Comparison of Conventional and Alternative Nursery Field Management Systems: Tree Growth and Performance[1]

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Abstract

The effects of 5 nursery field maintenance systems (cultivation, herbicide management, legume (bird's-foot trefoil) companion crop, winter cereal (rye) cover crop/mulch, and mixed grass sod) on the growth and performance of field-grown trees were investigated. Six tree species were included in this study: *Fraxinus pennsylvanica* 'Marshall's Seedless'; *Malus* 'Red Splendor'; *Gleditsia triacanthos* var. *inermis* 'Skyline'; *Acer rubrum* 'Northwood'; *Thuja occidentalis* 'Techny'; and *Picea glauca* var. *densata*. Height, lateral branch extension, and caliper growth were measured each year for 7 years. Plant quality was assessed at the end of the study. All growth parameters were affected by field management treatment. Field management treatment effects on growth were influenced by differences in climate between years and were species dependent. Caliper growth was more sensitive to cover crop competition than height growth. Height and caliper growth were initially reduced for deciduous trees grown together with cover crops, but treatment differences in height became less significant over time. Caliper of evergreens was also reduced, but field management treatment effects on height were variable. Trees grown under bare soil conditions (cultivation and herbicide management) were more densely branched than those grown with cover crops. Herbicide management and cultivation generally supported the most vigorous growth and resulted in the best quality plants. Of the cover/companion crops evaluated, the rye cover crop/mulch treatment only slightly reduced plant performance compared to cultivated and herbicide management treatments while bird's-foot trefoil and grass companion crops proved to be too competitive. A winter rye cover crop/mulch field management system appears to have potential as an alternative to conventional field production systems. Using such a system, quality plants can be produced with fewer inputs and fewer negative impacts on the environment and long term productivity.

Index words: cover crops, sustainable, alternative agriculture, allelopathy, mulches.

Species used in this study: 'Marshall's Seedless' green ash (*Fraxinus pennsylvanica* Marsh. 'Marshall's Seedless'); 'Red Splendor' flowering crabapple (*Malus* Mill. 'Red Splendor'); 'Skyline' thornless honey locust (*Gleditsia triacanthos* var. *inermis* Willd. 'Skyline'); 'Northwood' red maple (*Acer rubrum* L. 'Northwood'); 'Techny' eastern white cedar (*Thuja occidentalis* L. 'Techny'); Black Hills white spruce (*Picea glauca* var. *densata* Bailey); 'Norcen' bird's-foot trefoil (*Lotus corniculatus* L. 'Norcen'); 'Wheeler' winter rye (*Secale cereale* L. 'Wheeler'); 'Eton' perennial ryegrass (*Lolium perenne* L. 'Eton'); 'Ruby' red fescue (*Festuca rubra* L. 'Ruby').

Significance to the Nursery Industry

Three cover/companion crop systems were evaluated as alternatives to conventional nursery field management practices. An allelopathic winter rye cover crop/mulch system is suggested as an effective, alternative field management system that reduces environmental impacts and production costs. The research also provides a theoretical and applied basis for further research involving the selection of potential cover/companion crop species and development of alternative horticultural field production systems that require fewer inputs, decrease production costs, and reduce negative environmental impacts associated with nursery field production.

Introduction

The nursery industry faces a broad range of environmental, economic, and production challenges that will significantly affect the future of this segment of agricultural production. Nursery production systems impact the environment through land clearing, drainage modification, shelterbelt development, crop rotation, and field management strategies. Production practices including cultivation, field design, species selection, fertilization, irrigation, harvest procedures, and pest control can also elicit environmental concern and may reduce long term productivity. In addition, variable herbicide efficacy, herbicide phytotoxicity, and evolving pesticide tolerances are concerns associated with reliance on synthetic pesticides. These concerns have spawned considerable interest in alternative, sustainable methods of nursery field management such as minimum tillage, use of cover or companion crops, and integrated pest management. As environmental considerations become a higher civic priority, impacts of agricultural production practices will be more intensely scrutinized. Demand for environmentally sound production systems that address soil erosion, sedimentation, soil salination, upland and wetland habitat destruction, pesticide toxicity, pesticide and fertilizer runoff, ground and surface water quality, and long term productivity will increase.

Coupled with increased emphasis on environmental concerns, economic factors continue to have significant impacts on the nursery industry. Production costs continue to rise as labor, energy, chemical, irrigation, fertilizer, and equipment costs escalate. To remain competitive, promote economic stability, and maintain profitability, the nursery industry must minimize production costs and maintain productivity. Alternative production strategies that are less labor intensive, have fewer equipment needs, and require fewer synthetic inputs provide direct opportunities to manage production costs.

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In the past, cover/companion crops, usually grass, were frequently judged to be too competitive since tree growth was often reduced (11, 20, 25). Broadleaf cover crop species are generally considered to be less competitive than grasses, but are often more difficult to manage (5). Reduced growth in the presence of cover crops has been attributed to competition for available water and nutrients (8, 10, 13, 27). This competitive relationship is, however, more complicated than a simple reduction in shoot growth or dry matter accumulation. Effects on additional characteristics that impact the quality and value of nursery stock, such as crown density, conformation, pest damage, and foliage color, must also be considered. Potential concerns of other horticultural producers interested in cover crop based production systems, such as impacts on yield and quality, should also be appraised. In addition to cover/companion crop effects on plant performance, effects on production practices (fertilization, irrigation, pest control, harvest), production costs, productivity, and long term sustainability should also be evaluated. Effects on cold acclimation, erosion potential, moisture conservation, nutrient cycling, and populations of beneficial flora and fauna, must also be considered when assessing the comprehensive value of any alternative production system.

This research was designed to evaluate three cover/companion crop systems as alternatives to conventional nursery field production practices. Cultivation and herbicide field management treatments were included because they are standard methods of weed control in the nursery industry even though these practices leave soil in a bare, unprotected state and result in substantial erosion potential. 'Norcen' bird's-foot trefoil was included as a nitrogen fixing leguminous companion crop treatment. It was chosen based on concerns regarding competition for nitrogen by cover/companion crops and its desirable cover characteristics. 'Wheeler' winter rye was selected as a cover crop/mulch treatment based on research which has shown its potential for use in minimum tillage. 'Wheeler' rye and its residues are allelopathic (1, 2) and, thus, may have potential to inhibit weed growth in nursery production settings. A non-mowed grass companion crop (sod) was included because of its ease of establishment, wear tolerance, cold hardiness, longevity, and easy maintenance. Grass is, however, considered to be highly competitive and often competes excessively with the primary crop and reduces growth. Because of these characteristics, a grass plot provides a good basis for comparison of the suitability and competitiveness of other cover/companion crop options. The effects of field management treatment on plant growth and performance are the focal points of this paper.

Materials and Methods

A field plot [Waukegan silt loam (fine silty, mixed, mesic, Typic Hapludoll) with an average pH of 6.9, 4.3% organic matter, 1.0 ppm NO_3-N, 181 ppm P, and 445 ppm K] was established at the University of Minnesota, St. Paul Campus nursery facility. Sordan 79 hybrid sorghum sudangrass [*Sorghum bicolor* (L.) Moench x *Sorghum sudanense* (Piper) Staph.] was sown during the previous year to increase organic matter content and reduce perennial weed populations. Prior to initiation of the test plots the field was cultivated and divided into four blocks.

Six commonly grown tree species were planted in rows by species across blocks: *Fraxinus pennsylvanica* 'Marshall's Seedless'; *Malus* 'Red Splendor'; *Gleditsia triacanthos* var. *inermis* 'Skyline'; *Acer rubrum* 'Northwood'; *Thuja occidentalis* 'Techny'; and *Picea glauca* var. *densata*. Trees were planted 3.1 m (10 ft) apart in rows spaced 2.8 m (9 ft) apart across each block.

Five field management treatments were imposed: cultivation (3–5 cultivations/year); herbicide management (oxadiazon); legume companion crop—'Norcen' bird's-foot trefoil (*Lotus corniculatus* 'Norcen'); winter cereal cover crop/mulch—'Wheeler' winter rye (*Secale cereale* 'Wheeler'); and grass sod—80% 'Eton' perennial ryegrass (*Lolium perenne* 'Eton') and 20% 'Ruby' red fescue (*Festuca rubra* 'Ruby'). Field management treatments were assigned at random within each block resulting in a randomized, split-plot (species = main plots; treatments = subplots) experimental design with four replications. Each treatment plot measured 9.1 m (30 ft) by 16.5 m (54 ft) and included three trees of each of the 6 species evaluated. Statistical analyses of growth data for all three trees/treatment were compared to analyses where only center trees were included to assess for edge effects resulting from root growth into adjacent plots.

The cultivated treatment consisted of 3 to 5 cultivations/year depending on seasonal weed growth (approximately once each month during the growing season). Plots were cultivated to a depth of 10 to 15 cm (4 to 6 in) using a walk-behind tiller. The 10 cm (4 in) area surrounding each tree trunk was hand hoed.

Oxadiazon (3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2(3H)-one), a pre-emergent, granular herbicide (Ronstar 2G; Rhône-Poulenc Chemical Co., Research Triangle Park, NC), was used for the herbicide treatment. The oxadiazon was applied each spring using a walk-behind spreader at 3.92 kg ai/ha (3.5 lb ai/A) followed by irrigation.

Bird's-foot trefoil seed was scarified and seeded at 7.85 kg/ha (7 lb/A). Seed was inoculated with the appropriate *Rhizobium* spp. (LiphaTech, Milwaukee, WI) prior to planting.

Winter rye cover crop/mulch plots were cultivated prior to seeding in mid September of the establishment year. 'Wheeler' rye was seeded at 134.5 kg/ha (120 lb/A). To limit competition between the rye cover crop and the trees, the rye was killed the following spring using fluazifop-P (butyl ester of (R)-2-[4-[[5-trifluoromethyl)-2-pyridinyl]oxy] phenoxy]propanoic acid) (Fusilade 2000 1E; Zeneca Ag Products, Wilmington, DE) applied at 0.43 kg ai/ha (0.38 lb ai/A) just before trees resumed growth each spring (early to mid May). The herbicide was applied using a N_2-pressurized, back-pack sprayer calibrated to apply 1,524 liters of water/ha (163 gal/A) at 207 kPa (30 PSI) of pressure. The resulting rye mulch was left on the soil surface during the growing season. Subsequent to the establishment year, rye was reseeded directly into the existing mulch each fall without additional soil preparation.

A grass mixture containing 'Eton' perennial ryegrass (80%) and 'Ruby' red fescue (20%) was selected based on ability to produce a quick cover, cold hardiness, mature height, minimal maintenance requirements, and adaptability. The grass mixture was seeded at 67.3 kg/ha (60 lb/A). The grass sward was not mown.

The cultivated, herbicide, bird's-foot trefoil companion crop, and grass companion crop treatments were initiated immediately following tree planting in early May. The rye cover crop/mulch treatment was initiated in September of the establishment year. All seed was broadcast using an over-the-shoulder, hand cranked seeder and was lightly raked in to improve soil contact. Trees were grown under the various field management treatments for 7 years. To enable evaluation of the field management treatments regarding their effects on soil fertility, moisture status, and plant growth in the absence of complicating factors, the field was not fertilized and was only irrigated the first year during the period of cover crop establishment. Supplemental fertilization may have also negated the nitrogen fixing ability of the legume treatment.

Plant height, caliper, and growth of the terminal and three randomly selected side shoots were measured at the end of each growing season. Caliper was measured 15 cm (6 in) above the soil line. Because of apparent differences in plant crown density, numbers of primary growing points on 3 scaffold branches/tree were determined as a measure of branching density at the end of the study. In addition to plant height, width was also measured for *Thuja* at the end of the study as an indicator of plant form and to calculate crown volume. Although not of concern to nursery growers, flowering (flower number, flowering date) and fruit characteristics (coloration, fruit set) were noted for *Malus* because these characteristics would be of interest to fruit growers. At the conclusion of the 7-year study, plants were rated on a scale of 1 to 5 (1 = unsalable, 2 = poor, 3 = fair, 4 = good, 5 = excellent) by three qualified nursery professionals as a measure of plant quality and salability. Plants rated ≥4.0 were considered to be of high quality.

Soil fertility was determined at the end of each growing season [University of Minnesota Soil Testing Lab; Nursery and Florist Test (Spurway); 0.017 N acetic acid extraction]. Soil moisture (% oven dry wt) was determined on a monthly basis. In both cases, 3 sets of 8 × 15 cm (3 × 6 in) soil cores were sampled to a depth of 45 cm (18 in) within each field management treatment plot.

Endogenous plant elemental content was determined for all species except *Gleditsia* in August of the final year of the research. Collection of foliar samples was standardized with respect to leaf maturity, exposure, and location within the crown for each species. Samples were dried at 65C in a forced-air oven for 72 hr and ground to pass a 0.5 mm screen using a Wiley mill. Percent total N (with nitrate reduction) was determined using the salicylic acid macro-Kjeldahl method; P and K content was determined by atomic emission spectrometry (University of Minnesota Research Analytical Laboratory).

Cover/companion crops were characterized based on ease of establishment (time to germination), mature height, and % soil coverage. The ability of the field management treatments to exclude undesired vegetation was also assessed annually. Weed count data were collected (August) for 10 m^2 (111 ft^2) of each field management treatment plot by random tosses of a square meter frame.

Results and Discussion

Screening of cover/companion crop field management strategies for use in perennial horticultural production systems must consider the performance of the cover/companion crop as well as the primary crop. Weed control for the cultivated treatment was ephemeral; small weeds were almost always present and repeated cultivation was required to keep weed numbers and size under control. Oxadiazon provided excellent weed control except for one plot where common chickweed [*Stellaria media* (L.) Vill.], an escape weed for this herbicide, was a minor problem (7). Of the three cover/companion crops evaluated, the grass treatment was easiest to establish and maintain. The red fescue/perennial ryegrass sod provided complete soil coverage, attained a height of 25–28 cm (10–11 in), and effectively excluded other vegetation. The proportion of ryegrass decreased over time and after 7 years had essentially disappeared leaving a pure stand of fescue. Bird's-foot trefoil was initially slow to become established, resumed growth late (mid to late May) in subsequent years, did not provide complete soil coverage, and attained a height of 38–50 cm (15–20 in). Slow establishment, delayed regrowth, and uneven soil coverage enabled weeds to invade the trefoil plots resulting in the highest weed densities affiliated with any of the vegetative covers evaluated (7). Problem weeds included common lambsquarters (*Chenopodium album* L.), prickly lettuce (*Lactuca serriola* L.), Canada thistle [*Cirsium arvense* (L.) Scop.], and ladysthumb (*Polygonum persicaria* L.). The rye cover crop was easy and quick to establish, was easily killed by subsequent herbicide treatment resulting in a 3–5 cm (1–2 in) thick mulch during the growing season, and provided excellent weed suppression (6). A few weeds, mainly perennial species including dandelion (*Taraxacum officinale* Weber in Wiggers), curly dock (*Rumex crispus* L.), and Canada thistle [*Cirsium arvense* (L.) Scop.], did, however,

Table 1. Effects of 5 nursery field management treatments on height and caliper of 6 tree species after 7 growing seasons.

Field management treatment	*Fraxinus pennsylvanica* 'Marshall's Seedless'		*Acer rubrum* 'Northwood'		*Malus* 'Red Splendor'		*Gleditsia triacanthos* var. *inermis* 'Skyline'		*Picea glauca* var. *densata*		*Thuja occidentalis* 'Techny'	
	height	caliper	height	caliper	height	caliper	height	caliper	height	caliper	height	caliper
	(cm)											
Cultivation	545ab[z]	13.8a	437a	8.1a	401a	8.1a	442b[y]	8.2b[y]	216.1a	6.4a	170.4ab	—[x]
Herbicide management	557a	13.9a	427a	8.5a	405a	7.8ab	532a	10.3a	224.3a	6.3a	166.3b	—
Trefoil	473c	10.3b	377a	6.3b	377a	6.7bc	409b	6.7c	214.0a	5.6ab	175.6ab	—
Rye	488bc	10.2b	377a	7.3ab	382a	7.4abc	428b	6.9c	240.0a	6.3a	183.0a	—
Grass	470c	10.9b	396a	7.1ab	359a	6.1c	425b	7.1c	203.4a	5.2b	186.1a	—

[z]Treatment means within columns separated by Tukey's HSD (p = 0.05).

[y]Data presented for *Geditsia* are after 6 growing seasons because of excessive losses to *Nectria cinnabarina* during the seventh year.

[x]Multiple stemmed material; caliper not measured.

Table 2. **Effects of 5 nursery field management treatments on soil moisture levels in the upper 45 cm (18 in) of the soil profile during the growing season (May–Sept.) over a 7-year period.**

Field management treatment	Soil moisture (% dry wt) Sample depth (cm) 0–15	15–30	30–45	0–45
Cultivation	17.3c[z]	22.6b	23.9bc	21.3bc
Herbicide management	15.4c	21.5b	21.3c	19.4c
Trefoil	24.2ab	23.8b	22.7bc	23.6b
Rye	27.4a	27.6a	28.6a	27.9a
Grass	23.1b	22.3b	24.0b	23.1bc

[z]Treatment means separated by Tukey's HSD (p = 0.05).

become established during the 7-year study. These weeds could have been easily controlled with a spot, postemergent herbicide program. 'Wheeler' rye was not autoallelopathic since germination and establishment of subsequent rye plantings into the existing mulch were unaffected. The presence of cover/companion crops stabilized the soil surface and improved accessibility with harvest equipment especially under wet conditions. The grass companion crop was most effective in this regard.

Field management treatment effects on plant height and caliper growth after 7 growing seasons are presented in Table 1 (growth data for years 1–6 not shown, but are available from the senior author upon request). In general, growth was more variable for deciduous species than for evergreens and height was more variable than caliper. For two years, all cover/companion crops reduced tree growth compared to cultivation and herbicide management (data not presented). By the third growing season, differences in plant height between treatments were reduced. After 7 years, treatment mediated differences in height had been eliminated for *Acer*, *Malus*, and *Picea* while *Fraxinus* and *Gleditsia* (after 6 years) were still taller for the herbicide and cultivated treatments compared to trees grown with vegetative covers (Table 1). The opposite was true for *Thuja* which tended to be taller in the presence of covers. Although treatment mediated differences in caliper were also reduced over time, compared to plant height, caliper was a more consistent indicator of plant response to field management treatment and differences were still evident for all species after 7 growing seasons (Table 1). Caliper was reduced for *Fraxinus* and *Gleditsia* grown with vegetative covers compared to the cultivated and herbicide treatments. Caliper for *Gleditsia* was greatest for the herbicide treatment. Treatment mediated differences in caliper for *Acer, Malus*, and *Picea* were mixed. Compared to plants grown under cultivation and herbicide management, caliper was often reduced for plants grown with trefoil and grass companion crops.

Initial reductions in growth of newly transplanted trees in response to cover/companion crops were not unexpected. Root systems are limited following transplanting and water and nutrient uptake would be restricted even in the absence of competitive vegetation. As root systems expand and extract moisture and nutrients from larger soil volumes, the competitive capacity of trees would be expected to increase. This appears to have been the case for trees grown with vegetative covers in this research.

Differences in height and caliper growth in response to field management treatment might be explained by the time of year when the bulk of these two types of growth occur (17, 18, 19, 29) and by intrinsic seasonal growth patterns (determinate vs. indeterminate) associated with each species (19, 29). Height growth is most rapid immediately following bud break in early spring when soil moisture levels are usually at their peak. Cover crop competition for moisture at this time might be expected to be minimal and less likely to limit shoot growth. This may account for the relatively limited effects of treatment on height (Table 1). In contrast, most caliper growth occurs later in the growing season when soil moisture is often limiting resulting in an increased competitive cover crop effect and reduced caliper growth. During wet years, when soil moisture is adequate for both trees and cover/companion crops, groundcover effects on height and caliper growth would likely be minimal. Competition for moisture by vegetative covers would increase during dry periods and effects on growth would then be of increased consequence. The potential for negative competitive cover crop effects on growth of the primary crop would also be influenced by soil type and its effect on soil moisture holding capacity.

Seasonal and cumulative differences in height and caliper growth could have resulted from yearly variations in climate, including precipitation and temperature, combined with treatment effects on soil moisture. This theory is supported by soil moisture data (Table 2) and height and caliper increment data from year 7 (Table 3) which was a dry

Table 3. **Effects of 5 nursery field management treatments on height and caliper growth increment of 6 tree species for year 7 of a 7 year study.**

Field management treatment	*Fraxinus pennsylvanica* 'Marshall's Seedless' height	caliper	*Acer rubrum* 'Northwood' height	caliper	*Malus* 'Red Splendor' height	caliper	*Gleditsia triacanthos* var. *inermis* 'Skyline' height	caliper	*Picea glauca* var. *densata* height	caliper	*Thuja occidentalis* 'Techny' height	caliper
	(cm)											
Cultivation	45.1c	2.8a	31.1c	1.4a	36.5a	1.5b	—[x]	—[x]	33.1c	1.1b	27.5ab	—
Herbicide management	40.6c	2.3c	42.7b	1.3a	39.9a	1.4b	—	—	40.7bc	1.2ab	24.0b	—
Trefoil	46.4c	2.5bc	45.3ab	1.3a	44.0a	1.4b	—	—	42.3abc	1.3ab	31.4ab	—
Rye	69.6a	2.6ab	55.9a	1.5a	43.4a	2.0a	—	—	50.2a	1.4a	31.9a	—
Grass	57.0b	2.6ab	54.3a	1.5a	42.6a	1.4b	—	—	46.8ab	1.4a	31.8a	—

[z]Treatment means within columns separated by Tukey's HSD (p = 0.05).

[y]Multiple stemmed material; caliper not measured.

[x]Species excluded; excessive losses to *Nectria cinnabarina* by the seventh year of the research.

year. Monthly precipitation was below average except in July, November, and December when precipitation was above average (St. Paul Campus Climatological Observatory, Department of Soil, Water and Climate, University of Minnesota, St. Paul). For the period January through June, precipitation was only 38% [12.5 cm (4.9 in)] of normal [33.0 cm (13.0 in)]. Precipitation in July was 304% [30.5 cm (12.0 in)] of normal [10.1 cm (4.0 in)] most of which resulted from one rainstorm. Most of this precipitation would have been lost to runoff and percolation from the root zone of moisture in excess of field capacity. For the remainder of the growing season (August through September) precipitation was only 72% [12.6 cm (5.0 in)] of normal [17.5 cm (6.9 in)]. Interestingly, even during a dry year, cover/companion crop treatments did not reduce height and caliper growth compared to cultivation or herbicide management (Table 3). The rye treatment tended to promote the most consistent positive growth response. Soil moisture was highest for the rye treatment and tended to be higher for all cover/companion crop plots compared to herbicide management and to a lesser degree cultivated plots (Table 2). Similar results have been reported for orchard soils managed with cover crops (12, 16). Treatment effects on soil moisture were most dramatic near the soil surface (Table 2). These results may be correlated with increased water infiltration capacity (data not shown) and more favorable soil moisture conditions for these treatments especially the rye cover crop/mulch treatment (6). Higher soil moisture levels affiliated with the rye cover treatment compared to all other field management treatments was likely a mulch effect combined with increased infiltration capacity effects on soil moisture recharge. Conversely, soil moisture was usually lower for the herbicide treatment compared to the trefoil and rye treatments; probably in response to surface sealing, resulting in increased runoff and decreased infiltration, and elevated soil temperatures associated with herbicide plots (6). Similar effects on infiltration and soil temperature were observed for the grass plots, but these positive effects on soil moisture may have been partially offset by the water requirements of the grass sward. Even though cover crops would be expected to compete with the primary crop for soil moisture, such improvements in soil moisture status mediated by the presence of cover crops may render such competition moot so long as drought conditions are not severe.

In addition to soil moisture, plant nutrition was probably involved in the growth responses observed. Competition associated with vegetative covers has the potential to reduce tree growth especially where grass cover crops are concerned (4, 10, 27). In this research, soil analyses demonstrated that after 7 years N levels in the top 15 cm (6 in) of the soil profile were increased an average of 3.2 ppm NO_3-N compared to initial levels, but there were no differences among treatments (Table 4). When sampled to a depth of 45 cm (18 in), herbicide plots were higher, but still deficient, in N (4.1 ppm NO_3-N). The N fixing bird's-foot trefoil companion crop did not increase soil N perhaps because of the significant number of weeds present in the trefoil plots (7). There were no treatment effects on soil P. After 7 years, K in the top 15 cm (6 in) of the soil profile was reduced compared to initial values (445 ppm vs. 321 ppm; HSD = 83) only for the herbicide treatment (Table 4). More importantly, treatment differences in foliar N were documented through foliar analysis (Table 5). Foliar N was lowest for trees from the grass and bird's-foot trefoil plots; the treatments most likely to negatively influence plant growth and quality. Chlorosis of trees growing in the grass plots provides further evidence that these trees were stressed for N. Similar N deficiencies associated with cover crop competition have been previously documented (4, 10, 15, 23, 27). Conversely, endogenous P levels were higher for trees grown with vegetative covers (Table 5). Differences in foliar K were less distinct. While K levels were similar for trees grown in the herbicide, trefoil, and grass plots, K levels were higher for plants grown with grass compared to the cultivated and rye treatments. The fact that there was no relationship between field management treatment and the P and K content of the soil makes these results even more interesting. The trend toward higher P and K levels in foliage of trees grown with vegetative covers compared to bare soil treatments may have been in response to cycling of these less mobile nutrients by the vegetative covers (14).

Table 4. Effects of 5 nursery field management treatments on soil fertility[z] (nitrogen, phosphorus, and potassium) after 7 growing seasons at various depths within the soil profile.

Field management treatment	Sample depth (cm)	NO_3-N (ppm)	P (ppm)	K (ppm)
Cultivation	0–15	3.1a[y]	183a	380a
	15–30	2.7b	155a	272a
	30–45	2.5b	58a	150a
Herbicide management	0–15	3.3a	177a	321b
	15–30	4.4a	124a	227a
	30–45	4.5a	41a	140a
Trefoil	0–15	3.5a	167a	376a
	15–30	2.7b	152a	247a
	30–45	2.0c	56a	127a
Rye	0–15	3.0a	156a	367a
	15–30	2.3b	167a	248a
	30–45	2.3b	41a	115a
Grass	0–15	3.0a	163a	383a
	15–30	2.3b	146a	230a
	30–45	1.3c	42a	122a

[z]University of Minnesota Soil Testing Lab; Nursery and Florist Test (Spurway); 0.01 N acetic acid extraction.

[y]Treatment means within columns by sample depth separated by Tukey's HSD ($p = 0.05$).

Table 5. Effects of 5 nursery field management treatments on endogenous plant elemental content (N, P, K) averaged across species as determined by foliar analysis.

Field management treatment	Nitrogen (%)	Phosphorus (ppm)	Potassium (ppm)
Cultivation	2.13a[z]	1856c	8045b
Herbicide management	2.08a	1758c	8610ab
Trefoil	1.91b	2794b	8468ab
Rye	2.07a	3124b	8011b
Grass	1.59c	4668a	9287a

[z]University of Minnesota Research Analytical Labratory; inductively coupled plasma atomic emission spectrometry, dry ash method.

[y]Treatment means within columns separated by Tukey's HSD ($p = 0.05$).

Table 6. **Effects of 5 nursery field management treatments on width and crown volume of Thuja occidentalis 'Techny'.**

Field management treatment	Width (cm)[z]	Crown volume (cm^3)[y]
Cultivation	127.3a[x]	1,674,941a
Herbicide management	125.0a	1,573,862a
Trefoil	96.6c	893,277c
Rye	114.2b	1,274,743b
Grass	104.0c	1,123,609b

[z]Width of each plant at widest point.

[y]Plant form resembled a truncated cylinder. Crown volume estimated based on calculation of cylinder volume (r^2L) using height for length (L) and average width for diameter to calculate radius (r).

[x]Treatment means within columns separated by Tukey's HSD (p = 0.05).

While variations in height in relation to field management treatment were limited after 7 growing seasons, *Thuja* grown with vegetative covers tended to be taller and narrower than those grown in bare soil (Tables 1 and 6). This was especially true for *Thuja* grown in the bird's-foot trefoil and grass plots. This effect of vegetative covers on plant conformation was reflected in reduced crown volumes documented for *Thuja* grown with cover/companion crops compared to herbicide and cultivated treatments (Table 6). This disparate effect of cover crops on plant form for *Thuja* may be associated with the indeterminate growth habit of this species compared to the determinate growth pattern for the other species evaluated. Since under favorable conditions growth of indeterminate species continues throughout the growing season, cover crop effects on N availability and soil moisture would be manifested over a longer period than for determinate species and effects on growth would be magnified proportionately.

Field management treatment effects on branching density were species dependent (Table 7). Field management treatment effects on branching density were most variable for *Acer* followed by *Picea*, *Malus*, *Fraxinus*, and *Thuja*. Branching was reduced compared to the herbicide treatment for all species except *Thuja* when grown with grass and trefoil companion crops. Branching of trees from the grass plots was also reduced compared to plants from the cultivated plots for all species except *Thuja*. No reduction in branching was evident for *Fraxinus*, *Malus*, and *Thuja* grown with a rye cover crop compared to plants in the cultivated and herbicide treatments. Branching of *Acer* and *Picea* in the rye plots was reduced compared to herbicide management, but not the cultivated treatment. Compared to the herbicide treatment, branching of *Acer*, *Fraxinus*, *Malus*, and *Picea* trees in the grass plots was reduced 64%, 48%, 37%, and 25%, respectively. Branching of trees in the trefoil plots was also reduced an average of 26% compared to trees from herbicide plots. Branching density for *Picea* was highest for the herbicide treatment and in comparison was also reduced 29% for the bird's-foot trefoil treatment. *Picea* grown with vegetative covers had an open, tiered branching habit compared to the dense, well dispersed branching pattern associated with trees grown in the absence of vegetative groundcovers. Branching density for *Thuja* was also reduced by the bird's-foot trefoil companion crop compared to all other treatments, except cultivation, among which there were no differences in branching density.

Negative effects of vegetative covers on plant density (Table 7) may have resulted from N deficiencies associated with cover crop competition. Research with douglas fir indicates terminal growth may be a stronger sink than lateral growth resulting in less dense, taller plants when N is limiting (26). Endogenous hormone levels (cytokinins) might also be involved in this treatment effect on branching. Reduced root temperatures during budbreak have been associated with reduced cytokinin levels in xylem sap and has been reported to reduce budbreak and, subsequently, branch density (3, 24, 28). Soil (root) temperatures measured in conjunction with this research (6) were cooler for cover crop treatments compared to bare soil treatments (cultivation and herbicide management) and similar effects on plant cytokinin levels may explain differences in branching among treatments. Branching density was generally greatest for the herbicide treatment especially for evergreen species. These plants were, however, abnormally compact perhaps as a result of reduced soil moisture levels; slight, but long term herbicide injury; or an herbicide effect on adventitious bud development.

Plant quality ratings were indicative of field management treatment (Table 8). Plants of highest quality were generally from herbicide and cultivated treatments where all species received average quality ratings of 4.3 to 4.9. While quality of *Fraxinus* and *Malus* was reduced, there was no reduction in quality for *Acer*, *Picea*, and *Thuja* grown in the rye plots compared to trees from the cultivated and herbicide treat-

Table 7. **Effects of 5 nursery field management treatments on branching density of 6 tree species.**

Field management treatment	Branching density[z]				
	***Fraxinus pennsylvanica* 'Marshall's Seedless'**	***Acer rubrum* 'Northwood'**	***Malus* 'Red Splendor'**	***Picea glauca* var. *densata***	***Thuja occidentalis* 'Techny'**
Cultivation	8.1ab[y]	12.6ab	21.6ab	28.9b	14.5ab
Herbicide management	9.0a	16.0a	24.4a	32.8a	15.6a
Trefoil	6.7b	11.4b	17.5bc	23.2c	13.0b
Rye	8.0ab	10.4b	20.1abc	29.0b	15.8a
Grass	4.7c	5.7c	15.4c	24.6c	15.6a

[z]Number of primary growing points on three scaffold branches/tree. *Gleditsia triacanthos* var. *inermis* 'Skyline' was excluded because of excessive losses to *Nectria cinnabarina* by the seventh year of the research.

[y]Treatment means within columns separated by Tukey's HSD (p = 0.05).

Table 8. Effects of 5 nursery field management treatments on tree quality.

Field management treatment	Quality rating[z]					
	Fraxinus pennsylvanica 'Marshall's Seedless'	*Acer rubrum* 'Northwood'	*Malus* 'Red Splendor'	*Gleditsia triacanthos* var. *inermis* 'Skyline'	*Picea glauca* var. *densata*	*Thuja occidentalis* 'Techny'
Cultivation	4.9a[y]	4.3a	4.5a	4.3ab	4.4a	4.7a
Herbicide management	4.9a	4.5a	4.5a	4.9a	4.4a	4.7a
Trefoil	3.8b	3.2b	3.5bc	3.7b	3.6ab	3.0c
Rye	4.1b	3.8ab	4.3b	4.2b	4.0ab	4.0ab
Grass	3.9b	3.2b	3.2c	3.8b	3.2b	3.8b

[z]Trees rated for quality by three evaluators using a 1-5 rating scale (1 = low, 5 = high). Ratings averaged to give a mean quality rating for each tree.
[y]Treatment means within columns separated by Tukey's HSD (p = 0.05).

ments. Quality of *Gleditsia* grown in the rye plots was reduced compared to herbicide management, but not cultivation. With ratings of 4.1 or higher, the reductions in quality for *Fraxinus*, *Gleditsia*, and *Malus* were slight. Trees from the trefoil and grass treatments were rated as being of only fair quality with ratings of 3.0 to 3.9. *Fraxinus* exhibited the least variability in quality in response to field management treatment while *Thuja* was most variable. Although both species were of high quality for the cultivated and herbicide treatments, the ability of *Thuja* to compete and perform in the presence of vegetative covers was apparently less than for *Fraxinus*. Reductions in quality for both evergreen and deciduous species were primarily in response to negative effects on plant form and density rather than height. Quality of deciduous plants growing in grass plots was further reduced by their pale green color. Although qualitative in nature, plant quality ratings may be the most effective method of treatment comparison because they reflect the end product of each production system. Quality ratings also provide a measure of salability and value which are ultimately of most importance to nursery growers and consumers.

Flowering of *Malus* was reduced in the bird's-foot trefoil and grass plots, but not the rye plots. There were 106 ± 28.2, 100 ± 6.8, 83 ± 15.2, 103 ± 16.0, and 43 ± 22.3 flowers per shoot for the cultivated, herbicide, bird's-foot trefoil, rye, and grass treatments, respectively. Although inconsequential in a nursery situation, this effect could influence fruit production under orchard conditions since bird's-foot trefoil and grass companion crops might reduce fruit set. The rye cover crop/mulch treatment would not reduce fruit set through effects on flowering and might be a better alternative orchard floor management option than bird's-foot trefoil or grass.

Plant performance was generally best for the herbicide and cultivated treatments and poorest for the grass and trefoil treatments. Compared to trees from cultivated and herbicide treatments, any reductions in plant growth and performance associated with the rye treatment were small, and from a horticultural and salability standpoint, often insignificant (based on plant quality and growth data). Although data regarding the ability of supplemental fertilization to overcome cover crop competition are mixed (9, 10, 21, 22), employment of standard fertility practices may have reduced and possibly eliminated statistical differences in growth and quality for these plants. Since there were no differences in the height and quality of *Picea* from the cultivated, herbicide, and rye plots (Tables 1 and 8), there would be no difference in the value of trees from these treatments (6). Similarly, while the value of deciduous trees grown with bird's-foot trefoil and grass companion crops was typically reduced through reductions in caliper and plant quality, reductions for the rye treatment were not large enough to reduce wholesale value. For example, the value of *Malus* based on caliper was $193, $193, $153, $193, and $153 for the cultivated, herbicide, trefoil, rye, and grass treatments, respectively (6). Quality ratings for these plants were 4.5, 4.5, 3.5, 4.3, and 3.2 (HSD = 0.99), respectively. When 7-year production costs [$4,223/ha ($1,710/A) for cultivation, $5,090/ha ($2,061/A) for herbicide management, $218/ha ($88/A) for the bird's-foot trefoil companion crop, $1,428/ha ($578/A) for the rye cover crop/mulch, and $337/ha ($136/A) for the grass companion crop (6)], environmental suitability, and long term sustainability are factored in, the rye cover crop/mulch system becomes a viable alternative to cultivation and herbicide based field management systems. Even if the cheaper and more commonly used herbicide oryzalin had been used, the cost of the herbicide treatment ($2,094/ha; $848/A) would still have been 1.5 times that for the rye treatment. In addition to reducing production costs relative to cultivation and herbicide management with only limited reductions in tree growth, quality, and market value, the rye cover crop/mulch protected the soil surface, controlled undesired vegetation, increased water infiltration, improved soil moisture conditions, and augmented soil organic matter (6). These effects would clearly be beneficial regarding their capacity to reduce soil erosion and associated nutrient losses, improve soil fertility and reduce fertilizer requirements, improve soil moisture status and reduce the need for supplemental irrigation, and maintain long term productivity. Although many of these benefits were also associated with bird's-foot trefoil and grass companion crops, the poor weed suppression provided by the trefoil and excessively competitive nature of these two field management options as managed in this research do not support their use in woody plant production systems. It should be noted that because of the presence of weeds in the bird's-foot trefoil plots, negative effects of this treatment on growth and performance were likely partially in response to weed competition. While supplemental fertilization and irrigation may have reduced the competitive effects of these treatments, an ideal cover/companion crop would not require inputs above requirements of the primary crop and should initially be screened for accordingly. Once a cover/companion crop has shown potential for use in a field production system, further research might examine the effects of added fertility and moisture including a cost analysis of such inputs.

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