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Organic matter amendments to a calcareous forest nursery soil

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Application. Single applications of organic matter to a sandy loam calcareous nursery soil in the Southwest were not beneficial regardless of type of organic matter. Nutrient benefits from organic matter addition were short-lived. Conifer seedling growth response was a function of nutrient level rather than organic matter type.

Abstract. Organic amendments were added to a southwestern United States forest nursery sandy loam soil to determine the effects on soil nutrient reserves and subsequent growth of 1.5+0 ponderosa pine (*Pinus ponderosa* Laws.) seedlings. Treatments included irradiated sewage sludge, peat moss and pine bark each at 67 t/ha, sawdust at 43 t/ha, and a control that received no organic matter. Sludge caused immediate increases in soil nutrients, especially N and P. Sawdust resulted in near complete N immobilization 45 d after application. Peat moss and bark did not significantly alter soil nutrients. All treatment effects disappeared within 6 months of application.

Amendments did not significantly alter seedling survival, biomass or yield (caliper $\geq$ 3 mm). Seedling biomass was positively correlated with early soil nutrient status, but growth was not significantly improved. The modest, short-term nutritional benefits indicate single applications of organic amendments are ineffective in improving the nutrient status of sandy nursery soils of the Southwest.

Introduction

Organic matter (OM) is an essential component of nursery soils. It serves as a building block for soil humus, as a reservoir of nutrients and water, and may contribute nutrients directly. Organic matter also buffers the soil against pH fluctuations, stabilizes soil structure and provides a favorable environment for beneficial soil microbes (Davey & Krause 1980). Organic amendments are used widely to offset nursery soil OM depletions caused by intensive soil tillage and rapid microbial decomposition (Boyer & South 1984).

Organic matter contributes to soil cation exchange capacity, especially in sandy soils. However, sandy soils in the South are inherently low in OM, and

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attempts to stabilize or increase the OM levels have met with mixed results. It is especially difficult to maintain high soil test OM levels in southwestern nursery soils because of high temperatures and frequent irrigation (Donahue et al. 1983).

Generally, nursery organic amendments are of two forms: materials fairly resistant to soil decomposition (bark and peat moss), and those easily decayed (green manure and sawdust). Soil modifications associated with these forms are markedly different. Materials resistant to decomposition, such as peat moss and bark, potentially add to the humic fraction, thereby increasing soil CEC and water holding capacity. Decomposition is slow because they have low C/N ratios, high lignin contents and are generally applied as relatively large particles (Allison 1965 1973). The slow microbial decomposition of resistant materials rarely results in soil nitrogen (N) immobilization.

Sawdust and green manures decay rapidly because of small particle size and low lignin contents. Rapid decay causes soil N immobilization when microflora absorb soil nutrients more efficiently than higher plants, resulting in a smaller nutrient pool available to the crop (Turk 1943). Materials that decompose rapidly do not increase soil humic levels. In fact, green manuring can result in a net loss of OM because it stimulates soil microflora to oxidize existing OM more rapidly (Pieters & McKee 1938). Cover crops are beneficial in that their root systems can break up plowpans, and the OM turned under can serve as a micronutrient reservoir (Allison 1973).

Peat moss is routinely applied in northern nurseries with access to regional supplies at nominal cost. In the southern region, materials more readily available than peat moss are used such as pine sawdust or bark.

Byproducts such as animal waste or sewage sludge may also be valuable organic amendments (Casey 1980: Dutton 1978; Lyon et al. 1920). These contain appreciable quantities of N, phosphorus (P), potassium (K), zinc (Zn), iron (Fe) and other micronutrients. Heavy metals such as cadmium (Cd) or lead (Pb) are rarely present in sufficient quantities to limit plant growth or pose a problem to ground water. Byproduct availability is limited by the proximity to a source.

The objective of this study was to evaluate the effects of various OM sources on nutrient availability and subsequent growth of *Pinus ponderosa* seedlings in a bare root nursery in the southwestern United States.

Materials and methods

The study was installed at the US Forest Service Albuquerque Tree Nursery (ATN), New Mexico, US. The soil was classified as a sandy loam with a pH = 7.40, electrical conductivity (EC) = 3.32 mmhos/cm, equivalent sodium percentage (ESP) = 0.25, CEC = 7.98 meq/100 g, and calcium carbonate ($CaCO_3$) = 4.52%. Soils within the nursery are generally low in available P, Fe, N and Zn (Windle 1980).

The study consisted of five treatments: no OM addition, pine sawdust, composted pine bark, peat moss and irradiated sewage sludge (Table 1). Fresh sawdust particles were 0.5 to 3.0 mm, bark particles were 0.5 to 7.5 mm, and peat moss was horticultural grade. A sudan grass cover crop was turned under, and OM added June 14, 1984. Amendments were applied by hand at 67 t/ha (approx. 12 mm deep) except sawdust (43 t/ha). All plots were rototilled to a depth of 10-15 cm. Each plot was 1.2 m × 30 m.

The study design was a randomized complete block consisting of four blocks. The blocks crossed the middle five beds in a nursery unit and were separated by a 10 m buffer between blocks.

The field was fumigated with methyl bromide MC-33 (370 kg/ha) July 2-5, 1984. After fumigation, triple super phosphate was incorporated into the soil to provide 44 kg P/ha. The beds were sown with an Oyjord seeder July 30, 1984 using nonstratified ponderosa pine seed form the Kaibab National Forest (seedlot 12002). Based partially on the results of this study, sowing in late July

Table 1. Chemical analysis of pre-treated soil and organic amendments as determined by the Soil and Water Testing Laboratory, NMSU.

Element	Soil	Sludge	Sawdust	Peat moss	Pine bark
Total N (%)	.003	3.90	.02	.49	.13
$NaHCO_3$ P (ppm)	11	810	1	14	108
P (%)	–	1.4	<.01	.01	.02
K (%)	0.14	0.61	<.01	<.01	.08
Mg (%)	–	0.39	.01	.09	.06
Ca (%)	1.13	2.52	.08	.41	.48
Na (%)	–	0.21	.01	.01	.03
Co (ppm)	–	9	–	–	–
Cu (ppm)	<1	273	<1	2	5
Fe (ppm)	3	10,329	195	952	1510
Mn (ppm)	7	2,008	16	32	68
Mo (ppm)	–	2,257	<5	<5	<5
Zn (ppm)	<1	1,003	33	29	39
Ag (ppm)	–	127	<2	<2	<2
Cd (ppm)	–	199	<.5	<.5	<.5
Cr (ppm)	–	197	<2	<2	<2
Ni (ppm)	–	174	<5	<5	<5
Pb (ppm)	–	297	<10	<10	<10

Sewage sludge data courtesy D.E. Lytton & B.D. McCaslin (unpubl.).
A hyphen (–) indicates the ananlys was not conducted.

is standard operating procedure for the nursery. The target sowing density was 442 seeds per m^2. Conventional nursery fertilization and irrigation practices were followed throughout the study.

Composite soil samples were collected from the surface 15 cm of each treatment x block combination over the course of the two growing seasons. Shoot tissue samples were also collected at the time of soil sampling. Soil and plant nutrient analyses were conducted at the Soils and Water Testing Laboratory, New Mexico State University. Organic matter was determined with the Walkley-Black method (Black 1965) after sieving through a 2 mm screen, P by the Olsen method (Ludwick & Reuss 1974), NO_3 and other elements were determined using the techniques described in Ludwick & Reuss (1974). Tissue analysis included total Kjeldahl-N and elemental determinations from a perchloric digest.

Emergence began August 9, 1984, and was essentially complete by August 19, 1984. In November 1985, two 0.36 m^2 (1.2×0.3 m) samples were hand-lifted from the first three blocks. Seedling height, diameter and fresh weight were determined. Data were treated by analysis of variance (ANOVA).

Results

Organic amendments caused immediate, but short-term increases in soil test OM level (Fig. 1). Sawdust elevated soil test OM to nearly 4%, the highest level detected among amended plots. The variability in OM was also the greatest in the sawdust plots. Sewage sludge and bark had the least effect, increasing soil test OM from about 1.2% to only 2%. Two months after sowing, the soil test OM percentage had decreased to background levels of 1.0-1.5%, regardless of treatment. After this date, no significant differences were detected among treatments.

Organic amendments did not significantly alter pH, CEC, EC, ESP or $CaCO_3$. Soil reaction ranged from pH 7.2-7.5, CEC from 8.0-8.7 meq/100 g, $CaCO_3$ from 4.5-5.2%, EC from 1.7-3.3 mmhos/cm, and ESP from 0.16-2.60%. Soil EC decreased from 3.32 mmhos/cm before sowing to 1.69 mmhos/cm 14 mo later. The greatest increase in ESP occurred during July-August, 1985.

The addition of OM influenced soil nutrient status (Fig. 2a-d). Among the macroelements, NO_3-N was most affected by the type of OM added (Fig. 2a). Sludge increased soil NO_3 from 28 ppm to 72 ppm initially. Neither bark nor peatmoss altered N levels. However, N was almost totally depleted in sawdust plots only 30 d after sowing. Urea fertilizer (46-0-0) applied at 53 kg/ha across treatments in late August 1984 failed to increase soil N in the sawdust plots. By December 1984, soil N differences among test plots had disappeared and

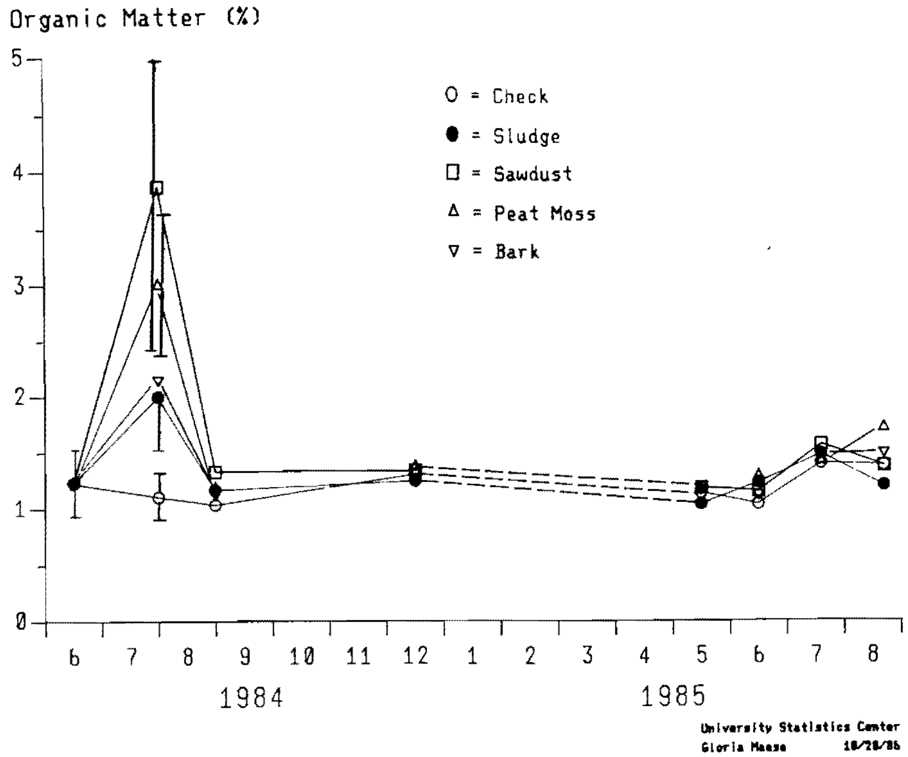
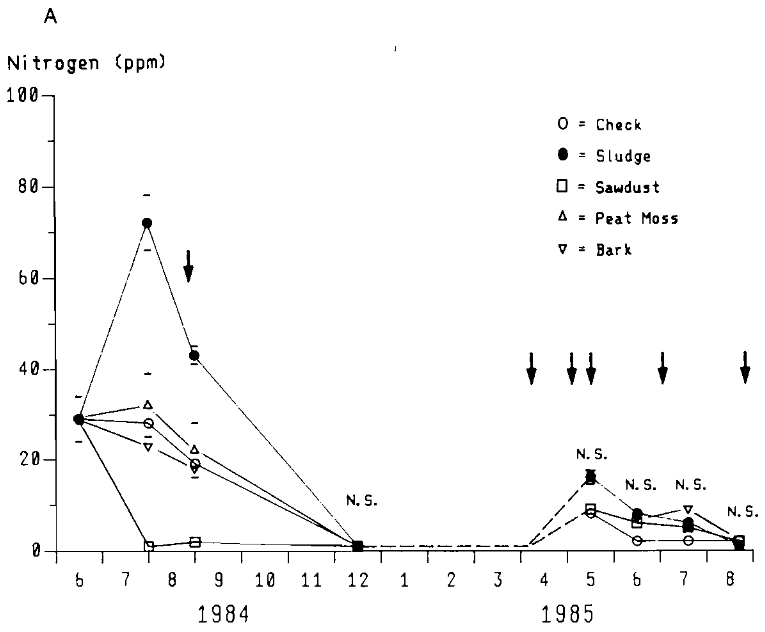


Fig. 1. Effects of organic amendments on soil test OM content at the Albuquerque Tree Nursery. Only the peat moss treatment is significantly different from the control ($\alpha = .05$) for the July 1984 sample only. Vertical bars represent ± 1 S.E. of the mean.

N averaged 1 ppm across treatments. Urea aplied in May 1985 increased soil N to 16 ppm, but N declined over the second growing season to 1 ppm by August 1985, despite four additional urea applications.

Only sludge influenced soil P (Fig. 2b). As with soil N, soil P in sludge plots remained elevated only 2 months and returned to ambient levels by December. Organic amendments did not significantly alter soil K (Fig. 2c). Nevertheless, sludge plots tended to have the highest K levels early on, and sawdust the lowest. Soil K levels decreased from 144 ppm before sowing to 56 ppm in August 1985. Only about 15 ppm can be accounted for by seedling uptake.

Soil Fe was low before sowing (2.8 ppm). The addition of sludge and peatmoss increased soil Fe to more than 5 ppm (Fig. 2d), but again the response was brief. In mid- and late August, 11 kg/ha of Sequestrene 138 Fe (EDDHA-Fe with 6% Fe) was applied across treatments. Iron was applied


A
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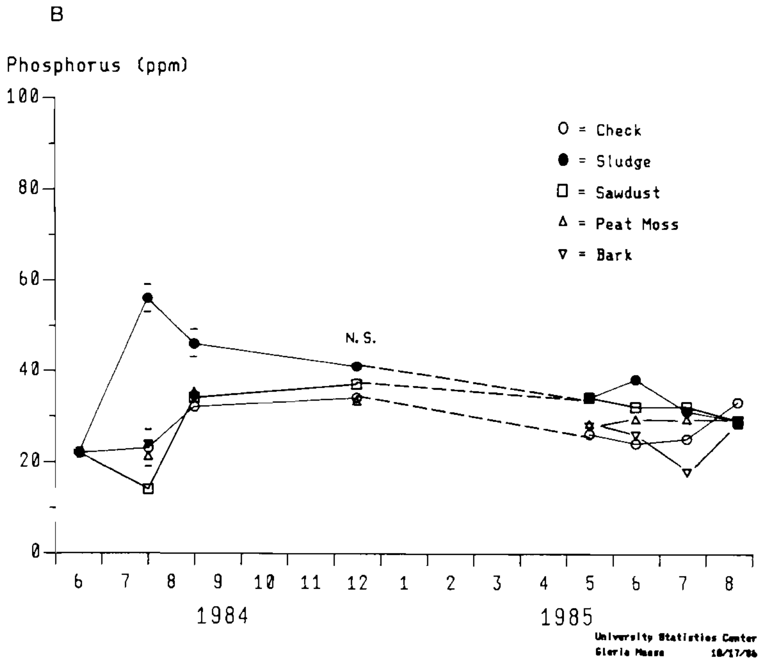
B
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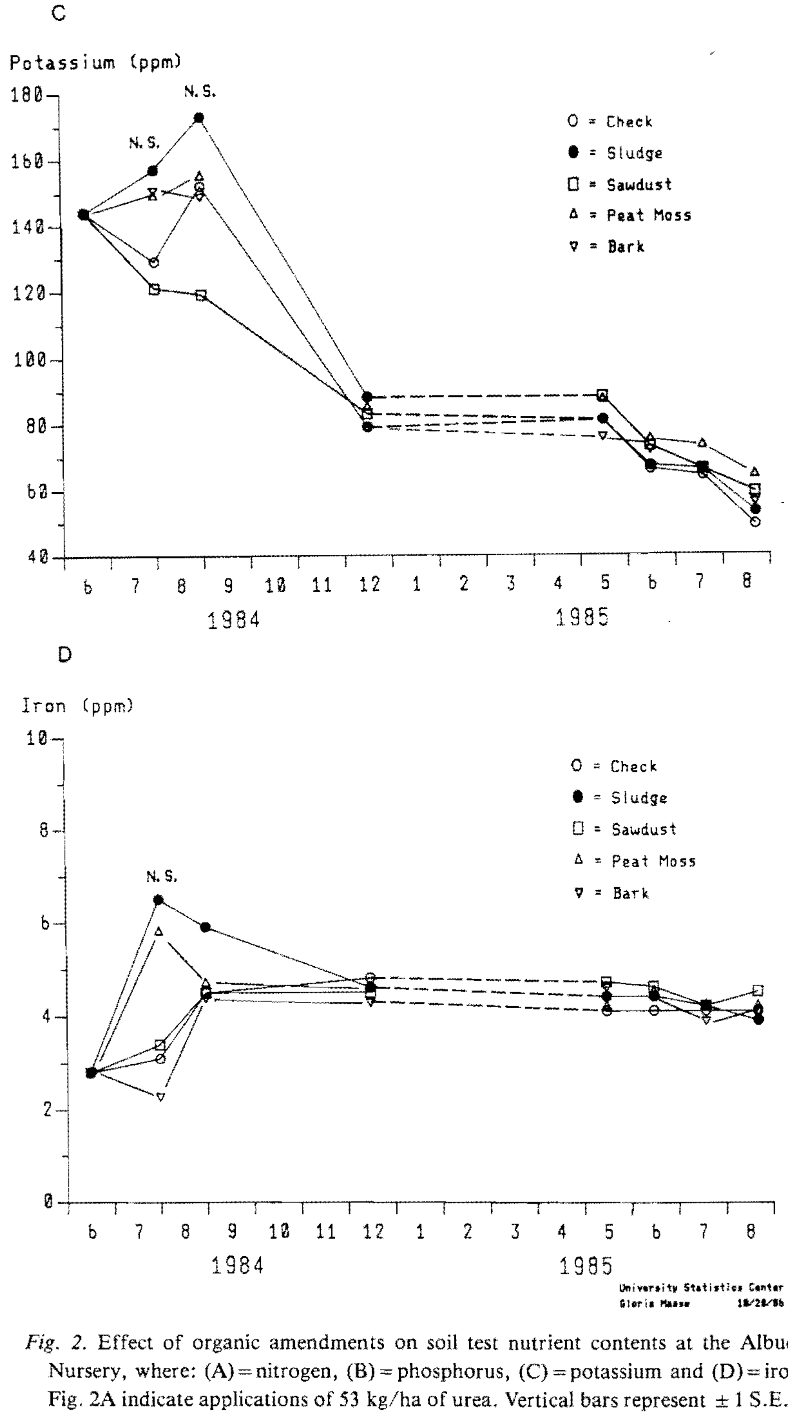

Fig. 2. Effect of organic amendments on soil test nutrient contents at the Albuquerque Tree Nursery, where: (A) = nitrogen, (B) = phosphorus, (C) = potassium and (D) = iron. Arrows in Fig. 2A indicate applications of 53 kg/ha of urea. Vertical bars represent ± 1 S.E. of the mean; N.S. = not significant.

seven times in 1985. In total, 105 kg/ha of Sequestrene 138 Fe were applied to the study plots.

Copper was the only other micronutrient affected by OM addition. The sludge-treated soil had 6.8 ppm Cu on the July 30, 1984 sampling date. Subsequent measurements did not detect significant differences among treatments.

Table 2. Seedling survival and morphology of ponderosa pine seedlings grown in soil receiving different organic amendments at the Albuquerque Tree Nursery (standard error of means in parentheses).

Treatment	Survival of emerged seedlings 12/84	Survival of emerged seedlings 11/85	Seedbed density 11/85	Seedling height 11/85	Seedling diameter 11/85
	%	%	No/m²	(cm)	(mm)
Control	85	54	292	10.5 (.14)	3.4 (.04)
Sawdust	83	60	309	9.7 (.14)	3.4 (.04)
Bark	84	58	311	11.4 (.15)	3.4 (.04)
Peat moss	85	56	288	10.3 (.15)	3.2 (.04)
Sludge	86	58	296	11.2 (.15)	3.5 (.04)

Treatment	Fresh weight shoot (g)	Fresh weight root (g)	R/S (g/g)	Yield (% ≥ 3mm)	Yield (% ≥ 4mm)
Control	3.84 (.10)	1.94 (.05)	.56 (.01)	66	26
Sawdust	3.59 (.09)	1.74 (.04	.54 (.01)	65	27
Bark	3.98 (.11)	1.86 (.05)	.51 (.01)	61	30
Peat moss	3.66 (.10)	1.72 (.04)	.51 (.01)	57	20
Sludge	4.16 (.11)	1.89 (.04)	.50 (.01)	68	32

The addition of OM and the concomitant impact on soil nutrient reserves had no significant impact on seedling survival or morphology (Table 2). Among emerging seedlings, 15% died before December 1984 and 43% died before lifting in November 1985. Seedlings grown in sawdust-amended plots tended to be the shortest and those in the sludge plots had the largest diameters, but neither differed significantly from the control. Organic matter additions decreased the R/S ratio.

Shoot fresh weight was not correlated with OM additions, but was positively correlated with early soil nutrient status. The fresh weight of seedlings lifted November 1985 was correlated with soil N and P levels determined 1 month after sowing. Shoot fresh weight was positively correlated with soil N level ($r = 0.81$, $\alpha = 0.05$) and P level ($r = 0.87$, $\alpha = 0.05$).

Root fresh weight at harvest was not correlated with early soil nutrient status. Furthermore, organic amendments appeared to have no impact on seedling nutrient status (Table 3). No significant differences in percentages were detected among treatments in December 1984 (presented) or in 1985 (data not presented).

Table 3. Effect of nursery organic matter addition on foliar nutrient status of four-month-old ponderosa pine seedlings (standard error of means in parentheses).

Nutrient	Treatments				
	Control	Sawdust	Bark	Peatmoss	Sludge
N (%)	1.72 (.09)	1.58 (.14)	1.68 (.11)	1.84 (.05)	1.75 (.09)
P (%)	0.15 (.02)	0.16 (.01)	0.16 (.02)	0.16 (.02)	0.15 (.02)
K (%)	0.93 (.13)	1.03 (.18)	1.01 (.08)	1.10 (.13)	0.93 (.06)
Ca (%)	0.63 (.09)	0.59 (.04)	0.62 (.05)	0.67 (.04)	0.66 (.08)
Mg (%)	0.09 (.00)	0.09 (.00)	0.09 (.01)	0.09 (.01)	0.09 (.01)
Zn (ppm)	58 (31)	70 (59)	38 (22)	39 (10)	96 (85)
B (ppm)	27 (25)	14 (2)	15 (1)	14 (1)	14 (15)
Fe (ppm)	260 (203)	178 (13)	180 (31)	154 (23)	220 (51)
Mn (ppm)	63 (19)	61 (24)	66 (14)	68 (23)	51 (25)
Cu (ppm)	7 (9)	2 (2)	2 (1)	3 (2)	4 (4)
Al (ppm)	225 (73)	224 (17)	226 (38)	191 (33)	273 (57)

Discussion

The OM level recommended for sandy loams in southern nurseries is 2.0-2.5% (May, 1980), and 3-5% in northern nurseries (van den Driessche 1984). However, South & Davey (1982) reported all sandy loam nurseries in the South average about 1.6% soil test OM. Oklahoma nurseries (forest nurseries closest to ATN) generally average less than 1% soil test OM (Mexal, pers. obs., Myatt 1980). Furthermore, virgin arid soils contain less than 1% OM, and cultivation reduces the soil OM equlibrium level (Hagin & Tucker 1982).

Organic amendments applied at the Albuquerque nursery had only short-term effects on the soil chemical properties measured. The addition of sawdust increased the nursery soil OM content to nearly 4%. However, less than 75 days after application, soil OM level had returned to 1.5%. This is not to say that all the OM had decomposed. On the contrary, there was still visable OM present in all the plots. However, all added OM less than 2 mm in size had apparently decomposed. Munson (1983) found the decomposition rate of added OM increased as the rate of application increased, and the nursery soil returned to equilibrium at about the same time (about 2 years), regardless of amount of OM applied. It is very unlikely that soil test OM level can be increased above the equilibrium level by single applications on sandy nursery soils in the South. That level for the Albuquerque nursery is about 1%. According to May & Gilmore (1985), it is possible to increase OM in nursery soils. They were able to increase OM from 2% to 3% by the addition of 396 t/ha over a six year rotation. Sawdust was applied every year including the years in pine seedlings.

Organic amendments did not significantly alter soil acidity. In previous studies, peat moss, sawdust and sewage sludge increased soil acidity (Munson 1983), but in another study sawdust had no effect (Lietzke & Peterson 1987). Soluble calcium is high in the ATN soil, ranging from 4,000 to 22,000 ppm (Windle 1980). Possibly, high $CaCO_3$ levels buffered the soil against pH changes.

Available soil N was rapidly depleted in sawdust-amended plots. Davey & Krause (1980) concluded from Allison (1973) that sawdust applied at 43 t/ha would immobilize 430 kg N/ha. Once soil N fell below 1 ppm in August, further decomposition of sawdust could have been inhibited. However, sawdust did not cause further depletion of N the following spring. Non-composted sawdust should be applied with sufficient N added to compensate for immobilization, especially if added before sowing pine seed.

Sewage sludge applied at 60 and 136 t/ha increased the biomass of slash pine nursery seedlings (Berry 1980). At the ATN, none of the amendments significantly affected seedling biomass, despite causing diverse soil nutrient responses. Seedling shoot biomass was correlated ($r \geq 0.80$) with soil N and P early in the growing season. However, soil nutrient differences occurred among plots over a brief period. Consequently, the biomass differences were slight.

Crop mortality was considerable in all plots but appears to be unrelated to OM treatments. Overall, about 15% of the seedlings died before December 1984, and a total of 43% died before lifting in November 1985. In absolute terms, fewer seedlings died in the amended plots. Although the differences were economically important, they were not statistically significant. Future research should examine this aspect of the study.

Soil EC ranged from 3.3-3.4 mmhos through August 1984, and high salt level may have independently caused seedling death, or predisposed damaged seedlings to other stresses, including cold.

Seedling death also could have resulted from severe N deficiency. Soil N fell from 33 ppm in July to less than 1 ppm in December 1984 and did not increase until urea was applied in May 1985. Nutrient imbalance can hamper natural hardening in the fall, which can result in freeze damage (Timmis 1974). However, N-induced mortality seems unlikely because sawdust-amended plots had the lowest N, but the least mortality.

Sludge, peat moss and Fe chelate applications increased soil Fe. Initially, Fe was near deficiency levels (Chen & Barak 1982), but frequent, routine applications (9) of Sequestrene 138 Fe maintained levels considered adequate.

Wakeley (1954) noted:

> So enthusiastically is soil organic matter regarded by many that there is danger of its being expected to cure ills with which it has no connection...

The addition of organic matter cannot replace good nursery management, only augment it. In addition, soil test OM in sandy to sandy loam soils reaches equlibrium between 0.8-1.2%. This level is probably maintained by roots severed at lifting. OM can be increased only by the repeated application. May & Gilmore (1984) reported OM was increased 0.5 percentage point by 198 t/ha applied in 3 or 6 applications over 6 years, and 1 percentage point by 396 t/ha applied in three applications in 6 years.

Amendments purportedly offer several benefits, including better water infiltration, nutrient availability and, in some cases, suppression of soil-borne disease organisms, especially bark (Pokorny 1982). The nutrient elements added with OM amendments could significantly offset losses to crop removals. Van den Driessche (1980) noted conifer seedling crops can remove up to 200 kg N/ha, 35 kg P/ha and 105 kg K/ha over two growing seasons. However, this study demonstrated that OM additions applied at the ATN provide at best a short-term impact on the soil nutrient pool available to the seedling crop. Furthermore, previous studies conducted at this nursery indicate OM additions did not improve infiltration (Tinus, unpubl.). Severe soil nutrient depletions caused by amendments such as fresh sawdust can decrease seedling size. The impact of nursery soil nutrient deficiencies can not only affect nursery yield, but also forest establishment and tree growth over the entire rotation. (Fisher & Mexal 1984).

The amendments applied did not improve nursery seedling growth. This is similar to results reported by others (Benzian et al. 1972; Coleman et al. 1986). Apparently, the soil nutrient additions derived from the OM applications were too brief in duration to significantly benefit growth. Amendments applied repeatedly over a prolonged period might prove more effective. However, Benzian et al. (1972) failed to show this for Sitka spruce in a cooler climate where decomposition is slower. Although the opportunity to incresae nursery soil OM has been demonstrated by others (May & Gilmore 1984), the opportunity to improve seedling performance appears remote in view of the findings discussed. This work does little to justify the expense of organic matter additions as currently practiced.

Acknowledgments

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