Increasing demands for water, forage and wildlife have increased emphasis on multiple-use management of forest lands. Such management requires a much fuller understanding of the forest ecosystem and the effects which disturbances such as fertilization have on it. This paper will review some of the potential impacts of forest fertilization on forage, wildlife and water and is based primarily on results of recent research at Fort Myers, Florida; Tifton, Georgia; and the Coweeta Hydrologic Laboratory, Franklin, North Carolina.

Forage

Fire has been the primary method of improving nutrient content of native forage in the pine-wiregrass (Pinus elliottii-Aristida stricta) ecosystem. Both N and P are high in forage emerging on recently burned areas (Hilmon and Lewis, 1962). However, these benefits are short-lived. For example, the P content of Aristida stricta dropped from 0.14% 3 weeks after a fire to 0.01% 1 year later. At their best, P and Ca levels in native plants are below minimal needs of cattle, and supplemental minerals must be fed. When forage and timber are combined in a management program, nutrient problems are intensified because fire must be eliminated for several years after trees are planted.

The low P content of fine sand soils in the ecosystem and the potential limiting effect this deficiency might have on integrated forage-timber management stimulated interest in the effects of rock phosphate on native plants. Killinger (1938) had reported higher P content of “wiregrass” from phosphated plots. In June 1959, 1 or 2 tons per acre of ground rock phosphate (31% P₂O₅, 48% CaO) were applied to cross-chopped and unchopped cutover pine-wiregrass range in southern Florida. South Florida slash pine (Pinus elliottii var. densa) was planted on all plots the following winter. Treatment effects on herbage yield and quality, utilization by cattle, saw palmetto (Serenoa repens) cover, and tree growth were studied intensively over a 5-year period.

Herbage quality.—Phosphorus and Ca levels were higher in the foliage of all species or groups of native plants sampled on phosphate plots. The magnitude of the response varied considerably. Phosphorus in goobergrass (Amphicarpum muhlenbergianum) ranged from 0.04 to 0.07% on unfertilized plots and from 0.42 to 0.59% on phosphate plots. Aristida stricta showed the least response; P levels were 0.03% on the unfertilized plots and from 0.11 to 0.16% with phosphate. Phosphorus levels in bluestems (Andropogon spp.), panicgrasses (Panicum spp.), and “other herbage” were midway between those presented for Aristida and Amphicarpum. With the exception of Aristida stricta, all herbage on the phosphate plots met minimum P and Ca requirements for proper cattle nutrition. The improvements in herbage quality were achieved with 1 ton per acre of rock phosphate; no significant increases in P or Ca were realized by adding the second ton. Phosphorus and Ca levels have remained high for 5 years. Similar responses to rock phosphate were found on chopped and unchopped sites.

Since Aristida stricta is the most abundant native forage plant, another experiment was designed to test whether fire would increase P uptake by this species on phosphate plots. A ton per acre of rock phosphate was applied in July 1962. One year later, Aristida foliage contained 0.10% P. One-half of the plots was burned in November 1963; and the other half, in February 1964. One month after each fire, P in Aristida exceeded 0.20%. At times during the following year, P levels in Aristida were near 0.30%.

Herbage yields.—Total herbage yields over 5 years
were 3.1, 5.7 and 6.5 tons (oven-dry) per acre on areas treated with 0-, 1-, or 2-tons per acre of rock phosphate. Only during the first year after treatment did the 2-ton treatment out-yield the 1-ton treatment. In 1960 yields were 0.8, 2.0 and 3.0 tons per acre for the three treatments, respectively. All of the increase in yields was in non-wiregrass components. In fact, yields of Aristida declined slightly where P was added.

Although the general study area was stocked moderately with cattle, they concentrated on the phosphate plots and heavily utilized the forage produced. For example, 95 to 97% of the non-wiregrass forage was used the first year. Subsequent yields were probably reduced as a result of the heavy use. Abusive use could be avoided on larger tracts by adjusting stocking to the capacity of the fertilized areas or by rotational grazing on small areas.

Considerable cattle damage to planted pines occurred the first year after planting. Both chopping and phosphate treatments attracted cattle, and pine survival was reduced about 12% as a result of either or both treatments. Despite some early browsing on surviving trees, pines on the phosphate plots were 25% taller than those on unfertilized plots after 5 years. Other studies have shown cattle damage can be avoided if moderate or light animal stocking is adjusted to the capacity of the fertilized areas by rotational grazing on small areas.

Shrub competition.—Saw palmetto was the dominant shrub on the Florida study area. Crown coverage was 10.4% in 1959. Chopping reduced coverage to 0.5%. After 5 years, palmetto coverage on the unchopped plots had increased to 20.8%—a natural trend where fire is excluded. On the unchopped plots which received rock phosphate, palmetto coverage was 43.3%; the rate of coverage increase was about double that on unfertilized plots. The rate of increase was similar on 1- or 2-ton phosphate plots.

Coverage of saw palmetto on the chopped plots was 3.8% after 5 years and no significant difference in coverage between fertilized and unfertilized plots was measured. These results indicate a need for some method of palmetto control where rock phosphate is applied. Control could be achieved by chopping prior to or coincident with fertilization. In older pine stands, fire could be used to reduce the rate of shrub increase.

Intensive Pine-Forage Culture

Some of the interactions between forage and timber in intensive-management situations are being studied at the Georgia Coastal Plain Experiment Station, Tifton. A long-term study of the integration of livestock and timber production on intensively managed pastures was started in 1957 (Hughes et al., 1967). Twenty-four 2-acre units in the lower Coastal Plain were renovated and planted to slash pine in February 1957. Trees were cultivated for 3 years; and then Coastal Bermudagrass (Cynodon dactylon) was sprigged and carpetgrass (Axonopus affinis), prostrate dallisgrass (Paspalum dilatatum) and Pensacola Bahia (Paspalum notatum) were seeded. Pastures were established without trees and with trees planted 12 x 12 feet and 20 x 20 feet. The annual fertilization rate has been 100-50-50 pounds per acre of N-P2O5-K2O.

Grazing was begun in 1961 when trees were 4 years old and averaged 12 feet tall. Lateral branches were pruned to a height of 8 feet in January 1962. Accumulations of pine straw and grass litter have been removed by burning annually in late winter. Weedy growth has been controlled by application of a selective herbicide in the spring or by clipping at intervals during the summer growing season.

Seven years from planting, slash pine growing in fertilized pastures in this study had an average survival of 73%, a height of 24 feet, and a diameter of 5.8 inches. Comparable seedlings set in an undisturbed, unfertilized, cut-over site had an average survival of 92%, a height of 14 feet, and a diameter of 3.2 inches.

Liveweight gains of cattle (1961 - 1963) averaged 238, 191, and 154 pounds per acre for pastures with no trees, trees spaced 20 x 20, and trees spaced 12 x 12 feet, respectively. Comparable gains have continued through plantation age 9. Pensacola Bahia and Coastal Bermudagrass appeared to be the best grasses and carpetgrass the poorest under the conditions of this experiment.

A number of problems have been encountered in attempts to grow trees and improved grasses together under intensive management. Young, fast-growing pines are more susceptible to attacks of insects and disease. The increased rate of tree growth may be partially offset by a reduction in tree numbers. The presence of pines in pastures reduces the production of forage and beef. As the trees grow larger and the canopy closes more completely, this reduction may be expected to increase until there will be little grass left (Burton et al., 1959). Recent research suggests that Pensacola Bahia is more shade tolerant than some other improved grasses.

Other intensive-culture research at the Coastal Plain Station is exploring possibilities of cutting hay in pine-pasture plantations during the early years when cattle might damage trees. Tree spacing configurations which may extend the period of high forage production are also being explored.
Wildlife

Potentially, forest fertilization can affect the yield and nutrient content of wildlife food plants, their composition in the forest, and the rate of succession. Specific information, however, is lacking on these effects. Only one attempt has been made to determine soil fertility standards for game food plants. In Wisconsin, Wilde (1946) collected soil samples from areas supporting vigorous and bearing trees and shrubs of the desired species. This survey indicated the state had large areas of soils in a critical state of fertility, so far as some game food plants were concerned. Indirect evidence, such as increases in nutrient content of browse plants after fire (DeWitt and Derby, 1955) and increased seeding of fertilized forest trees (Chandler, 1938), indicates a potential improvement in wildlife food through fertilization.

The potential for unfavorable response must also be recognized. For example, squirrels preferred cones of fertilized slash pines over cones of unfertilized trees in a Florida seed orchard (Asher, 1963). Other data from this study showed cone losses from all causes were significantly greater in the fertilized plots than in the controls, suggesting that insects also prefer cones from fertilized trees. A study of effects of fertilizers on conifers in New York (Heiberg and White, 1951) showed trees fertilized with KCl were strongly preferred for food by the varying hare (*Lepus americanus americanus*).

These examples illustrate a strong potential wildlife reaction to fertilization, beneficial in some cases and detrimental in others. Further research should fully define the potential response of wildlife to forest fertilization.

Water

Specific information about effects of forest tree fertilization on water yield and quality is quite limited. However, conversion of an Appalachian hardwood forest to grass provides information useful in anticipating the effect forest fertilization may have on water yield, particularly when considered in relation to findings from other water-yield experiments. Moreover, results from studies of use of forest soil as a filter for the renovation of high nutrient content sewage effluent bear directly on the question of how fertilization affects water quality. These allied studies provide clues to expected impact of tree fertilization on quality and quantity of streamflow.

*Water yield.*—At the Coweeta Hydrologic Laboratory in the Appalachian Mountains of western North Carolina, a 22-acre, steeply sloping watershed was converted from a poor quality white oak-red oak-hickory cover (Type 44, Forest Cover Types of North America) to Kentucky 31 fescue (*Festuca arundinacea*) between May 1958 and April 1960. Basal area per acre was 95 square feet per acre prior to the conversion. Annual precipitation averages 73 inches, and 33 inches of this total leaves as streamflow. In the conversion to grass, trees were cut, piled, and burned and the soil surface was scarified, fertilized, limed, and planted to grass. Fertilization rates were 3 tons of ground limestone and 40, 106, and 200 pounds per acre elemental NPK. A topdressing of 23 pounds per acre of N was added during the first summer to correct N deficiency and a dense, luxurious grass cover was secured (Fig. 1).

The first year after the watershed was completely under grass, dry weight of living and dead grass averaged 3.5 tons per acre, and water yield (Fig. 2) was 0.67 inch less than yield from the original forest.

![Fig. 1. This 22-acre steep Southern Appalachian watershed was converted from forest to grass. By withholding or adding fertilizer, annual water yield was varied over a 6-inch range.](image-url)
bottom of the forest and height growth. Evapotranspiration should increase in the denser stand and water available for streamflow should decrease. In regions which receive precipitation almost entirely during the dormant season, fertilization might have no effect on water yield if stands normally dry soils to wilting during the growing season. Available water might simply be exhausted more rapidly with no net change in water yield. But even in these regions, if more rapid water use by vegetation shortens the time soils contribute moisture to ground water or streamflow, yield could be reduced. Even small reductions in yield in areas already critically short of water might be more important than larger reductions in regions having a water surplus. However, because the range of fertilizer treatments, cultural practices, species, climate, and soils varies infinitely, it is impossible to quantify the magnitude of an expected yield change.

Water quality.—Fertilizer is a potential source of pollution if it reaches streams in sufficient quantities to impair quality of agricultural, domestic, or industrial water. The beneficial effect of a good forest cover on infiltration is widely recognized, and for the most part, overland flow in upland forests is unusual.

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1 The basis for predicting yield changes is a month-by-month regression of flow from the treated watershed against flow from the control watershed when each was under stable hardwood cover. After treatment, the deviation of actual from predicted flow is attributed to the conversion to grass. Actual minus predicted monthly flow and variance of the yield increase summed for the year provide estimates of annual yield change and its error. The prediction error on an annual basis averages about 0.7 inch at the 0.05 probability level.
To reach streams, salts must leach through the soil and evidence indicates that appreciable contamination in this manner is unlikely.

Most forest soils are considered excellent filters because they have reasonably high exchange capacities for most commonly used fertilizers and because the trees take up and recycle the elements. This is best illustrated by research at Pennsylvania State University where treated sewage effluent rich in nutrients has been sprayed on forest and agricultural crops at rates of 1 to 2 inches per week during the growing season since 1963 (Sopper and Sagemuller, 1966). The concentration of alkyl benzene sulfonate (ABS), a constituent of detergents difficult to remove from water by conventional treatment methods, in the effluent was from 4 to 9 times greater than maximum allowable standards for drinking water set by the U. S. Public Health Service; but the nitrate N, Mg, and chloride concentrations were within allowable limits. At a 2-inch weekly irrigation rate, the total pounds of constituents applied to a red pine plantation in 1963 and 1964 per acre were as follows:

<table>
<thead>
<tr>
<th>Elemental Constituents</th>
<th>June 16-Dec. 5, 1963</th>
<th>April 8-Nov. 18, 1964</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>31</td>
<td>27</td>
</tr>
<tr>
<td>Nitrate nitrogen</td>
<td>52</td>
<td>202</td>
</tr>
<tr>
<td>Organic nitrogen</td>
<td>72</td>
<td>54</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>88</td>
<td>116</td>
</tr>
<tr>
<td>Potassium</td>
<td>146</td>
<td>234</td>
</tr>
<tr>
<td>Calcium</td>
<td>340</td>
<td>449</td>
</tr>
<tr>
<td>Magnesium</td>
<td>195</td>
<td>242</td>
</tr>
<tr>
<td>Sodium</td>
<td>490</td>
<td>527</td>
</tr>
<tr>
<td>Chloride</td>
<td>469</td>
<td>590</td>
</tr>
</tbody>
</table>

The 1964 application rate was equivalent to approximately 2500 pounds per acre of 10-10-10 fertilizer.

Water samples collected at the 12-inch soil depth showed a 98% reduction in ABS concentration. Nitrate N and organic N were reduced 68 and 75%, respectively, and less than 1% of the P reached 12 inches. Concentrations of K, Ca, and Mg were reduced 75, 77, and 88%, respectively. Of the constituents applied, lowest renovation was obtained for nitrate N, Na, and chloride, constituents which are not appreciably absorbed by the soil. Average concentration of all constituents in the percolate at 12 inches was considerably less than allowable limits set by the U. S. Public Health Service.

Four inches of effluent per week were applied in a hardwood forest, and Pennypacker et al. (1967) report that most changes in concentration of P and K percolate occurred in the top 12 inches, whereas ABS, nitrate N, Ca, Mg, Na, and chloride equilibrated at about 48 inches. Organic N did not appear to equilibrate and was still being renovated at 72 inches.

Available information indicates that careful application of usual fertilizers to upland forested watersheds does not constitute a pollution hazard if water reaches the stream by moving through the soil. By maintaining a buffer strip of perhaps 10 to 20 feet on either side of the stream, water quality can be preserved. However, information on movement of many elements through soil is not available and requires further study. Also forested flood plains and low-lying coastal areas which flood periodically are in a different category. The extent to which fertilizers are washed into streams from these areas and the resulting effect on water quality are unknown at this time.

Summary

The impacts of fertilizers on forest ecosystems are considerable and reach far beyond effects on tree species. Yield and quality of cattle forage and wildlife food plants may be increased significantly by fertilization. These beneficial responses may be partially offset by animal damage to trees. Composition of plants in the understory may be altered; in fact, the rate or even direction of plant succession may be affected. For example, shrubs competitive for forage or tree seedlings sometimes increase rapidly after fertilization. On upland forest ecosystems, at least, water yield may drop sharply after fertilization, but most available evidence indicates water quality is unaffected. The complex effects of fertilizers on the forest ecosystem certainly need further study.

Literature Cited


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