EVALUATION OF FOLIAR UREA APPLICATIONS IN THE PRESENCE AND ABSENCE OF SURFACTANT ON THE NITROGEN REQUIREMENTS OF CONDITIONED PINUS RADIATA SEEDLINGS

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ABSTRACT

The rationale behind foliar urea spraying of **Pinus radiata** D. Don seedlings after conditioning was investigated. Field application of urea (5% w/v) from the boom sprayer with and without surfactant resulted in inconsistent amounts of spray retained by the shoot, and surfactant additives gave no advantage. An increase in nitrogen subsequently resulted from recovery of spray runoff by roots.

Dipping individual needles into Tween 80, Silwet L-77, and Citowett enhanced retention 1.8, 1.8, and 1.5 times, respectively, over that in the absence of surfactant. Foliar urea uptake was 13–26 times faster than nitrate-nitrogen uptake and 3.5–7.5 times faster than ammonium-nitrogen. Absorption of urea-nitrogen within 6 hours was 100% while ammonium and nitrate uptake was 40% and 55% complete, respectively. These results led to exclusive use of urea with surfactant in subsequent nitrogen applications.

Effective interception and retention of spray on needles in the field was dependent on a suitable application technique. Nursery seedlings absorbed 1.3 times and almost twice as much urea in the presence of Tween 80 and Silwet L-77, respectively, when aerosol and atomiser applications were used.

In glasshouse experiments two spray applications of urea 1% (w/v) containing 0.5% (v/v) Tween 20 raised the level of nitrogen in needles of wrenched seedlings from 0.9% to 1.6% N. It was predicted that a single, finely dispersed spray of 2% (w/v) urea could produce a similar increase in nitrogen concentration. The absorbed foliarly applied ^{15}N urea 2% (w/v), 0.287 atoms % excess, contributed 12.5% of the nitrogen absorbed for production of new roots. Thus, foliar urea applications could be significant in root growth of conditioned seedlings.

Keywords: seedlings; conditioning; surfactant; foliar spraying; retention; absorption; urea; ^{15}N-urea; **Pinus radiata**.

With surfactant additives: Since surfactants are known to increase wetting of leaf surfaces by reducing spray surface tension (Holly 1976), the surfactants Citowett and Silwet L-77 were included in the spray application to see whether greater nitrogen incorporation by *P. radiata* seedlings could be obtained. *Pinus radiata* seedlings, 7 days after undercutting, were sprayed with 5% (w/v) urea containing 0.1% or 0.5% Citowett (York & Co. Ltd, non-ionic additive) or Silwet L-77 (Union Carbide, non-ionic organosilicone additive) or no surfactant (control). The variation in volume delivered by the sprayer from nozzles varied by 3%.

The surface of the plot was covered with 2.5 cm bark mulch to eliminate root uptake of applied nitrogen. Consequent increases in nitrogen were attributed to foliar uptake. Twenty seedlings from each treatment were harvested and bulked 15 min after spray application and 5 days after spraying with each sampling treatment replicated three times. Seedling shoots harvested after spraying were washed with water to remove unabsorbed spray and the bulk washings of 20 seedlings were retained for urea-nitrogen analyses by the Kjeldahl method. Seedling shoots were dried and the nitrogen content was determined.

Needle Dipping in Surfactant Solutions

Non-ionic hydrocarbons (Tween 80 and Citowett) and an organosilicone surfactant type (Silwet L-77) were tested for potential effectiveness for subsequent field applications. Regression equations were developed to assess urea deposition as a function of needle dry weight. Previous results showed variation due to shoot morphology as well as retention of solution by the stem when seedling shoots were dipped (D. Court unpubl. data). Consequently, individual needles were used in this experiment. Both non-ionic hydrocarbon and a silicone surfactant were tested since the organosilicones have been reported to exhibit excellent wetting and penetrating characteristics (Jansen 1973).

Individual needles from *P. radiata* seedlings were dipped into either water or surfactant solutions of Tween 80, Silwet L-77 at concentrations of 0.1% and 0.5%, or Citowett at concentrations of 0.1% and 0.05%. The volume of liquid retained per treatment was estimated from the weight loss of the container after 10 needles had been dipped individually and bulked. Each treatment was replicated 10 times in order to obtain a range of needle weights. Needles were washed and dried, dry weights of 10 bulked needles were recorded, and regression analyses from the 10 replicates were used to estimate the spray retained on *P. radiata* needles.

Application of Foliar ^{15}N Fertilisers

Six- and 9-month-old *P. radiata* glasshouse-raised seedlings were placed in a growth cabinet (photoperiod of 16 hours, irradiance approximately 75 W/m^2 from a mixture of fluorescent and incandescent lamps and day/night temperature of 27°/22°C) to acclimatise for 2 weeks. Seedlings were dipped into solutions containing 3000 ppm ^{15}N as either urea, potassium nitrate, or ammonium sulphate (11.76 atom % excess) with 0.5% Tween 20 surfactant. ^{15}N labelled compounds were obtained from Isocommerz, Gmbh; DDR. Four seedlings were harvested at 0, 1, 2, 3, 6, 12, 24, and 38 h after dipping and were washed in distilled water to remove unabsorbed nitrogen. The total nitrogen retained on foliage was calculated from regressions of needle weight against adsorbed liquid. Seedlings were also analysed for absorbed isotopic nitrogen.

^{15}N Analysis

After micro-Kjeldahl digestion and distillation, the distillate was adjusted to pH 3.0 and volume reduced to 1 ml on a hot plate. After transfer to vacutainer tubes, samples were evaporated to dryness in an oven at 80°C. The dried samples were stored for ^{15}N determinations which were made on a AEI MS 10 mass spectrometer. The dried ^{15}N samples were reacted with lithium bromide and resulting nitrogen gas was analysed for isotope ratio of masses 28 and 29. Unlabelled samples were treated similarly and atom % excess values were calculated using unlabelled plant material to provide natural abundance values. The variation in duplicates was ± 0.002 atom % excess. From the nitrogen content and the atom % ^{15}N excess the quantity of isotopic nitrogen present in the sample could be calculated.

Absorption of ^{15}N-urea in the Field

Pinus radiata seedling shoots in the nursery were sprayed to runoff with 1% ^{15}N-urea (5 atom % excess) containing either 0.1% Silwet L-77 or 0.5% Tween 80 or no surfactant, using a Pierce Instant Aerosol. The surface of the plot was covered with plastic strips over which 2 cm peat mulch was applied to trap the spray. Plastic screens before and after each treatment protected seedlings from spray drift. After 24 hours, five seedlings from each treatment were washed and dried and analysed for ^{15}N isotopic enrichment.

Multiple Foliar Urea Applications

Nine-month-old glasshouse-raised *P. radiata* seedlings were either given a simulated undercut and wrenched fortnightly for 2 months, or left unconditioned. Simulated undercutting occurred at a sand depth of 40 mm where the tap root was horizontally severed with a hacksaw blade, cutting both planter bag and root system.

The undercut seedlings were transferred to a tray of sand into which regenerating roots could grow. Wrenching was simulated fortnightly by drawing the blade horizontally under the planter bag. This wrenching is different from the operation in the nursery where a broad tilted blade is used. Half of the seedlings in each treatment were watered via root application with nutrient solution plus nitrogen (N+) and the other half with nutrient solution but no nitrogen (N–). Nitrogen salts were replaced by potassium chloride and calcium chloride, a modified Long Ashton formula (Hewitt 1966), to include 140 ppm N as nitrate and ammonium. After 2 months of conditioning, the seedlings were sprayed with a pump-operated atomiser at weekly intervals for a month with 1.0% (w/v) urea containing 0·5% Tween 20. Three seedlings were harvested at weekly intervals during spraying, washed to remove unabsorbed nitrogen, and analysed for nitrogen concentration.

Tissue Distribution of Absorbed ^{15}N

Conditioning creates a strong sink resulting in the translocation of shoot-mobilised nitrogen to roots. This experiment was designed to see whether nitrogen derived from foliar application to the shoot could be immediately used in new root growth.

Eighteen-month-old seedlings growing in the nursery were conditioned in the morning, and in the early afternoon of the same day were sprayed by atomiser containing

2% (w/v) ^{15}N-urea (0.287 atom % excess) with 0.5% Tween 20 surfactant. Five seedlings at each time interval were harvested at 0, 2, 4, 8, 20, and 30 days, spanning August through to September. Seedlings were washed, divided up into needles, stem, old (or pre-existing roots), and new white roots, and these tissues were analysed for distribution of isotopic nitrogen. Prior to spraying, seedlings were nitrogen deficient (1.07% N), and a single application raised needle nitrogen only to 1.2% N.

RESULTS

Field Application of Urea in the Presence and Absence of Surfactants

The results from successive harvests of plants after a field application of urea in the absence of surfactant showed that there was no immediate effect on total nitrogen content (Fig. 1) or foliar nitrogen concentration, irrespective of whether seedlings were sprayed. Prior to spraying, foliar nitrogen concentration was at luxury levels – control (C) 2.5% N, undercut (U) 2.0% N. One and 3 days after spraying C+ was 2.4% N, and U+ 2.0% N indicating insignificant foliar nitrogen uptake.

Six days after spraying and to the end of the harvesting interval (almost 2 months), marked increases were apparent in nitrogen levels of sprayed undercut and control seedlings but these were most likely due to root uptake of spray runoff. In relation to nitrogen sprayed in the immediate vicinity of the seedling (approximately 12 mg N per seedling), increases of 7.6 mg N for undercut seedlings and 11.2 mg N for control seedlings almost 2 months later could be accounted for from the application.

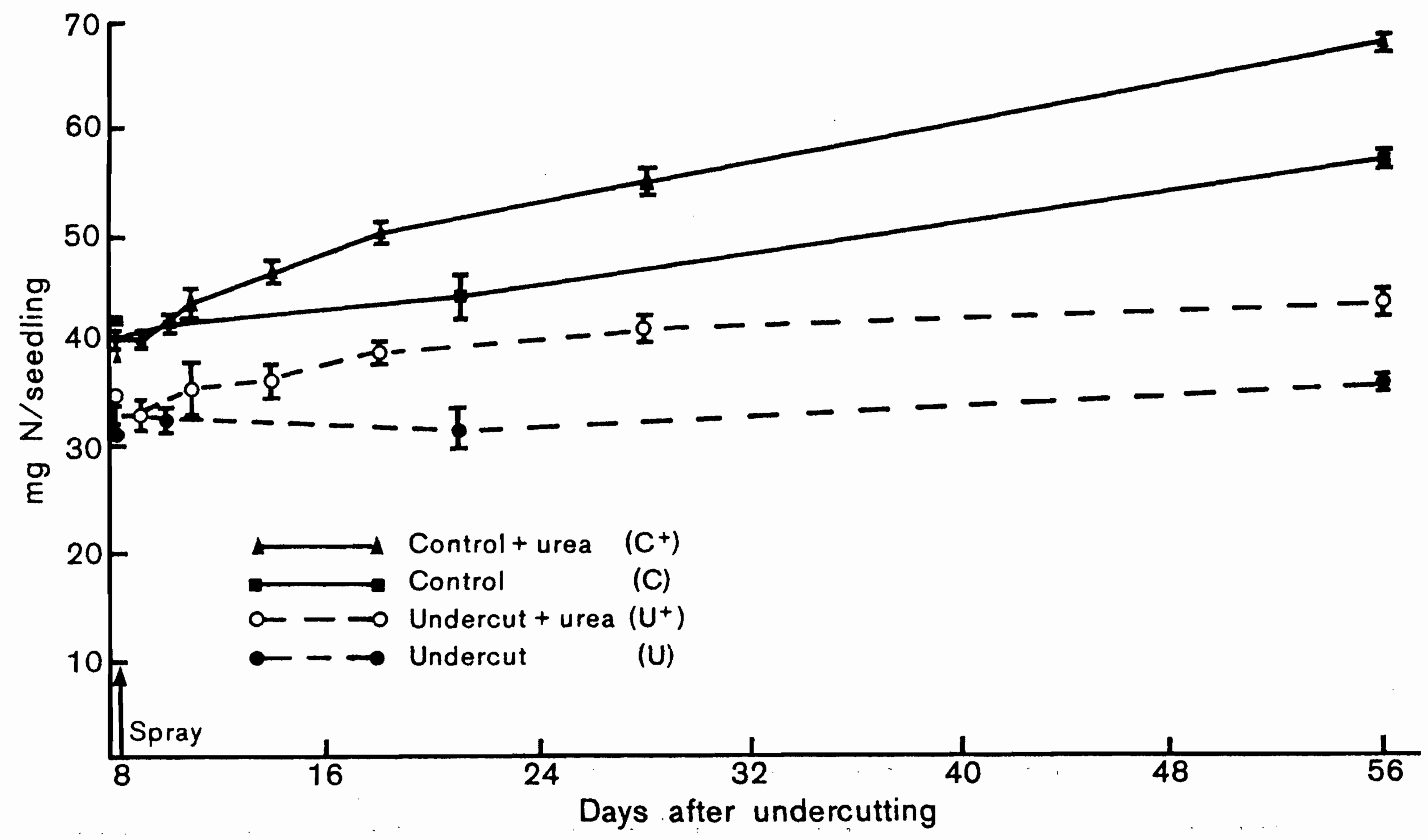

FIG. 1—Nitrogen content (mg) of control (C) and undercut (U) seedlings and foliar urea (5% w/v) sprayed control (C±) and undercut (U+) seedlings. Seedlings were sprayed 8 days after undercutting. Each point represents the mean ± SE. At Day 56 all treatments were significantly different at p = 0.05.

The increase in shoot nitrogen content 5 days after a foliar urea application to undercut seedlings in the absence of surfactants was approximately 3 mg (Table 1). In the absence of surfactants seedlings absorbed 0.1 ml spray/g dry weight of needles. Although seedlings appeared completely wetted by the surfactant treatment, only 0.04 ml spray/g dry weight was absorbed in the presence of surfactants. The results indicate that undercut seedlings boom-sprayed with urea alone retained and assimilated marginally more nitrogen than those which had wetting agents added. The reasons for the poor foliar response could lie in the selection of suitable surfactant and fertiliser nitrogen as well as in the spray technique where spray pressure and droplet size are critical factors in deposition.

TABLE 1—Effect of surfactant additives in foliar urea (5% w/v) spray applications on nitrogen content of seedling shoots 5 days after undercutting. Seedlings were harvested 5 days after spray application

Treatment	Shoot nitrogen uptake (mg)
Undercut (sprayed, no surfactant)	3.37*
Undercut + 0.1% Citowett	1.67
Undercut + 0.1% Silwet L-77	0.47
Undercut + 0.5% Citowett	1.40
Undercut + 0.5% Silwet L-77	1.23

* This treatment mean differs significantly (at p = 0.05) from the other four means

Effect of Surfactants on Solution Retention by Needles

Since inadequate gains in nitrogen were obtained in the field experiments, further evaluation was necessary to determine whether there could be any sound basis for the addition of surfactants.

The volume of solution retained was highly correlated with needle dry weight for all treatments (Table 2). Presumably the volume of solution retained is dependent on the surface area which in turn is correlated with dry weight. The value of the intercept,

TABLE 2—Relationship between volume of solution retained on needles (y) and needle dry weight (x), R^2 = coefficient of determination

	Regression equation	R^2	Volume solution intercepted (ml/g dry weight)
0.1% Silwet L-77	0.004 + 0.699 x	0.97	0.70
0.5% Silwet L-77	0.004 + 0.599 x	0.89	0.60
0.1% Tween 80	0.005 + 0.661 x	0.85	0.67
0.5% Tween 80	−0.010 + 0.731 x	0.92	0.72
Water	−0.009 + 0.397 x	0.81	0.39
0.05% Citowett	0.006 + 0.593 x	0.96	0.60
0.1% Citowett	0.029 + 0.300 x	0.85	0.33

which is equivalent to the volume of solution retained at the needle margin after draining, was negligible in comparison to the change in slope and smaller than that obtained for dipping whole seedlings (D. Court unpubl. data). The volume of solution retained per gram needle dry weight was similar for 0.5% Tween 80 and 0.1% Silwet L-77, but less for Citowett. The volume retention values were almost double for 0.1% Silwet L-77 and 0.5% Tween 80 and 1.5 times more for 0.05% Citowett over that in the absence of surfactant. The presence of 0.1% Citowett gave a solution retention value similar to dipping in water only.

There appears to be a critical surfactant concentration range which is dependent on the surfactant. Below this concentration insufficient wetting occurred; above the concentration, the volume of solution retained by needles declined, most likely as a consequence of solution runoff.

Foliar Uptake of ^{15}N Fertilisers

In order to test the foliar uptake potential of a range of nitrogen sources, the absorption of urea, nitrate, and ammonium solutions was compared using ^{15}N-labelled compounds. The concentration range where phytotoxic symptoms became perceptible after a foliar urea, ammonium, and nitrate application in the presence of 0.5% Tween 20 had previously been established (D. Court unpubl. data). Phytotoxicity occurred at 2000 ppm N for nitrate solutions, whereas in ammonium-treated seedlings needle scorch occurred between 4000 and 8000 ppm N. Seedlings treated with urea showed phytotoxic symptoms at 8000 ppm N. Since *P. radiata* seedlings can tolerate at least 5000 ppm urea-N (1% w/v urea) without any deleterious effects this amount was used subsequently for glasshouse seedling experiments.

One hundred percent of urea retained by needles was absorbed within 6 hours under the cabinet conditions (Fig. 2), while maximum absorption of nitrate (55%) and ammonium nitrogen (40%) occurred after about 24 hours. Initial uptake rates (within 6 hours) of nitrogen into the needles were:

Urea 0.26–0.52 mg N/g/h
Ammonium sulphate 0.07 mg N/g/h
Potassium nitrate 0.02 mg N/g/h

Initial urea-nitrogen uptake rate was between 13 and 26 times faster than nitrate-nitrogen uptake and 3.5–7.5 times faster than ammonium-nitrogen uptake. The decrease in urea uptake at 38 hours probably represents translocation of label from needles to the stem and roots. The decline was not detected in seedlings which had assimilated nitrate and ammonium nitrogen.

At zero time, which includes a 10-minute drying interval, up to 15% of urea applied to seedlings was already absorbed, while over 95% of the applied ammonium and nitrate solutions could be washed from foliage (Fig. 2).

Effect of Surfactants on Absorption of ^{15}N-urea

In order to test unequivocably that the presence of surfactants in a foliar ^{15}N-urea application can lead to an enhancement of nitrogen incorporation under field conditions, and not just in the growth cabinet or glasshouse experiments, the effect of 0.1% Silwet L-77 and 0.5% Tween 80 on uptake of ^{15}N-labelled urea was compared.

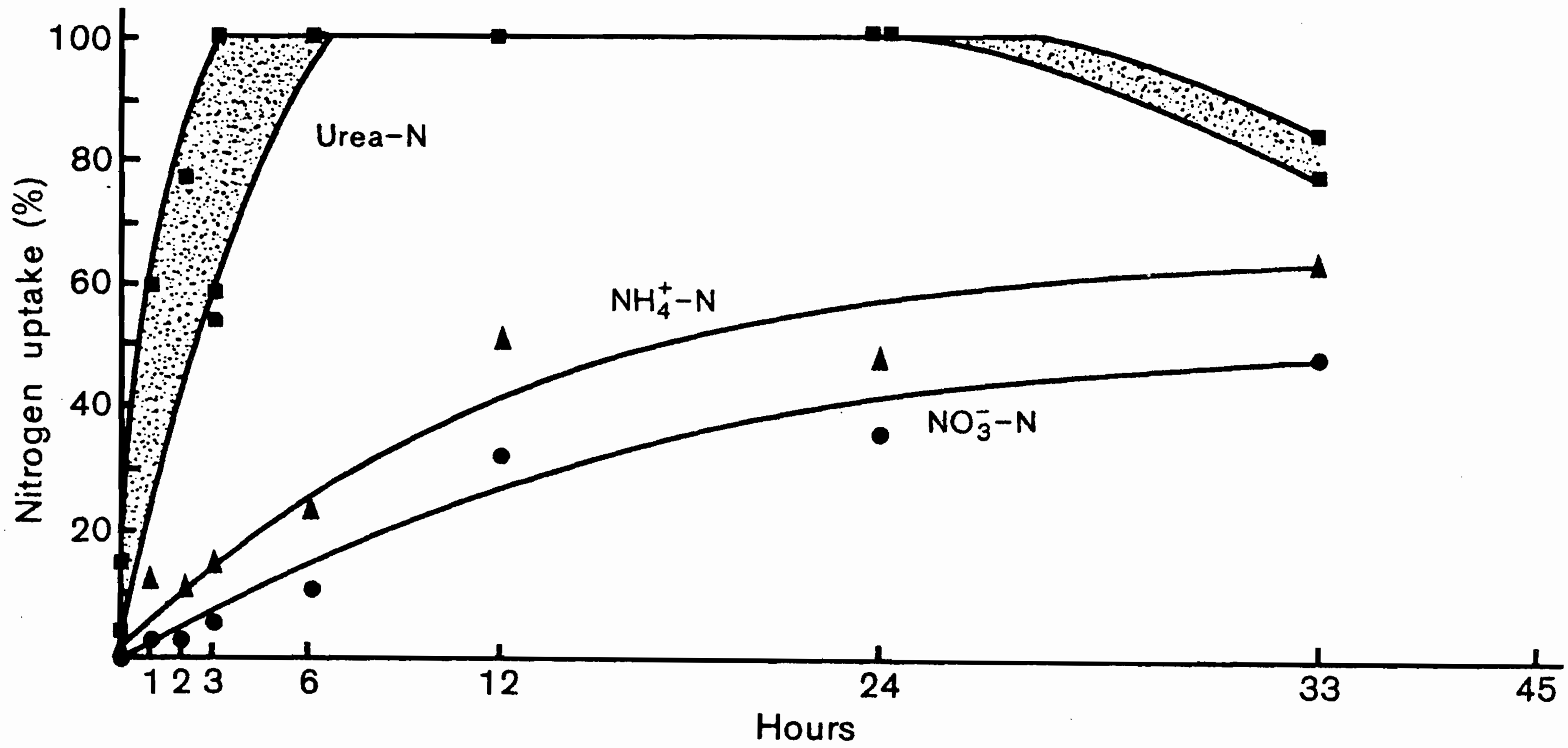

FIG. 2—Percentage uptake of foliarly applied 3000 ppm ^{15}N-urea, ammonium sulphate, and potassium nitrate (11.76 atom % excess) in 6- and 9-month-old **P. radiata** seedlings. Points represent the means of four seedlings. N absorbed is expressed as a percentage of N retained, calculated from the regression of needle weight for 6- and 9-month seedlings. The shaded area for ^{15}N-urea incorporation in needles represents the maximum and minimum degree of variation present in ^{15}N assimilation, with time.

Foliarly applied urea was absorbed in all treatments but was significantly enhanced in the presence of surfactants. Almost twice as much was taken up with Silwet L-77 as in the control treatment (Table 3). With a finely dispersed aerosol spray application of nitrogen, each seedling intercepted at least 0.5 ml of spray solution. Brushing seedling foliage with ^{14}C-urea in the presence of 0.5% Tween 80 and 0.5% Silwet L-77 revealed that carbon uptake was also enhanced 1.3 and 2.0 times respectively over that without surfactant (A. Coker unpubl. data).

Effect of Multiple Foliar Urea Applications to Conditioned Seedlings

Since a single foliar urea spray application at a concentration higher than 5000 ppm N (1% urea) could produce needle scorch in seedlings in the glasshouse, multiple foliar applications could be a more suitable alternative to alleviating nitrogen deficiency

TABLE 3—The effect of surfactants on ^{15}N-urea nitrogen uptake in *P. radiata* seedling shoots after a foliar 1% (w/v) urea (5 atom % excess) spray

	Enrichment (atoms % ^{15}N excess)
Urea	0.677
0.5% Tween 80 + urea	0.906
0.1% Silwet L-77 + urea	1.180*

* This treatment mean differs significantly (at p = 0.05) from the other means

symptoms resulting from conditioning in the field. Results of changes in nitrogen concentration effected by weekly spraying of conditioned and control glasshouse seedlings are shown in Fig. 3.

The initial nitrogen percentage values of needles in the –N treatments were very low at 0.9% N for wrenched plants and 1.1% N for controls. Initial values for the +N wrenched plants were 1.5% and for the controls 1.6%. After the first spray (1.0% w/v urea), needle nitrogen percentages in the plus and minus nitrogen plants increased to values in excess of 1.5%, an amount marginal to support growth. With successive sprays there was less effect on total needle nitrogen percentage even though similar quantities of nitrogen were being applied. While seedling shoot nitrogen was different initially because of the pretreatments, all plants showed similar nitrogen increase rates after foliar applications, thereby indicating the efficacy and efficiency of foliar uptake.

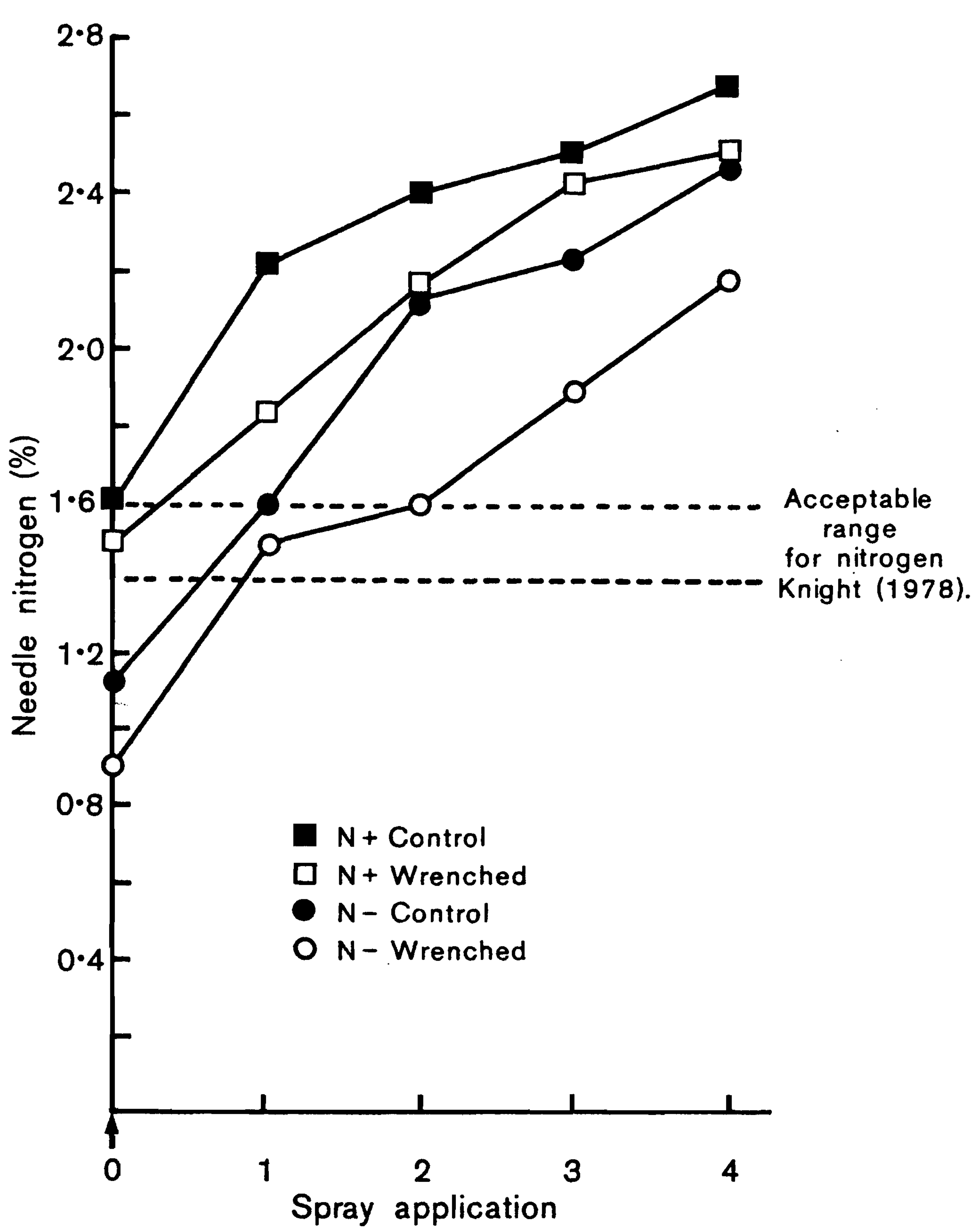

FIG. 3—Effect on percentage needle nitrogen of **P. radiata** seedlings of weekly foliar urea 1.0% (w/v) spraying with 0.5% Tween 20 after conditioning. The +N seedlings received soil nitrogen applications prior to foliar spray. Each point represents the mean of three seedlings; arrow indicates the end of conditioning.

Since the amount of urea that can be retained by a nursery seedling is about 0.6 ml/g dry weight of needle, it was predicted that a single 2% (w/v) urea application could raise needle nitrogen percentage from 1.0% to 1.6% N.

Urea application to conditioned seedlings from the first spraying onwards resulted in continued shoot height growth (Table 4) thereby immediately overcoming the effect conditioning had on restricting shoot height growth. The greatest height growth response was found in urea-sprayed +N control plants as expected. Shoot height increment was less in both control and conditioned plants without any applied nitrogen.

TABLE 4—Total height increment of urea-sprayed, conditioned, glasshouse seedlings. Foliar urea (1% w/v, with 0.5%Tween 20) was applied to +N, –N watered, wrenched, and control seedlings each week for a month. Values are means for three plants.

Treatment	Height increment (cm)
+N control	4.07
–N control	2.78
+N wrenched	3.41
–N wrenched	1.61

Tissue Distribution of Foliarly Absorbed ^{15}N-urea in Conditioned Seedlings

Isotope moved from needles fairly rapidly, with the stem becoming heavily loaded with nitrogen after 2 days and isotope being detected in the root at 4 days (Fig. 4). By 8 days, label in needles had stabilised and no further ^{15}N moved from needles thereafter, although translocation from stem to root continued. No significant loss of total isotope occurred during the experiment (Day 0, total isotope was 28.0 $\pm$ 4.9 μg ^{15}N, and at Day 30, 25.9 $\pm$ 4.3 μg ^{15}N), so it was valid to assume that the proportion of isotope lost from the shoot was identical to that detected in the root. After 20 days, 12–15% of the foliarly applied nitrogen was found in the new roots.

DISCUSSION

The results reported here show that effects of foliar urea spraying in field trials can be inconsistent. At best a 2–3-mg nitrogen contribution to undercut seedlings was achieved (Fig. 1 and Table 1) 5–6 days after application mainly as a consequence of root recovery of spray runoff rather than foliar uptake. The remaining nitrogen unavailable to the seedling was probably lost in the soil through increased activity of soil micro-organisms, ammonium volatilisation, and fixation of ammonium by soil particles (Hagin & Tucker 1982). Consequently, seedling foliar applications in the nursery at present would be more aptly described as soluble fertiliser applications ensuring that nitrogen is available to the constrained root mass.

Regression equations relating the volume of solution retained on needles with *P. radiata* needle dry weight showed enhanced retention with all the surfactants used

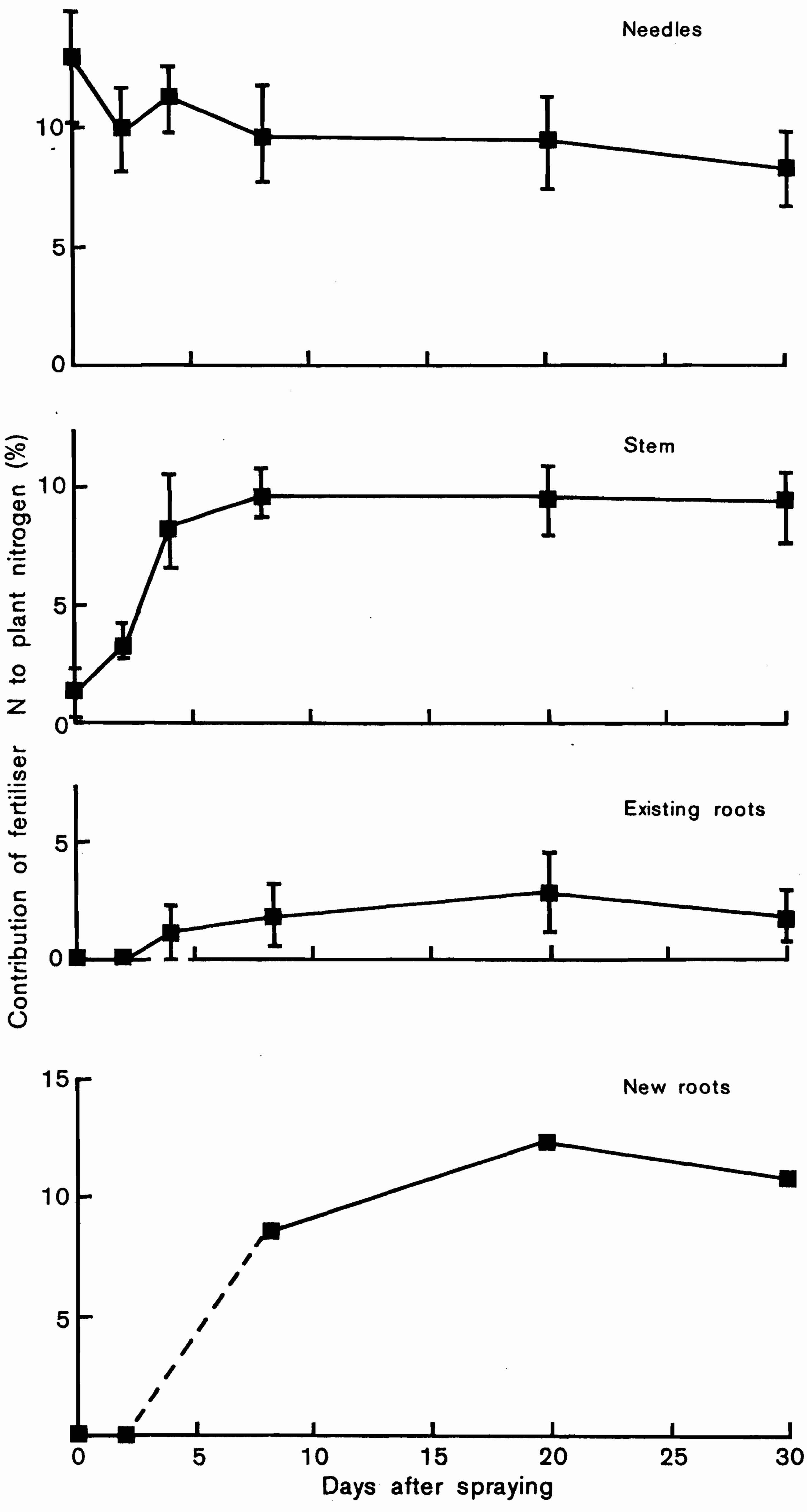

FIG. 4—Percentage contribution of applied ^{15}N-urea to seedling nitrogen after wrenching. Points are the means of five seedlings, and vertical bars represent the standard error except for roots where sample was bulked.

except for 0.1% Citowett (Table 2). In the presence of non-ionic hydrocarbon surfactants Tween 80 (0.5%) and Citowett (0.05%), retention of spray by dipping individual needles increased 1.7 and 1.5 times while the organosilicone Silwet L-77 increased retention by a factor of 1.8.

Dipping intact seedlings into 0.5% Tween 20 increased absorption two- to three-fold, probably through increased retention of spray solution on needle fascicles as well as on other nonabsorbing surfaces of the seedling (D. Court, unpubl. data).

Factors contributing to the effectiveness of spray absorption include the degree of stomatal opening (Wallihan *et al.* 1964), penetration of spray (Klein & Weinbaum 1985; Franke 1967), and age of leaves (Klein & Weinbaum 1985). Poor foliar absorption has been reported to be caused mainly by epicuticular waxes impeding cuticular penetration (Leece & Kenworthy 1972). In experiments reported here, absorption of urea was not the limiting factor since uptake was complete within 6 hours (Fig. 2). The curve for urea uptake does not correspond to first-order diffusion kinetics and this concentration-independent uptake has been called "facilitated diffusion" (Yamada *et al.* 1965). This feature has been used to advantage in combination with other nutrient combinations since phosphate and iron uptake is favoured in the presence of urea (Wittwer 1964). The most likely explanation for initially increased ^{15}N assimilation in the presence of surfactants was the enhanced retention of urea spray by needles followed by rapid absorption. Almost twice the amount of urea was assimilated in the presence of Silwet L-77 and 1.5 times more in the presence of Tween 80 as without surfactants (Table 3) in the field. Both carbon and nitrogen of urea are assimilated to the same extent. It has been suggested that urea may be absorbed intact since the enzymes for its degradation are localised primarily in the cytoplasm (McKee 1962), and in the epidermal and subepidermal cells of *Picea glauca* Voss (Durzan 1973).

Since experimental treatments in the glasshouse, simulating field conditions, show unequivocal uptake of nitrogen by foliar absorption in the presence of surfactants, the failure of this to occur in the field boom-spraying trials must be due to poor spray technique, particularly droplet size and spraying pressure. Selection of a spray nozzle which delivers the appropriate droplet size could be a critical factor in optimising spray interception by seedlings. Applications must ensure that wetting does not occur to the extent that deposition is reduced (Richardson *et al.* 1986). If spray containing surfactant is directed too forcefully on to needles, only a surface film is deposited before excess solution runs off as droplets, and the potential gains obtainable in seedling nitrogen content are lost. In glasshouse experiments reported here, dipping and the finely dispersed aerosol spray gave the best results. Controlled droplet application (CDA) for fungicidal spraying of seedlings using a mechanised spinning disc unit to atomise the spray has resulted in three times more fungicide landing on seedlings than with the boom and nozzle application (J. W. Ray pers. comm.). A similar technique for nutrient application to *P. radiata* seedlings in the field may be more suitable.

Providing spray delivery is optimised, foliar urea spraying could increase nitrogen by 1.0% N to 1.5% N thereby alleviating nitrogen deficiency symptoms. This could also be achieved by increasing nitrogen concentration in the spray to non-phytotoxic levels or alternatively by multiple applications. Urea has been used exclusively in applications since for a given concentration it is less phytotoxic than ammonium sulphate or calcium nitrate. If nitrogen concentration is raised to the extent that the osmotic pressure in the solution is higher than in sap, water will be drawn from needles and scorching will occur (Hagin & Tucker 1982). There appears to be a narrow threshold to the concentration of nitrogen tolerated which varies depending on seedling physiology, particularly plant water potential, and climate at time of spray application. Nursery seedlings tolerate higher urea-nitrogen concentrations (8000–10 000 ppm) than glasshouse seedlings which show phytotoxic symptoms at 8000 ppm. In the experiments reported here 1% (w/v) urea was used for treatments with glasshouse seedlings whereas nursery boom spraying was with 5% (w/v) urea, the current recommendation (Knight 1978). The lack of appearance of needle scorch at 5% urea application in the nursery probably reflects the small quantity of spray retained using the current application technique. With increased spray coverage of needles, 5% (w/v) urea applications in the presence of surfactant are not recommended.

Using a hand-operated atomiser, two foliar applications of urea (1% w/v) raised needle nitrogen percentage of wrenched seedlings from 0.9% to 1.6% N (Fig. 3). In the field, after conditioning of seedlings during autumn and winter, foliar nitrogen concentrations decrease to below 1.5% N without foliar feeding (Coker 1984) and so the use of multiple foliar applications can overcome the loss in nitrogen. It was predicted that a single 2% (w/v) urea application in the presence of surfactant could raise needle nitrogen percentage by the same order.

Nitrogen derived from fertiliser urea applied to the shoots of conditioned and unconditioned nursery seedlings was rapidly distributed in all tissues and used in new root growth.The requirement of high nitrogen status in seedlings for rapid root expansion has previously been reported for transplanted seedlings (Switzer & Nelson 1963). In conditioned *P. radiata* seedlings, shoot to root translocation is enhanced and this tendency was reflected in the distribution of ^{15}N (Fig. 4). Labelled nitrogen applied by foliar spraying contributed 12.5% of the applied nitrogen to new roots after only one addition. New roots comprised a sink to which the added nitrogen was preferentially translocated. In stressed or conditioned seedlings even when the shoot is nitrogen deficient the tendency for shoot to root translocation remains.

Further research is necessary to improve the efficiency of foliar applications of fertilisers, since field applications are not as efficient as research glasshouse trials with *P. radiata* seedlings.

CONCLUSION

Foliar urea sprays are a promising means by which the quality of conditioned nursery seedlings may be improved. Urea is less phytotoxic than nitrate and ammonium forms for a given nitrogen concentration when used as a foliar nitrogen fertiliser and is completely absorbed 6 hours after application under favourable conditions. While the absorption process appears to be rapid and efficient, the technique of applying sufficient nitrogen is more problematical. Nursery spray trial applications of foliar urea in the presence and absence of surfactant resulted in poor and variable retention of spray by the shoot, with subsequent nitrogen gains resulting from root uptake. Surfactant additives could enhance the amount of spray retained by seedling foliage. However, effective retention was dependent on the technique of application. Dipping and finely dispersed spray application containing surfactant produced favourable results while nursery boom-spraying resulted in no immediate rise in seedling nitrogen content.

Nitrogen deficiency symptoms at 1% N as experienced by conditioned seedlings could be alleviated with multiple applications of 1% (w/v) urea containing surfactant if application problems were solved. In conditioned and transplanted seedlings foliar urea applications could significantly improve root regeneration.

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