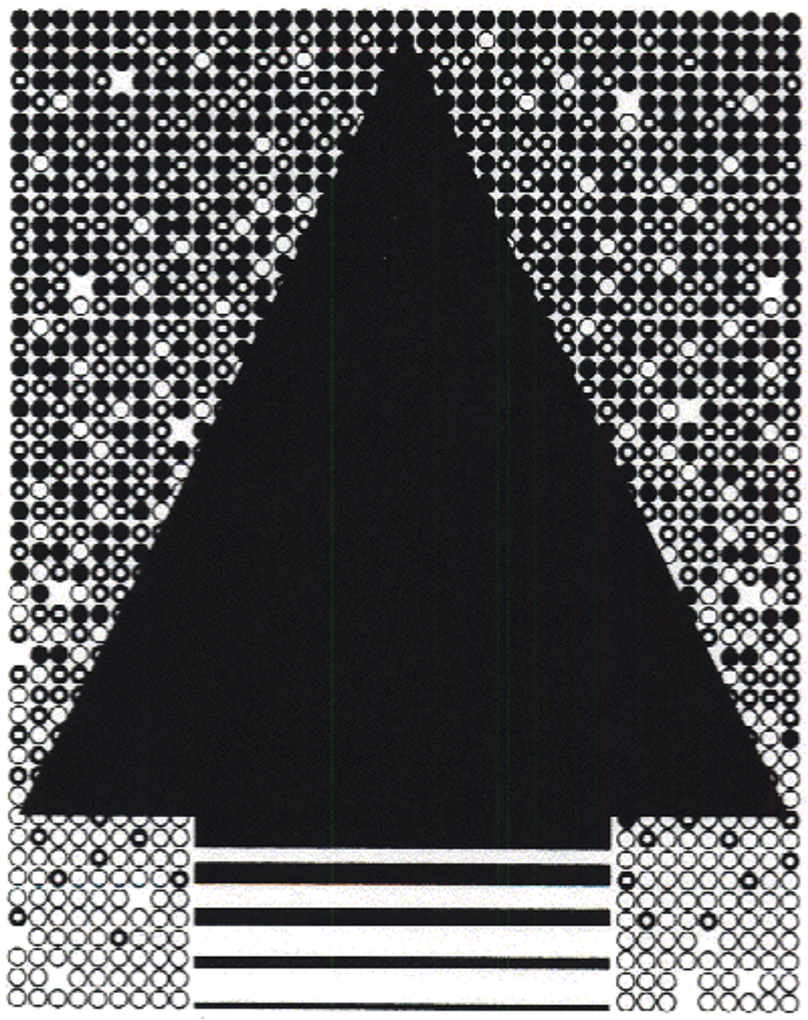

POSTER ABSTRACTS

North Carolina State Forest Nutrition Cooperative: Improving Loblolly Pine Productivity Through the Silvicultural Manipulation of Site Resources

H. L. ALLEN and S. R. COLBERT

The North Carolina State Forest Nutrition Cooperative (NCSFNC) is playing a leading role in the development of technology to diagnose and ameliorate nutrient limitations in loblolly pine plantations in the southeastern United States. Research goals are to further an understanding of the connections between site resource availability and carbon assimilation and allocation in forest stands, and to apply this knowledge to increase production efficiency of southern pine stands through the silvicultural manipulation of site resources. The focal point for the NCSFNC research effort is the establishment, maintenance, and measurement of uniform field trials by forest industry cooperators. Fifteen regionwide studies examine silvicultural options for improving stand establishment (through cultivation, weed control, and fertilization) and established stands (through fertilization, thinning, and woody vegetation control). University staff compile, analyze, and report data on tree and stand growth and soil and foliar nutrients. Fundamental research to understand the ecophysiological processes underlying stand nutrition and productivity is also conducted. Results from the field trial data base indicate that the productive potential of loblolly pine in the Southeast is not being realized. Silvicultural treatments at plantation establishment could increase site index (age 25) and mean annual increment (MAI) by as much as 3.0 to 4.6 m and 10.5 to 14.0 m^3/ha annually, respectively, on most sites. These gains are possible while maintaining or actually decreasing regeneration costs. For established stands, MAI could be increased by over 7.0 m^3/ha annually.

Nitrogen and Sulfur Fertilization of Lodgepole Pine

ROBERT P. BROCKLEY

Nitrogen fertilization has been shown to improve the growth of lodgepole pine in the interior of British Columbia. However, response to nitrogen is variable. Some stands respond extremely well and others respond poorly. Foliar analysis data indicate that on some sites, sulfur deficiencies may be induced or aggravated by nitrogen additions. A study was undertaken to document the effects of nitrogen, applied alone and in conjunction with different forms and amounts of sulfur, on the growth of seven lodgepole pine stands in the interior of British Columbia. Preliminary results indicate that applied alone, nitrogen was generally ineffective in increasing the weight of needles produced during the first year after fertilization. Combined N+S applications, however, often resulted in relatively large responses. In those trials where sulfur had a positive effect on growth, sulfate-sulfur was generally more effective than elemental sulfur in increasing needle weight. In most cases, the effect of sulfur application rate was not significant. However, a significant sulfur source x application rate interaction was measured in two trials. The N (and N + elemental S) treatments exhibited extremely high foliar N:S ratios and low foliar sulfate-S levels one year following fertilization. The uptake of sulfur in the N + sulfate-S treatments was apparently adequate to maintain favorable foliar N:S ratios and foliar sulfate-S levels. Subsequent measurements of these trials will indicate whether these early results apply also to stemwood response.

Tissue Nitrogen Concentrations and Productivity of Tree Seedlings

KEVIN R. BROWN

Relations between tissue nitrogen concentrations and productivity of woody plants may vary with species. In this study, I examined the effects of steady-state nitrogen nutrition (Ingestad and Lund 1986, Scand. J. For. Res. 1:439-453) on growth and nitrogen nutrition of Sitka spruce (*Picea sitchensis*), western redcedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*) grown from seed for 80 days in a glasshouse. Nitrogen was supplied at rates of 0.025, 0.05, 0.07, or 0.09 g N/g N per day in solution culture. The experimental approach maintained constant tissue nitrogen concentrations in each treatment. Relative growth rates (RGR) of spruce and cedar increased linearly with whole-plant N (wpN); RGRs of hemlock increased curvilinearly, with maximum RGRs occurring at about 17 mg/g wpN. The RGR of the three species were similar in the 0.025, 0.05, and 0.07 N regimes; in the 0.09 N regime, RGRs per day of spruce (0.062 g/g) and cedar (0.062 g/g) exceeded those of hemlock (0.045 g/g). The greater RGRs of spruce and cedar resulted from higher

whole-plant and foliar N concentrations (26.1, 28.6 mg/g of spruce; 23.6, 27.5 mg/g of cedar; 18.9, 23.0 mg/g of hemlock), not from greater N-use efficiency at the whole-plant or leaf level. The higher tissue N concentrations resulted in greater net assimilation rates by western redcedar and greater production of leaf area by Sitka spruce, relative to those of western hemlock. The nutrient addition technique may result in further insights into seedling nutrient use and have practical implications for seedling culture in nurseries.

Utilizing Municipal Wastewater in the Short-Rotation Intensive Culture of Hybrid Poplars

MICHAEL CARLSON, ERIC JACKSON, GEORGE NERCESSIAN, and VICKY BERGER

Vernon, a city of 23,000, is located at the north end of the semiarid Okanagan Valley of south central British Columbia. For the past nine years, treated municipal wastewater has been used to spray irrigate managed and wild grasslands near Vernon. This practice has resulted in no discharges of treated wastewater into nearby water courses and lakes. Management of the grassland system is operationally complex and expensive, and Vernon is looking for less expensive ways to treat its waste in an equally acceptable fashion environmentally. Since 1985, demonstration and research plantations have been planted with fast-growing interspecific hybrid poplars in an effort to gain knowledge and experience in establishing and managing short-rotation intensive culture plantations irrigated with nutrient rich wastewater. The largest plantation (13 ha) was planted in 1988 and is providing the opportunity to compare the relative effectiveness of grasslands and fast-growing tree plantations in combining with native soils not only to absorb wastewater but to treat and utilize its constituents. Short-rotation intensive culture tree plantations are thought to offer several advantages over grass culture for land treatment and utilization of municipal wastewater. Longer growing (irrigation) seasons, improved percolation due to deeper root penetration, greater evapotranspiration demands, and lower irrigation system operation and maintenance costs are among the hypothesized advantages of a tree culture system.

Response of Young True Fir Stands to Nitrogen Fertilization

H. N. CHAPPELL and W. S. BENNETT

Sixteen single-tree fertilization screening trials were established in young stands of Pacific silver fir (*Abies amabilis*) and noble fir (*Abies procera*) in the Cascade Mountains in western Washington and Oregon. Plantations and naturally regenerated even-aged stands selected for this study were 6 to 18 years breast-height age and spanned an elevation range of 980 to 1,340 m. Fertilizer treatments included nitrogen applied as ammonium nitrate and urea, alone and in combination with phosphorus, sulfur, and micronutrients. Unit needle weights and foliar N and P concentrations were determined after one growing season. Foliar N concentrations and needle mass were significantly increased by fertilizer treatments for both species. Fertilizer treatments significantly increased basal area growth for both species for four growing seasons, but did not influence four-year height growth for either species. Addition of other nutrients did not significantly increase growth above the level of nitrogen-only treatments.

Sludge Fertilization on Coarse-Textured, Nutrient-Deficient Soils: The Potential for Secondary Nutrient Deficiency

ROB HARRISON, DONGSEN XUE, and C. L. HENRY

Fertilization of forest land with municipal sewage sludge is an accepted means of improving the fertility status of soils in many parts of the Pacific Northwest, particularly in nitrogen-deficient sites of Washington's west side. Although nitrogen has generally been the constituent of sludge fertilization most studied, sewage sludge contains variable amounts of many other plant nutrients. One nutrient generally in low supply in sludge is magnesium. Since decreases in foliar magnesium levels with sludge additions have been widely noted, it could be that magnesium fertility may limit response of tree growth to sludge fertilization, particularly at high application rates on marginal soils. This poster gives and discusses data from several sites that have either shown reduced foliar magnesium levels or serious magnesium deficiencies following sludge fertilization. In one instance, deficiencies were rapidly corrected by fertilization with magnesium sulfate fertilizer.

Nitrate Leaching from Fertilization of Three Douglas-fir Stands with Municipal Sludge

CHARLES L. HENRY and DALE W. COLE

Typically the limiting criterion for applications of municipal sewage sludge is the amount of nitrogen. The 10 mg/L nitrate-N EPA drinking water standard has given designers a limit to the amount of nitrate which can seasonally move through the soil profile, taking into account dilution within the aquifer. Except in special cases where trace metal concentrations are very high due to large industrial inputs, application rates are limited by nitrogen loading. This is especially the case in forest sites where a non-foodchain crop is being grown. This study was designed to investigate nitrate leaching from Douglas-fir stands of three different ages which received single and multiple annual applications of 47 dry tons per hectare of sludge. Plate lysimeters under continuous vacuum were used to collect monthly samples of soil solution. Stand age had a strong effect on leaching losses. Average solution concentrations during the first year were 57 mg/L in a 55-year-old stand, 10 mg/L in a 10-year-old stand, and 25 mg/L in a clearcut, compared to controls at 0 mg/L. These resulted in annual nitrate-N leaching losses of 479, 73, 115, and 3 kg/ha, respectively.

Effect of Drainage and Fertilization of a Peatland on Photosynthesis and Water Relations of Tamarack and Black Spruce

ANCELM G. MUGASHA, S. ELLEN MACDONALD, and DONALD J. PLUTH

We investigated the effect of drainage and NPK fertilization on net assimilation and water relations of immature tamarack (*Larix laricina*) and black spruce (*Picea mariana*) growing on contiguous undrained and drained minerotrophic peatland sites in central Alberta. The drained site was ditched in the fall of 1987. The four NPK (at 0-0-0, 0-80-120, 200-80-120, and 400-80-120 kg/ha) fertilizer treatments replicated three times on each site were imposed in late May 1989. Simultaneous gas exchange measurements and foliar sampling were carried out in late June-early July 1989, mid-August 1989, and mid-August 1990. Drainage increased net assimilation rate (NA), mesophyll conductance to CO_2 (g_m), and foliar N concentration of tamarack and black spruce. With the exception of black spruce in 1989, drainage had no effect on stomatal conductance (g_s), suggesting that there was no improvement in plant water relations. Drainage increased water use efficiency (WUE) of both species, increased photosynthetic nitrogen use efficiency (PNUE) of black spruce, and decreased that of tamarack. NPK fertilization with the higher nitrogen dosage resulted in greater decrease in NA, g_m, g_s and PNUE of both species. WUE was not affected by NPK fertilization. Tamarack had higher photosynthetic water and nitrogen use efficiencies than black spruce in both years.

Fate of Fertilizer Nitrogen in a Douglas-fir Ecosystem

G. E. NASON and D. J. PLUTH

Nitrogen cycling in a 38-year-old, medium-productivity stand of Douglas-fir on southeastern Vancouver Island, British Columbia, was examined after spring and fall application of nitrogen at 200 kg N/ha as ammonium nitrate ^{15}N-enriched urea. Douglas-fir responded to nitrogen-fertilization by increasing the nitrogen concentration of existing foliage and both the concentration and content of nitrogen in new shoots. At the first fall after fertilization (seasons of application combined), ammonium nitrate caused a 26% increment over control in nitrogen content of current foliage, whereas urea gave a 13% increase. Recovery of urea-N in soil was complete at three weeks but declined to 50-60% at two years. The balance of the fertilizer nitrogen was accounted for by Douglas-fir uptake and volatilization. Availability of nitrogen declined exponentially such that six months after fertilization only 5 to 10% of applied nitrogen remained in inorganic forms. Fifty percent of urea-N was immobilized within three weeks of application. Fertilizer uptake to foliage at one year was 15 and 21% of applied for the spring and fall applications, respectively. From kinetic analysis of tracer data in one-year-old foliage and soil ammonium fractions, the rate of uptake of nitrogen in the first year by fall-fertilized trees was about double that of spring-fertilized trees. A simulation model utilizing two kinetic fractions of both foliar N (mobile, structural) and soil organic N (active, stabilized) accounted for most of the variation in the soil and foliar N and ^{15}N abundance data obtained in the first year after spring fertilization.

Response of Coastal British Columbia Forests to Fertilization

S. A. Y. OMULE and G. M. BRITTON

Twelve-year results from British Columbia Ministry of Forests' Experimental Project (EP) 703 suggest that operability in closed canopy, immature stands of Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) can be accelerated by fertilizing and thinning treatments. About 70% of the Douglas-fir stands and about 60% of the western hemlock stands responded well to applications of nitrogen fertilizer. Fertilization increased top height growth on the average over a 12-year period by 0 to 5% for western hemlock and by 4 to 10% for Douglas-fir, in the thinned and unthinned stands. It increased gross volume growth on the average over a 12-year period by about -1 to 7% for western hemlock and by about 5 to 19% for Douglas-fir, in the thinned and unthinned stands. Thinned stands responded slightly better than the unthinned stands.

Does Fertilization Enhance Long-term Nitrogen Availability in Coniferous Forests?

C. E. PRESCOTT, M. A. McDONALD, S. P. GESSEL, and C. L. HENRY

The potential for forest fertilization to improve nitrogen availability through enrichment of litter was examined in a 70-year-old stand of coast Douglas-fir at Pack Forest, Washington. Rates of key processes involved in the cycling of nitrogen were measured in plots which had received repeated applications of nitrogen as inorganic fertilizer (approximately 1,000 kg/ha) or in sewage sludge (approximately 6,000 kg/ha) at least 10 years previously. Greater amounts of nitrogen were returned in litterfall on sludge-treated and fertilized plots. Litter decayed more rapidly on sludge-treated plots, but not on fertilized plots, relative to control plots. Forest floor material from all plots mineralized similar amounts of nitrogen during a 40-day aerobic incubation. Biomass production by Douglas-fir seedlings during a six-month greenhouse bioassay was similar in pots containing forest floor material from all plots. These preliminary findings suggest little long-term enhancement of rates of nitrogen cycling through litter as a consequence of forest fertilization.

Response of Douglas-fir and Western Hemlock Pole-size Trees and Seedlings to Nitrogen and Phosphorus Fertilizers

M. A. RADWAN, J. M. KRAFT, D. S. DeBELL, and J. S. SHUMWAY

Three experiments were conducted to determine effects of nitrogen and phosphorus fertilizers on growth and levels of tissue nutrients of Douglas-fir and western hemlock. Both pole-size trees and potted seedlings were used. Test soils were relatively high in nitrogen and low in extractable phosphorus, and seedlings were tested in the same soils as the trees. Fertilizers were urea, ammonium nitrate, and triple superphosphate. In general, fertilization changed levels of some tissue nutrients of trees and seedlings. Basal area growth of the trees was not significantly affected by any of the fertilization treatments. Seedling growth was dramatically improved by the phosphorus fertilizer, but was negatively affected by the nitrogen fertilizer. Results clearly show differences between pole-size trees and seedlings in response to nitrogen and phosphorus fertilizers. They also suggest that nitrogen not be applied where soils are high in nitrogen and low in phosphorus, and phosphorus applications be confined to sites with low phosphorus soils and young trees, before canopy closure.

Douglas-fir and Spruce Fertilizer Screening Trials in the British Columbia Interior

K. I. SWIFT and R. P. BROCKLEY

Although the responsiveness of lodgepole pine to fertilization has been well documented, very little fertilizer response information has been collected for other coniferous species in the interior of British Columbia. Foliar nutrient concentration data collected for other species indicate that severe nitrogen deficiencies are common. Studies in plantations have indicated that deficiencies of nitrogen and other nutrients may be aggravated by prescribed burning or windrowing. In 1988, a study was undertaken to obtain preliminary fertilization response data for two interior species: interior spruce

(white spruce, Engelmann spruce, or naturally occurring hybrids) and Douglas-fir. A total of 17 fertilizer screening trials were established in 15- to 20-year-old plantations (12 Sx; 5 Fdi). Factorial combinations of nitrogen (0, 100, and 200 kg N/ha) and a "complete mix" fertilizer (0 and 1,170 kg N/ha) were tested in each trial. The "complete mix" contained the following nutrients (kg/ha): N, 0; P, 100; K, 102; Ca, 129; Mg, 51; S, 50; Fe, 9; Zn, 3.5; Mn, 3.7; Cu, 1.5; B, 1.5; Mo, 1.0. When applied singly, nitrogen and a "complete mix" fertilizer had little effect on the weight of needles produced during the first year after treatment. Combined applications, however, resulted in relatively large increases in needle weight. Examination of foliar nutrient data indicates that sulfur is most likely the nutrient that caused the observed N x "complete mix" interaction. The extremely high foliar N:S ratios and low sulphate-S reserves measured following fertilization with nitrogen alone indicate that fertilized trees may have been unable to use the added nitrogen effectively. The sulfur contained in the "complete mix" fertilizer was apparently sufficient to maintain a more favorable N:S balance. These results indicate that although nitrogen deficiencies undoubtedly hinder the growth of these two species in the B.C. Interior, growth response may be poor unless other nutrients are added in conjunction with nitrogen. Subsequent measurements of these trials will show whether these early results apply also to stemwood response.

Response to Fertilization of Western Hemlock and Western Redcedar on Old-growth Cedar-Hemlock Cutovers

WILLIAM A. THOMPSON and GORDON F. WEETMAN

Forest fertilization was examined as a possible solution to poor growth of young western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*) planted on old-growth cedar-hemlock cutovers on northern Vancouver Island. Six years after planting, over 50% of the stems were under 1.5 m in height. In addition, the cutovers were invaded by salal (*Gaultheria shallon*), an evergreen ericaceous shrub, which covered most of the plantations. Height growth of fertilized hemlock increased substantially over that of the control during the first three years following fertilization with a single nitrogen (N) addition—from 30 cm/yr at 100 kg N/ha to 35 cm/yr at 200 to 300 kg N/ha. The response declined in the fourth year. A similar but smaller response to nitrogen fertilization was found for cedar—up to 10 cm/yr at 300 kg N/ha. A modest growth response of 10 cm/yr for hemlock and 5 cm/yr for cedar to single phosphorus addition of 100 kg P/ha was recorded, with no decline after four years. Nitrogen and phosphorus responses were synergistic for hemlock but additive for cedar, yielding annual responses over three years up to 55 and 15 cm/yr, respectively, when fertilized with 200 or 300 kg N/ha and 100 kg P/ha. Relative height growth of hemlock was directly proportional to nitrogen content of the foliage over the range 0.7 to 1.9% foliar N (% g N/g dry weight). Higher foliar N concentrations (up to 2.4%) did not yield higher growth rate. Relative height growth of cedar was marginally correlated with foliar N. Differences in foliar N between fertilized and unfertilized plots had largely disappeared by the fourth year following fertilization, at which time annual height increment for hemlock and cedar was directly proportional to canopy size. Other results are reported in two 1989 articles by Weetman et al. (Can. J. For. Res., 19:1501-1511, 19:1512-1520). Nitrogen and phosphorus fertilization can temporarily relieve nutrient limitation for young hemlock and cedar growing on nutrient-limited sites. [Research funded by the B.C. Science Council]

Organic Waste Recycling in British Columbia Forests

M. D. VAN HAM, M. McDONALD, J. P. KIMMINS, and C. C. PEDDIE

Following the lead of the University of Washington and Metro Seattle, British Columbia has initiated trials investigating the efficacy of a number of different organic wastes as forest fertilizers. A cooperative program between the University of British Columbia and the Greater Vancouver Regional District began with a series of experimental applications of anaerobically digested sewage sludge in University of British Columbia's Malcolm Knapp Research Forest at Haney, 60 km east of Vancouver. These trials, which covered a total area of 0.42 hectare, monitored the movement of nutrients and heavy metals in streams, groundwater, and soil, as well as uptake by tree and understory foliage. The effects on vegetation composition and biodiversity were recorded, and a study of pathogen transmission (focusing on *Giardia* spp.) by small mammals was conducted. These studies were expanded in the second phase of the study, when sludge applications were made to about 5 ha of an experimental watershed in the research forest. This part of the project will focus on the effects of sludge applications on streamwater quality and tree growth, but will monitor the same variables as for phase 1. Anaerobically digested sewage sludge has also been applied to small plots on an industrial Tree Farm License on northern Vancouver Island. A further component of this study has been the application of other organic

wastes instead of, or in combination with, sewage sludge. These include pulp mill sludges and fly-ash from a local pulp mill and fish wastes from fish farms. Nutrient movement and effects on forest floor decomposition are being considered in this study. Data from these various studies will be presented as they become available.

Fertilizing to Reduce Western Spruce Budworm Impacts

BOYD E. WICKMAN, RICHARD R. MASON, and ARTHUR R. TIEDEMANN

A recent study demonstrated that nitrogen fertilization of a grand fir (*Abies grandis*) stand infested with western spruce budworm (*Choristoneura occidentalis*) with urea at 350 kg N/ha reduced defoliation and significantly increased the radial and shoot growth of infested host trees. Although budworms also benefited from the fertilization by increasing in numbers and size, the addition of nitrogen apparently stimulated the growth of more foliage than could be consumed by the increasing population. The results indicate that fertilization of infested stands might be used in some cases to offset the damaging effects of defoliation and to "buy time" until the budworm outbreak collapses naturally. A more comprehensive study was begun in 1988 to evaluate the effects of nitrogen alone as urea at 350 kg N/ha and two other fertilizer treatments using nitrogen, phosphorus, potassium, and sulfur at 100, 25, 25, and 25 kg/ha, respectively, on budworm-infested stands and on a wider range of forest resources.

Effect of Nitrogen Fertilization of Ponderosa Pine on Soil Gases and Solutions

D. ZABOWSKI and C. L. HENRY

A mature ponderosa pine forest located in the eastern Cascade Mountains of Washington State was fertilized in the spring of 1989. Fertilizers applied included urea, ammonium nitrate, and domestic sewage sludge. Both of the chemical fertilizers were applied at rates of 220 kg N/ha; the sewage sludge was applied at a depth (2.5 cm) designed to yield an equivalent amount of available N within one year of application. Soil solutions and soil gases were monitored prior to and for one year following treatment. Results showed that volatile ammonia losses were 10 to 15% of the applied N; losses were initially high but dropped rapidly. No significant denitrification losses were detected. The flux of CO_2 from the forest floor increased with both the urea and sludge treatments following fertilization, but dropped to background levels within two months. Soil CO_2 levels were highest in the Oa horizon of the sludge-treated plots immediately following application (1.2%). Solution ammonium increased with all treatments but nitrate did not; solution pH increased only with the urea treatment.