EFFECTS OF FERTILIZATION ON UNDERSTORY VEGETATION

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ABSTRACT

The understory component of a forest stand is important for various reasons including its potential utilization, its effects on the growth of the tree overstory component, and its relation to various environmental factors. The mass and species composition of the understory component can change rapidly with time and hence potential effects have been assessed in relation to the stage of understory development. Two main effects of forest management practices that have been considered are the direct chemical effects of fertilization and the effects of changes in the overstory as a result of fertilizer applications.

INTRODUCTION

The aim of this paper is to indicate the types of changes that may occur to the understory component of forest stands when fertilizers are applied to coniferous ecosystems. In order to provide a background to such changes, the structure and some of the dynamics of the understory will be described.

The constituents of the understory of a forest stand can be defined in various ways. Here the understory of older stands is taken as trees less than breast height, shrubs, ferns, herbs, and mosses; that is, anything for which a diameter at breast height is too small to be measured. In younger stands, before the trees have reached breast height, everything is potentially understory—so understory is regarded as anything not the desired tree species.

IMPORTANCE OF UNDERSTORY

The understory component of a forest stand is important for various reasons such as its potential utilization, its effects on the growth of the tree overstory component, and its relation to various environmental factors. These three aspects will be discussed in further detail.

THE UNDERSTORY AS A PRODUCT

Understory may be of interest as a product either for its own intrinsic properties (for example, floral material, drugs, essential oils, berries, tanning materials, forage for animals) or for its aesthetic values. The value of these is a function of the forest type and location but, as quantity and quality are important, fertilization can have a significant effect on both. Hilman and Douglass (1968) reviewed the effect of forest fertilization on the herbage production potential of forests, and concluded that both quantity and protein production of grasses were increased in a series of southern pine forests. These changes were critical for animal forage in the area.

EFFECTS ON TREE GROWTH

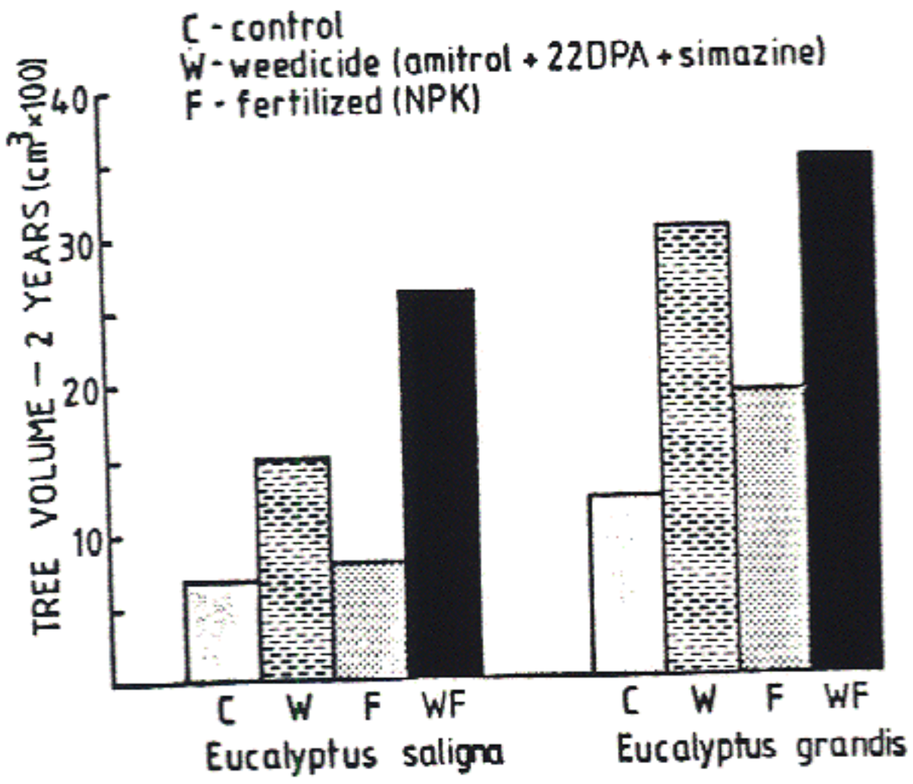
The negative effects of understory on tree growth are those usually studied, especially in young stands. They are the result of direct competition for water, light, or nutrients, or can be the result of allelopathy. Weed removal results in marked growth response in young coniferous plantations and a positive interaction between weed removal and fertilizer applications can be shown (Table 1), although it has proved difficult to isolate causal factors. Similar effects have been found in *Eucalyptus* spp. plantations (Figure 1). There was an added effect when weeds were removed by the use of triazines, which appeared to stimulate N uptake directly (Conner and White 1968). Powers and Jackson (1978) have indicated that the dense understory had to be removed from young, dry area *Pinus ponderosa* stands before responses to N were achieved.

Table 1. Effect of weed control on the growth of planted *Pinus radiata* at Green Hills, New South Wales, Australia.

Treatment	Ht at 1 yr (cm)
Nil	44
Hand weed control	56
Hand and chemical[a] weed control	64
Hand and weed control plus fertilizer[b]	70
$L.S.D._{0.05}$[c]	9

[a]Atrazine. [b]3.6 g N per tree as ammonium sulfate plus 3.3 g P per tree as superphosphate. [c]$L.S.D._{0.05}$ = least significant difference between means at the 5% level.

Figure 1. Volume response at 2 yr following applications of weed control and fertilizer at age 1, *Eucalyptus saligna* and *Eucalyptus grandis* (from Cameron and Turvey 1977).



The presence of the understory can exert a beneficial effect on tree growth, which can arise from the maintenance of nutrient availability and can best be seen in areas where the understory has been manipulated. For example, *Pinus radiata* (D. Don) has been planted on yellow-brown sands that occur on the west coast of North Island, New Zealand. The trees planted on these sands benefit from association with marram grass (*Ammophila arenaria* L.) and perennial tree lupine (*Lupinus arboreus* Sims), plants that are used to stabilize the sand before forest establishment.

The bulk of N used by the pines on these sands is fixed from the atmosphere by the lupine plants through their symbiotic association with the bacterium *Rhizobium lupini*. Vigorous plants growing among marram grass can fix at least 160 kg/ha N during the first year of growth from seed (Gadgil 1971). Lupines are shaded out as the pines develop, but subsequent thinnings cause a regrowth of lupines thus further increasing the N supply (Gadgil 1976, Mead and Gadgil 1978). The response of the pines to the lupines compared with N fertilizer (Table 2) indicated that lupines have the potential of stimulating pines on these sites.

In a series of Douglas-fir stands located in western Washington, ranging in age from 22 to 73 yr, the understory aboveground biomass and litter returns represented a significant portion of stand organic matter before crown closure, but decreased in importance as the stand increased in age (Turner and Long 1975). While the understory represented only a small proportion of the organic matter distribution (less than 5% of the standing plant biomass), it constituted a significant proportion of the total productivity (up to 17%) and an even higher proportion of the organic matter that was returned to the forest floor (up to 43% of total return). There were significant differences in nutrient contents (Table 3) and concentrations between understory species in that some species rejected certain nutrients and accumulated others.

ENVIRONMENTAL CONSIDERATIONS

Many understory species establish rapidly on areas that have been disturbed by procedures such as logging, fire, and establishment clearing (Dyrness 1973). The result of this process is usually a reduction in erosion and nutrient losses. Species occupying a site immediately after disturbance often have high nutrient demands, or at least an ability to accumulate high concentrations of nutrients. Data obtained from Australian wet

Table 2. Average diameter at breast height 9 yr after establishment and basal area for *Pinus radiata* on N-deficient sands in New Zealand, showing growth response to lupines in comparison with N fertilizer (from Mead and Gadgil 1978).

Treatment[a]	Mean dbh[b] (cm)	Basal area increase between ages 10 and 18 (%)
Control	22.9[y]	239
P+K+B	21.8[y]	248
N+P+K+B	24.1[x]	319
Lupines + P+K+B	24.4[x]	307
Lupines + N+P+K+B	24.1[x]	300

[a]115 kg/ha N, 50 kg/ha P, and 50 kg/ha K applied at 10 yr of age and 112 kg/ha P and 9 kg/ha B applied at 16 yr of age. [b]Means followed by the same superscript letters do not differ at $P \leq 0.05$ using Duncan's test.

Table 3. Nutrient contents (in kilograms per hectare) of the understory species in a series of Douglas-fir stands in western Washington listed according to increasing stand age (from Turner et al. 1978).

Stand age (yr)	Component	Organic matter	N	P	K	Mn
9	Salal	4680	40	10.0	42	5.9
	Other vascular	590	6	1.3	9	0.1
	Moss	60	1	0.1	1	0.03
22	Salal	6300	46	5.1	40	6.3
	Other vascular	1208	21	3.5	20	0.2
	Moss	30		0.1		0.01
30	Salal	4112	40	4.0	17	8.6
	Other vascular	376	6	1.0	6	0.2
	Moss	563	3	0.9	3	0.3
42	Salal	3394	28	2.8	6	4.4
	Other vascular	524	9	0.8	6	0.4
	Moss	320	2	0.5	2	0.1
73	Salal	1110	7	0.8	5	3.3
	Other vascular	147	2	0.4	3	0.1
	Moss	1575	9	3.5	7	1.9
95	Salal	176	2	0.1	1	0.5
	Other vascular	23		0.1		0.1
	Moss	1002	7	1.9	5	1.7

sclerophyll forests (Turner and Lambert 1977) showed that understory species invading a site immediately after a fire had very high concentrations of N and K (Table 4). The concentration of K in the ash was relatively high and this was reflected in the K concentrations in the *Amaranthus* and *Bidens* spp. The high N concentrations in these species were probably a function of the increased soil ammonium-N levels immediately after the fire (Humphreys and Lambert 1965). These effects could be intensified by application of fertilizers at the time of disturbance. The data for U.S. southern pine forests from Hilman and Douglass (1968) showed that grasses on unfertilized plots had 0.04%–0.07% P while those on fertilized plots had 0.42%–0.59% P.

Early colonizing species also often have very high productivity and particular components of the ecosystem can be stabilized rapidly after disturbance (e.g., the forest floor). In plantations of *Eucalyptus grandis* in New South Wales, Australia, the forest floor reached its equilibrium weight at 2 yr of age, although the relative composition of the various components changed with age (Bradstock, Sydney Univ., pers. commun. 1979). Hence an accumulation of nutrients in the understory and litter components indicates that these components have an important role in nutrient conservation.

UNDERSTORY DEVELOPMENT

After disturbance various species become established, the species and density involved depending upon the seed source and the form of disturbance. Some of these species may have a life span of only 1 or 2 yr and are replaced by other, more enduring species (Dyrness 1973). The understory changes in composition and mass with increasing stand maturity. The actual composition at any given time depends upon the stand history, quality, age, and stocking. Associated with these factors there are simultaneous changes in the nutrient composition of the various species.

As a case study, the development of a relatively poor quality Douglas-fir stand can be described, the possible controlling factors suggested, and the potential effects of fertilizer applications inferred. Seven Douglas-fir stands ranging in age from 9 to 95 yr were selected and within them, by species, tree and understory biomasses were estimated (Turner and Long 1975, Long 1977). Two trends of direct interest were the decrease in the total understory biomass with increasing stand maturity and the decreasing importance of the vascular species (Figure 2). A relation between overstory foliar biomass and understory biomass was reported (Figure 3) and this was supported by data from other studies (Long and Turner 1975).

With time and overstory canopy development, salal (*Gaultheria shallon*) became the dominant understory species in terms of coverage and biomass. Diversity of the stand in terms of both richness and evenness was drastically reduced. With further development of the overstory, the importance of *G. shallon* was diminished and there was an associated increase in understory diversity. The data provided circumstantial evidence that the direction and rate of understory

Table 4. Nutrient concentrations (in percent) in foliage from selected understory species grouped according to relative predominance after fire (from Turner and Lambert 1977).

Species	N	P	K
Species present within 3 mo after fire			
Amaranthus hybridium	4.11	0.37	7.97
Bidens pilosa	3.09	0.29	4.55
Species present 1 yr after fire			
Acacia longifolia	3.43	0.24	2.09
Pteridium spp.	2.82	0.18	1.64
Species present 5 yr plus			
Persoonia linearis	1.12	0.18	0.58
Casuarina spp.	1.31	0.11	0.60
Species present after frequent burns			
Imperata cylindrica	0.73	0.08	0.71

Figure 2. Development of understory biomass and tree foliar biomass in a series of poor-quality Douglas-fir stands.

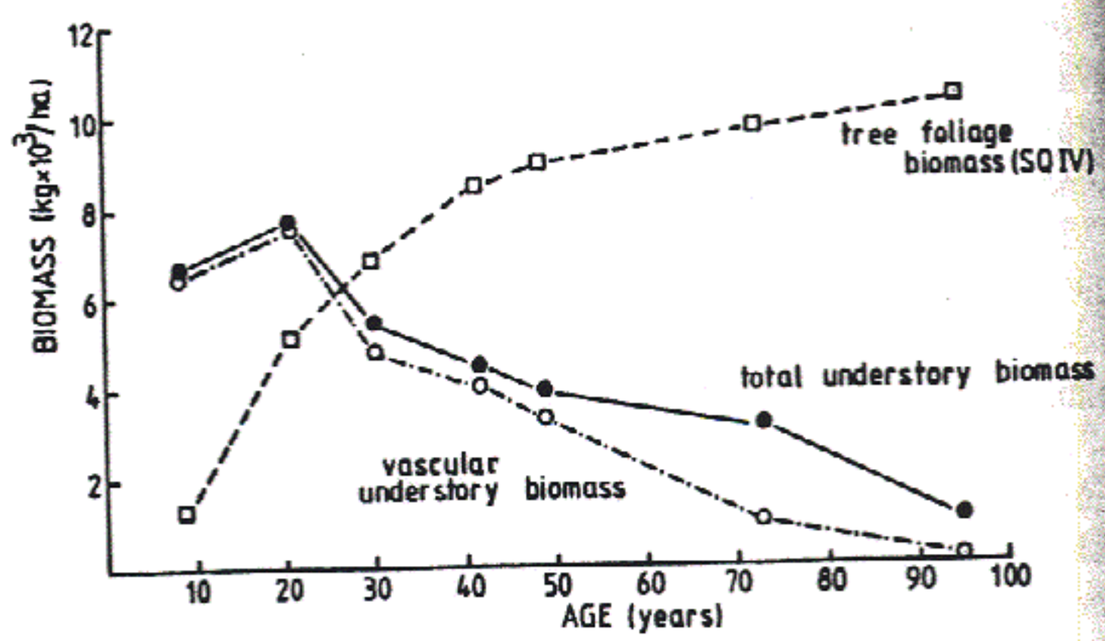
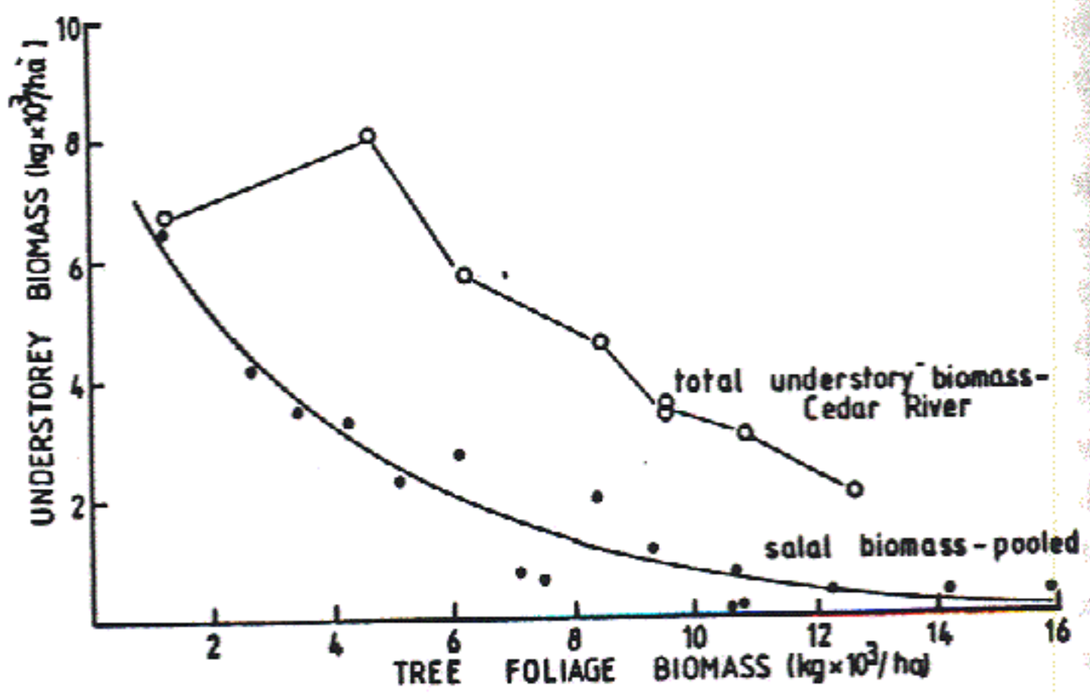


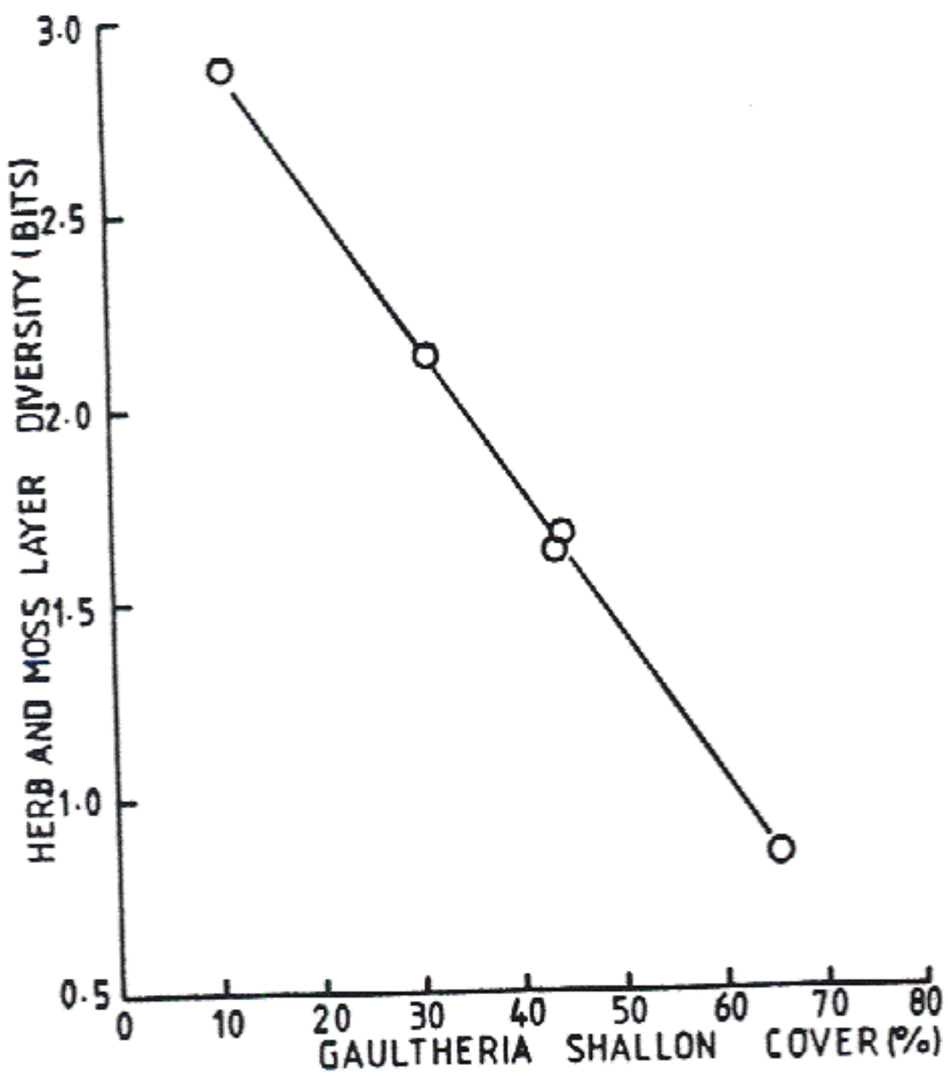
Figure 3. Relation between tree foliage biomass and understory biomass for a series of Douglas-fir stands western Washington (from Long and Turner 1975).



development were closely associated with the amount of foliar biomass supported by the overstory. Long (1977) showed that as the dominant understory species declined the diversity of the herb and moss layer increased (Figure 4). The maximum understory biomass did not occur in the open but in partial shade, that is where tree foliar biomass was between 3000 and 5000 kg/ha.

With increasing stand age, nutrient concentrations in the understory species changed, the changes differing according to species and nutrients. To obtain an overall assessment of the changes in nutrient concentration with increasing stand maturity, weighted mean nutrient concentrations for the understory species were reported by Turner et al. (1978; Table 5). The vascular plants (predominating in younger stands) tended to accumulate macronutrients while the mosses (predominating in older stands) tended to accumulate micronutrients. The weighted means for some nutrients showed some of the effects of this change. Nitrogen, for example, tended to have the maximum mean concentration near the time of maximum understory biomass.

Figure 4. The relation between herb and moss layer diversity in *Gaultheria shallon* cover (Long 1977).



EFFECTS OF FERTILIZER APPLICATIONS ON THE UNDERSTORY

Very little information is available on the effects of fertilization on understory components, particularly in established stands. Routine fertilizer plots are probably not suitable for such a study as the understory component is often suppressed at the time of establishment of the trial (even if only by trampling). Two main types of effect might be expected: (1) direct chemical effects of the fertilizers on the understory, and (2) indirect changes in the overstory as a result of the fertilizer application.

Direct chemical effects are a function of fertilizer type, quantity, season of application and stand condition. Nitrogen deficiency in a stand can be expected to be reflected in the N status of the understory species. Heavy applications of N (as urea), especially during the growing season, may have a toxic effect on all or some of the understory species, but no quantitative information is available.

Heilman and Gessel (1963) compared tree and understory biomass in fertilized and unfertilized Douglas-fir plots (Table 6). In most situations the effect of N fertilizer additions was to increase the N concentrations in the understory species. Growth was affected but there was insufficient detail concerning species composition to assess any changes.

One effect to be expected from fertilizer additions to a stand is an increase in tree foliar biomass (Turner 1977, Turner and Olson 1976). This is a result of both an increase in needle production and retention of older needle age classes. Both changes result in a decrease in light intensity available to the understory and in reduced litterfall. From Figure 2 it can be seen that even a temporary increase in tree foliar biomass causes a decrease in total understory biomass. Much of this is attributable to a decrease in salal biomass and, depending upon the magnitude

Table 5. Mean nutrient concentration for understory component of Douglas-fir stands in western Washington, calculated according to the relative biomass of each species (from Turner et al. 1978).

Stand age (yr)	Ash (%)	Concentration (%)					Concentration (ppm)			
		N	P	K	Ca	Mg	Mn	Fe	Na	Zn
9	7.77	0.78	0.134	0.92	0.86	0.27	824			
22	7.47	1.01	0.131	0.91	0.91	0.28	983	311	34	24
30	5.12	0.80	0.165	0.85	1.11	0.26	1629	398	53	24
42	3.20	0.90	0.136	0.85	0.70	0.18	1540	120	37	36
73	3.04	0.81	0.183	0.60	0.50	0.15	2428	536	44	28
95	2.89	0.78	0.161	0.62	0.41	0.14	2058	550	51	35

Table 6. Distribution of organic matter and N (in kilograms per hectare) and N concentration (in percent) for foliage and understory components in fertilized and control plots of Washington Douglas-fir (Heilman 1961, Heilman and Gessel 1963).

	Tree foliage		Understory			
	Organic matter	N	Organic matter Salal	Organic matter Total	N Content	N Concn.
Upper Pack (30 yr)						
Unfertilized	8 020	72	10 200	11 000	59	0.48
Fertilized	13 150	140	1 950	2 250	19	0.84
Lower Pack (38 yr)						
Unfertilized	8 000	78	950	1 330	10	0.75
Fertilized	14 170	148	220	740	4	0.54
Darrington (32 yr)						
Unfertilized	5 300	49	3 000	3 190	21	0.66
Fertilized	9 610	96	945	1 245	12	0.96
Matlock (38 yr)						
Unfertilized	8 980	87	1 825	1 840	10	0.54
Fertilized	16 150	232	3 000	3 030	20	0.66
Whidbey (52 yr)						
Unfertilized	11 950	126	22	26		
Fertilized	13 855	171	66	68	1	

of the decrease in total understory biomass, species such as *Pteridium aquilium* may be almost completely eliminated. Also, depending upon the response time involved, an increase in diversity may eventuate because of the removal of the dominant understory species.

GENERAL CONCLUSIONS

From reported studies it is clear that the understory component of forest stands has not been assessed in much detail and that the effects of manipulation have been poorly elucidated. Sufficient data are known, however, to suggest that the following sequential effects on the understory component may be expected.

In a young stand (less than 10 yr), fertilizer additions usually result in increased understory growth, and hence increased competition between species and a subsequent reduction in tree growth. When the trees have outgrown the understory, increased shade effect may lead to larger understory plants with a higher nutrient content and a lower diversity. These may be the best conditions for forage production.

The effect of fertilizer applications on the understory component of older stands depends upon whether the trees respond. If they respond, increased foliar biomass results in increased shade and a reduction in total biomass mainly at the expense of dominant vascular plants. Depending upon the response time required, diversity of the understory may increase as may its nutrient content.

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