Ureaforms in the Fertilization of Young Pines

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In the CRIFF program to determine the role of nitrogen in forest fertilization in the Southeast, soluble forms of nitrogen have been compared with ureaform. Greenhouse experiments on seedlings grown from seed in the presence of nitrogen fertilizers and on year-old transplants showed that soluble forms are most useful at low rates. As rates are increased, the soluble forms become less desirable because of reduced growth and, ultimately, because of induced mortality. For seedlings at transplanting age, only ureaform did not show increasing damage at the highest rates tested when nitrogen was in the root zone. Incubation studies showed that ammonification dominates nitrogen transformations in acid forest soils with nitrification proceeding only to a minor extent.

The role for nitrogen fertilizers in establishment of pine forests in the Southeast has been slow in developing because of excessive mortality attributed to high salts, weed competition, the stimulation of pathogenic fungi, and suppression of mycorrhizae (Björkman, 1967; Pritchett and Robertson, 1960; Smith *et al.*, 1966). Recently, Pritchett and Smith (1969a) reported that 48% of over 30 experiments on young pines in the southeastern coastal plain showed response to nitrogen fertilizers. Thus, it appears that nitrogen can be used successfully both at stand establishment and late in stand development.

In fertilization of young pines it is of obvious interest to test the effect of slowly soluble forms of nitrogen. Significant decrease in the harmful effects of soluble nitrogen would permit use of sufficiently large amounts at planting to improve the economics of nitrogen fertilization by reducing application costs and prolonging effects. Basic work showing favorable results with ureaform in the fertilization of young fir and pine seedlings was reported by Austin and Strand (1960). Pellets containing ureaform and superphosphate, placed in the planting hole, gave striking increases in growth; mortality with soluble fertilizers was eight times that for the ureaform pellets. Subsequent use of ureaforms was generally favorable as summarized by Mustanoja and Leaf (1965): "Considerable attention has been given to the search for more persistent forms of N fertilizers. A few possible solutions have been presented, of which ureaformaldehyde looks most promising. In many cases seedling growth has been successfully promoted with ureaformaldehyde pellets, although Swan (1960, 1961) also reports some failures, and Walters *et al.* (1961) have been unable to get growth response from pellets . . . . . Bengtson and Voigt (1962) have shown that ureaformaldehyde leaches much less readily than NH_4NO_3, and is especially good in areas with high rainfall or in heavily irrigated nurseries." Malac and Broerman (1967) reported that a 9-g pellet (25% ureaformaldehyde and 25% superphosphate) gave a 20% increase in height after the first growing season but that there were no statistical differences in height or diameter between treated and untreated seedlings after 6, 7, or 8 years. This result would perhaps not be unexpected for such small amounts of fertilizer.

This paper describes greenhouse experiments with nitrogen sources of varying solubility on pine seedlings grown from seed, and with ureaform, urea, and ammonium nitrate on seedlings of transplanting age. Field experiments were also carried out with these fertilizers applied to seedlings after transplanting. Ureaforms depend on biological reactions to release their nitrogen (Hays and Haden, 1966). In view of the low pH and sandy nature of forest soils in the Southeast, it was of particular interest to determine whether ureaform would undergo breakdown in the usual manner in a variety of forest soils.

METHODS AND MATERIALS

Five experiments to examine ureaforms and soluble nitrogen sources for young slash pine seedlings used: (1) seedlings from seed germinated in soil with N sources dry-mixed in the soil prior to sowing; (2) year-old seedlings transplanted to potted soil and surface-fertilized after growth was initiated; (3) year-old seedlings transplanted to potted soil and fertilized the same day; (4) field transplants of year-old nursery seedlings receiving the N sources in three types of placement; and (5) field transplants of year-old nursery seedlings comparing ureaform and ammonium nitrate in different soil types. A sixth experiment used an incubation method to show mineralization and nitrification in typical southeastern forest soils.

Soils used in the several experiments are typical of forest soils of the Lower Coastal Plains. They are also among the soils on which growth responses by pine frequently occur when fertilized (Pritchett and Smith, 1968). The chemical and physical properties of these soils have been intensively characterized (Smith *et al.*, 1967) and their reaction to fertilizer additions has been documented (Pritchett and Smith, 1969b). Where deficient, basal applications of phosphorus were added to the soils used in the experiments except where phosphorus level was also a variable.

Experiment 1. Rates of N imposed were 0, 5, 25, and 125 ppm of N (soil dry-weight basis). Sources included: $(NH_4)_2SO_4$ (with 0.1% N-Serve) (Dow Chemical Co.); $NaNO_3$; urea; ureaform (Nitroform, Hercules Inc.) (UF); the cold water-soluble (CWS) and water-insoluble (CWI) fractions of Nitroform (Hays *et al.*, 1965); methylenediurea (MDU) which is present in ureaforms (Hays and Haden, 1966); and two experimental ureaforms, one with an unusually high water-soluble portion (HS) and one with a low water-soluble portion (LS). After 10 months, seedling height and diameter were determined (Tables I and II). Analyses of the ureaform materials were as follows. Cold Water-Soluble Fraction (CWS): 39.3% N; 2.4% WIN; 0.5% HWIN; AI 79 (Association of Official Agricultural Chemists, 1965a); 24.0% free urea. Cold Water-Insoluble Fraction (CWI): 38.4% N; 37.2% WIN; 21.2% HWIN; AI 43. Methy-

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lenediurea (MDU): 41.6% N. High-Solubility Ureaform (HS): 37.7% N; 14.8% WIN; 3.3% HWIN; 8.7% free urea; AI 78. Low-Solubility Ureaform (LS): 38.4% N; 32.5% WIN; 15.6% HWIN; 4.2% free urea; AI 51.

Experiment 2. Seedlings were transplanted from the nursery to pots containing Bladen loamy sand. After growth was apparent, 0, 15, and 450 ppm of N were applied as ureaform, urea, ammonium sulfate, ammonium nitrate, and sodium nitrate. Seedling heights and diameters were recorded at time of treatment and again 1 year from treatment. Data were then expressed as the percentage increase to eliminate the effect of initial size (Table III).

Experiment 3. In Experiment 1 seeds were planted in fertilized soils, and in Experiment 2 fertilizers were applied after transplanting mortality had occurred and the seedlings were established. This experiment was installed to test the effect of ureaform and ammonium nitrate applied on the day of transplanting. Year-old nursery stock was transplanted into potted Leon fine sand and rates of 0, 100, 200, and 400 ppm (dry soil basis) of N from both sources were surface-applied to six replications. The seedlings were allowed to grow for 4 months in the greenhouse. Their heights and diameters were then measured, shoot and root dry-weights determined (80°), and foliar nitrogen concentrations assayed by a micro-Kjeldahl procedure (Table IV).

Experiment 4. Machine-planted slash pine seedlings in six-tree plots were treated in April with 0, 55, 110, 220, and 440 kg of N/ha as ureaform, urea, and ammonium nitrate. Each material was placed in a local placement (a hole 25 cm from seedling), a 0.3-m band, and a 1-m broadcast (*i.e.*, over bedded row). Initial heights and diameters were recorded

Table I. Height Growth in Response to Nitrogen Levels (Average of All Sources)

	N Levels (ppm N)			
	0	5	25	125
Height, cm[a]	20.1	17.8	18.3	17.6
Diameters, cm[b]	0.35	0.36	0.40	0.42

[a] Significant at P (0.05). [b] Significant at P (0.01).

Table II. Diameter Response to N Sources of Different Solubilities (Average of All Levels)

	Sources									
	Control	$(NH_4)_2SO_4$	$NaNO_3$	Urea	CWS	MDU	HS	UF	LS	CWI
Diameter, cm[a]	0.35	0.35	0.40	0.41	0.41	0.41	0.40	0.39	0.37	0.36

[a] Significant at P (0.05).

Table III. Percentage Increase in Shoot Heights and Stem Diameters of Potted Slash Pine Seedlings in Response to N Sources and Rates

N, ppm	UF	Urea	$(NH_4)_2SO_4$	NH_4NO_3	$NaNO_3$	Average
			Heights			
50	98	92	104	90	84	94
150	85	64	71	102	69	78
450	91	55	62	46	24	56
Average	92	70	79	79	59	
Control 76						

Rates significant at P (0.01); sources significant at P (0.05).

N, ppm	UF	Urea	$(NH_4)_2SO_4$	NH_4NO_3	$NaNO_3$	Average
			Diameters			
50	99	107	125	89	113	106
150	99	125	103	107	92	105
450	91	97	79	82	42	78
Average	96	110	102	93	82	
Control 87						

Rates significant at P (0.01); sources significant at P (0.01); source × rate at P (0.01).

Table IV. Effect of Slow-Release (Ureaform) and Soluble (Ammonium Nitrate) N Sources Applied to Slash Pine Seedlings at Transplanting

Sources[a]	Rates[a] N, ppm	Diameter, mm	Heights, cm	Shoot wt, g	Root wt, g	Tissue N, %
Ureaform	100	34.2	61.2	7.4	6.2	1.1
	200	32.5	44.4	6.8	5.3	1.0
	400	26.6	47.7	6.5	3.5	1.4
NH_4NO_3	100	38.7	46.1	7.9	4.2	1.5
	200	19.6	47.4	5.9	2.1	2.8
	400	Dead	Dead	Dead	Dead	Dead
Control		24.0	45.1	3.9	3.0	1.0

[a] Sources and rates significant at P (0.01).

Table V. Field Survival of Slash Pine in Response to N Sources in Three Placements

Source	Placement	Rate (kg N/ha) 55	110	220	440	Average
Ureaform	Broadcast	91	75	50	83	75
	Band	58	83	67	75	71
	Local	75	75	67	58	69
						72
Urea	Broadcast	67	75	67	50	65
	Band	75	50	42	8	44
	Local	75	42	83	58	65
						58
NH_4NO_3	Broadcast	83	75	67	75	75
	Band	75	67	67	58	67
	Local	75	75	50	83	71
						71
Average	Broadcast	80	75	61	69	69
	Band	69	67	59	47	61
	Local	75	64	67	72	68
Average		75	67	62	63	66
Control						79

Sources significant at P (0.05); sources × rate at P (0.05).

Table VI. Diameter Increment of Field Transplants of Slash Pine in Response to N Sources and Rates

Source	Placement	Rate (kg N/ha) 55	110	220	440	Average
Ureaform	Broadcast	110%	113%	208%	172%	151%
	Band	218	129	185	186	180
	Local	170	135	137	154	149
						160
Urea	Broadcast	152	157	153	289	188
	Band	191	185	133	94	151
	Local	117	141	169	137	141
						160
NH_4NO_3	Broadcast	121	125	212	180	160
	Band	127	112	150	147	134
	Local	116	140	155	265	169
						154
Average	Broadcast	128	132	191	214	166
	Band	179	142	156	142	155
	Local	134	139	154	185	153
Average		147	138	167	180	158
Control						88

Rate significant at P (0.05); rate × placement at P (0.10).

at treatment time and again in winter, and the data were expressed as percentage increase to eliminate the effect of initial size (Tables V and VI).

Experiment 5. Twelve of 35 field experiments located throughout the Southeast compared ureaform with certain ammonium nitrate treatments common to all the experiments. In three, equal N rates (90 kg of N/ha) from ureaform were compared with ammonium nitrate with 90 kg of P/ha common to both; in four, 180 kg of N from ureaform was compared to 90 kg of N from ammonium nitrate with both in the presence of 90 kg of P/ha; and five experiments compared 180 kg of N from ureaform with 90 kg of N from ammonium nitrate where neither received P supplements. Average seedling volumes for the plots were measured after 1 year (Table VII).

Experiment 6. MINERALIZATION AND NITRIFICATION SOILS. The soils used were Plummer sandy loam, Immokalee fine sand, and Klej sand, all from the properties of Hudson Pulp and Paper Co., Putnam County, Fla. A fourth was a Wagram soil from Continental Can Co. property, Telfair County, Ga. The soils were collected in the field, stored in plastic bags, and used within a few weeks.

UREAFORM. Nitroform (Hercules Inc.) analysis: WIN 25.7%; HWIN 12.4; AI 52 (Association of Official Agricultural Chemists, 1965a); total N 38.4%.

PROCEDURE. Incubation experiments were run as previously described (Hays *et al.*, 1965) with the exceptions that the amount of water used with the soil was based on determination of the centrifuge moisture equivalent (ASTM Designation, D425-67T) and that potassium sulfate solution was used for the extraction (Bremner, 1965a). The flasks were covered with a 1-mil film of polyethylene which was drawn tight and fastened with tape. This achieves aeration without water loss in the manner described by Bremner (1965b) and avoids the necessity for adding water to make up for evaporation losses.

A volume of 1 N K_2SO_4 solution sufficient to give a total of 270 ml of water was added to each flask. After mechanical

Table VII. Volume of Trees and First Year Survival of Unfertilized and Comparative Ammonium Nitrate and Ureaform Treatments

Soil	Control	Ammonium nitrate, 90 kg N/ha + 90 kg P/ha	Ureaform, 90 kg N/ha + 90 kg P/ha	Survival: Ammonium nitrate	Survival: Ureaform
Rutledge	38 cc	194 cc	118 cc[a]	96%	82%
Leon	140	136	138	94	87
Lakeland	23	19	21	31	100
		Ammonium nitrate, 90 kg N/ha + 90 kg P/ha	Ureaform, 180 kg N/ha + 90 kg P/ha		
Plummer	37	209	238[b]	99	100
Bladen	14	44	33	92	92
Leon	41	97	137[b]	93	100
Leon	47	190	192[b]	100	100
		Ammonium nitrate, 90 kg N/ha	Ureaform, 180 kg N/ha		
Rutledge	96	85	77	100	90
Blanton	86	110	151[b]	95	89
Leon	23	37	45[b]	97	98
Eustis	62	29	37	77	83
McLauren	39	29	30	74	73

[a] Significant at P (0.05). [b] Significant at P (0.01), comparisons with ammonium nitrate treatments.

Table VIII. Mineralization Experiments

		Ureaform					
		N Conversion to NH_3 and NO_3^-					
		Untreated			Neutralized		
Soils	Weeks	% NH_3	% NO_3^-	Total	% NH_3	% NO_3^-	Total
Plummer	3	42.7	2.7	45.4	19.7	7.9	27.6
pH 3.70	12	52.0	4.1	56.1	28.1	4.1	32.2
	24	57.0	4.1	61.1	22.7	4.1	26.8
Immokalee	3	37.2	1.4	38.6	14.1	1.4	15.5
pH 4.40	12	49.2	2.7	51.9	25.1	6.6	31.6
	24	48.6	6.8	55.4	14.7	6.8	21.5
Klej	3	34.5	2.7	37.2	12.1	2.7	14.8
pH 4.61	12	28.0	8.7	36.7	15.2	6.3	21.5
	24	47.9	10.3	58.2	6.8	22.8	29.6
Wagram	3	30.6	1.4	32.0	12.5	1.4	13.7
pH 5.37	12	36.8	5.0	41.8	10.2	13.3	23.5
	24	39.2	15.5	54.7	4.5	24.0	28.5

shaking for 1 hr, the samples were filtered through glass-fiber filter paper. Nitrite was determined colorimetrically (American Public Health Association, 1965), ammonia was determined by the magnesium oxide distillation method (Association of Official Agricultural Chemists, 1965a), and nitrate was determined by the phenoldisulfonic acid method (Association of Official Agricultural Chemists, 1965b).

Experiments were run with ureaform and urea in each of the four soils cited. Soils were used untreated and neutralized to pH 7.2 to 7.9. pH Values were determined during mineralization, but variations were generally not considered large enough to be significant. Determinations of NO_3^-, NO_2^-, and NH_3 were run at 3-week intervals through 15 weeks and again at 24 weeks. Selected values are shown in Table VIII.

RESULTS AND DISCUSSION

Very Young Seedlings. Seedlings grown from seed in the presence of nitrogen showed the repression of heights frequently reported in the literature (Table I). As little as 5 ppm of nitrogen caused a significant reduction in height. Diameter, however, was significantly increased at rates above 25 ppm of nitrogen. Table II shows the effect of the various sources. The two least soluble ureaform sources, (LS) and (CWI), failed to produce a significant diameter response; the ammonium sulfate also gave no increase, perhaps due to a toxic effect of N-Serve. Ureaform and its more soluble components supplied enough nitrogen to elicit the diameter response. The nitrate source gave adequate growth but was characterized by high mortality. Frequent occurrences of pathogen attacks were noted during the early growth of the seedlings. This problem limits the usefulness of this technique for evaluating nitrogen sources.

Year-Old Potted Seedlings. Established year-old potted transplants showed a clear response to nitrogen fertilizers. All sources stimulated height growth at the 50-ppm level (Table III). Ureaform and ammonium sulfate produced the largest increments; only ureaform maintained the height increment at the higher rates. Seedlings receiving all their N as the nitrate source died at the 450 ppm of nitrogen rate, and those receiving the other soluble sources gave increments below that of the unfertilized controls.

Diameter increments in response to nitrogen gave a somewhat different response pattern, particularly for urea. Ureaform, urea, and ammonium sulfate yielded the largest increments. Only urea and the ureaform gave increases over the unfertilized seedlings at the highest (450 ppm of nitrogen) rate. The sodium nitrate source was undesirable above 50 ppm of nitrogen.

In this experiment, only ureaform maintained both height and diameter increments at the high rates. The soluble sources gave their best response for both measures at the low rate (50 ppm). Although the soluble sources elicited diameter responses at 150 ppm of nitrogen, the impairment of the height increments penalized this response.

Seedlings fertilized the day of transplanting showed a greater sensitivity to nitrogen sources (Table IV). Ammonium nitrate caused mortality at the 400 ppm of N rate. Ureaform was not lethal at this rate. In fact, ureaform stimulated a response over controls in all growth parameters at all rates. The effect of the N fertilizers, especially the soluble source, was greatest on root growth. Even with diminished root systems, the seedlings accumulated high nitrogen contents in their tissue. Tissue N for ureaform-fertilized seedlings was rather typical for slash pine tissue. These data suggest that soluble N greatly reduces successful root development and may cause N to accumulate to toxic levels in the tissues.

The results with year-old potted seedlings (Table III and IV) suggest that ureaform can be safely used at transplanting with controlled rates and placement (*cf.* Strand and Austin, 1966).

Field Transplants. Survival of field transplants fertilized soon after planting was decreased, especially by urea, in one test (Experiment 4 and Table V). Such a decrease in survival is not typical and is not usually observed in fertilization of field transplants (compare Experiment 5 and Table VII). Except for urea, mortality in Experiment 4 did not generally increase with increases in fertilizer concentration, suggesting that the low survival was not directly due to nitrogen *per se* but possibly to volatilized ammonia. Growth was erratic and was severely affected by tip moth attacks. In spite of the decreased survival, the effect of placement of the various fertilizers is of interest and is considered significant.

In view of erratic height growth, only diameter increments are reported. All sources caused an increase over the unfertilized control, *ca.* 150+ % for fertilized *vs.* 88% increase in diameter for unfertilized (Table VI). Ureaform yielded a 150+ % increase in all placements, while one or more placements of the other materials resulted in small increments. At the lowest rate, urea was best when broadcast, while ureaform was best in the band placement. Urea in band placements was especially harmful at rates greater than 110 kg of nitrogen/ha.

Of interest is the fact that year-old transplants responded to nitrogen and that the largest growth increment over all sources was at the high rate, indicating more tolerance for nitrogen than expected from literature reports.

Field Trials. In 12 field trials the response to soluble and ureaform nitrogen depended on soil type (Table VII). When nitrogen was apparently deficient (*e.g.*, Rutledge soil), ureaform failed to give as large a response as ammonium nitrate at equal nitrogen levels. In the Lakeland soil, where no response occurred in the first year, survival was 100% in the presence of ureaform and only 31% when ammonium nitrate was applied. This difference probably relates to the reduced solubility of ureaform and the excessively drained characteristic of the Lakeland soil.

Ureaform at twice the rate of ammonium nitrate generally gave as large or larger volume response than the ammonium nitrate. Further, a slight improvement in survival was noted.

Similar responses occurred where ureaform nitrogen was twice the level of ammonium nitrate nitrogen without phosphorus (Table VII); namely, where nitrogen responses occurred, the ureaform treatment gave an additional volume increment over ammonium nitrate. Volume increment and survival differences with both sources were probably penalized by the absence of P, which has often been reported to interact with nitrogen fertilization (Bengtson, 1968).

Incubation Experiments. The four soils used were obviously poor nitrifying soils. The soils themselves, on incubation, all showed excess ammonia over nitrate, with the exception of some of the later values for the Wagram soil. Urea was broken down to ammonia readily; conversions to ammonia of 90% or higher were shown in 3 weeks in all soils. Conversions to nitrate were low, reaching a maximum of 25% and frequently being below 10%. The same low degree of nitrification was observed for ureaform (Table VIII).

The most significant point in the ureaform experiments is that, in the untreated soils, total release of nitrogen (NH_3 plus NO_3^-) ranged from 55 to 61% over a period of 24 weeks. This is somewhat lower than the normal 65–70% conversion (to nitrate) in agricultural soils (Hays and Haden, 1969), and the release pattern is also somewhat different. Nevertheless, there is no doubt that ureaform undergoes biological breakdown in these forest soils and that it is functioning as a slow-release fertilizer.

Anticipating that acid soils would not give good nitrification, we ran parallel experiments with the soils neutralized Shih (1949) had reported improved nitrification in Florida soils with the use of lime. The results with ureaform in the neutralized soils were surprising. While nitrification was slightly improved in some cases, ammonification was greatly decreased. This would seem to indicate that the organisms responsible for breakdown of ureaform to ammonia are sensitive to pH and perform more effectively at low pH. This effect may be due to the fact that such soils have existed for a long time at low pH, causing fungi to predominate in the natural flora. Nitrifiers appear to be few or ineffective, as liming failed to improve nitrification appreciably. Further, it is clear that nitrification is not essential for a nitrogen fertilizer to be effective in producing growth increments. In fact, nitrate nitrogen was, in general, the least desirable source tested. Literature reports (Pharis *et al.*, 1964; Benzian, 1965; McFee and Stone, 1968) repeatedly show that nitrate nitrogen is an undesirable source for conifers.

CONCLUSIONS

The five sets of experiments described indicate that young pines are responsive to nitrogen fertilization even at high rates. At low rates, soluble nitrogen sources appear to show their greatest usefulness. However, as rates are increased, the soluble forms become less desirable, because of either diminished height or diameter increments or, ultimately, because of induced mortality. This is especially true if soluble N fertilizers are applied at the time of transplanting. Only ureaform did not show increased and/or severe damage at the highest rates tested.

The relatively low value of the forest crop will limit repeated fertilizer applications. If forest culture develops similarly to agriculture, placement by a modification of the planting machine may develop as the standard practice and may reduce the number of subsequent applications. Further, because of the perennial nature of the forest crop, a slow release of fertilizer at a rate the forest plants can absorb and recycle for subsequent use in later development may be desirable. The tolerance generally demonstrated by young pines for ureaform and its characteristic release pattern make it attractive for both these aspects of forest fertilization. The long-term benefits will be evaluated in subsequent experiments.

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