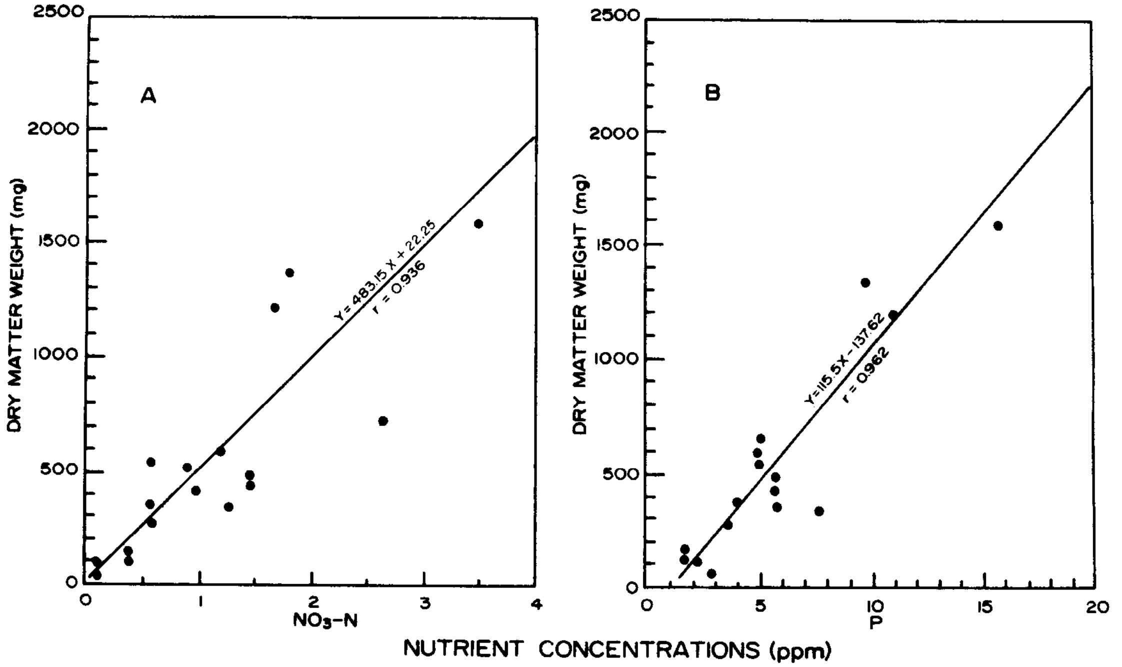

Fig. 3. *Relationship of plant production to nitrate nitrogen and phosphorus concentration of the soil. Both regressions are significant at .05 level of probability.*

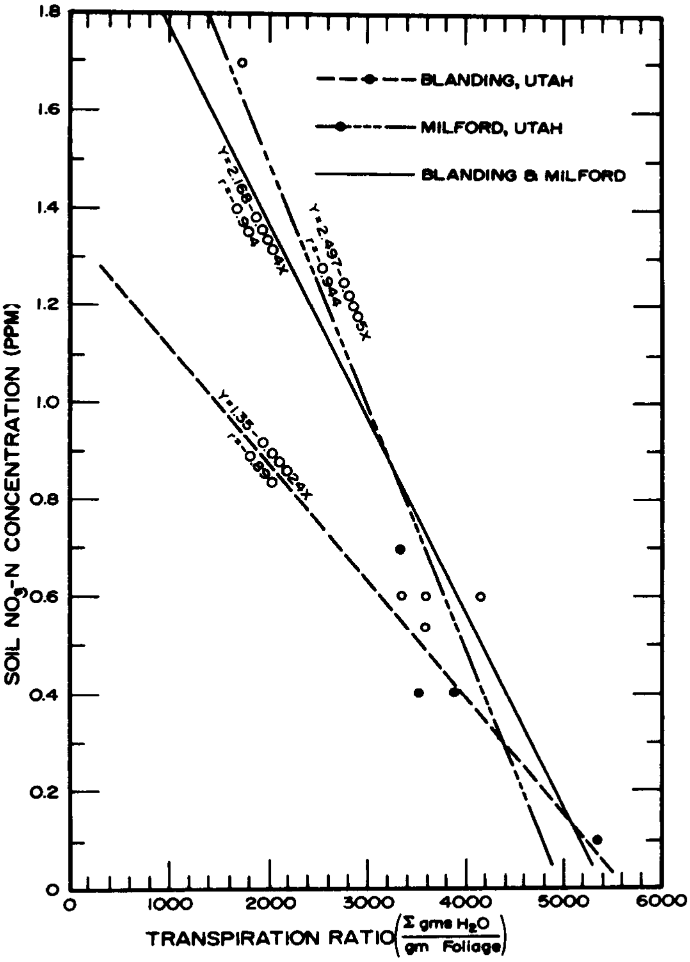

Fig. 5. *Correlation between transpiration ratios and nitrate nitrogen concentration. Regressions are significant at .05 level of probability.*

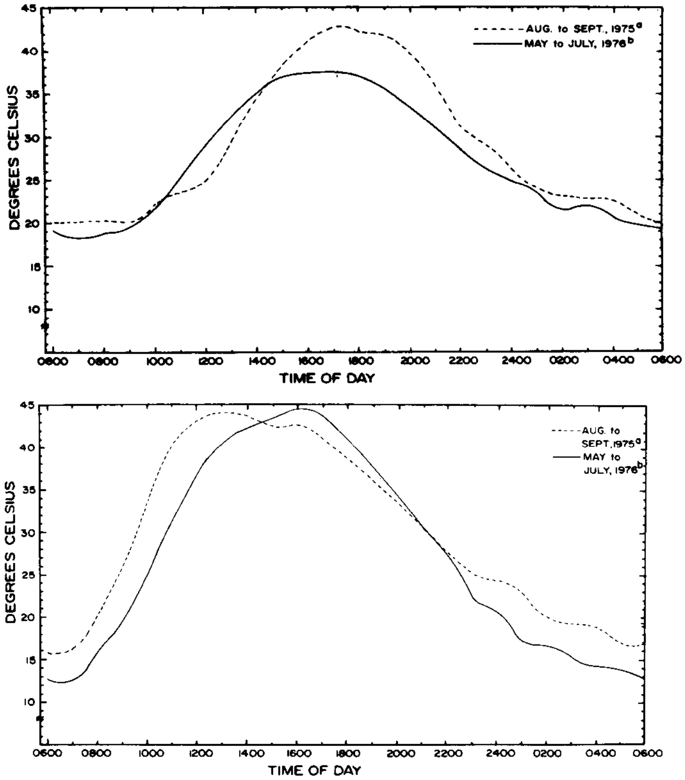

Fig. 6. *Top: average daily soil temperature distribution at a depth of 3 cm for the Blanding site during 1975 and 1976. Bottom: same for the Milford site during 1975 and 1976.*

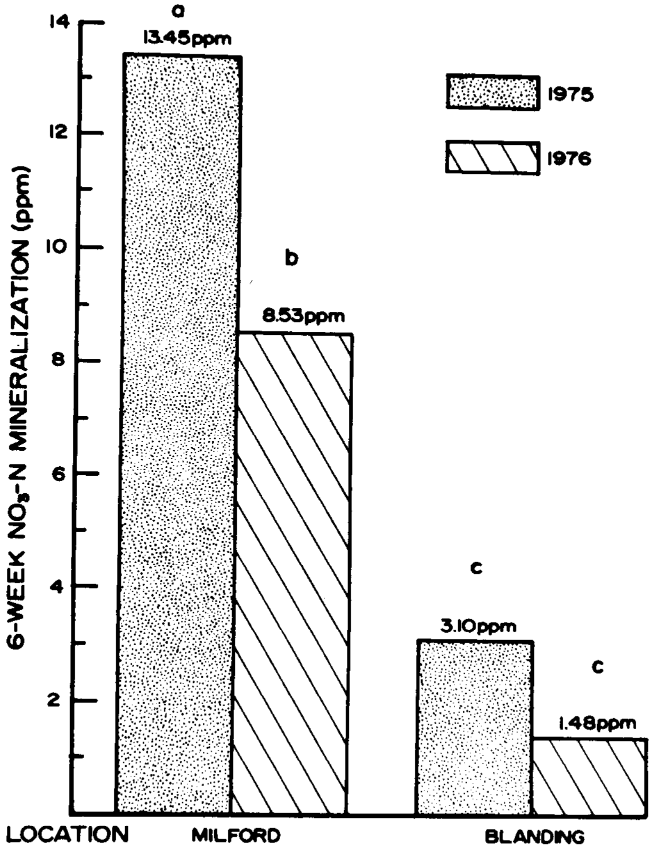

Fig. 7. *Yearly variations in NO₃-N mineralization rates within each study site. Lower case letters indicate significant differences at the .05 level of probability.*

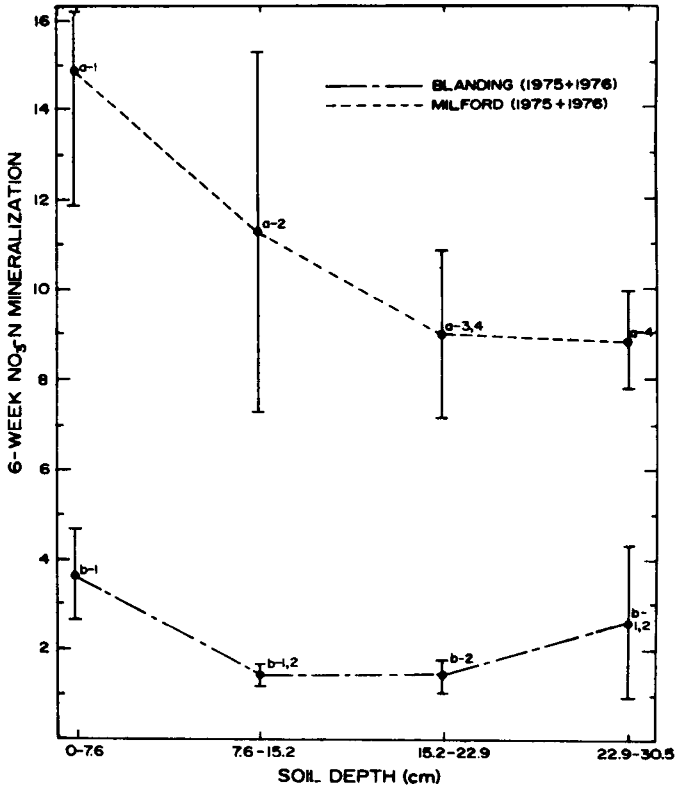

Fig. 8. *Average NO₃-N mineralization rates for each of the 7.6 cm layers of soil profile. Lower case letters indicate significant differences between locations within a given depth increment and numbers indicate significant differences among depths within a location at the .05 level of probability.*

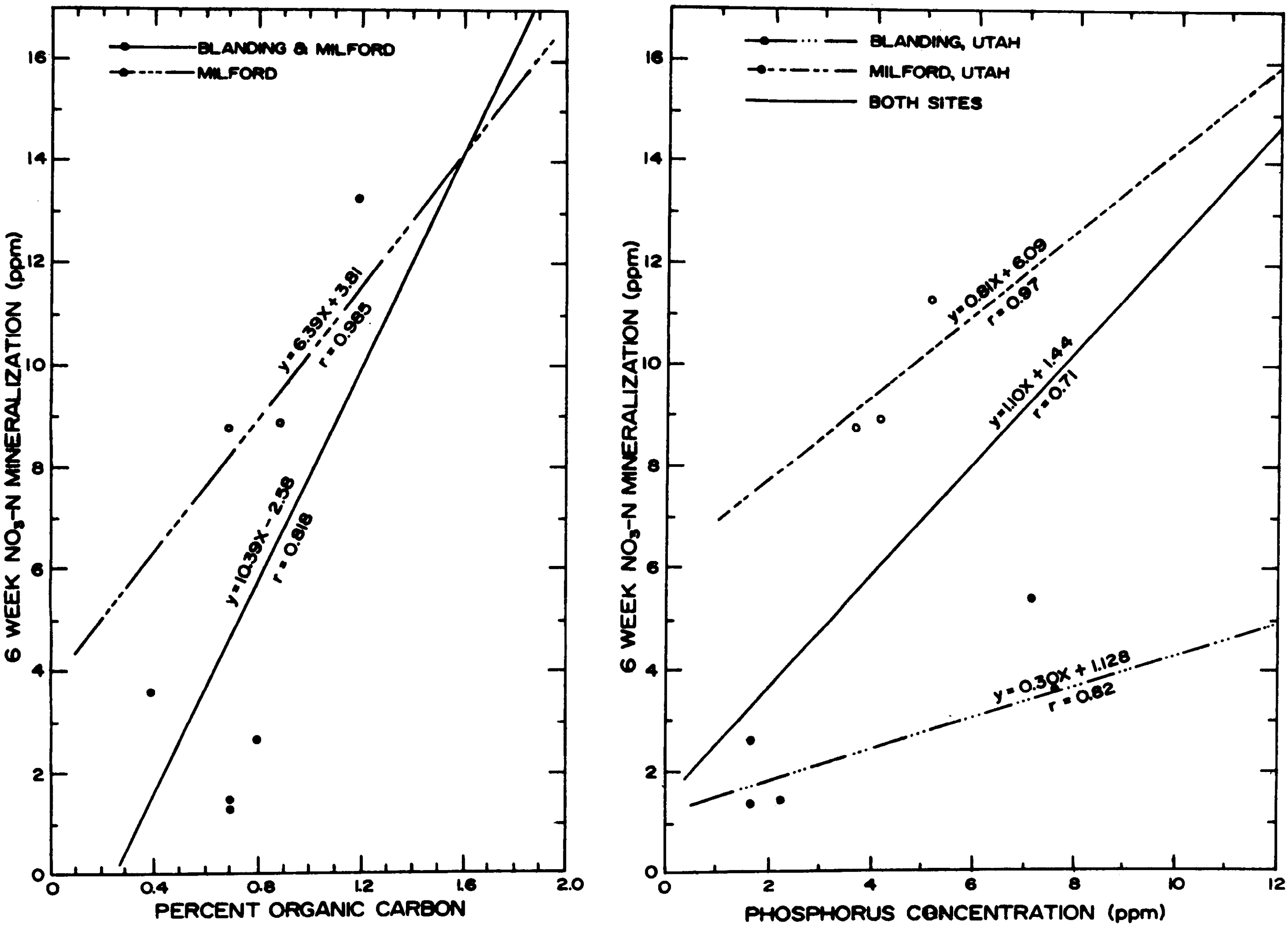

Fig. 9. *Correlation between NO_3-N mineralization and percent organic carbon (left) and phosphorus (right) in the soil. Regressions are significant at .05 level of probability.*

plants grown in nutrient-deficient soils is not fully understood. Tradition would dictate that transpiration is controlled by physical parameters when water is not a limiting factor. Debreczeni and Debreczeni (1974) have shown that nitrogen is the primary nutrient affecting transpiration, as well as photosynthesis. The Debreczenis theorized that the transpiration process of plants in nitrogen-deficient soils may increase as a way to cause increases in water flow toward the roots, which in turn would facilitate the movement of ions to the root surfaces.

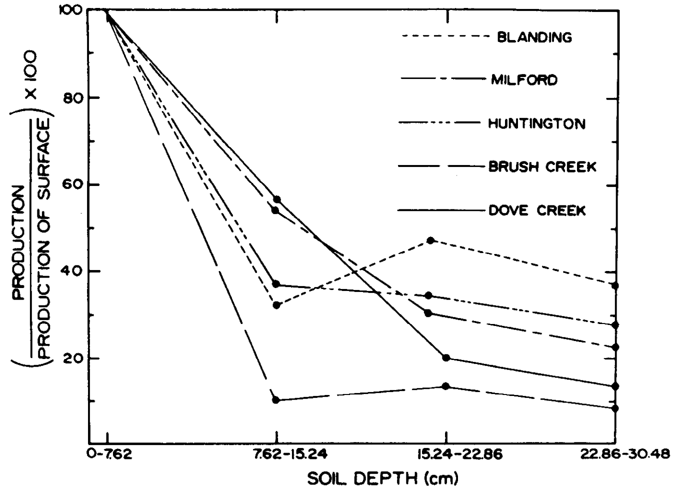

Fig. 10. *Percent of production from subsoils as compared to production of the surface control.*

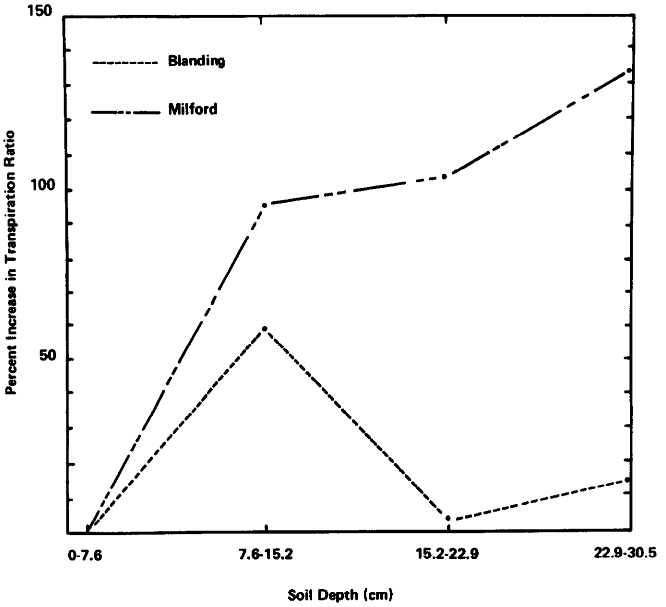

Fig. 11. *Percent increase in transpiration ratios as a function of soil depth.*

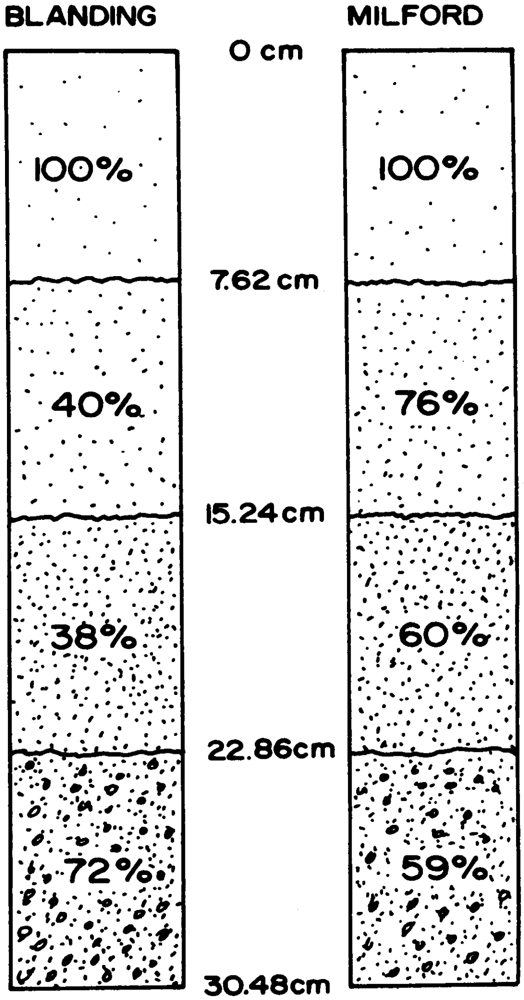

Fig. 12. *Schematic profiles showing relative NO_3-N mineralization of the subsoils as compared to surface soils of the two study sites.*

Nitrogen Mineralization

Analysis of our nitrogen data revealed a significant year by site by treatment-depth interaction. We attribute the significant differences in the mineralization rates between years primarily to concomitant variations in average soil temperatures (Fig. 6). In the second season, soil temperatures averaged lower than in the first season, which corresponds to the variations in nitrate nitrogen mineralization rates illustrated in Figure 7.

The site by treatment-depth interaction was also significant (Fig. 8). Good correlations were obtained at the 95% level (especially for the Milford site) when comparing the amount of nitrate nitrogen mineralized over a 6-week period with both the percent of organic carbon and the phosophorus concentration (Fig. 9). Correlations between the entities that add to soil fertility, including organic carbon, phosphorus, total nitrogen, etc., were expected to be high because of the effects of these factors on the microbial populations that are responsible for the mineralization processes. The correlation coefficient for percent organic carbon for the Blanding site (not shown in Fig. 9) was 0.67, significant at only the 80% level. The correlation coefficients obtained for the average of the sites illustrated in Figure 9 were significant at the 95% level.

Summary and Conclusions

Our results indicate that significant decreases in plant production and significant increases in the amount of water required to grow each gram of vegetation occur when the top 7.6 cm layer of surface soil is removed. Plant production on the better sites decreased by about 45% and by 65 to 85% on the less fertile sites (Fig. 10). The amount of water required to produce a gram of above-ground biomass increased by 60-95% when the top 7.6 cm soil layer was removed (Fig. 11). In semiarid areas where soil moisture is usually the limiting factor during the growing season, such an increase in water requirements could be very significant to the survival of the existing plant community.

Our nitrogen mineralization values were significantly lower than those reported by other investigators, who measured nitrogen mineralization "potentials," optimizing all of the known variables involved in the mineralization process. The values obtained in this study were nitrogen mineralization rates of natural soils under natural environmental conditions.

The nitrogen mineralization results varied between the Blanding Milford sites (Fig. 12). Only the third incremental soil layer (15.2-cm to 22.9-cm layer) at the Blanding site gave significantly different results than did the surface layer. Because concentrations of organic carbon are greater in subsoils than in surface soils, subsoil layers have a greater potential to mineralize more nitrate nitrogen than does a surface layer. Because of the lower fertility in our subsoils, however, the microbial populations necessary to achieve this potential evidently did not exist. The end result was a nonsignificant decrease with depth in nitrogen mineralization rates at Blanding. The Milford site showed a significant decrease in mineralization rates between the surface layer and the second incremental layer, and between the second and third incremental layers.

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