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Title: EFFECT OF DIFFERENT LEVELS OF FERTILIZER, APPLICATION INTERVAL AND CONTAINER TYPE ON GROWTH OF SEEDLINGS OF BLACK LOCUST (*Robinia pseudoacacia* L.)

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Black locust seedlings were raised in white ray leach super cells from seed of an unknown California source in the shade house at Oregon State University, Forest research Laboratories. When the seedlings were 25 days old, application of 4 levels of nitrogen i.e. zero, low, medium and high (0, 100, 200, 400 ppm) in the form of ammonium nitrate fertilizer was started. Each N level was associated with and without 50 ppm of phosphorus in the form of phosphoric acid to make 8 doses. Positive N doses, both with and without P, were applied after each 5 days (D_5) and 10 days (D_{10}) to make 14 treatments.

Nitrogen alone had a significant ($P < 0.05$) effect when raised from 0 to 100 ppm (D_5) in all growth parameters i.e. shoot length, diameter, leaf area and total dry biomass. Medium level of N (200 ppm) resulted in significantly higher responses to seedlings that had received P. High N level (400 ppm) did not prove to be effective in increasing different growth parameters which is in agreement to our

hypothesis of luxury consumption.

Nitrogen and phosphorus interaction caused tremendous positive response in all growth variables generally at low and medium N levels. Phosphorus applied to 0 and low (D_{10}) levels of N caused significantly higher nodulation. On all other growth variables, P had no effect different than without P at these two N levels. Nitrogen application interval (D) had significant effect on P_{50} seedlings at low (100 ppm) N level on almost all growth variables. Seedlings getting nitrogen fertilizer every 5 days (D_5), had higher growth than those receiving fertilizer every 10 days.

Concentration of N and P in plant tissue was not affected by presence or absence of P but it was affected by level of N. Nitrogen and phosphorus use efficiency was maximum at 200 ppm (D_{10}) N level in seedlings with added P. This was also the level at which average growth per subsequent additional unit (100 ppm) of N after the first input of 100 ppm was maximum.

Another experiment tested the effect of 4 container types (polythene bag, deepot, ray leach cell and Spencer-Lemaire) on growth of black locust seedlings. Results indicated that growth of seedlings was not only dependent on the volume of the container but shape was also instrumental in determining the development of seedlings.

Seedlings in deepots had the highest mean growth in shoot height, diameter, leaf area and total dry biomass by the end of the experiment. These were significantly greater

(P >0.05) than the seedlings grown in Spencer-Lemaire and ray leach cells.

Seedlings in Spencer-Lemaire had the minimum growth whereas ray leach seedlings were found to be more efficient in growth per unit volume of growing medium. Polythene bags were cost effective as the growth of seedlings in these was not different than deepot which are definitely more costly than polythene bags.

EFFECT OF DIFFERENT LEVELS OF FERTILIZER, APPLICATION INTERVAL AND CONTAINER TYPE ON GROWTH OF SEEDLINGS OF BLACK LOCUST (*Robinia pseudoacacia* L.)

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EFFECT OF DIFFERENT LEVELS OF FERTILIZER, APPLICATION INTERVAL AND CONTAINER TYPE ON GROWTH OF SEEDLINGS OF BLACK LOCUST (*Robinia pseudoacacia* L.)

1. INTRODUCTION

1.1 GENERAL

Black locust (**Robinia pseudoacacia** L.) is a leguminous medium sized tree extensively planted for stabilization of soils, erosion control, fuel wood and fodder production. It has rough fissured bark and light green foliage, leaves 20 cm long composed of 13 to 15 leaflets which are oval in shape and minutely spine-tipped. The roots bear nitrogen fixing nodules which enable it to thrive on soils of low fertility (Hallett, 1989.)

Black locust grown in many parts of the world, rivals poplar as the second most extensively planted genus after eucalyptus. It has a wide range of economic, aesthetic and ecological uses that make it well suited for agroforestry. It is widely distributed not only in Europe but throughout temperate and Mediterranean zones. Its' ideal habitat is one with a temperate moist climate and silty or sandy loams of loose structure. But it is the ability to withstand a variety of poor conditions that make it such a valuable species. Some important black locust cultivating countries, in order of area planted, are Republic of Korea, Hungary, the USSR, Romania, Bulgaria, Yugoslavia, Czechoslovakia, and China. In the United States it has been planted on large areas of abandoned farmlands for timber production and erosion control (Keresztesi, 1980) and for soil stabilization on disturbed sites (Roberts et al 1983). In Pakistan black locust was introduced some 30 years ago and it is well adapted to the sub-tropical climate of the North-eastern mountainous region ranging in elevation from 3000 to 5000 feet (AMSL). It is widely planted in northern part of Pakistan on private grazing lands for erosion control and along banks of streams and fields for soil stabilization. It is becoming one of the most sought after agroforestry tree species because of its cash value as fuel wood and fodder.

1.2 PROBLEM STATEMENT

As the single most costly industrial input into agricultural productivity, chemical fixed nitrogen accounts for up to 35% of the total productive capacity of all crops (Gordon et al, 1979). Each pound of industrially fixed nitrogen requires 30 cu.ft. of natural gas. The mass application of fertilizer in agriculture may become more and more expensive in the future; hence intensive research was carried out on intercropping systems to maximize crop yield per unit land area with a minimum input of nitrogen fertilizer (Ofori and Stern, 1987). Nitrogen fixing trees may also gain more importance in agroforestry.

It has been demonstrated that intercropping of legumes is effective with other agricultural crops in tropical climates and with a range of species in temperate climates (Sanchez, 1976). The potential value of black locust for nitrogen fixation is recognized in most parts of the world. With rising oil prices, the importance of black locust as a N fixing species is increasing (Keresztesi, 1980).

In forestry too, nitrogen fertilization is becoming increasingly important, however, in the competition for chemically fixed nitrogen, forestry will be a lower priority than agriculture.

A growing body of evidence points to the physical benefits of incorporating trees into farming system. The most significant contribution of trees may be their favorable influence on soil fertility (Auten, 1945). Under closed stand conditions one ton of black locust litter liberates to the soil the equivalent of 56 pounds of N per acre annually which is in the form of soluble nitrates and is equivalent to an annual application of over 264 pounds of pure dry ammonium sulphate per acre.

Desirable characteristics of trees for intercropping include a rapid growth rate, drought resistance, survivability, nitrogen fixing capacity, ability to withstand repeated pruning, a multipurpose nature, and possession of small leaves or leaflets (Ssekabembe, 1985). Black locust meets almost all of these characteristics and shows attributes necessary for fuel wood plantations including sustainable growth on marginal sites, vigorous coppicing and ease of establishment (Dickman et al 1985). If the effectiveness and efficiency of N_2 fixation by black locust can be increased, it may be possible to reduce the need for nitrogenous fertilizers (Reinsvold and Pope, 1987).

The use of legumes in farming systems in the tropics is particularly important for two reasons: 1. high prices of commercial fertilizer relative to the weak financial resource base of peasant farmers and 2. reduction of the fallow period in common land use systems as a result of increasing population pressure with a concomitant decline in soil productivity (Yamoah, 1986).

In Pakistan each year about 12 million black locust bare root seedlings are produced in nurseries out of which hardly 8 million are plantable after culling. Heavy seedling loss is due to management practices; mainly spacing of seedlings in the nursery bed, improper fertilization and extraction technique.

In Pakistan there are two planting seasons; spring (February) and Monsoon (August). Outplanting of black locust seedlings is possible only from late winter to early spring due to bare root nature of the seedlings. Two years old seedlings are produced by sowing in spring, top clipping the following spring (i.e after one year in the flat) and transplanting at a 9 x 9 inch spacing in beds where they remain for another year. This practice is fairly costly in terms of time and space, yielding only 60% of the seedlings that were originally sown. Results could be substantially improved if suitable containers were used with appropriate doses of fertilizer to enhance the initial growth and adaptation to the harsh planting environment.

Growing of black locust seedlings in containers would make its planting possible in late spring as well as Monsoon if sturdy seedlings were produced with improved management practices including fertilization. Nitrogen and phosphorus are often deficient in nursery soils and limiting for growth of trees. Symbiotic nitrogen fixation in black locust seedlings can be affected by the availability of various nutrients (Reinsvold and Pope, 1987). One way to address the problem is to produce seedlings with optimum biomass in suitable containers and with application of suitable doses of fertilizer. This study, therefore, focused on determining the effect of different dosages of N and P fertilizers, time interval of their application and size and shape of containers on growth of black locust seedlings.

1.3 OBJECTIVES

Production of high quality seedlings for subsequent outplanting with high rates of survival and growth is the basic idea of raising nursery stock. Morphological and physiological characteristics of plants often change in response to resource availability (Hilbert, 1990). One of the primary factors affecting the quality of seedlings is soil fertility maintained through fertilizer and organic amendments. Nitrogen and phosphorus, which are essential for growth, are usually deficient in a containerized nursery. Size and shape of a container are also important factors in determining the seedling quality and size and shape of the roots. A vigorous root system maintains favorable moisture and nutrient balance for optimum growth. This study was, therefore, conducted with the objectives:

1: to evaluate the effect of:

A. i) different levels of nitrogen fertilizer alone

ii) application interval of nitrogen fertilizer (and their interaction)

iii) interaction of nitrogen and phosphorus applied together

on the production of total biomass and its partitioning in black locust seedlings by:

B. a) measuring the root, shoot length, their dry weight, collar diameter and leaf area

b) counting the number of nodules

c) nutrient analysis of different tissues for N & P.

2: determine the effect of four different kinds of containers on the total biomass production of black locust seedlings by measuring the parameters as in 1.B above (except for nutrient analysis).

1.4 HYPOTHESES

There is a relationship between nutrient uptake and plant growth (Landis, 1985). At some low concentration a nutrient or a set of nutrients is limiting to plant growth. As the supply of nutrients is increased the growth rate increases rapidly until a critical point is reached beyond which plants may continue nutrient uptake but show no further increase in growth (luxury consumption). Further increase in nutrient supply causes toxicity due to extremely high concentration of the element in the tissue and plant growth begins to decrease.

Container shape and volume both directly influence seedling growth and development (Klingaman, 1983). Deep pots generally allow longer and better developed root system. In this context it is hypothesized that:

i) there is increase in total biomass of black locust seedling with increase in N supply, alone and in conjunction with phosphorus, from some minimum level till a certain limit beyond which further addition does not bring growth response.

ii) there is a level of N alone and another with P at which the growth response of the seedlings is maximum.

iii) seedlings getting P with all levels of N will grow bigger than plants without P.

iv) the bigger the container volume the greater the biomass production of the black locust seedling.

2. LITERATURE REVIEW

Forest nurseries are established and maintained to produce planting stock for large scale afforestation and reforestation. Better growth of seedlings can be achieved with improved management practices like fertilization, irrigation regime, container size etc. Optimum fertilizer application is one aim of best management to raise good quality seedlings to ensure survival and better growth after outplanting.

2.1 NITROGEN

All the essential elements are important in the nutrition of plants from a physiological point of view, but N is the most important single element. It forms 2-4% the dry weight of an average pot plant and occurs in all plant proteins and chlorophyll. Deficiency of N causes a marked reduction in plant growth rate. High N level results in more vegetative growth and less reproductive growth or delayed flowering.

Nitrogen compounds, including oxidized and reduced forms as well as free N, are available to plants. Gamborg and Shyluck (1970) proposed that a mixture of ammonium and nitrate is the most suitable inorganic N source for growth of plant cells. Some fertilizers contain only NO_3, such as calcium nitrate whereas others like ammonium phosphate are composed exclusively of NH_4. Ammonium nitrate contains equal amounts of both nitrogen ions. It has, however, been found that the total concentration of these two ions is not as important as their relative balance (Landis et al, 1989)

Haystead (1979) showed that application of relatively low (20-60 kg/ha) N dressing at sowing did not increase growth in the early stages of the establishment. He suggested that higher rates of application (100 kg/ha of N), when the seedlings are in a condition to take up N rapidly, could have a greater effect.

On the other hand Marshall (1981) reported that root elongation of young black locust seedlings was inhibited by 10 gm. of a fertilizer/liter concentrate applied shortly after germination. He attributed reduction in nodulation to decrease in root growth. He showed that shoot height, shoot and root dry biomass also did not increase with high fertilization. He suggested that fertilization may be more effective if applied several weeks after germination. Tinus and McDonald (1979) stated that mineral nutrients should not be added during the germination of seedlings, because maintenance of nutrient poor medium could help control damping off fungi. Moreover the concentrated fertilizer solution may "burn" succulent germinants. The low growth response of black locust seedlings to N fertilization on an N deficient field site suggested that only minimal amount of soil N are required in addition to the N fixed to support maximum growth (Plass, 1972). One reason nitrogen fertilization did not promote growth may be its inhibitory effect on nodulation.

Ingestad (1982) pointed out that with increase in rate of nitrogen application or internal concentration, there was linear increase in growth of birch seedlings until a saturation point beyond which growth was reduced. Beyond the saturation point, he explained, N assimilation will be more than the requirement for metabolic process and will be stored in amino acids or protein forms.

Hilbert (1990) developed a theoretical model to explain the physiological and morphological responses of plants to N availability. Plants grown in higher N environment will have higher leaf N concentration and higher soot:root ratio than plants grown with low N availability.

Turner (1922) reported that with the increase in N supply there was significant increase in shoot growth of barley plants but a relatively small increase in root growth thereby increasing shoot:root ratio.

Switzer and Nelson (1963), however, demonstrated different results. In their experiment with the increase in nutrient concentration of N,P,K, the rate of root growth was stimulated more than top growth of loblolly Pine seedlings, resulting in decrease in shoot to root ratio. An investigation of a number of relationships using regression analysis showed that there was no significance between survival and any seedling characteristic employed. They, therefore, cautioned against the reliability of employing survival as an index of stock quality as influenced by the nursery cultural measures.

In lodgepole pine, root to shoot ratio (inverse of shoot:root) decreased with increase in N application but the rate of decrease was progressively less as N application increased (Van Den Driessche, 1977). In another experiment (1982) he demonstrated that there was significant increase in shoot height, root collar diameter and seedling dry weight in coastal, and interior Douglas-fir, sitka spruce and lodgepole pine with each increase in the rate of N fertilization from 60 kg N/ha through 140 kg N/ha to 235 kg N/ha. This was accompanied with a decrease in root:shoot ratio when fertilization was increased from 140 to 235 kg/ha. He noted different effects on survival of different species after outplanting in relation to fertilization in the nursery.

Wright (1983) suggested that levels of nutrients in the containers were more important than how they were applied. With the increase in nitrogen concentration there was increase in its absorption by "Helleri" holy plant and increased growth to a certain limit. Nitrogen level of 45 ppm was sufficient for growing healthy vigorous plants but adding an additional 30 ppm resulted in 20 % more growth. The extra fertilizer cost brought a manyfold increase in the value of plant.

Swanson et al (1989), determining the growth response of seven container grown species to three concentration of eleven fertilizers, found that impact of fertilizer on plant survival depended more on the type rather than its concentration. They did not observe a difference between 5 gm and 10 gm Agriform pellets as long as the same amount of actual N was applied.

Nitrogen fixation by black locust-Rhizobium was inhibited when grown in a nutrient solution containing NH_4NO_3 as compared solution without NH_4NO_3 (Roberts et al, 1984). This reduction in N fixation was due to smaller nodule size and less nodule activity. Relative growth rate (final fresh weight/original fresh weight) was, however, 3 times more and leaf area 2 times larger in the N treated than in the untreated plants.

Leaf area and dry matter content of birch leaves, stems and roots increased with increasing level of N from 0 to 80 ppm beyond which a decrease occurred. This was followed by another increase at > 400 ppm level while a level of 1400 ppm was found to be lethal (Ingestad and Lund, 1979).

Ingestad (1979) found that nitrogen content in different organs was strongly dependent on the N supply. On a dry weight basis, roots of birch contained highest percentage of N as compared to other organs. On the other hand, Switzer and Nelson (1963) reported a greater percentage of N in leaves of loblolly pine. They also reported an increase in internal N concentration with increase in external N concentration.

Cromer and Jarvis (1990) reported increase in specific leaf area (leaf area/leaf mass) of Eucalyptus grandis with increasing N. However, relative growth rate of stem was shown to be higher than that of other organs indicating that stems were a major preferred sink for carbon.

2.2 PHOSPHORUS

The effect of different nutrients on the number of nodules/plant has been demonstrated by Lynd and Ansman (1989). It was shown that number of nodules/plant was more in plants given 100 mg of phosphorus per kg of soil (100 ppm) than the control in Arachis hypogaea (1989 A) and Canavalia eusiformis (1989 B). On the other hand Hart (1989) reported extremely varied effect of P concentration on the number of nodules in white clover plants but showed that the nodule weight/plant increased significantly with P supply from 1 to 100 $mM/(m)^3$.

It is generally accepted that root systems proliferate in zones of high nutrient supply. Caradus and Snaydon (1988) found that root and shoot dry weight and root elongation rate was higher in white clover populations treated with P than untreated.

Taylor and Goubran (1976) demonstrated the effect of P on fresh root and shoot weight and leaf area of apple where these parameters were respectively 86, 27 and 18% more in plants supplied with 50 ppm of P than without P. Root length, however, increased in P stressed plants. Phosphorus utilization efficiency (plant biomass/ plant P concentration) in three legumes and 2 cereals was shown to be highest at lowest P concentration and decreasing with increasing of P concentration from 5 to 400 μM (Fageria and Baligar 1989). Legumes showed more phosphorus utilization efficiency than cereals.

Hallmark and Barber (1984) found no effect of P on dry root weight of soybeans but dry shoot weight was shown to be more in plants supplied with 100 mg/kg (100 ppm) of P than P stressed plants. Concentration and influx of P was also more in plants supplied with phosphorus.

A low phosphate dose of (0.04 μM) was shown to cause symptoms of severe P deficiency, low P content and decrease in dry weight of 8 annual pasture species (Asher and Loneragan, 1967). Increasing P supply to 0.2 μM caused 2-4 fold increase in P concentration and increase in dry weight in all species. Raising application of P above 5 μM concentration started causing adverse effects on the plants.

2.3 COMBINED EFFECT

Response to an increased supply of NH_4NO_3 was observed in growth of leaves but not in roots and stems of six week old white spruce seedlings (Etter, 1971). Increasing N supply from 5.6 ppm to 112 ppm while keeping P at a constant level of 62 ppm, resulted in enhanced growth in leaves but not in roots. He suggested that 50-60 ppm of N (NH_4NO_3) and 6-7 ppm of P is quite adequate for the early growth of white spruce.

Van Den Driessch (1980) reported a significant increase in shoot length, shoot and root dry weight of 1 year old Douglas-fir seedlings by increasing N (NH_4NO_3) supply from 0 to 25 kg/ha. Further increase to 100 kg/ha did not cause any significant difference. Moreover, tissue analysis showed that each additional N fertilizer level increased N concentration but decreased P concentration in the shoot. With increasing rate of P application from 0 to 160 kg/ha there was no significant increase of P concentration in the shoot. He also reported correlation between shoot dry weight and survival after outplanting of 2-0 seedlings, suggesting that survival benefit of adding N fertilizer was due to the increase in seedling size.

The combined effect of soil nitrogen and phosphorus was determined on nodulation and growth of black locust plants by Reinsvold and Pope (1987). It was demonstrated that with increase in level of P there was increase in mean number of nodules per plant and plant dry weight. On the other hand considerably more variation was demonstrated on nodulation and plant dry weight with addition of N alone. Seedlings with medium level of 50 mg/kg (50 ppm) of added N produced more nodules and nodular dry weight when compared with two extreme levels. For number of nodules, nodular dry weight and total dry weight, the interaction between N and P factors and the interaction between seedling age and the level of added P were found to be significant. Foliar N concentration was significantly affected by P x N interaction but this increase was not associated with P or N levels.

A simple linear model was developed by Tingxiu and Guofan (1988) to show relationship between black locust biomass and 13 soil physico-chemical properties including available N and P (ppm). They showed that available P had the most significant effect and was one of the main factors which influenced plant growth followed by N.

Van Den Driessch and Wareing (1966) demonstrated that by increasing N level from 2 ppm to 200 ppm and P level from 0.3 to 30 ppm, there was corresponding increase in relative growth rate (change in growth/change in time) and net assimilation rate (leaf area/ground area covered by the canopy) in 3 pine species. While holding P at 0.3 ppm level, increase in N did not result in increase of RGR or NAR but a decreasing trend was shown.

Fischer and Garbett (1980) demonstrated the response of semimature slash pine and loblolly pine growth to N and P fertilization. Trees getting 220 kg N + 50 kg P/ha had the maximum growth followed by N and in P alone.

Israel and Rufty (1988) showed that phosphorus utilization efficiency and biomass concentration in 2 nitrogen regime soybean plants increased with increase in P supply up to external concentration of 0.25 to 0.5 ppm beyond which P utilization efficiency declined and P concentration in the tissue increased without any additional growth. However, N utilization efficiency did not decrease with increase in external P concentration.

2.4 TYPE OF CONTAINER

The size and shape of container also have effect on the quality of the seedlings. Matching the container size to the natural shape of the root distribution may stimulate both top and root growth. Klingoman and king (1983) showed that not only volume of container but its diameter had an effect on the dry weight of shoot and root.

In a study comparing the effect of rigid green plastic containers and poly bags on seedling growth, Whitcomb (1983) found that root spiraling occurred in the rigid container when it reached the bottom. In poly bag the root tips died when they were trapped in the folds at bottom and lateral roots formed, increasing fibrousness.

The shape of the container is important in affecting future growth of the seedlings (Tinus and McDonald, 1979). A narrow deep container is more compatible with the growth habit of forest seedlings. The rigid wall containers with internal vertical ribs or grooves and bottom holes train the root down and help egress through the holes.

A large increase in volume associated with slight increase in diameter of a container, though, affects plant growth, economically limits increase in container diameter. Barnett (1974) found that growth in a 3/4 inch diameter tube was less than in the slightly larger one but no growth advantage was noticed in a tube with diameter greater than one and a quarter inch for loblolly pine.

Cunningham and Geary (1989) found that large differences in container diameters and lengths caused only small differences in seedling shoot height and root collar diameter of *Eucalyptus camaldulensis*. They found, however, marked increase in seedling shoot and root dry weights with the increase in diameters or lengths of the container and influence on shoot:root ratio by container length. The effect of container volume on growth of seedlings diminished rapidly past an optimum size. Keelas and Edgar (1979), however, found a direct effect of container volume, rather than depth on shoot height of *Eucalyptus regnans*.

Carlson and Endean (1976) found no effect on shoot length, shoot and root dry weight of white spruce by increasing the container volume 4 times (from 133 cm^3 to 524 cm^3) while holding the length:diameter ratio to 3:1 respectively. After changing length:diameter ratio to 1:1, there was significantly higher total dry biomass than the plants grown in 3:1 or 6:1 containers.

Kinghorn (1974) suggested that by using flat bottom pots and plastic bags, whether perforated or not, larger tops could be grown but the roots may be so coiled in the bottom that great lengths of non-functional roots may be produced, ignoring balanced shoot:root principles.

The ultimate aim of a nursery technique or seedling husbandry is to raise quality seedlings to ensure better survival and performance after outplanting. There is no consensus in the available literature regarding the effect of nursery fertilization on survival after outplanting but a positive correlation between fertilization and growth has been accepted by most of the researchers (Landis, 1985). Authors have been using different indices as indicators predictors of survivability of seedlings. The majority of them recommend nutrient status and some size variable of a seedling. The aim of this study is not in the context of performance of seedlings after outplanting but to provide information on effect of N and P as well as container type on seedling growth and form in the nursery. A wide array of seedling size and growth variables have been included in this study unlike most previous studies on black locust.

3. MATERIALS AND METHODS

The study was conducted in the shade house of Forest Research Laboratories OSU, Corvallis under uniform temperature and irrigation conditions. To prevent direct sunlight and promote uniform conditions, black plastic sheets were hung on the western side of the shade house.

Seed was procured from California with an unknown source. Average seed was 0.45mm long, 0.3mm wide and 0.2mm thick. There were 47 seeds to a gram. A pilot study was run to determine the best method of seed treatment to quicken germination. Treatment of seed in concentrated H_2SO_4 for 40 minutes gave the quickest germination. Therefore, seeds were soaked in concentrated H_2SO_4 for 40 minutes and then thoroughly washed in running water for 5 minutes just before sowing on June 30, 1990. Growth medium was lightweight consisting of 10 parts of mineral soil (loam and pumice) and one part each of peat moss and vermiculite. Half pound of commercial Lilly Miller Trace elements of the following composition were thoroughly mixed with the medium.

Magnesium	6.0 %	Copper	2.4%	Iron	14.4%
Molybdenum	0.06%	Zinc	5.6%	Boron	2.4%

Two independent experiments were run which lasted from June 30 to November 4, 1990.

3.1 EXPERIMENT 1: EFFECT OF DIFFERENT LEVELS OF NITROGEN AND PHOSPHORUS FERTILIZER AND APPLICATION INTERVAL ON GROWTH OF BLACK LOCUST SEEDLINGS.

This experiment was conducted to determine the effect of N fertilizer, with and without P, its level and application interval on black locust seedlings grown in white Ray leach super cells (a container system consisting of 98 cells). A total of 1176 containers each 21 cm.long and 4 cm. top diameter (160 cm^3) were filled with the lightweight medium and one pre-treated seed was sown in each container on June 30, 1990. Containers were arranged on benches in the shade house and mist sprayed to prevent seed displacement, twice a day till germination was complete. Irrigation was continued thereafter depending on moisture condition in the growth medium on daily or alternate day basis.

More than 50% germination was complete by July 10, 1990 and more than 50% seedlings had true leaf on them by July 18, 1990. The failed containers and the ones with dying seedlings were removed and the remaining 1008 seedling containers were rearranged in 15 trays with at least 21 seedlings to a treatment and 3 treatments to a tray. The trays were arranged in 3 replications with 14 treatments i.e. 5 trays in each replication. The seedlings of each treatment in a tray were separated by at least one empty row of cells to reduce the chances of contamination by fertilizer given to the adjacent treatment.

Treatments were randomly assigned to each replication separately. Baseline data with regard to the seedlings' height was recorded on July 25, 1990 that fall in the range of 1.5 to 1.6 cm. Fertilizer application was commenced on July 26, 1990 i.e. 15 days after the completion of 50% germination. There were a total of 14 treatments, with 12 treatments getting 6 levels of fertilizers i.e. 100, 200 and 400 ppm of nitrogen alone and each N level associated with 50 ppm of phosphorus added once with the first fertilizer application. Each N level was applied at intervals of 5 and 10 days making a total of 12 doses. The 13th treatment consisted of adding of 50 ppm of P alone at the time of first fertilization. Ammonium nitrate and phosphoric acid were the sources for N and P respectively. The 14th treatment was an unfertilized control. Since no N was involved in two of the treatments, therefore, that resulted in an unbalanced design in factorial combination.

The following abbreviations will be encountered: N_0, N_{100}, N_{200}, and N_{400} will refer to the 0, 100, 200, 400 ppm and also called zero, low, medium and high levels of nitrogen fertilizer respectively. Similarly P_0 and P_{50} will refer to 0 and 50 ppm of phosphorus respectively whereas D_5 and D_{10} will refer to the interval of 5 and 10 days respectively at which N fertilizer was applied from July 26 to October 29, 1990. The level of significance is $P < 0.05$ unless stated otherwise.

Ammonium nitrate was selected because it contains both positively charged NH_4 cations and negatively charged NO_3 anions in equal amounts. Nitrogen levels were selected because the levels prescribed in literature range from 50 ppm to 500 ppm. Since phosphoric acid lowers the pH of irrigation water and a lower pH range (5.2 to 5.5) is the optimum for nutrient availability, therefore, phosphoric acid was used to supply phosphorus (Landis et al, 1989).

To test how much nutrient solution was required to saturate a cell, water was added to two containers. It was observed that leaching started after adding about 40 ml of water. Based on this observation, required amount of NH_4NO_3 fertilizer was prepared as shown in Table 1.

Table 1. Schematic presentation of treatment levels

Fertilizer	P_*	N applied after every 5 and 10 days		
	N_0+P_0	$N_{100}+P_0$	$N_{200}+P_0$	$N_{400}+P_0$
NH_4NO_3	0	.2941 gm/l	.5882 gm/l	1.1764 gm/l
H_3PO_4	0	0	0	0
	N_0+P_{50}	$N_{100}+P_{50}$	$N_{200}+P_{50}$	$N_{400}+P_{50}$
NH_4NO_3	0	.2941 gm/l	.5882 gm/l	1.1764 gm/l
H_3PO_4	.629 ml/l	P_*	P_*	P_*

* P was added at the initial fertilizer application only.

In first fertilizer application, required quantity of phosphoric acid was added to half of the N treatments before nitrogen application. Liquid N fertilizer (ammonium nitrate) was applied to each container in each treatment, except N_0+P_0 and N_0+P_{50}, with a beaker in a way to completely saturate the growing medium and flush out excess fertilizer salts (Landis, 1989). The treatment N_0+P_{50} was given phosphoric acid only. Subsequent fertilization (without P) was continued every 5th and 10th day according to schedule.

The plants were watered to avoid any water stress. Dead plants were removed from the experiment. Weeds, if any, were removed from the containers the day fertilizer was applied.

The containers were rearranged leaving two empty cell spaces among adjacent cells on Sept: 12, after taking the first sample to provide more space to the seedlings. In this way there were 15 seedlings on the average per tray representing one treatment.

The first and second samples were obtained on Sept: 9 (late summer) and Oct: 14, 1990 (early fall) respectively with sample size of 5 plants from each treatment. The last sampling date was Nov: 4, 1990 (mid-fall) with a 1 to 5 plant sample from each treatment as most of the plants had lost some of their leaves. Therefore, plants with most of the leaves intact were sampled.

3.2 EXPERIMENT 2: EFFECT OF DIFFERENT SIZE CONTAINERS ON GROWTH OF BLACK LOCUST SEEDLINGS.

The second experiment was carried out to see the effect of size and shape of four different containers on growth of black locust seedlings. Containers included 20 cm long and 6.5 cm diameter plastic bag with 48 perforations of 5mm in diameter. These bags were fitted in collars in a way that their bottoms were touching the bench. There were two kinds of hard plastic containers: one ray leach supercell 21 cm long and 4 cm top diameter and another deepot 25 cm long with 6.25 cm top diameter each with four holes at the base. These containers were fitted in their usual frames. The fourth kind was Spencer-Lemaire book planter (a compact batch of 6 containers each 14 cm long and 3x2.5 cm at the top). Rubber bands were tied around an entire batch. All the containers were filled, leaving 1 cm at the top for water, with the same kind of soil as in experiment 1 on June 30, 1990.

One pre-treated seed was sown in each container on July 1, 1990. The containers were randomly assigned to each of four replications and mist sprayed twice a day until germination was complete. Watering was continued according to need of the plants as in experiment 1.

It was observed that about 50% germination was complete by July 12, 1990 and entire germination was complete by July 25, 1990. The failed containers and the ones with dead seedlings were removed and there remained on the average 20 seedlings in each container system in each replication.

Table 2. Type of containers and their sizes

Name of container	Length x top diameter (cm)	Volume $(cm)^3$
Polythene bag	20 x 6.0	675
Deepot	25 x 6.25	640
Ray Leach cell	21 x 4	160
Sp. Lemaire	14 x 3 x 2.5	70

To avoid confounding the effect of container and fertilizer, medium dose of the latter was applied only 3 times (July 27, Sept: 8, and Sep: 24, 1990) to ensure survival of the plants till the end of the experiment.

The first random sample of 4 plants from each container type (treatment) was obtained on Sept: 5, 1990 (late summer) and the last one of 6 plants on Nov: 4, 1990 (mid-fall) for growth analysis.

3.3 DATA COLLECTION

Morphology is an important indicator of seedling quality and its survival and growth in the field. Since any single growth parameter of seedling does not explain all the variability, therefore, indices incorporating a number of measurements, involving living seedlings and destructive sampling, were used. Five randomly selected seedlings, from each treatment, were measured for the following growth parameters after 45 and 80 days and 1 to 5 seedlings (with most of the leaves intact) 100 days after first fertilizer application. The final sampling also included analysis of roots, stem and leaves for N and P.

SHOOT HEIGHT: Height of seedlings was measured to nearest mm from root collar to the tip of the leaves on the longest branch.

STEM LENGTH: Stem length to the leaf abscission point was measured nearest to mm in the final sampling only.

STEM DIAMETER: Diameter at root collar was measured in mm with a caliper accurate to 1/10 of a mm.

ROOT LENGTH: Length of root was measured to nearest of mm from root collar to tip of the longest root as measure of root elongation. Roots were washed in gently running water to remove the soil taking care not to loose rootlets.

SHOOT:ROOT RATIO: This indicates a balance between transpirational and water absorbing area. Dry weight of shoot as well root was taken to nearest of mg. For that purpose the tissue was oven dried at 70 ^{0}C for 24 hours and dry weight of leaves, stems and roots was recorded separately.

LEAF AREA: Leaf area of all the leaves was measured in cm^2 accurate to 1/1000, with leaf area meter at all three harvests in order to get information about the photosynthetic capability of the seedlings.

NUMBER OF NODULES: The number of nodules was recorded regardless how minute those were.

SPECIFIC LEAF AREA: This is the leaf area $(cm)^2$ produced by one gram dry weight of leaf (Leaf area/ leaf weight).

NUTRIENT ANALYSIS: Different dry tissues i.e. leaves, stems and roots of seedlings from the final sample were analyzed for N and P concentration in experiment 1. Since there was not enough tissue in a replication, therefore tissues of a treatment from all the three replications was combined for analysis. This prevented any meaningful statistical analysis of the data. Therefore, only the values will be presented and discussed without referring to any statistical significance.

Vector analysis, as proposed by Bigg (1990) but slightly different, was used to describe the relationship between weight, N concentration and N content of these leaf and stem. Weight, N concentration and N content of all the treatments were converted to values on a scale 0-100 relative to N_{100} P_{50} D_5 treatment which was considered as standard with all its values changed to 100 (Table 5). Relative content of N was plotted on x-axis, concentration on y-axis and the diagonal line passing through origin marked the relative weight of leaf or stem of the standard treatment. This treatment was selected because its values were lying almost in the middle of the extreme values coming from other treatments. This helped in scattering the points around the standard instead of clumping at one end of the diagram by selecting any other treatment as standard.

3.4 DATA ANALYSIS

3.4.1 EXPERIMENT 1

This was a randomized block design. Levels of N fertilizer were duplicated by applying them with and without phosphorus. Then each fertilizer level was applied after each 5 or 10 days interval except the N_0 level with and without P. Since N application interval (days) was not involved in two N_0 treatments, therefore, a factorial combination was not possible. Analysis was conducted using the GLM procedures of the SAS personal computers package to find out the significance of treatments. Standard error was determined for all the treatments and incorporated in the concerned appendices. In figures, standard error has been shown for P_{50} D_5 treatments only.

Contrasts were run to find out the significant effect of main factors i.e. N, P and D and their interaction. The following H_0 hypotheses were tested.

i) $\mathbf{H_0}$ P_0: $N_0 = N_{100} = N_{200} = N_{400}$ (All N levels are equal
P_{50}: $N_0 = N_{100} = N_{200} = N_{400}$ (with or without P

ii) $\mathbf{H_0}$ N: $P_0 = P_{50}$ (P has no effect at any level of N

iii) $\mathbf{H_0}$ P_0: D *N (There is no interaction between any
P_{50}: D*N (N level and application interval with
(or without P

For comparison of treatment means of interest, Waller-Dunkan K ratio (100) was used once the contrast showed a factor and interaction of factors to be significant.

3.4.2 EXPERIMENT 2

Experiment 2 was also a randomized block design with 4 treatments (containers). Analysis of variance was computed in the SAS personal computer package to find out the significance of container size/ shape on the growth of the seedlings. Waller-Dunkan K ratio (100) was used to compare the means at 0.05 level of significance.

ANOVA

source of variation	DF
Replication	3
Treatment	3
Error	9

4. RESULTS

4.1 EXPERIMENT 1

Results in the form of means are summarized in appendix 1 to 12. This section presents effects of phosphorus (P), nitrogen (N), nitrogen application interval (D) and their interactions on the way they affected shoot, root and other growth parameters.

Shoot length was significantly higher in P_{50} seedlings than in P_0 at medium and high N levels (Table 3). By increasing N from 0 to low (100 ppm) level, there was significant increase in shoot length (Appendix 1, Fig. 1). Another increase was recorded in shoot length of D_{10} seedlings in late summer and early fall when medium (200 ppm) N level was applied. High (400 ppm) N level did not increase shoot length. It was higher in P_{50} D_5 seedlings than D_{10} seedlings at low N level for all sampling dates.

Stem length measured to leaf abscision point in the mid-fall sampling only, had the same trend as that of shoot length. It was significantly higher in P treatments than without P at similar positive N levels (Fig. 1a). At low N level D_5 seedlings had significantly higher stem length than D_{10} seedlings.

Plants with phosphorus had higher mean diameter than P_0 plants at some N levels (Appendix 2, Fig. 2). In case of late summer sampling, P_{50} D_{10} plants recorded higher diameter

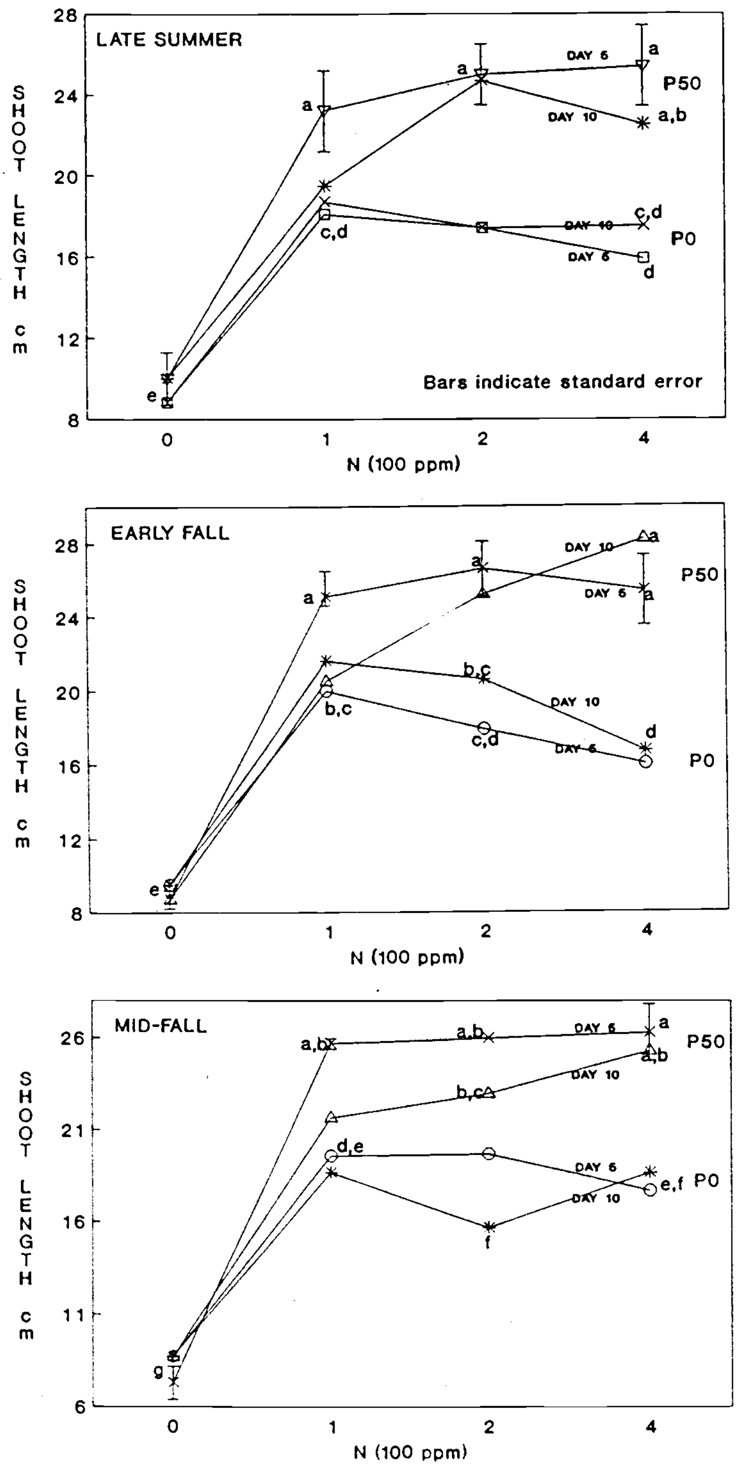


Fig. 1 Effect of N & P fertilizer levels on shoot length of black locust seedlings at 3 harvesting periods.

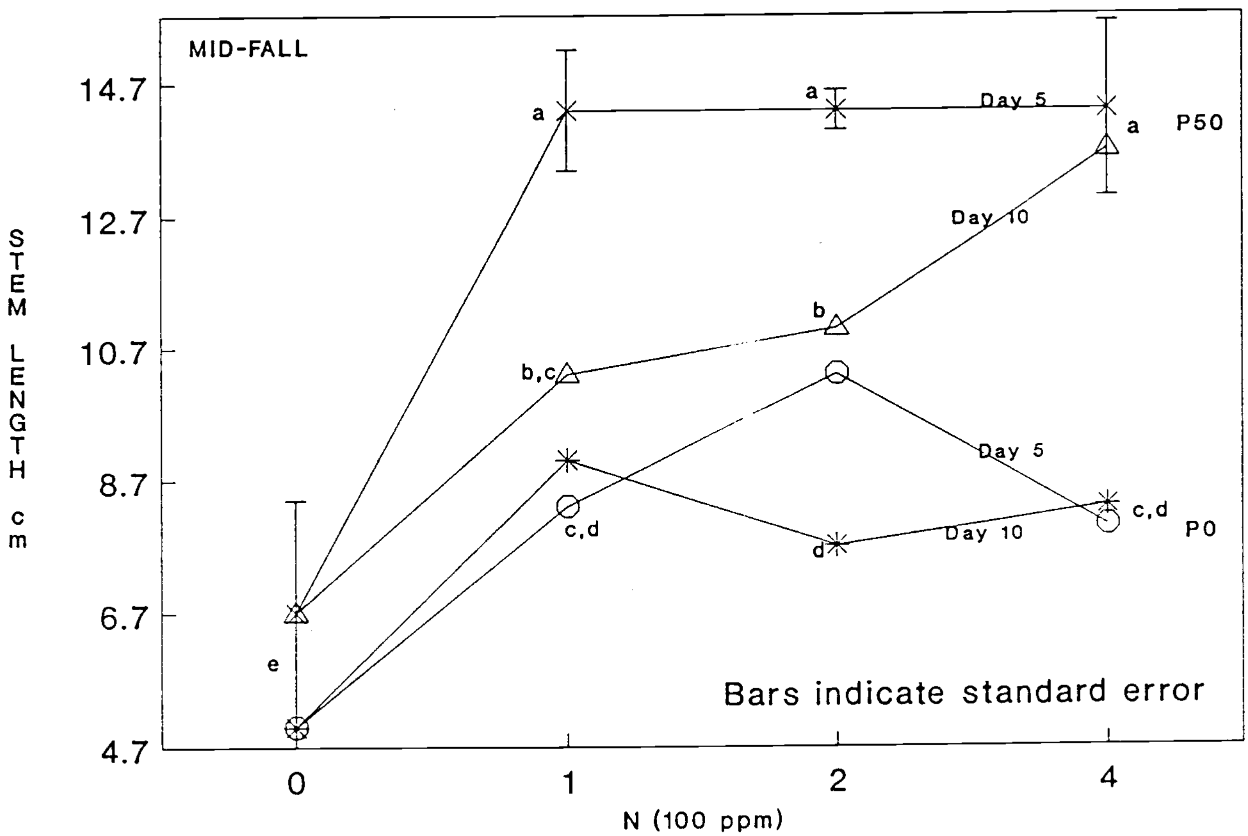


Fig. 1.a Effect of N & P fertilizer levels on stem length of black locust seedlings at mid-fall.

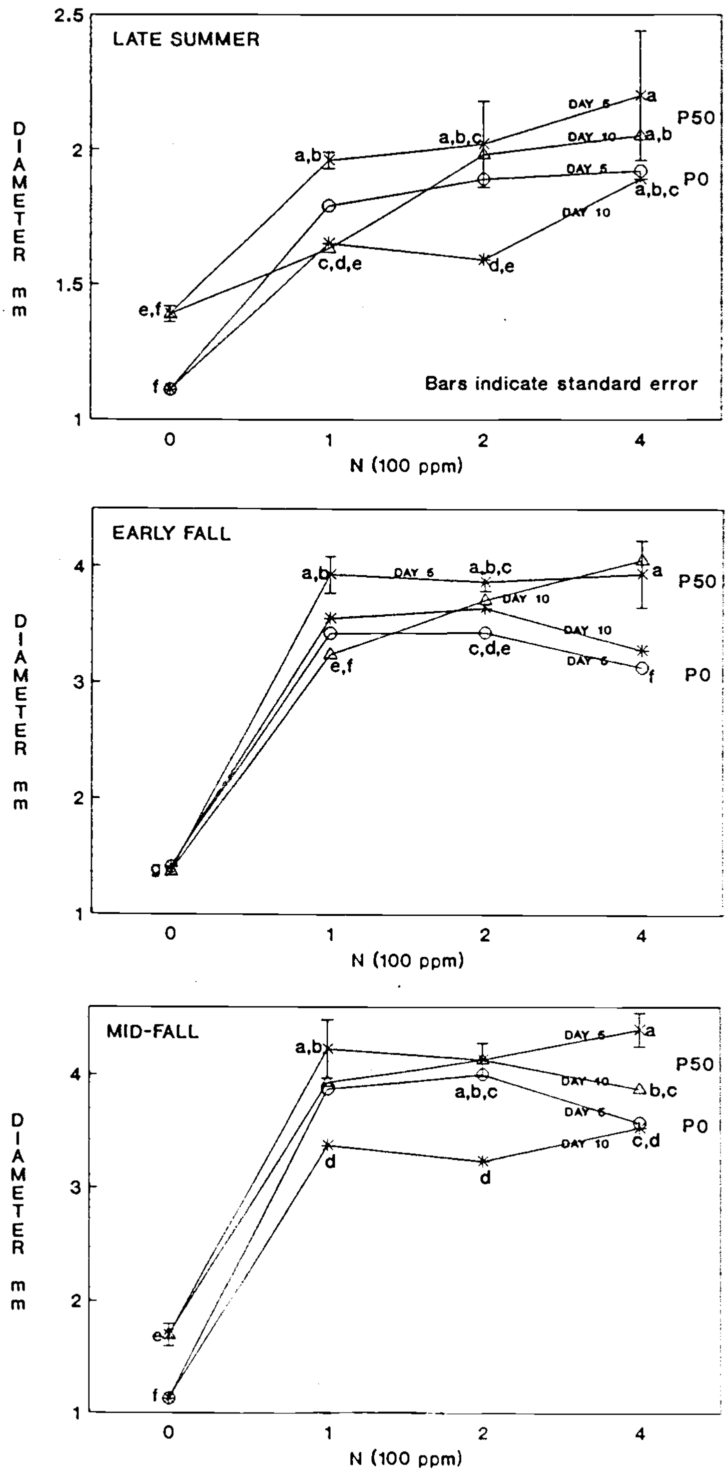


Fig. 2 Effect of N & P fertilizer levels on diameter of black locust seedlings at 3 harvesting periods.

than P_0 D_{10} plants at medium N level. Similarly in early fall, seedlings with P attained significantly higher diameter than without P at high levels of N (Appendix & Fig. 2). Nitrogen application regime (D) affected diameter significantly at low N level in P_{50} seedlings. In mid-fall, P_{50} seedlings had significantly higher diameter than plants without P at low (D_{10}), medium (D_{10}) and high (D_5) N levels. At N_0 level, P_{50} plants had significantly higher diameter than P_0 plants. Diameter increased significantly with the low N level but further addition resulted in no significant increase.

Leaf area was significantly higher in P_{50} seedlings than P_0 at all positive N levels except low (D_{10}). This was the case for late summer and early fall sampling periods (Appendix & Fig. 3). At mid-fall sampling date, when shedding of leaves had already started, it was significantly higher at low (D_{10}), medium (D_{10}) and high (D_5) N levels only. By increasing N from 0 to low level there was significant increase in leaf area except at N_{100} P_0 D_{10} treatment in mid-fall (Appendix & Fig. 3). Medium N level resulted in another significant increase in P_{50} D_{10} seedlings, whereas leaf area remained unchanged in P_0 plants. Leaf area of D_5 seedlings was significantly higher than D_{10} at low N level for the first two sampling dates. For mid-fall, D_5 seedlings had higher leaf area values than D_{10} seedlings at N_{100} P_0 and N_{200} P_0 levels.

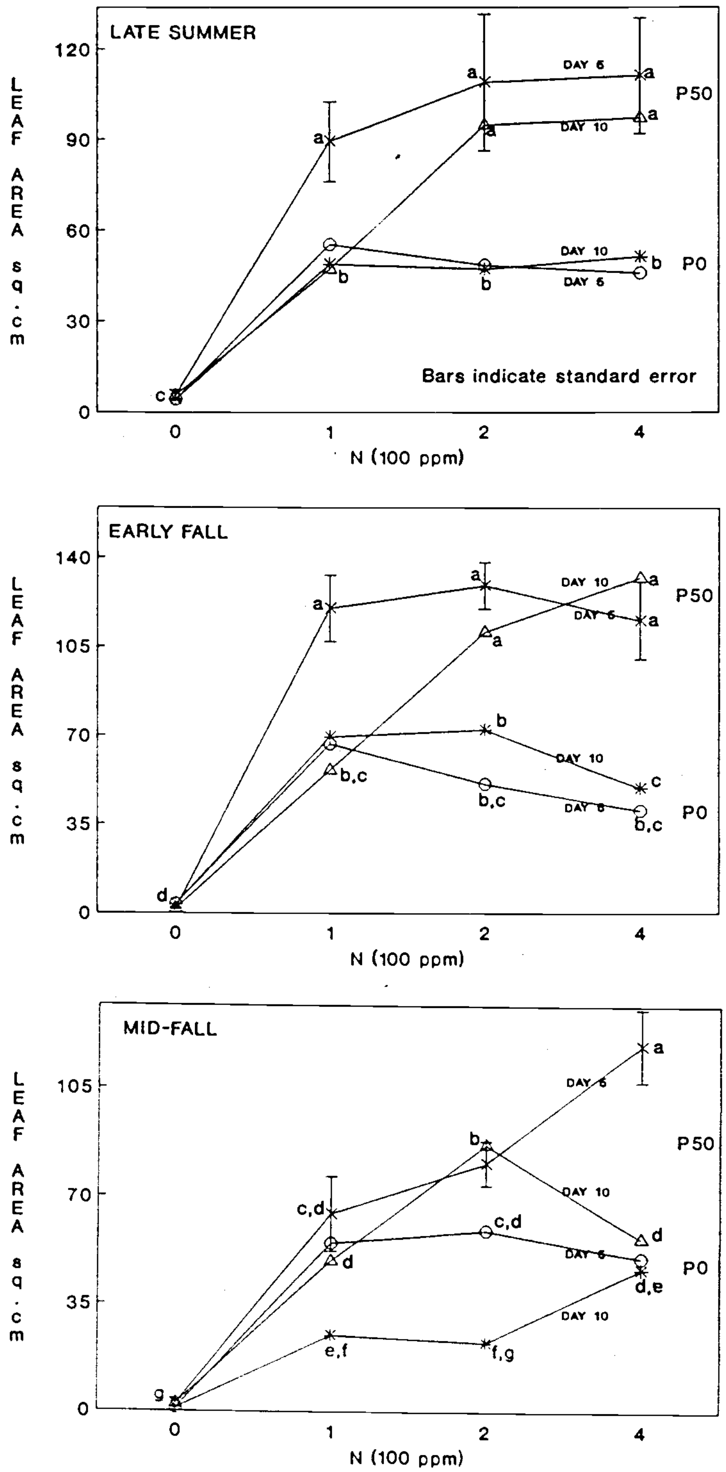


Fig. 3 Effect of N & P fertilizer levels on leaf area of black locust seedlings at 3 harvesting periods.

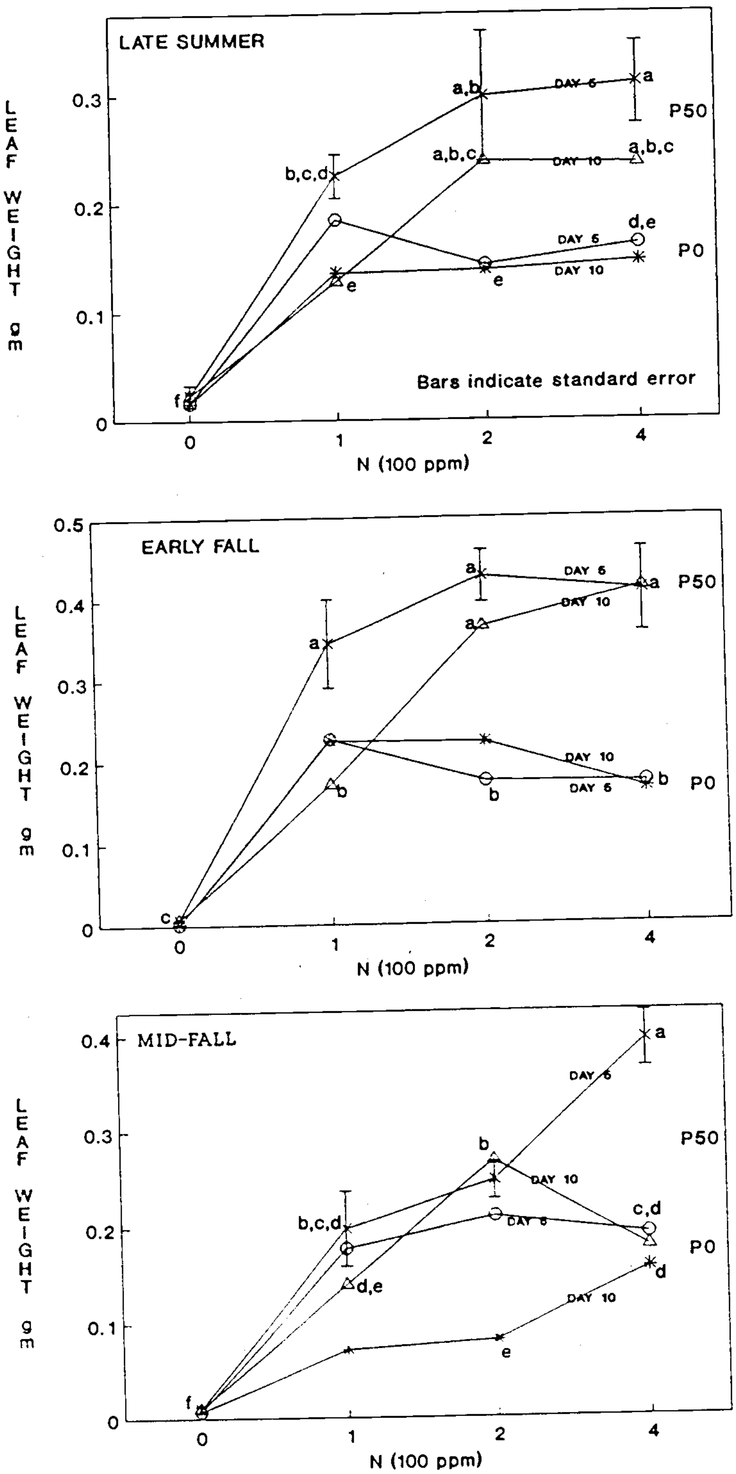


Fig. 4 Effect of N & P fertilizer levels on leaf weight of black locust seedlings at 3 harvesting periods.

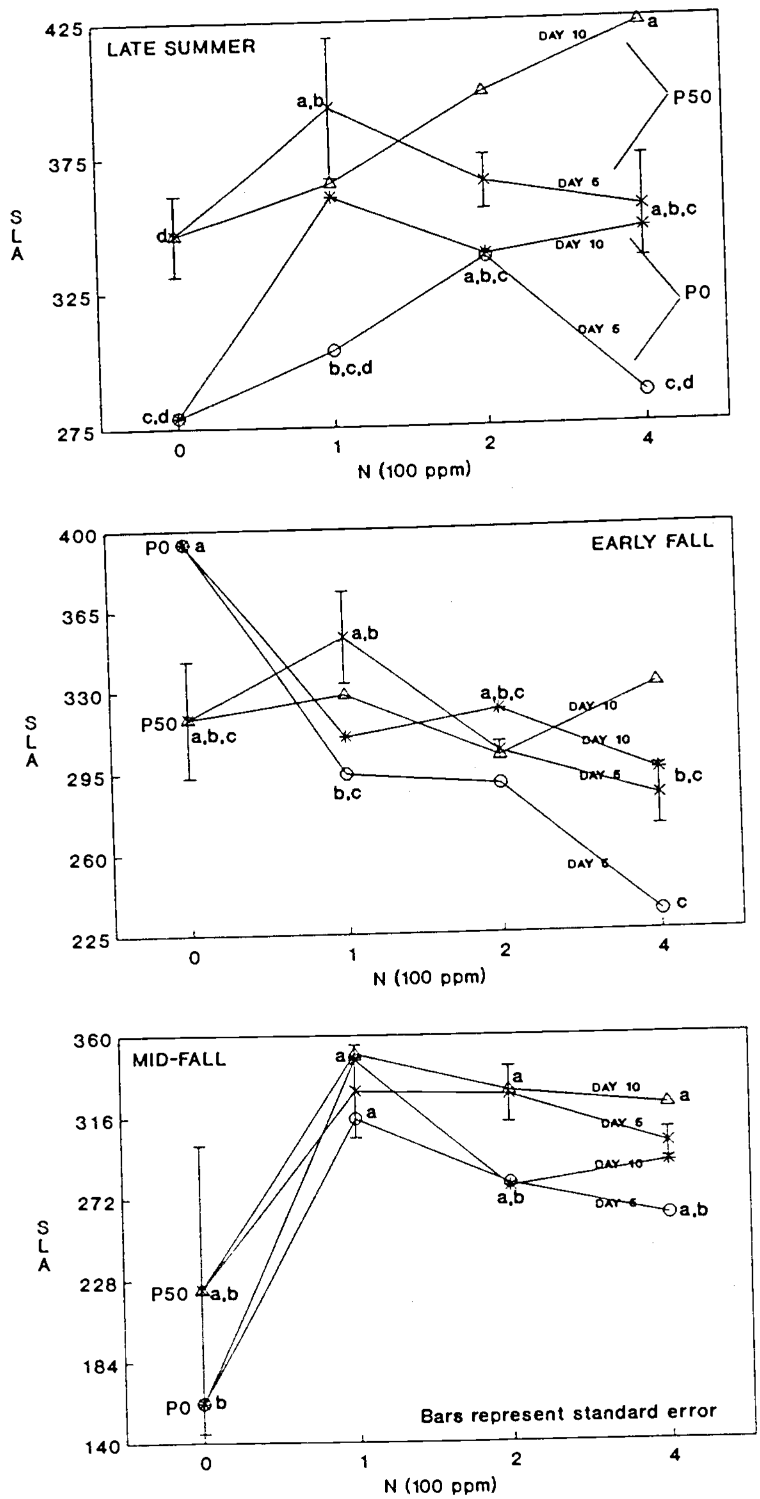


Fig. 4.a Effect of N & P fertilizer levels on S.L.A of black locust seedlings at 3 harvesting periods.

Leaf weight followed much the same pattern as that of leaf area. Leaf weight was significantly higher in P_{50} plants than without P. For first sampling date this increase was at medium and high N levels. For early fall the increase was in also at low (D_5) level beside medium and high N levels (Appendix & Fig. 4). In mid-fall, leaf weight was significantly more in P_{50} plants at medium (D_{10}) and high (D_5) levels only. It was due to the fact that shedding of leaves had taken place in some of the sampled plants. Leaf weight increased significantly with increasing N from 0 to low level almost the same way as leaf area increased.

Specific leaf area (SLA) was not significantly affected by treatment as evident from late summer results (Fig. 4a). It was, however, higher at N_0 P_0 level than positive N levels in early fall sampling. At mid-fall, on the other hand, SLA was minimum at N_0 P_0 level and rose significantly with application of low N level.

Stem weight had the combined effect of stem diameter and length. Therefore, stem weight was higher in seedlings with higher diameter and length (Appendix & Fig. 5). It was significantly higher in seedlings with P than without P at medium and high N levels for all sampling. Stem weight was also higher at low (D_5) level apart from medium and high N levels for last two sampling. There was significant effect when N was increased from zero level. Another increase occurred in P_{50} D_{10} seedlings when medium N level was

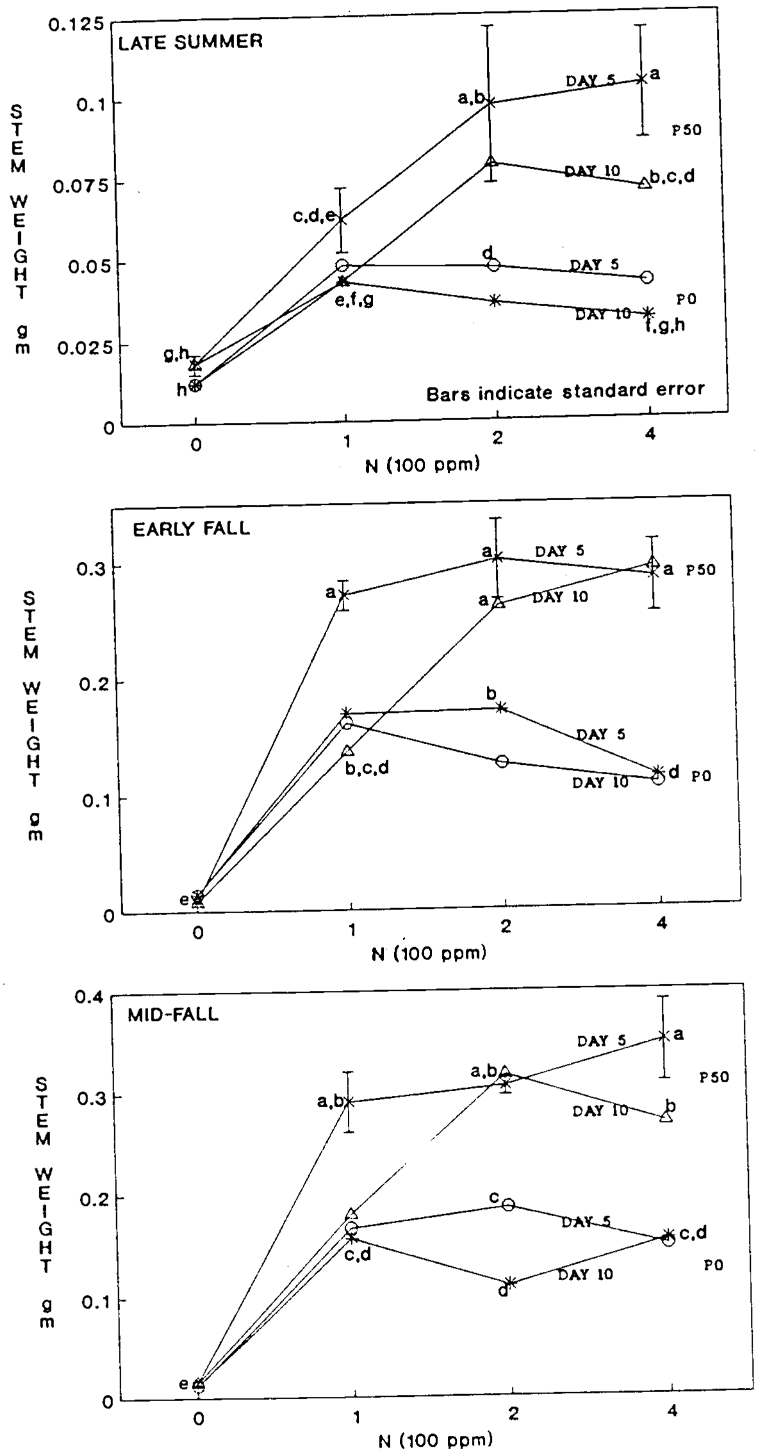


Fig. 5 Effect of N & P fertilizer levels on stem weight of black locust seedlings at 3 harvesting periods.

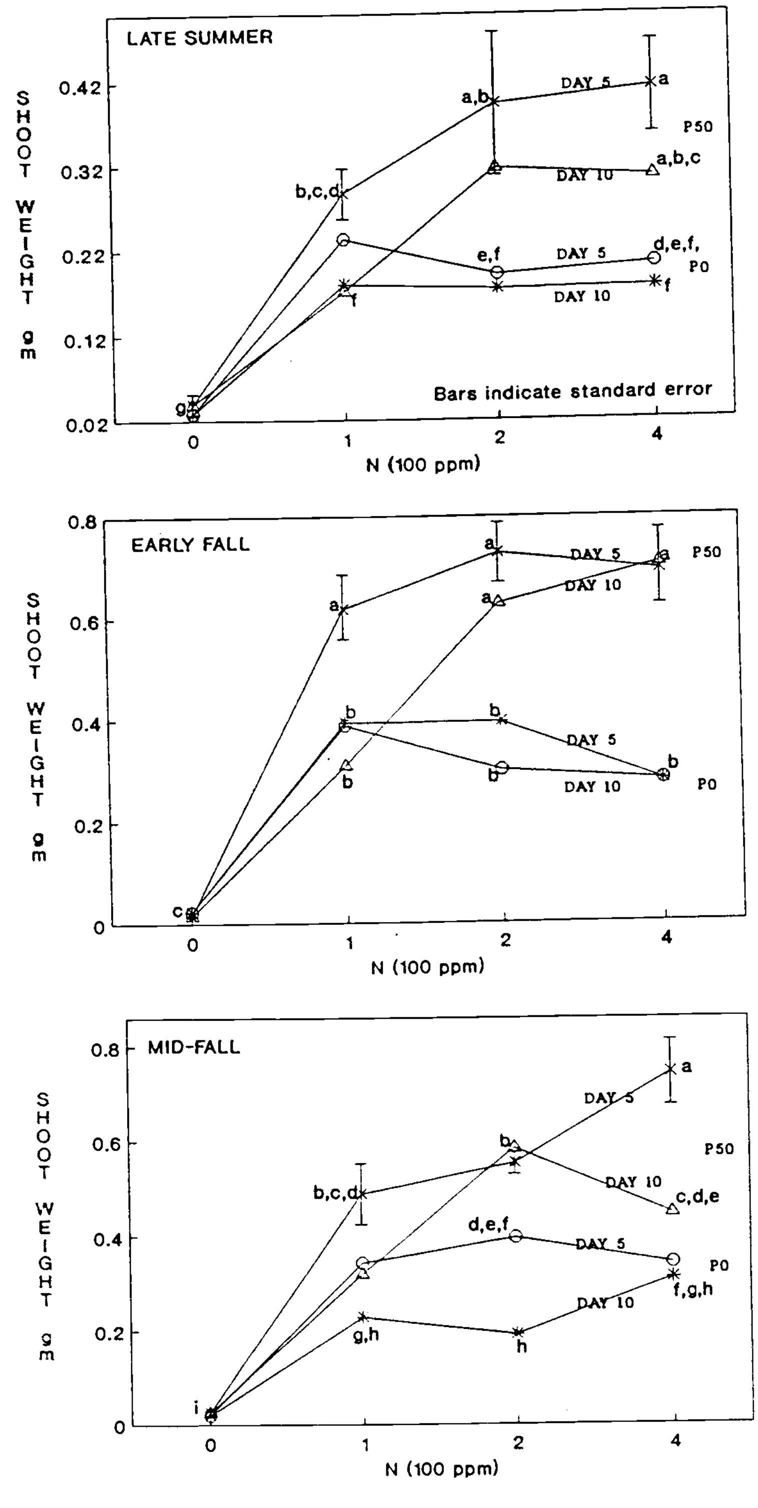


Fig. 6 Effect of N & P fertilizer levels on shoot weight of black locust seedlings at 3 harvesting periods.

Table 3. Analysis of variance and contrast of shoot length, diameter and leaf area at three sampling periods.

Anova: shoot length

Source	DF	Probability > F Late summer	Early fall	Mid-fall
Replication	2	0.0005	0.0329	0.0006
Treatment	13	0.0001	0.0001	0.0001
Error	26			
Contrast				
$P_0:N_0=N_{100}=N_{200}=N_{400}$	3	0.0001	0.0001	0.0001
$P_{50}:N_0=N_{100}=N_{200}=N_{400}$	3	0.0001	0.0001	0.0001
$N:P_0=P_{50}$	3	0.0001	0.0001	0.0001
$P_0:N*D$	2	0.7950	0.7193	0.1809
$P_{50}:N*D$	2	0.0456	0.4421	0.0937

Anova: diameter

Source	DF	Probability > F Late summer	Early fall	Mid-fall
Replication	2	0.1734	0.4050	0.2529
Treatment	13	0.0001	0.0001	0.0001
Error	26			
Contrast				
$P_0:N_0=N_{100}=N_{200}=N_{400}$	3	0.0003	0.0001	0.0001
$P_{50}:N_0=N_{100}=N_{200}=N_{400}$	3	0.0004	0.0001	0.0001
$N:P_0=P_{50}$	3	0.0776	0.0006	0.0004
$P_0:N*D$	2	0.5523	0.9692	0.1327
$P_{50}:N*D$	2	0.1648	0.1908	0.0776

Anova: leaf area

Source	DF	Probability > F Late summer	Early fall	Midfall
Replication	2	0.0230	0.4479	0.0589
Treatment	13	0.0001	0.0001	0.0001
Error	26			
Contrast				
$P_0:N_0=N_{100}=N_{200}=N_{400}$	3	0.0090	0.0005	0.0008
$P_{50}:N_0=N_{100}=N_{200}=N_{400}$	3	0.0001	0.0001	0.0001
$N:P_0=P_{50}$	3	0.0001	0.0001	0.0001
$P_0:N*D$	2	0.8711	0.7005	0.1335
$P_{50}:N*D$	2	0.0578	0.0754	0.0003

applied. Nitrogen application interval was effective in P_{50} seedlings at low N level in early fall and mid-fall sampling. Similar effect could be seen at high N level in mid-fall as well as late summer sampling since D_5 seedlings had significantly higher values than that of D_{10} seedlings.

The pattern of dry biomass allocation within shoot, though not statistically tested, apparently changed with time. Leaf weight far exceeded the stem weight in late summer, the difference narrowed down in early fall and finally stem weight equalled or exceeded leaf weight in mid-fall (Appendix. 4 and 5).

Dry shoot biomass followed the same trend as that of leaf weight because a high proportion of shoot biomass was in the leaf in late summer and early fall sampling. Total shoot weight was significantly higher in P_{50} seedlings than P_0 at medium and high N levels in all sampling. In early fall, low (D_5) N level along with medium and high N levels, resulted in higher shoot biomass (Appendix & Fig 6). The rest of effects on shoot biomass were the same as that on leaf weight.

Root length, though, not a good parameter for evaluating seedling quality, demonstrated some peculiar characteristic by reacting negatively to P treatment (Appendix & Fig. 7). It was not significantly different between P_0 and P_{50} seedlings but the general increase of root length in P_0 seedlings seemed to be real. In early

Table 4. Analysis of variance and contrast of shoot, root and total weight at three sampling periods.

Anova: shoot weight

Source	DF	Probability > F Late summer	Early fall	Midfall
Replication	2	0.0437	0.2724	0.0482
Treatment	13	0.0001	0.0001	0.0001
Error	26			
Contrast				
$P_0: N_0=N_{100}=N_{200}=N_{400}$	3	0.0056	0.0002	0.0012
$P_{50}: N_0=N_{100}=N_{200}=N_{400}$	3	0.0001	0.0001	0.0001
$N: P_0=P_{50}$	3	0.0001	0.0001	0.0001
P_0:N*D	2	0.8804	0.6566	0.1554
P_{50}:N*D	2	0.0196	0.0486	0.0073

Anova: root weight

Source	DF	Probability > F Late summer	Early fall	Midfall
Replication	2	0.0066	0.3367	0.0402
Treatment	13	0.0019	0.0001	0.0001
Error	26			
Contrast				
$P_0: N_0=N_{100}=N_{200}=N_{400}$	3	0.0316	0.0005	0.0016
$P_{50}: N_0=N_{100}=N_{200}=N_{400}$	3	0.0004	0.0001	0.0001
$N: P_0=P_{50}$	3	0.0527	0.0001	0.0001
P_0:N*D	2	0.7285	0.6399	0.6282
P_{50}:N*D	2	0.0767	0.0518	0.0265

Anova: total weight

Source	DF	Probability > F Late summer	Early fall	Mid-fall
Replication	2	0.0320	0.3073	0.0427
Treatment	13	0.0001	0.0001	0.0001
Error	26			
Contrast				
$P_0: N_0=N_{100}=N_{200}=N_{400}$	3	0.0062	0.0002	0.0004
$P_{50}: N_0=N_{100}=N_{200}=N_{400}$	3	0.0001	0.0001	0.0001
$N: P_0=P_{50}$	3	0.0001	0.0001	0.0001
P_0:N*D	2	0.8463	0.6399	0.4311
P_{50}:N*D	2	0.0230	0.0416	0.0038

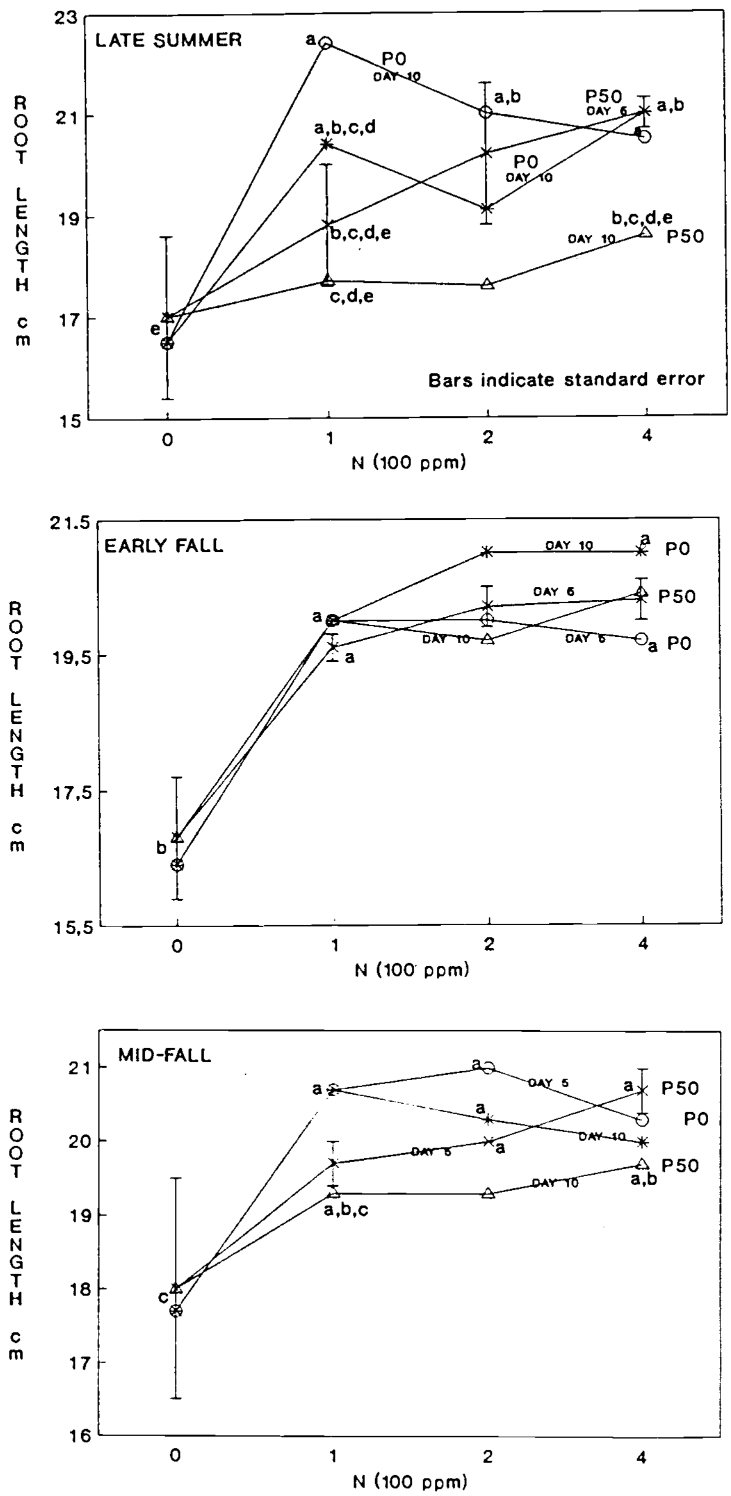


Fig. 7 Effect of N & P fertilizer levels on root length of black locust seedlings at 3 harvesting periods.

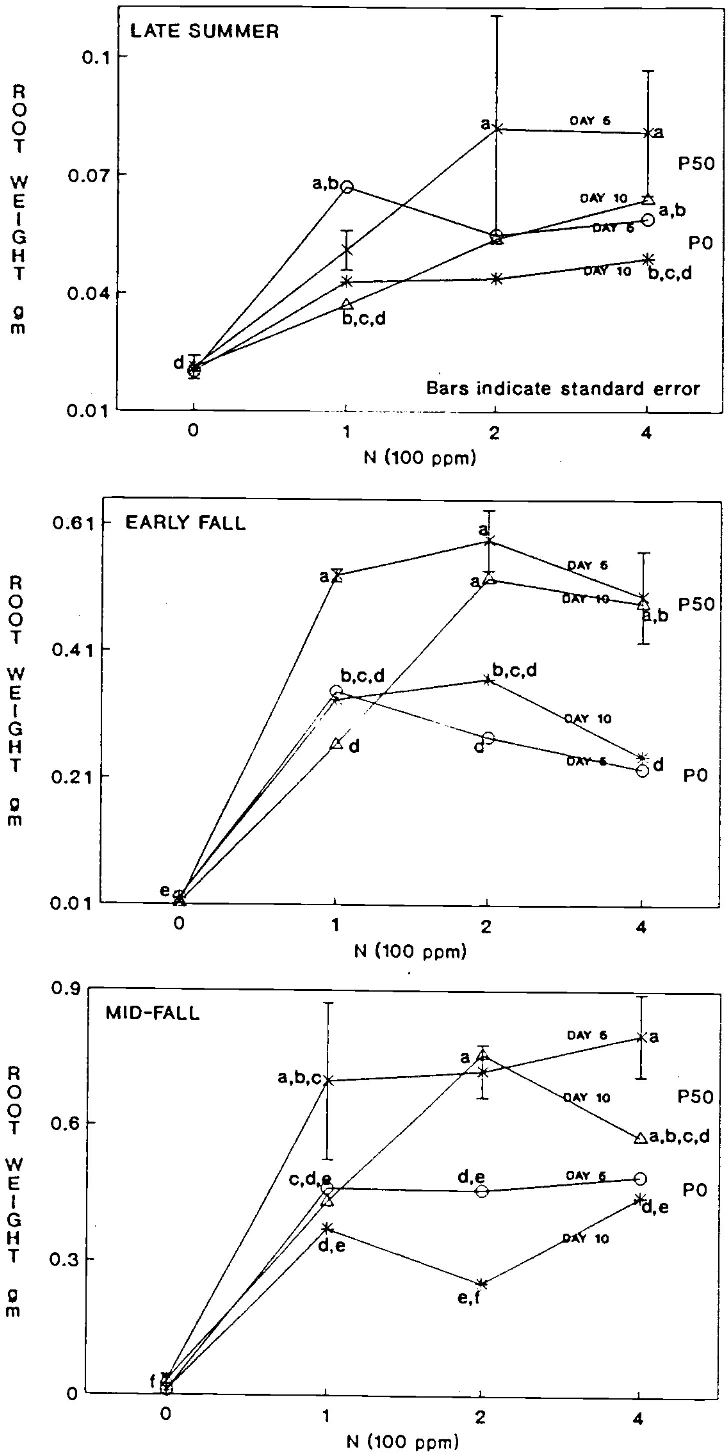


Fig. 8 Effect of N & P fertilizer levels on root weight of black locust seedlings at 3 harvesting periods.

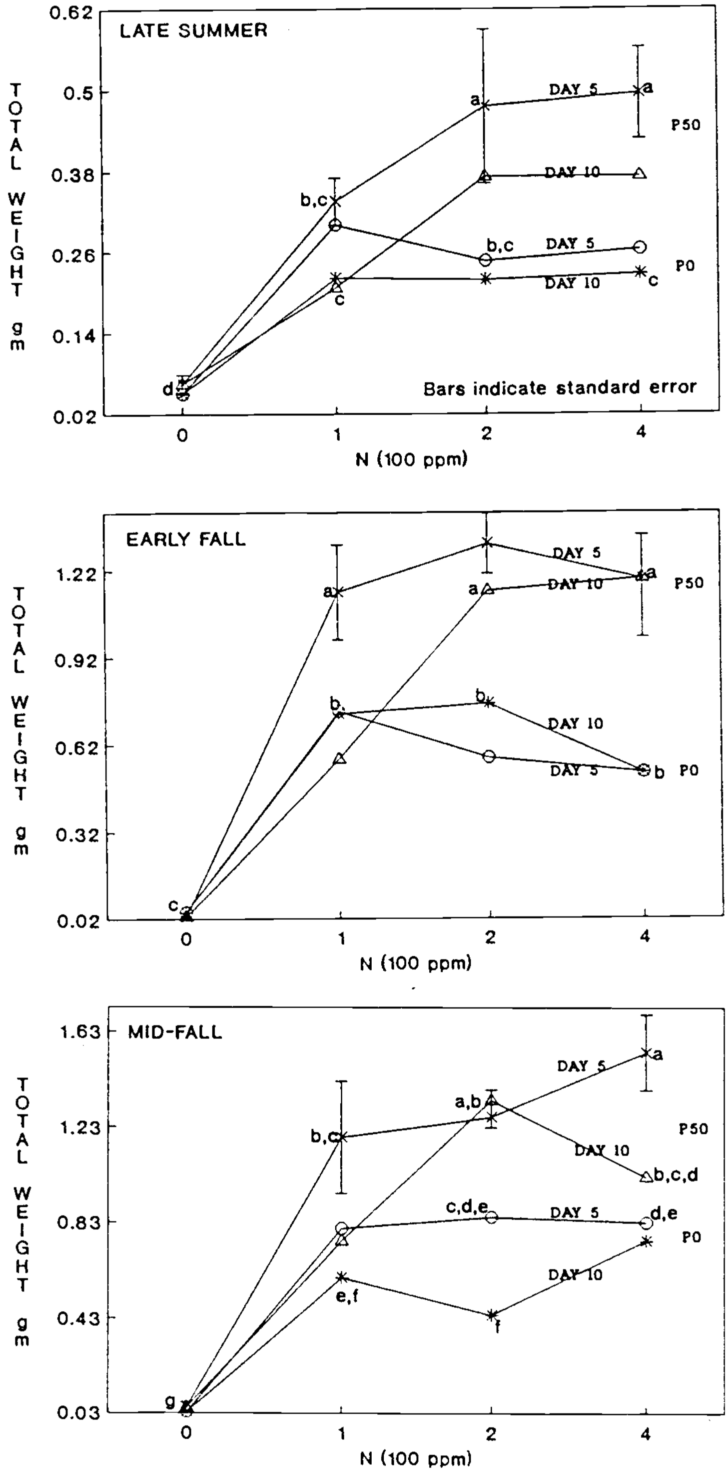


Fig. 9 Effect of N & P fertilizer levels on total weight of black locust seedlings at 3 harvesting periods.

and mid-fall sampling, root length was significantly lower at N_0 level. It did not increase with increasing level of N beyond 100 ppm level.

In late summer treatment had no significant effect on mean root weight. For early and mid-fall sampling, root weight was significantly higher in P_{50} seedlings than without P at medium and high N levels (Appendix & Fig. 8). Root weight increased with increasing N from 0 to low level for the last two sampling. For late summer, significant difference was observed in N_{100} D_5 plants only. Further N addition (N_{200}) caused significant increase in root weight in P_{50} D_{10} seedlings for the last two sampling and D_5 plants for the first one. Root weight was higher of D_5 seedlings than D_{10} at low N level as evident from early (0.052) and mid-fall sampling (Table 5).

Total dry biomass followed the pattern of its other components. It was significantly higher in P_{50} seedlings at medium and high N levels for late summer. For early fall, total biomass was higher also at low (D_5) N level apart from medium and high levels (Appendix & Fig. 9). At medium, low (D_5) and high (D_5) levels, it was higher in P_{50} plants for mid-fall. It increased with increasing N from 0 to low level. Another increase was observed in P_{50} plants when N level was raised from low to medium N level in late summer. For early and mid-fall sampling the increase was only in D_{10} seedlings when N was increased from low level (Table 5).

To find out that the effect of N application interval (D) was real and not due to accumulation of N over time, the slopes of D_5 and D_{10} were compared separately for P_0 and P_{50} treatments. For this purpose an overall model (full model) was compared to reduced model of D_5 and D_{10}. To test the H_0 hypothesis that the two lines were parallel, the following test statistics was computed.

$$F= [SSR(_{full}) - SSR(_{reduced})/DF(_{full}) - DF(_{reduced})] / MSE(_{full})$$

Results were quite comparable with what were obtained by running contrasts as already described for different growth variables.

Allocation of total dry biomass within entire plant was not subjected to statistical analysis as harvesting periods were not used as factors. However, dry matter budegetting seemed to have changed with time. Allocation to root was far less than shoot by late summer at each treatment level. The difference in allocation narrowed down as root biomass was slightly less relative to shoot biomass by early fall. The pattern of dry matter allocation reversed by mid-fall as shoot biomass exceeded root biomass (Appendix 10). Ratio of Shoot:root (S:R), therefore, kept on decreasing with ontogeny (Fig. 10). In late summer, shoot:root ratio was significantly higher in P_{50} seedlings than P_0 at low (D_5), medium and high (D_5) N levels. In early fall S:R ratio was higher in P_{50} D_{10} seedlings at high N level only. By mid-fall the ratio was generally equal for P_0 and P_{50} seedlings

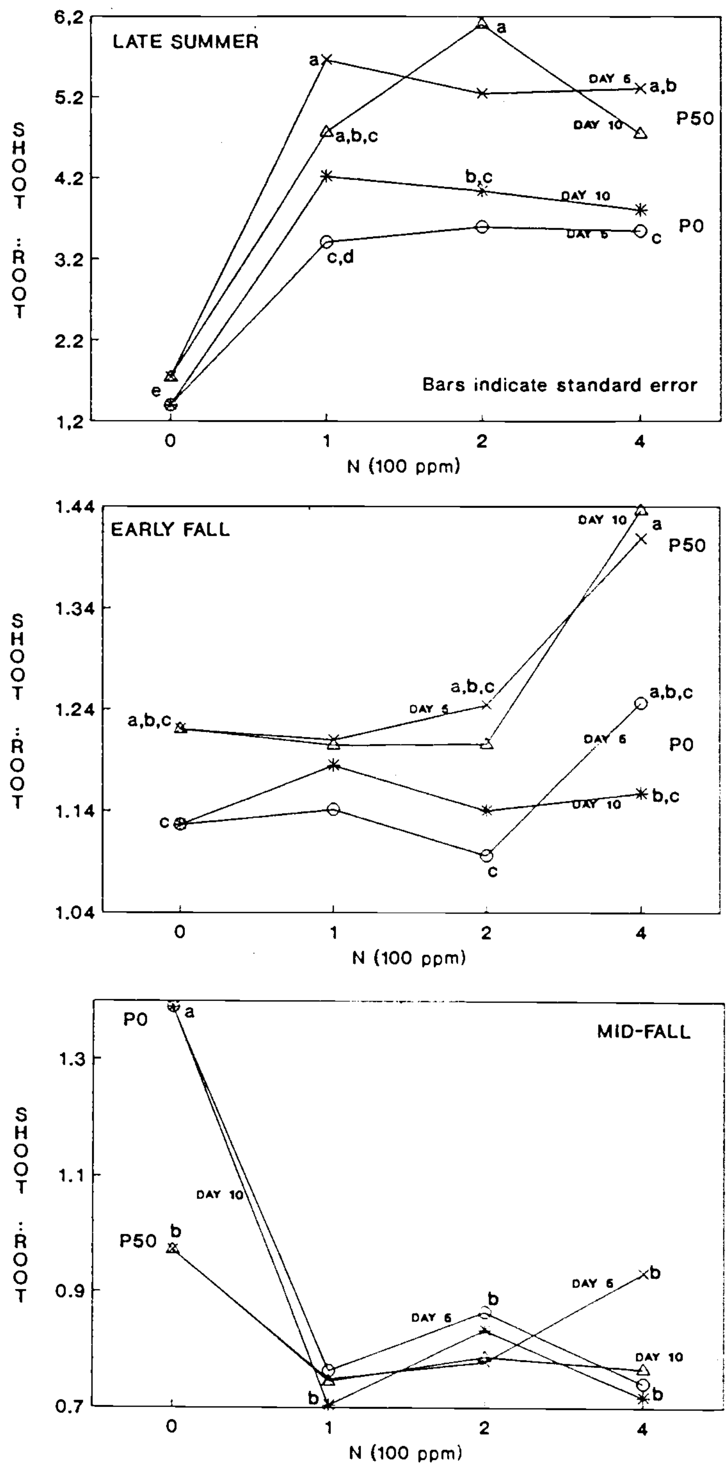


Fig. 10 Effect of N & P fertilizer levels on shoot: root of black locust seedlings at 3 harvesting periods.

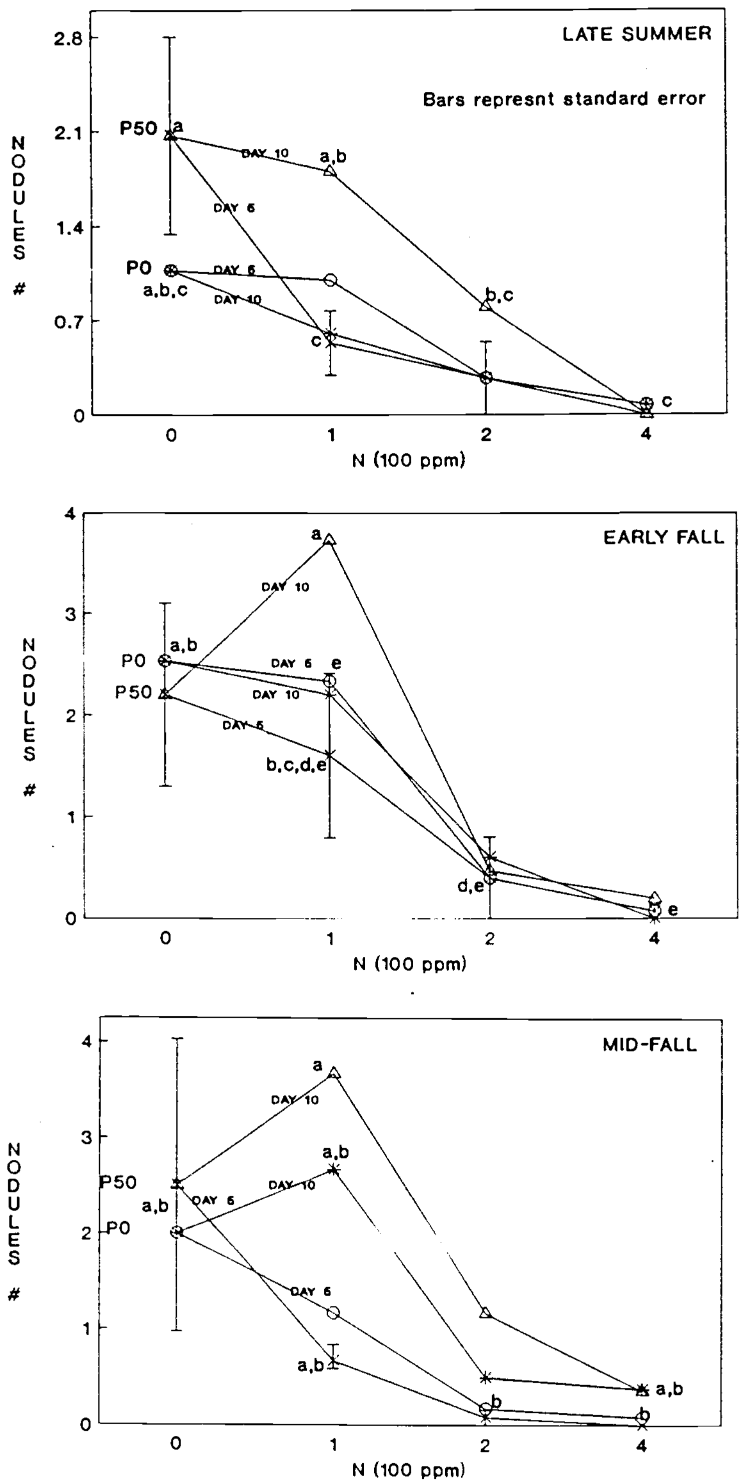


Fig. 11 Effect of N & P fertilizer levels on nodulation of black locust seedlings at 3 harvesting periods.

at all N levels but significantly higher in P_0 seedlings only at N_0 level. There was significant effect on S:R ratio by increasing N from 0 to low level in late summer and mid-fall, while subsequent addition did not bring any significant difference. At N_0 levels the S:R ratio was significantly less in late summer and at N_0+P_0 level higher in mid-fall.

Number of nodules/ seedling was more in plants which were N deficient or getting low level of N. It was significantly higher in seedlings at zero and low (P_{50} D_{10}) N levels than medium and high levels (Appendix & Fig. 11). than D_5 plants. Nodulation was significantly higher in N_{100} P_{50} D_{10} seedlings

Results with regard to nutrient status of seedlings could not be subjected to statistical analysis as explained in sec. 3.3. Nutrient analysis of sampled plants' tissue indicated no effect of P fertilization on N or P percentage in leaf and stem (Appendix 12). In roots, however, both N and P concentration was more in P_{50} plants than P_0 at 0 and low (D_5) N level. Level of N affected both N and P concentration in tissues differently at different N levels (Fig. 12, 13).

Nitrogen concentration was maximum at high (D_5) N level in leaf while P concentration was maximum at zero N level. Concentration of phosphorus after dropping sharply at low (D_{10}) N level remained at steady state for the remaining N levels. Similar trend was observed for P concentration in stem, root and entire plant. Nitrogen concentration, however, took a slightly different shape as it steadily rose with increasing N from 0 to high level (Fig. 14). Stem and root were the strongest sinks for N and P at all N levels except N_0 level where N was equally shared by different tissues and P was maximum in leaves.

Results of the vector analysis of leaf and stem relative to N_{100} P_{50} D_5 treatment, considered as standard, showed that treatments with decreasing N content and weight were the ones with zero, low (D_{10}) and medium (D_{10}) N levels without P (Fig. 15. a) The treatments in which there was increase in concentration but decrease in weight, were the high (N_{400}) levels. Medium N level with P (N_{200} P_{50}) exhibited increase in weight as well as N content whereas N_{400} P_{50} D_5 treatment showed increase in all the three variables.

Nitrogen use efficiency (total plant dry weight/ internal N concentration) was determined for seedlings harvested in mid-fall. It was more for P_{50} seedlings at all positive N levels except low (D_{10})level. At 0 level of N, nitrogen use efficiency was minimum and it increased with addition of low dose of N (Fig. 15). Further N addition resulted in gradual decrease. However, it increased in P_{50} D_{10} seedlings when medium level of N was applied.

Similarly phosphorus use efficiency was generally more in P_{50} seedlings. It was minimum at zero N levels, increased

Table 5. Relative nitrogen %, N content and weight of leaf and stem at different treatment levels.

LEAF

Treatment	N %	N CONTENT	WEIGHT
N_0P_0	88	3	3
N_{100} P_0 D_5	116	103	89
N_{100} P_0 D_{10}	81	29	36
N_{200} P_0 D_5	94	99	106
N_{200} P_0 D_{10}	102	42	41
N_{400} P_0 D_5	175	170	97
N_{400} P_0 D_{10}	131	103	79
N_{100} P_{50} D_5	100	100	100
N_{100} P_{50} D_{10}	87	61	70
N_{200} P_{50} D_5	110	137	125
N_{200} P_{50} D_{10}	121	163	135
N_{400} P_{50} D_5	166	330	199
N_{400} P_{50} D_{10}	116	104	90
N_0 P_{50}	102	5	5

Root

Treatment	N %	N CONTENT	WEIGHT
N_0P_0	66	3	4
N_{100} P_0 D_5	115	65	57
N_{100} P_0 D_{10}	91	49	54
N_{200} P_0 D_5	126	81	64
N_{200} P_0 D_{10}	115	44	38
N_{400} P_0 D_5	142	72	51
N_{400} P_0 D_{10}	134	71	53
N_{100} P_{50} D_5	100	100	100
N_{100} P_{50} D_{10}	92	57	62
N_{200} P_{50} D_5	116	122	105
N_{200} P_{50} D_{10}	112	122	109
N_{400} P_{50} D_5	128	153	120
N_{400} P_{50} D_{10}	114	105	92
N_0 P_{50}	67	3	5

with addition of low N level and then gradually decreased. Phosphorus use efficiency, however, increased in P_{50} D_{10} seedlings as soon as medium level of N was added. Treatments had significant effect on all growth parameters used in this study in all the three sampling. As expected control plants (N_0+P_0) and plants with P alone (N_0+P_{50}) had the minimum growth in all variables except the number of nodules. Effects of P, N and their interactions on all growth variables were almost identical i.e. either positive or negative, though varied in magnitude. Response of phosphorus with nitrogen was obtained beyond low (D_{10}) N level. Nitrogen had positive effect when increased from zero to 100 ppm level and generally no effect with further increase.

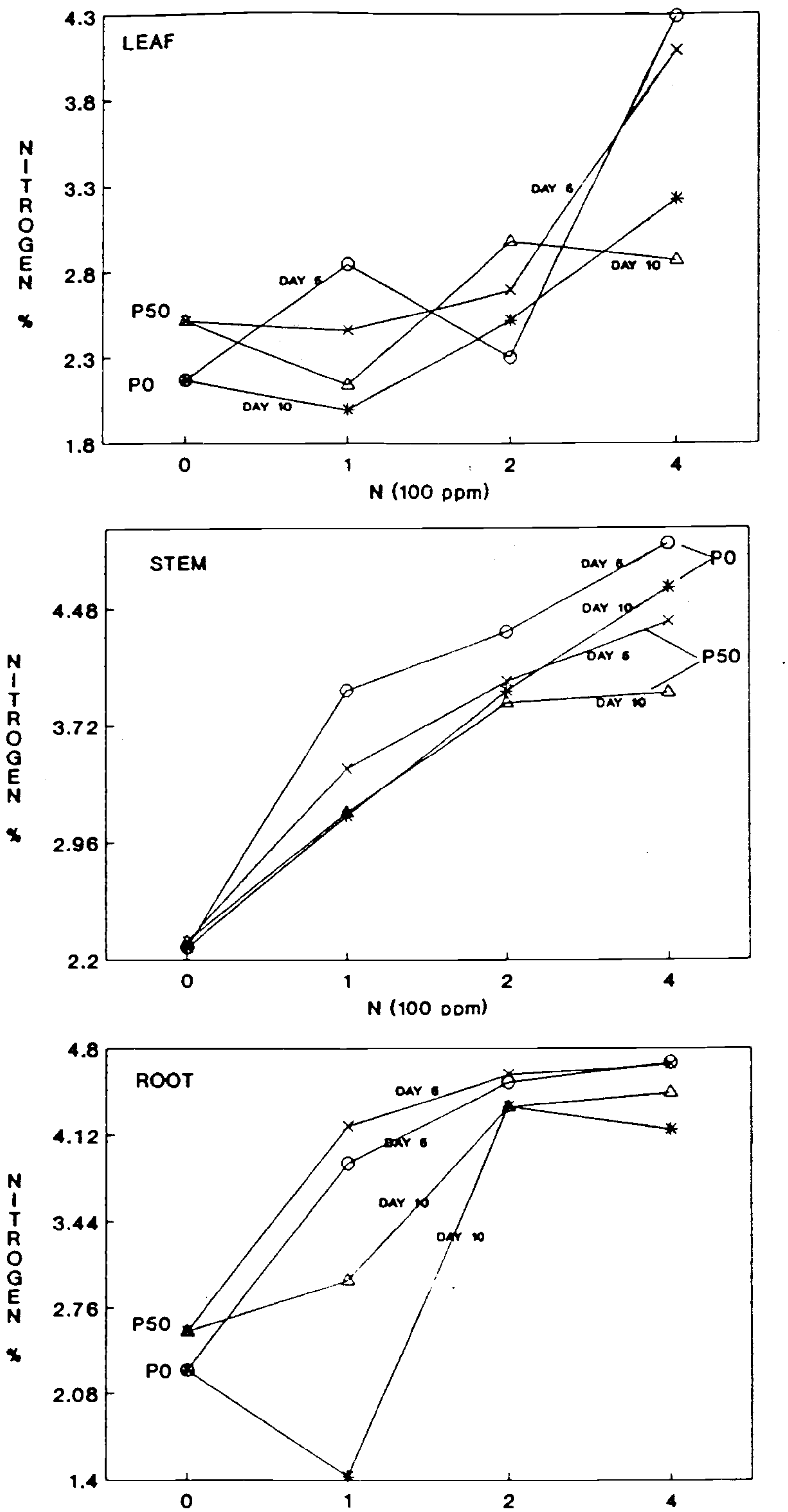


Fig. 12 Effect of N & P fertilizer levels on nitrogen percentage in black locust seedlings at mid-fall.

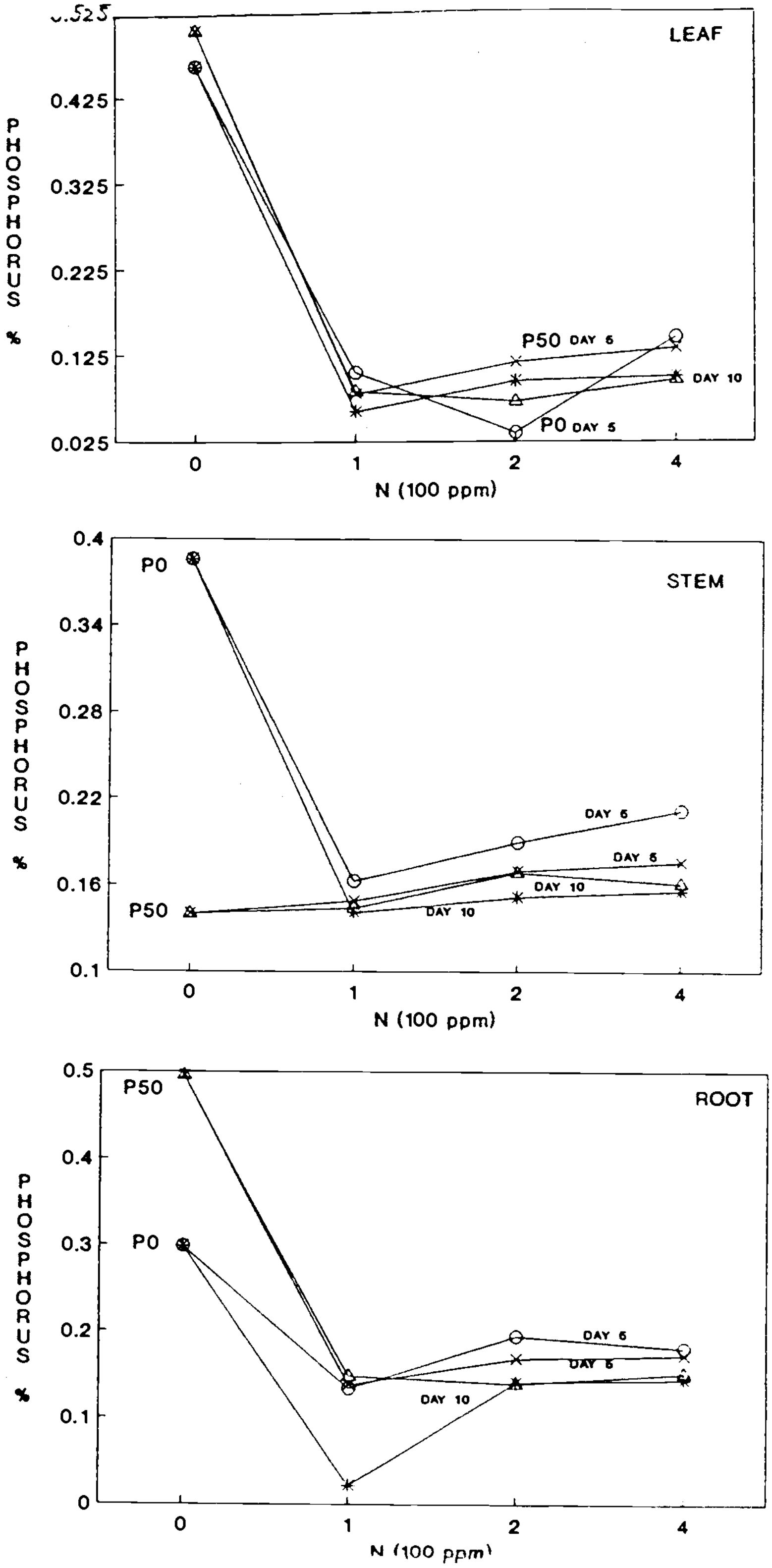
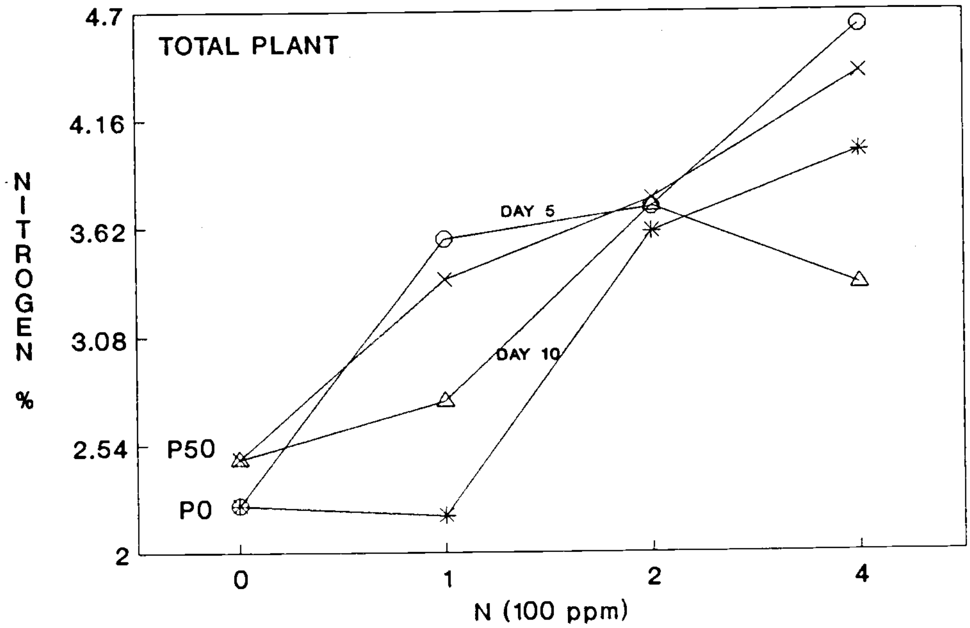


Fig. 13 Effect of N & P fertilizer levels on phosphorus percentage in black locust seedlings at mid-fall.



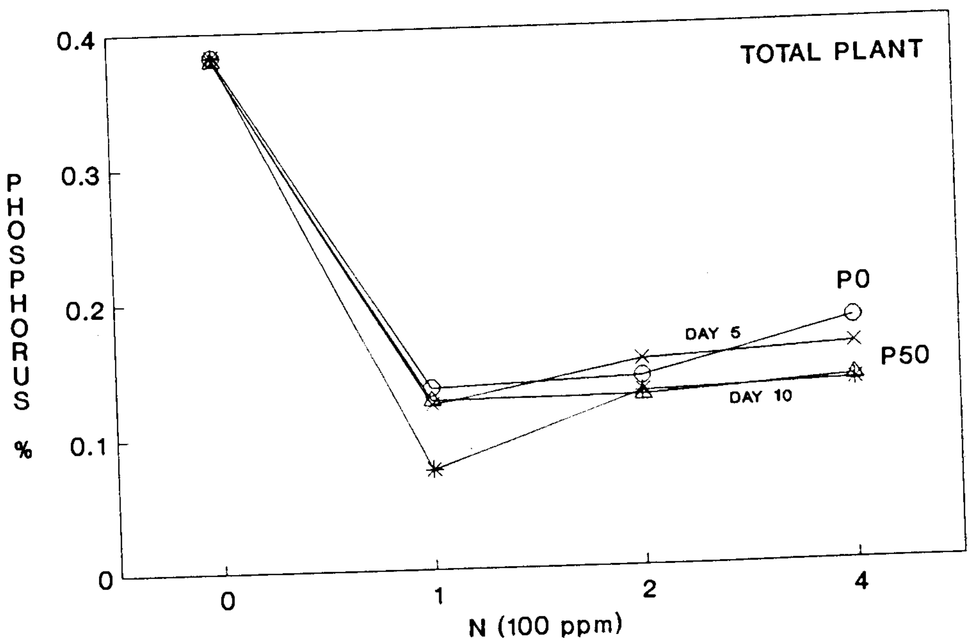


Fig. 14 Effect of N & P fertilizer level on plant N and P percentage in black locust seedlings at mid-fall.

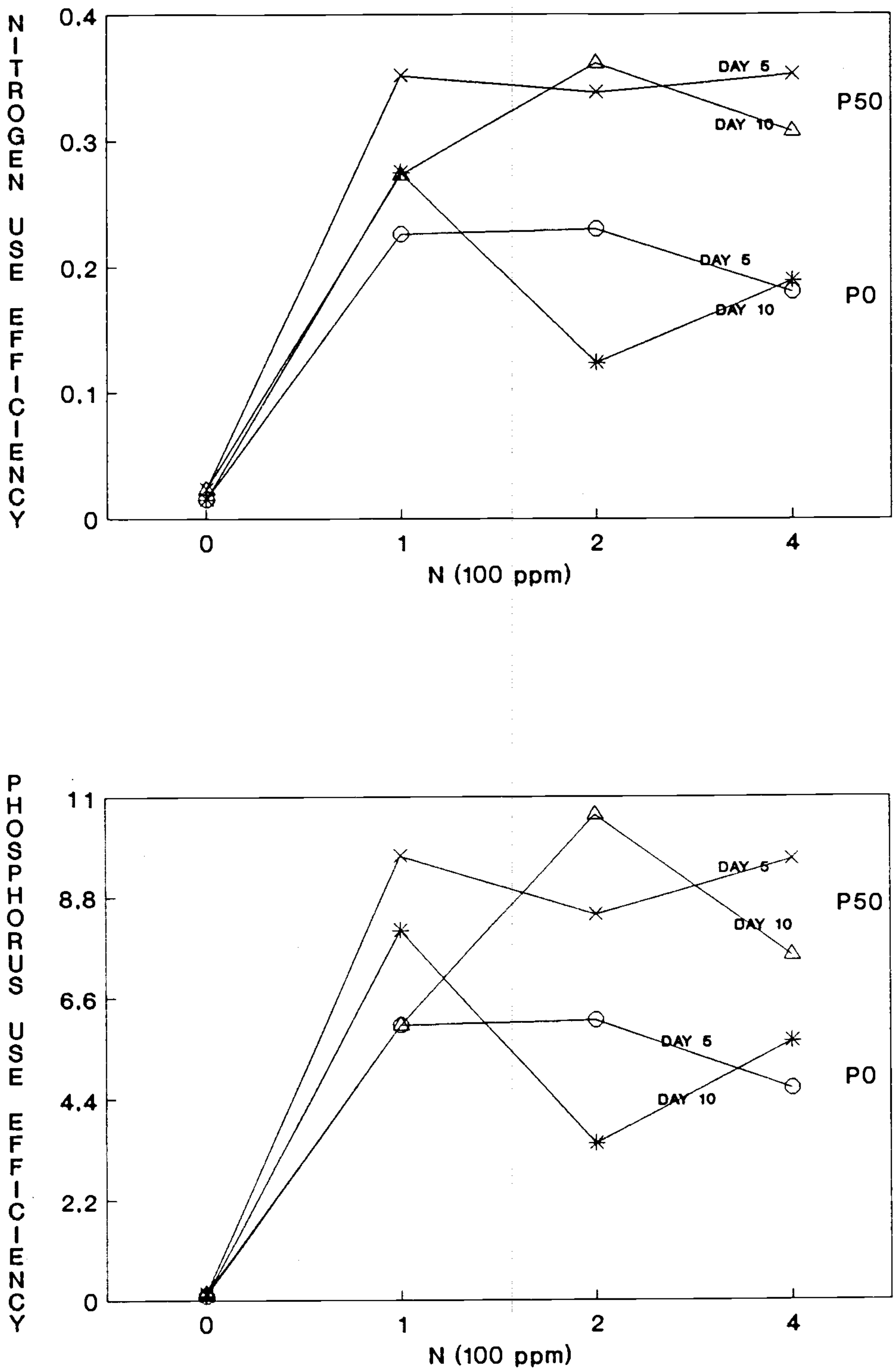


Fig. 15 Effect of N & P fertilizer levels on N and P use efficiency in black locust seedlings at mid-fall.

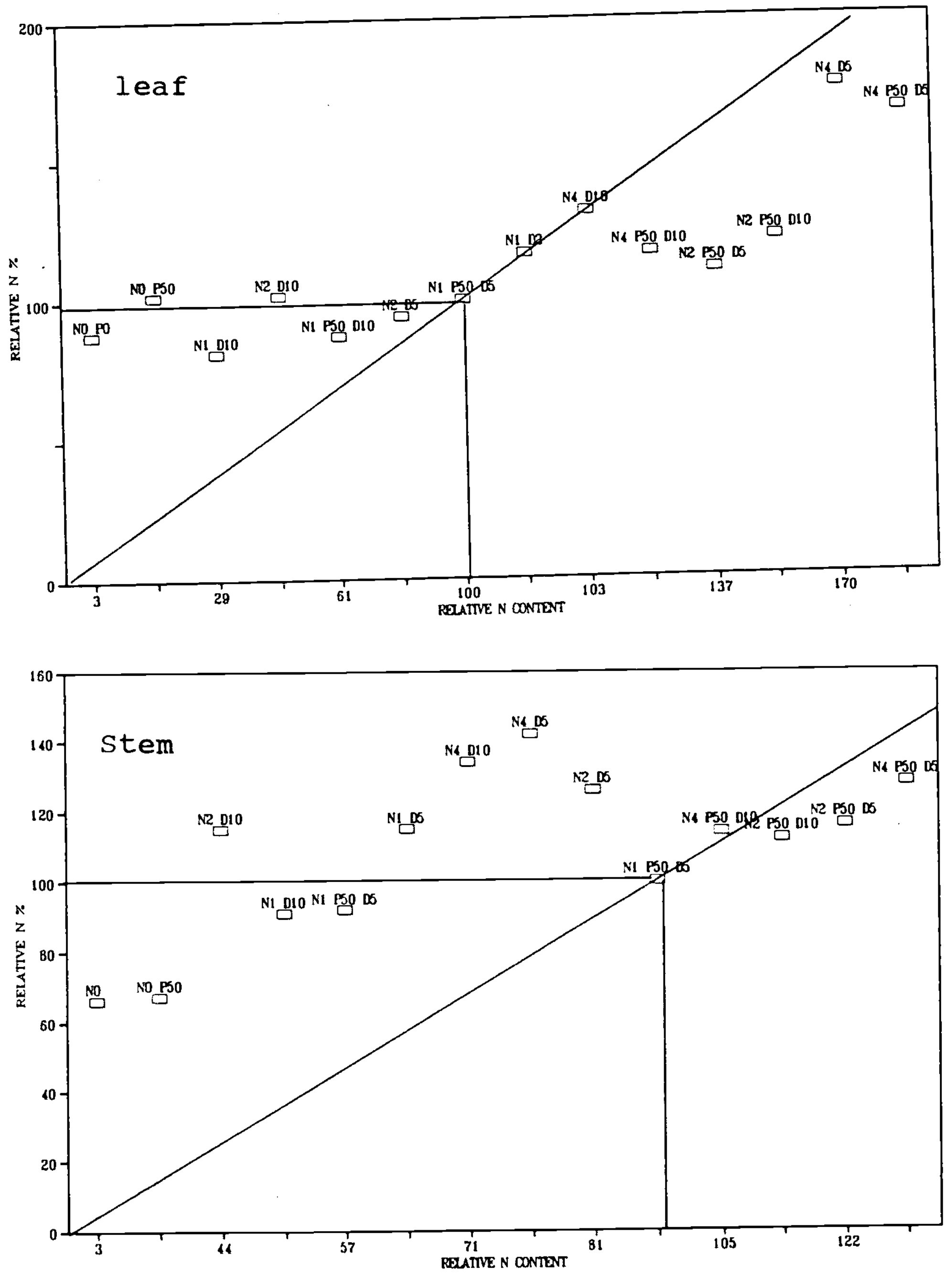


Fig. 15.a Relationship between relative N %, N content and weight of leaf and stem at different levels of fertilizer.

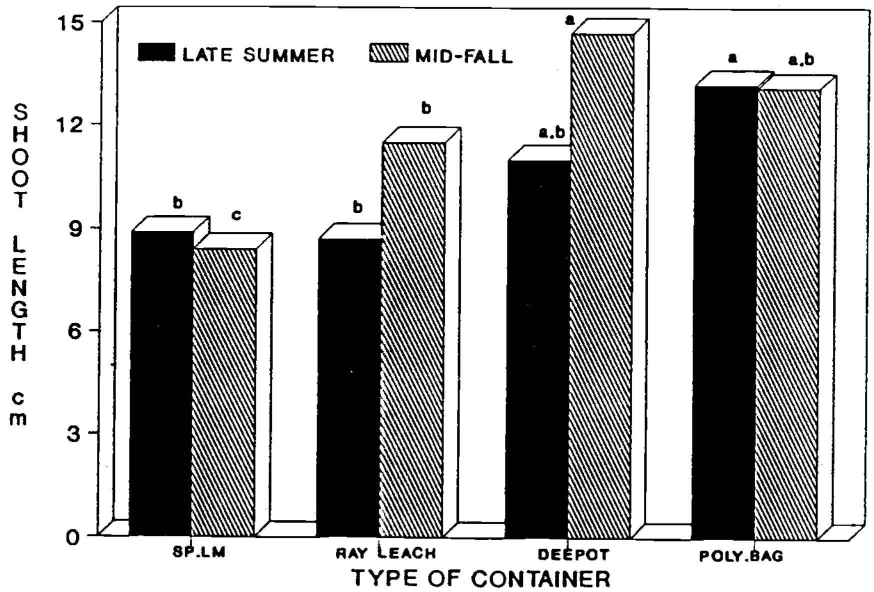
4.1 **EXPERIMENT 2.**

Results in the form of means are given in appendix 13 to 23. The treatments in this experiment were 4 different kinds of containers with varying sizes and shape. The relationship between the volumes of containers was: polythene bag = deepot = 4 ray leach = 9.5 Spencer-Lemaire. Significant effects at $P < 0.05$ level on all physical parameters were achieved by mid-fall when growth had almost ceased. In late summer, when growth was in progress, significant difference was observed in root and shoot length, diameter, leaf and total dry weight only. The treatments explain at least 63 % of variability in parameters as estimated with ANOVA for late summer and 73 % for mid-fall.

By late summer shoot length of seedlings in polythene bags was significantly higher than Spencer-Lemaire and ray leach seedlings (Appendix 13, Fig. 16). In mid-fall, it was significantly more in deepot than Spencer-Lemaire and ray leach seedlings.

Diameter of seedlings in polythene bags was 20% more and significantly higher than the seedlings in rest of the containers by late summer (Appendix 14, Fig. 17). Whereas by mid-fall it was 67% less and lower in Spencer-Lemaire seedlings.

Seedlings in polythene bags had leaf area significantly different from that of seedlings in Spencer-Lemaire and ray



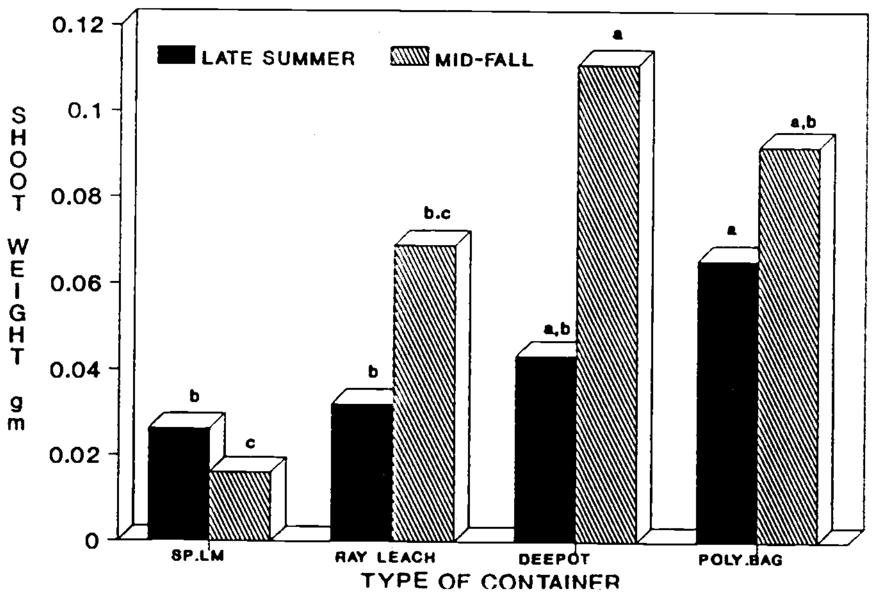


Fig. 16 Effect of containers on shoot length and weight of black locust seedlings at 2 harvesting periods
*Bars of the same style with the same letters are not significantly different

leach cells by late summer. Mean leaf area of seedlings in polythene bags was double that of deepot seedlings but not significantly higher. In the last sampling, leaf area of deepot seedlings was not different than polythene bag seedlings and significantly higher than that of other two container seedlings.

Leaf weight was significantly higher in polythene bag seedlings than the rest of the containers for late summer sampling date (Fig. 18). By mid-fall leaf weight of seedlings in deepots was not different than polythene bag seedlings but was significantly higher than that of ray leach cell and Spencer-Lemaire seedlings.

A significant difference in stem weight was observed only for last sampling. Seedlings in deepots had higher stem weight than that of ray leach and Spencer-Lemaire seedlings (Fig. 17).

The difference in shoot biomass was not significant between seedlings of ploythene bags and deepots by late summer (Fig. 16). It was higher in polythene bag seedlings than Spencer-Lemaire and ray leach container seedlings. In mid-fall, shoot biomass of deepot seedlings was higher than that of Spence-lemaire and ray leach cells.

Root length was minimum in Spencer-Lemaire seedlings and significantly different than ray leach and deepot seedlings by late summer (Fig. 19). By mid-fall, it was significantly higher in deepot seedlings than the seedlings

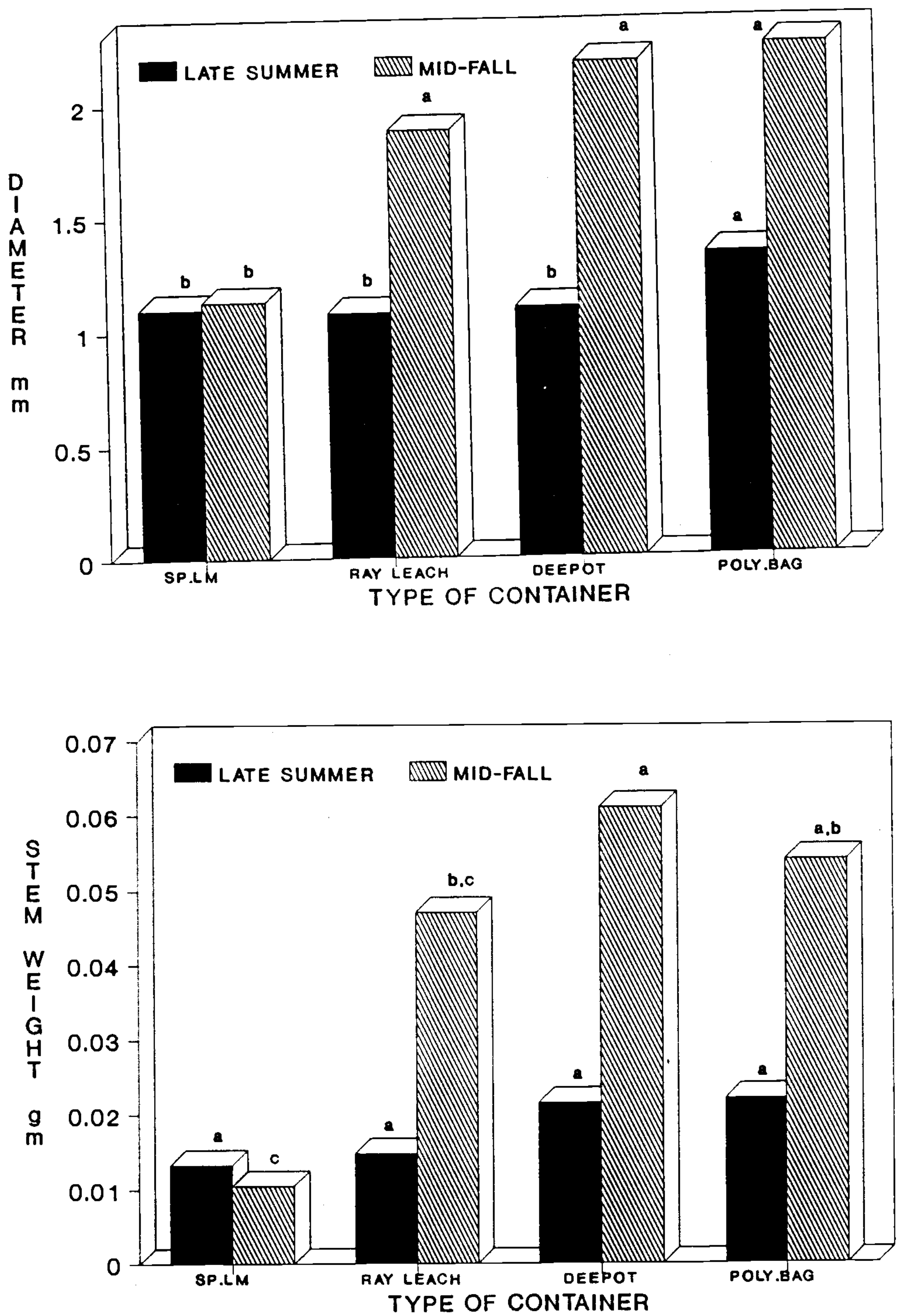


Fig. 17 Effect of containers on stem diameter and weight of black locust seedlings at 2 harvesting periods.
*Bars of the same style with the same letters are not significantly different.

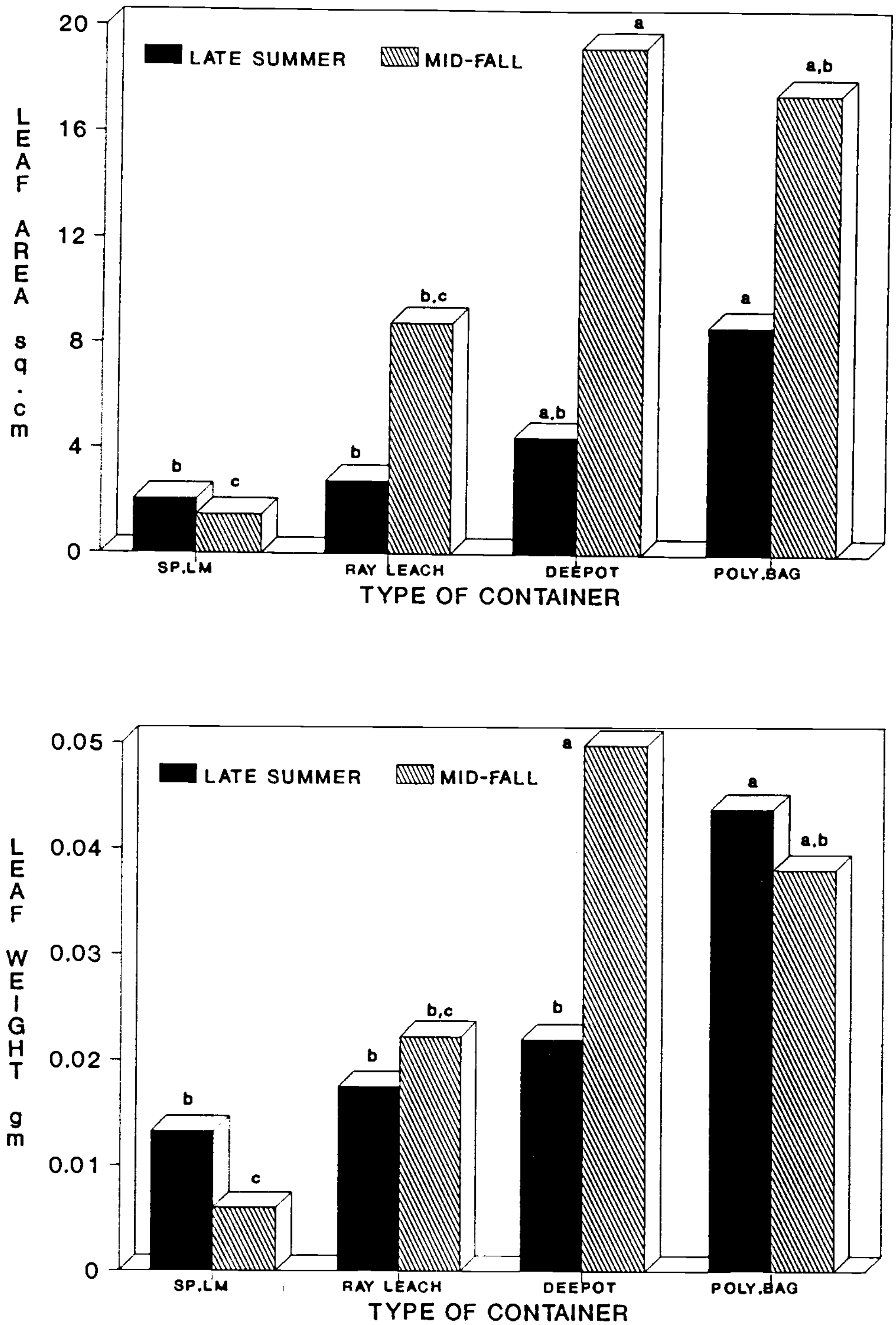


Fig. 18 Effect of containers on leaf area and weight of black locust seedlings at 2 harvesting periods.
*Bars of the same style with the same letters are not significantly different.

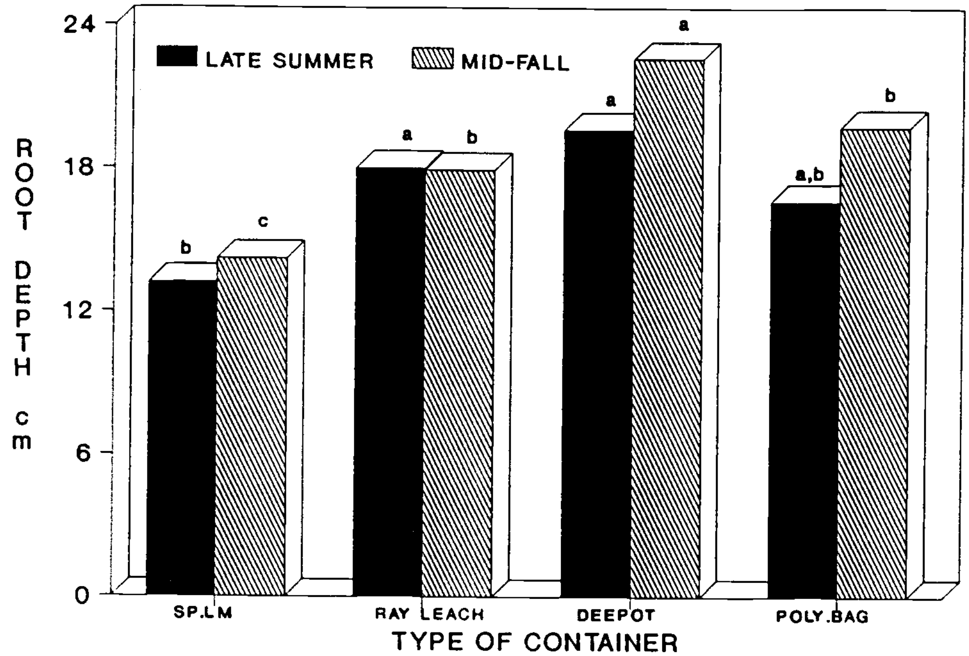
in rest of the containers whereas it was significantly lower in Spencer-Lemaire seedlings than the other container seedlings.

Type of container affected root weight for mid-fall only. It was significantly lower in Spencer-Lemaire seedlings than the rest of the seedlings (Fig. 19).

Total plant biomass was lowest in Spencer-Lemaire seedlings by late summer (Fig. 20). In final sampling it was higher in deepot seedlings than that of the seedlings in Spencer-Lemaire and ray leach.

By late summer, nodulation was more in polythene bag seedlings than Spencer-Lemaire seedlings (Fig. 21). It was significantly higher in polythene bag as compared to ray leach and Spencer-Lemaire seedlings in the last sampling.

Shoot to root ratio was not affected by container treatment in either of the two sampling. Similarly specific leaf area was the same in the seedlings in all types of containers (Fig. 20 & 21).



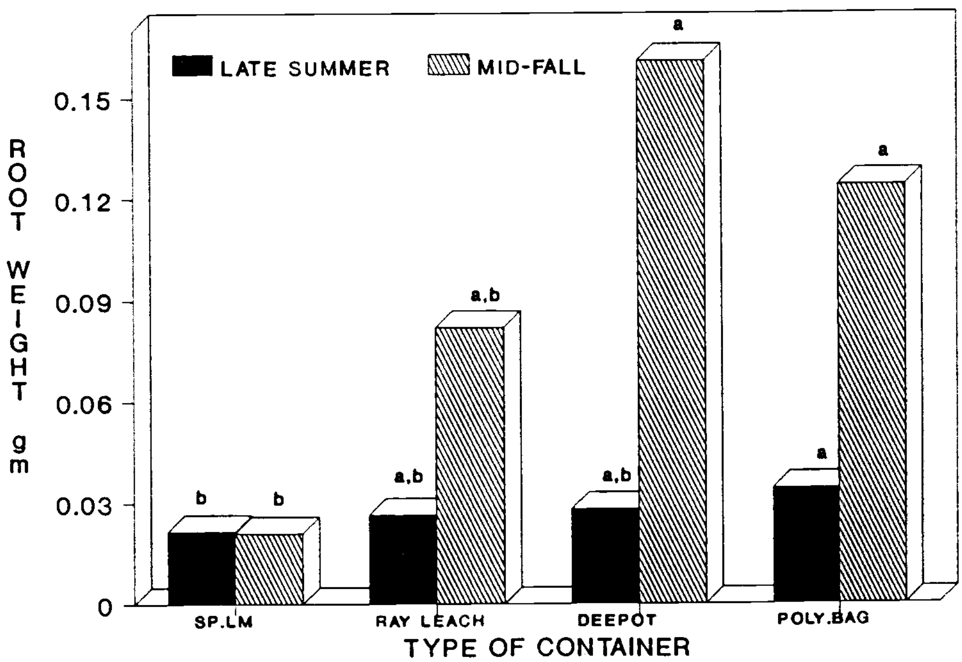


Fig. 19 Effect of containers on root length and weight of black locust seedlings at 2 harvesting periods.
*Bars of the same style with the same letters are not significantly different.

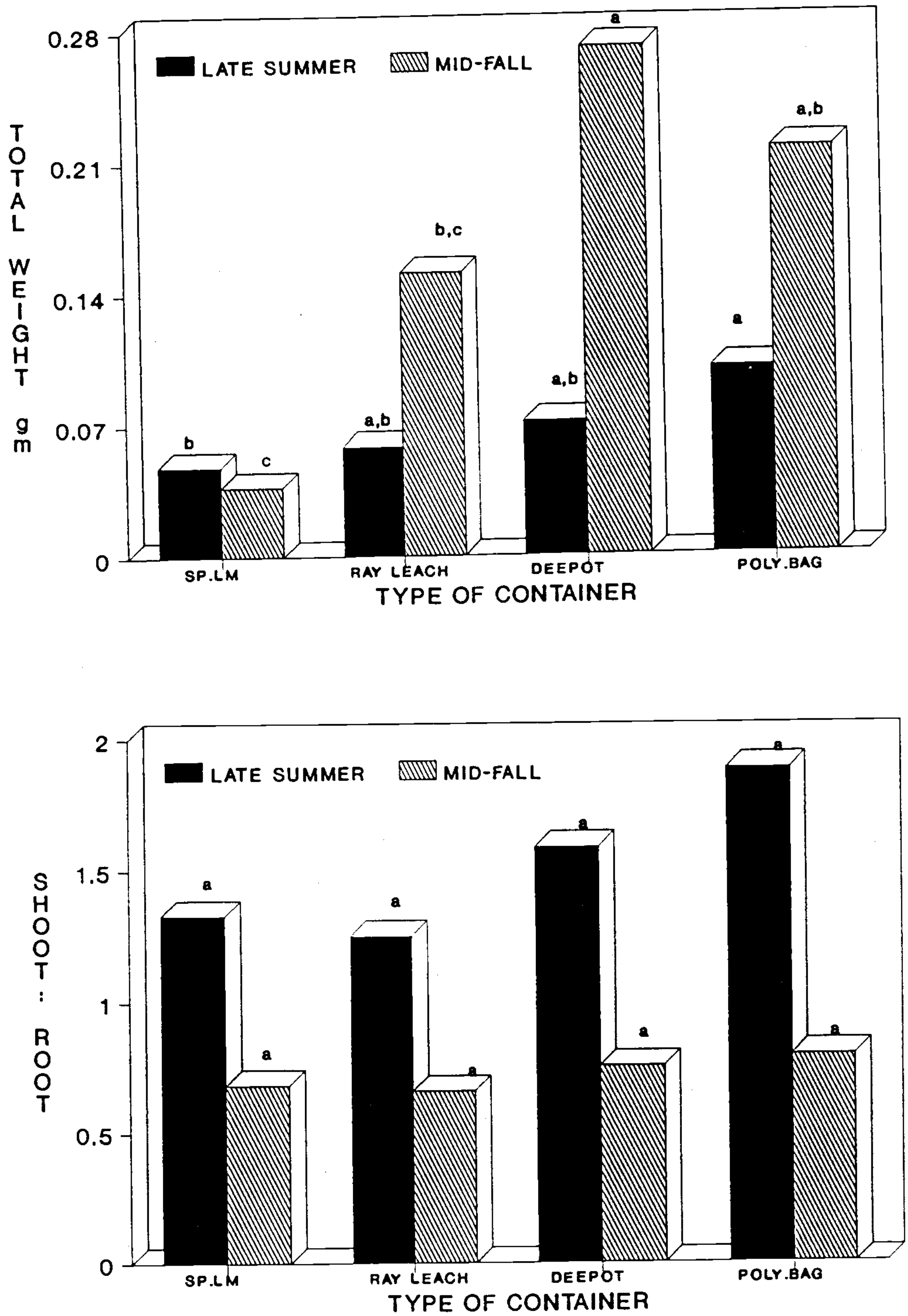
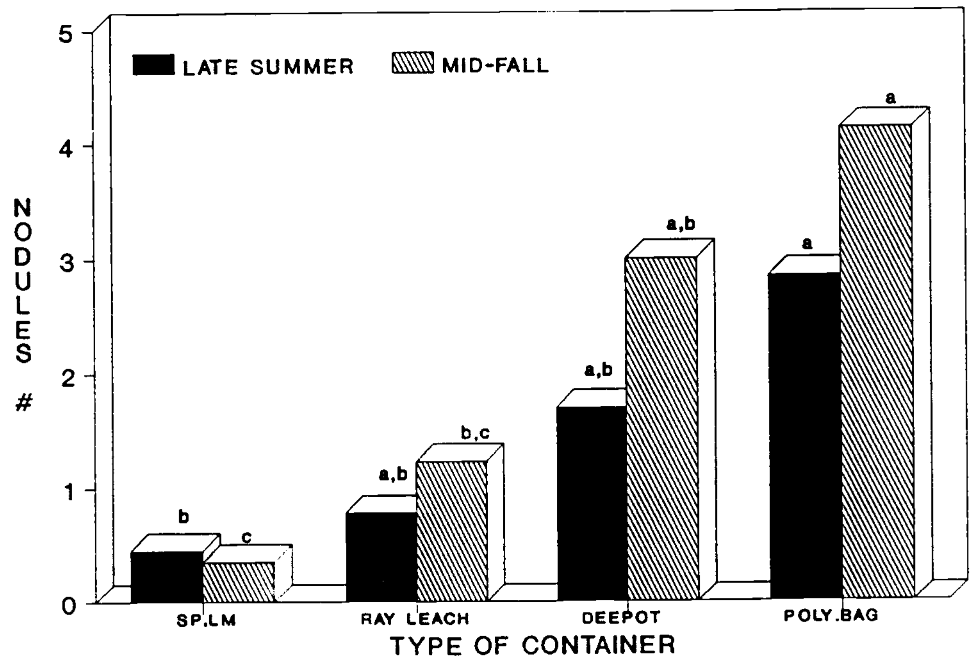


Fig. 20 Effect of containers on total weight and S/R ratio of black locust seedlings at 2 harvesting periods.
*Bars of the same style with the same letters are not significantly different.



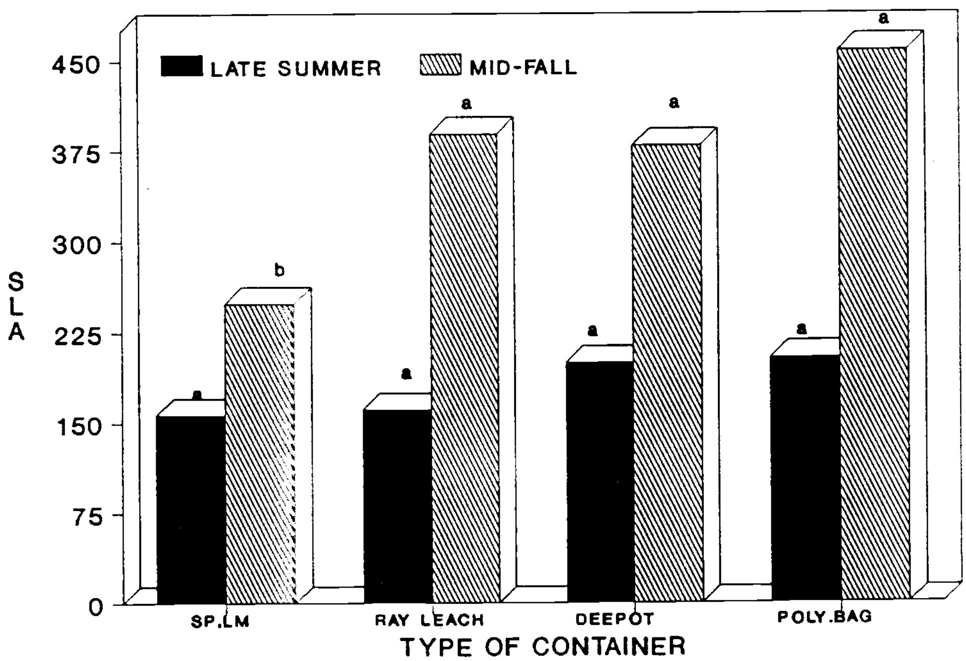


Fig. 21 Effect of containers on nodules and Sp. leaf area of black locust seedlings at 2 harvesting periods.
*Bars of the same style with the same letters are not significantly different.

5. DISCUSSION

5.1 EXPERIMENT 1

To maintain a high photosynthetic capacity, N and P are required in relatively high amounts compared to other nutrients (Landis, 1985). Nitrogen is needed for synthesis of proteins and enzymes and ultimately for growth while P is needed in ATP, an energy source for biochemical reactions.

In this study P and N both played a significant role in increasing seedling growth: N at its low level and P x N generally at medium level of N. At zero level of nitrogen, shoot length and stem length were minimum due to severe deficiency of N. Addition of 100 ppm N substantially enhanced shoot and stem lengths indicating that external concentration of N around 100 ppm was optimum for shoot length under the environment in which black locust was grown. Addition of 200 and 400 ppm N proved to be supra-optimal and then toxic as no increase in growth resulted from those levels. Similar results were obtained by Ingestad (1982) for loblolly pine and Van Den Driessche (1980) for Douglas-fir when there was no growth beyond a saturation point of N supply.

In case of treatments where 50 ppm of P was applied, there was no effect of P on shoot and stem length at zero and 100 ppm N (D_{10}) levels as these were not more in P_{50} seedlings than P_0 seedlings at those levels. Generally the minimum amount of a nutrient for normal growth is not an absolute value, but depends on the relative amounts of certain other elements that are available (Arnon, 1972). In this case when nitrogen was supplied frequently i.e. after each 5 days, its' concentration rose to near optimum and resulted in higher growth than the same N concentration of plants without P. Addition of medium level (200 ppm) of N at 10 days interval resulted in further growth. Higher N concentration (400 ppm) did not cause any increased growth. This may be because N concentration was probably optimum at medium D_{10} level and further N input either caused toxicity (Marshall, 1981) or deficiency of some other elements (e.g. phosphorus) due to dilution (Landis, 1985).

Low level of N significantly increased root collar diameter of seedlings but further fertilization had no effect. Diameter depends on how dry matter is allocated to various organs. A strong correlation (R^2 =0.83) was noted between root collar diameter and total dry biomass. This implies that treatments affected diameter the same way as they affected total biomass and, therefore, either of the two criterion can be used to evaluate seedling quality (Switzer and Nelson, 1963).

Leaf area and leaf dry weight sharply increased with low N level suggesting that there was direct effect of N treatment on the growth rate of leaves, resulting in enhanced photosynthetic and overall growth. Roberts et al.

(1983) reported similar result for black locust seedlings that were getting 5 Mm of NH_4NO_3. In this experiment, further addition of N, did not cause any change in leaf. Similar result was reported by Etter (1972) for white spruce and Ingestad and Lund (1979) for birch.

Phosphorus increased leaf area at low and medium N levels in a manner similar to that reported by Taylor and Goubran (1976) for apple. Increase in leaf area was associated with increase in leaf dry weight in P_{50} seedlings. This caused a slight decrease in specific leaf area. The most plausible explanation of this phenomenon could be that expansion of photosynthetic area was more sensitive to P availability but increased external N level enhanced thickness of leaf lamina more than leaf expansion. This result is in contrast to that of Cromer and Jarvis (1989) for eucalyptus but is consistent with the result of Koo (1989) for red alder.

Stem and shoot dry weights were affected by the independent variables the same way as shoot length. The somewhat anomalous trend of leaf area, leaf weight and shoot weight in the last sampling (mid-fall) could be attributed to the fact that there were only a few samples in some of the treatments, as compared to 5 in the earlier two sampling periods. Some of those sampled plants may have lost a few of their leaves.

Seedlings at 0 level of N were nutrient stressed. With the addition of a low dose of N (100 ppm), root elongation was strongly stimulated, indicating that N was severely deficient at N_0 level. Due to higher availability of N, root elongation remained at steady state beyond 100 ppm N level. These results are not exactly the same as obtained by Marshall (1981) for root elongation but comparable in the sense that increasing N fertilization above a low level did not result in significant root elongation. Similarly in this study it was found that in phosphorus starving seedlings, root elongation was more than P_{50} seedlings. This result is similar to the finding of Taylor and Goubran (9176) when root elongation was inhibited in apple plants supplied with 50 ppm of P because of comparatively acidic root environment.

Root weight followed the pattern of root length with regard to nitrogen levels. Roberts et al, (1983) obtained larger root mass in black locust seedlings grown in an environment where N was available. Since they used only two levels of N, further comparison with our results are not possible. Root weight had the opposite trend with relation to P fertilization indicating that specific root length (root length/ dry root weight) was more for P_0 seedlings. Since one of the major nutrients i.e. phosphorus was deficient, therefore, roots had to grow more to explore for the limiting nutrient. Roots in P_{50} seedlings were thicker due to storage of dry matter sent from shoot and, therefore, heavier per unit root length.

Effect on total seedling dry weight was also similar to shoot and root dry weight. Reinsvold and Pope (1980) showed that dry weight of black locust seedlings was more in treatments involving P and N. Similarly slash pine (Fischer and Garbett, 1980) obtained maximum growth when supplied with N and P as compared to growth with any of the two elements alone.

Nodulation was maximum at zero and low levels of N and was inhibited by increasing N level. Earlier findings suggest that nodule activity declines when soil N is readily available. Similar results were obtained by Koo (1989) for nodule dry weight in red alder. Roberts et al, (1984) attributed the negative growth response with the increase in N level to the inhibitory effect on nodulation. This indicated that nodule formation was stimulated more in N deficient plants in order to supplement N availability through symbiosis. On the other hand, P favors nodule formation (Reinsvold and Pope, 1987; Lynd and Ansman, 1989 A) and negative effects of N fertilization are reduced by P fertilization (Koo, 1989). These results confirmed the previous findings but in this experiment, P effect was suppressed by higher N levels. However, low N (D_{10}) level was not strong enough to reduce P effect. Therefore, maximum nodulation was found at N_{100} P_{50} D_{10} level followed by N_0 P_{50} level seedlings.

Allocation of dry matter early in the growing period was 3 to 4 times higher to leaves than stems in positive N treatments. Leaves were apparently the strongest sink for growth resources in order to expand more rapidly and intercept more light energy for maximum photosynthesis. With ontogeny, stem growth became a stronger sink. This finding is in conformity with the result obtained by Cromer and Jarvis (1989) for eucalyptus.

As for dry matter budgeting between shoot and root is concerned, 4 times more allocation was made to shoot (higher shoot:root ratio) in positive N treatments by late summer. More allocation to shoots during the early growing period had the advantage of enhancing photosynthesis. With ontogeny photosynthate was translocated to roots when enough reserve built up (Appendix 10). By termination of the experiment only slightly and more than 50% of dry matter was allocated to roots (lower shoot: root ratio).

In N_0 treatments, allocation to shoot was slightly more than half of the total biomass (lower shoot:root ratio), and this ratio remained unchanged during the entire experimental period. Comparatively higher allocation was made to roots in nutrient deficient plants. Because: 1. root elongation for nutrient searching in the initial stage and 2. food storage for later use was more important than leaf expansion and shoot elongation. Brouwer (1962) stated that when N supply is sub-optimal shoot growth will be slowed sooner than root growth. Conversely, any treatment that increases the uptake of minerals is more likely to increase shoot growth relative to root growth. These results are similar to the findings of Turner (1922), Van Den Driessche (1977, 1982) and Hilbert (1990). Decrease in shoot:root ratio in P deficit seedlings in the first two sampling were similar to the results of Taylor and Goubran (1976) for apple.

In case of N, use efficiency (total plant biomass/ internal N concentration) declined with addition of N beyond 100 ppm (D_5). This was associated with increased nitrogen concentration on individual tissue basis as well as on the basis of whole plant. This finding is supported by the results of Ingestad (1979) for birch and Van Den Driessche (1980) for Douglas-fir. Sorensen (1971) stated that nitrate activates nitrate reductase enzyme, but, after fertilization with high amounts of N, the nitrate concentration in the plant can rise to toxic levels. In this experiment, internal N concentration probably rose to toxic level with application of high N level as there was no growth of seedlings. These results are also supported by the relative growth rate (expressed as percent increase over initial total biomass) pattern which was minimum at 0 level of N and increased significantly with the addition of 100 ppm before gradually dropping off again with further N application.

Vector analysis did not give a clear picture with regard to all different treatments, but as a group P_{50}

treatments were separated from P_0 treatments. At N_{100} D_{10} level, with and without P, there was decrease in content and weight relative to that of standard treatment (N_{100} P_{50} D_5). Location of these points in Fig. 15 a. suggests toxicity or antagonism (Bigg, 1990) but in reality there was deficiency of N. At medium N level with P, there was increase in N content and weight whereas the concentration of N remained unchanged. The implication is that the initial level (100 ppm) was limiting and 200 ppm level was just sufficient (Timmer and Stone, 1978). At high (N_{400}) level without P, toxicity effect was evident as there was increase in concentration and content but no increase in weight. There was 3 fold increase in N content but slight increase in concentration and weight at N_{400} P_{50} D_5 level indicating luxury consumption of N.

Any change in concentration of one element is usually accompanied by changes in concentration of others (Landis, 1985). A dilution effect occurs when an increase in concentration of one limiting nutrient causes increased plant growth that results in a decrease in the concentration of other nutrients. In this experiment at 0 level of N, there was maximum concentration of P. Addition of 100 ppm N resulted in enhanced growth that caused a sharp decline in P concentration in plant tissue. At all positive N levels, concentration of P was the same in the seedlings. Similar results were reported by Van Den Driessche (1980) for

Douglas-fir as with addition of N, concentration of N increased but that of P decreased.

Growth or biomass production is the net result of photosynthesis and respiration. Increase in maintenance respiration is caused by increase in amino acids and protein level in plant tissue which in turn are stored when N fertilization is in excess of an optimum level (Ingestad, 1982). So excessive levels of fertilizer increase maintenance respiration and decrease dry matter production. Internal N concentration in plant tissues suggested that N efficiency decreased with increase in external N level due to breaking down of photosynthate in maintenance respiration.

Application of low N (D_{10}) level to plants with P, did not increase growth above the plants without P presumably because there was no adequate uptake of P. The synergistic relationship between P and N is well documented but there must be some minimum threshold level of one element to enhance the uptake of another element. In this study when low N level was applied after each 5 days interval, significantly higher growth was achieved by P_{50} seedlings than P_0. This indicated that there was uptake of P at that N level. Similar results were obtained when medium (N_{200}) level was applied with 10 days interval. Seedlings produced at this level had growth variables not different than the seedlings that attained maximum growth with higher concentrations and more frequent fertilizer input. However, nitrogen seemed to be optimum as medium (N_{200}) level was applied at 5 days intervals because high (N_{400}) addition did not result in increase growth but a plateau was established.

5.2 EXPERIMENT 2

The containers in this experiment were different in size as well as shape. We hypothesized that bigger volume container will produce bigger seedlings as container volume is directly related to the size of the seedlings (Tinus and McDonald, 1979, Kellas and Edgar, 1979) but container lengths and diameters were of more importance than volume alone (Carlson and Endean, 1976). Cunningham and Geary (1989) found small differences in shoot height and diameter of seedlings of Eucalyptus camaldulensis with increase in diameters and lengths of containers.

Nearly all growth parameters were maximum in seedlings with highest volume of the growing medium, though not proportionate to the increase in volume. Seedlings in Spencer-Lemaire were under stress from the very beginning due the to small volume (70 cm^3) of the container which was apparently not enough to meet their nutrient requirements. There was a very marginal increase in diameter between late summer and mid-fall sampling.

Seedlings in deepots had maximum growth rate in all parameters between late summer and mid-fall. In terms of percentage, there was 33% increase in shoot length, 97% in diameter, 170% in shoot dry biomass and 470% in root dry weight. These seedlings grew 2 times more in total dry biomass compared to seedlings in polythene bags and ray leach supercells.

On the basis of volume of growing medium it was expected that seedlings in the polythene bags would excel in growth. The results, however indicated that these seedlings ranked second when adjudged on the basis of growth per unit volume of the medium and also on the basis of rate of growth (expressed as percent increase over original weight). The plausible reason could be the transparent nature of polythene that allowed growth of algae inside along the bag walls. The algae probably retained more water and caused stagnation resulting in inhibition of root respiration and normal root growth. This was evident from the root length which was disproportionately smaller to the container volume. On the other hand the tapering nature of deepots helped in guiding the roots downward. Tinus and McDonald (1979) proposed that narrow deep container would be more suitable for growth of forest seedlings. However, the result of this experiment did not indicate that reduced root length of polythene bag seedlings was due to the nature and color of the material of the polythene bag or its shape.

In terms of growth per unit volume of growing medium, ray leach supercells were the most efficient. Volume of growing medium in deepots was 4 times more than that of ray leach, whereas total dry biomass of seedlings was less than double. Carlson and Endean (1976) did not produce bigger white spruce seedlings by increasing container volume 4 times while keeping the taper of the container constant.

It is not the volume of the container that determines growth of the seedlings but diameter, depth and diameter/ depth ratio play an important role. Kingman and King (1983) reported that containers less than an inch, and 4 inches in diameter tended to produce smaller Shumard's red oak seedlings in terms of dry weight than those closer to 2 inches. Similarly 8 inch deep containers produced bigger seedlings than 4 inch or 16 inch containers. In this study, top diameter of deepots and polythene bags was almost equal, but length and taper of deepots was probably more effective in inducing growth in the seedlings.

The plants in the Spencer-Lemaire attained the least values in all growth variables in both sampling with the exception of shoot length and diameter in the first sampling. Results of late summer sampling revealed that plants in polythene bags had the maximum growth in all dependent variables followed by deepot seedlings. In mid-fall the results reversed and the seedlings in deepots had the maximum response followed by polythene bags except for diameter and nodulation.

6. CONCLUSIONS

Black locust may have an important role in planting on marginal sites, as pioneer species or in mixed planting with some nonfixing species. It was shown that black locust trees seldom respond to N fertilization in the field (Plass, 1972). Our study, however, suggests that fertilization with phosphorus and a minimal level of N are required to induce nodulation and support optimum growth in the nursery. This is supported by the earlier findings of Reinsvold and Pope (1980).

An interesting outcome of this study is that response of plants was more sensitive to fertilizer level rather than application interval. Note that plants getting 100 ppm every 5 days, nominally got the same amount of N that was received by the plants getting 200 ppm every 10 days. Similarly the amount of N received by N_{200} D_5 plants was approximately the same as that of N_{400} D_{10} plants (Table 6). Generally there was no significant difference in growth response as long as the seedlings received the same concentration of N. Frequent i.e. (D_5) fertilization took double the time and labor compared to fertilization after every 10 days without commensurate response in growth. Therefore, frequent fertilizer application is not worthwhile either economically or biologically.

An input-output study can only be of some significance

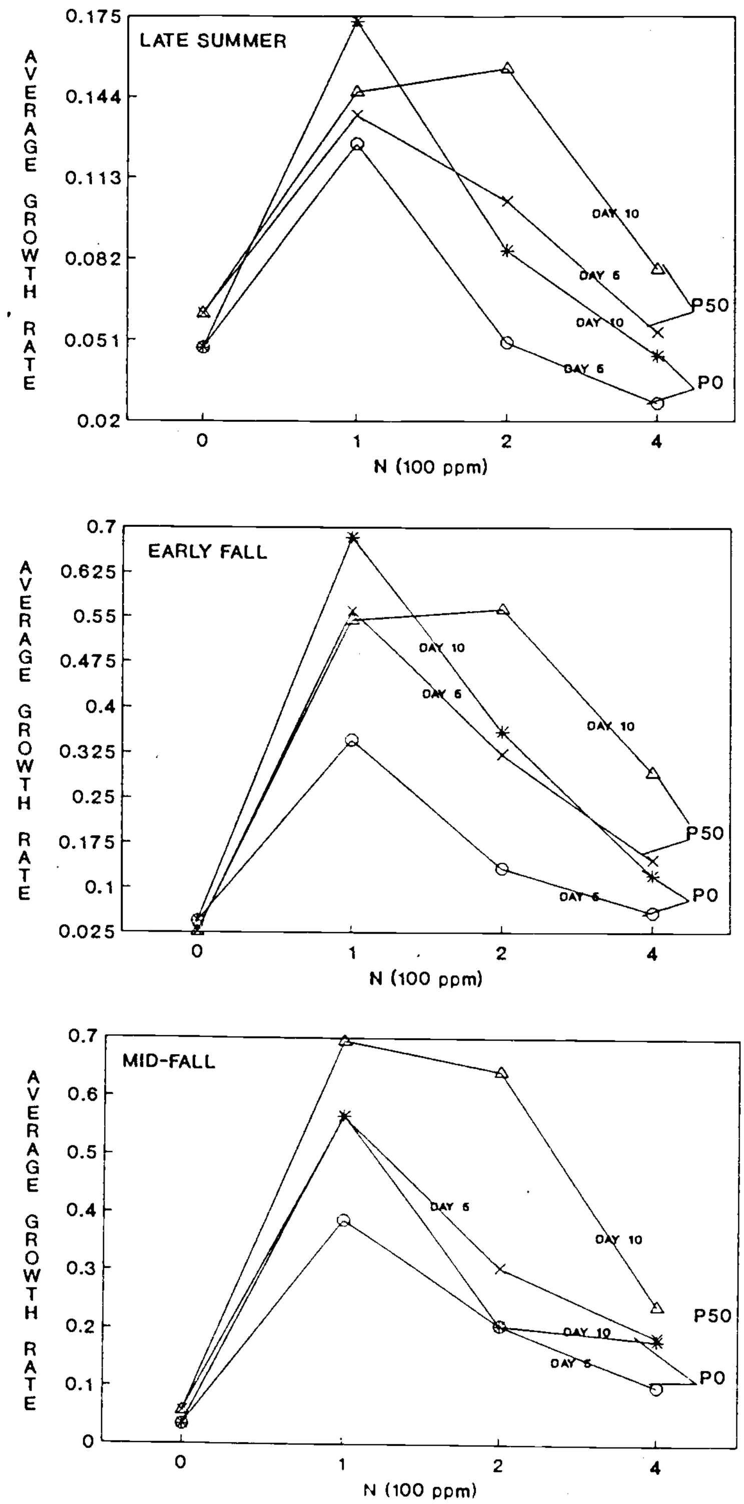


Fig. 22 Average growth rate per 100 ppm N at each treatment level of fertilizer

Table 6. Average growth rate of seedlings per 100 ppm of N at (a) late summer (b) early fall (c) mid-fall.

(a) Late summer

Treatment	N level	Absolute growth	Av.growth/100 ppm N
P_0	0	0.048	0.048
D_{10}	100	0.221	0.173
	200	0.218	0.085
	400	0.227	0.045
	0	0.048	0.048
D_5	200	0.300	0.126
	400	0.246	0.050
	800	0.263	0.027
P_{50}	0	0.061	0.061
D_{10}	100	0.207	0.146
	200	0.371	0.155*
	400	0.371	0.078
	0	0.061	0.061
D_5	200	0.335	0.137
	400	0.475	0.104
	800	0.494	0.054

Absolute growth at any N level is the mean total growth attained by the seedlings. Average growth rate at any N level is the absolute growth minus the growth at zero N level obtained per 100 ppm of N.

*Growth obtained with any subsequent addition of 100 ppm N after the first input of 100 ppm, was maximum at this level

(Table 6 cont:)
(b) Early fall

Treatment	N level	Absolute growth	Av.growth/100 ppm N
P_0 D_{10}	0	0.044	0.044
	100	0.727	0.683
	200	0.761	0.359
	400	0.524	0.120
D_5	0	0.044	0.044
	200	0.735	0.346
	400	0.575	0.132
	800	0.505	0.058
P_{50} D_{10}	0	0.026	0.026
	100	0.571	0.545
	200	1.151	0.563*
	400	1.193	0.292
D_5	0	0.026	0.026
	200	1.146	0.560
	400	1.314	0.322
	800	1.191	0.146

(c) Mid-fall

Treatment	N level	Absolute growth	Av.growth/100 ppm N
P_0 D_{10}	0	0.034	0.034
	100	0.600	0.566
	200	0.444	0.205
	400	0.755	0.180
D_5	0	0.034	0.034
	200	0.805	0.386
	400	0.854	0.205
	800	0.831	0.100
P_{50} D_{10}	0	0.057	0.057
	100	0.752	0.695
	200	1.343	0.643*
	400	1.023	0.240
D_5	0	0.057	0.057
	200	1.187	0.565
	400	1.273	0.304
	800	1.543	0.186

when supported by its economic viability. Table 6 explains the growth pattern as it changed with each additional unit (100 ppm) of N. The first input of N resulted in substantial output in the form of growth in all 4 groups of treatments. The second input ended up with diminishing returns except in N_{200} P_{50} D_{10} treatment in which case the return was still positive. This was the only level that continued to provide highest returns per unit (100 ppm) of N throughout the experimental period (Fig. 22). There was a linear increase in absolute total biomass of P_{50} plants when N fertilizer was increased from 0 to 200 ppm applied after each 10 days. This was also the level beyond which relative growth rate sharply dipped down, in some cases to zero. Nitrogen and phosphorus use efficiency was also maximum at this level. In this study, therefore, medium level (N_{200} P_{50} D_{10}) was the most effective in enhancing growth.

Of course, it is not known how much output (growth) per unit of input (N fertilizer) is economical because it can't be predicted at which treatment level seedlings will perform better in the field. The results of this experiment indicated that N_{200} P_{50} D_{10} fertilizer level may be more suitable as the growth variables at this level were not different than higher fertilizer level seedlings.

As shown in experiment 2, physical characteristics of seedlings can be changed by altering container dimension. For planting on drier sites, seedlings with a low shoot:

root ratio are required and this will need deeper containers relative to diameter. Wide and short containers will produce seedlings which can be suitable for wetter sites and deeper soils because of smaller root biomass. However, increase in diameter of container, whenever required, should be accompanied by appropriate decrease in length or associated with taper, as greater container volume may result in little increase in seedling biomass but may substantially increase production cost (Cunningham and Geary, 1989). In this experiment growth of seedlings in polythene bags was not different than that of deepot seedlings, whereas, the ratio of cost of containers was 1:10 respectively. On an economic basis, polythene bags are preferable to any of other containers used in this study assuming that performance of seedlings after outplanting will also not be different.

Black locust is not traditionally raised in containers. However, further investigation is needed to address future demands of raising seedlings that can be planted out in any wet season of the year.

The two experiments remained in operation for only 100 days, therefore, the results cannot be projected beyond certain reasonable time frame. The period was, however, enough to put the hypotheses to test. In light of the findings of these two experiments it is summarized with respect to my initial hypotheses as follows:

1. With increase in level of N from 0 to 100 ppm, there was increase in all growth parameters in seedlings without P. This increase continued till 200 ppm was added in case of seedlings supplied with P.

2. Growth response of seedlings without P was maximum at 100 ppm N level while in seedlings with P, it was maximum at 200 ppm N level.

3. Seedlings with P grew bigger than seedlings without P at N level of 100 ppm (D_5) and higher.

4. Bigger volume containers produced bigger seedlings.

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APPENDICES

APPENDIX 1

TREATMENT MEANS FOR SHOOT LENGTH (cm)

Means in the same column with the same letters are not significantly different at $P < 0.05$

Treatments	Late summer	Early fall	Mid-fall
1 N_0 P_0	8.8 ± 0.3^{e}	9.5 ± 0.3^{e}	8.7 ± 0.3^{g}
2 N_{100} P_0 D_5	$18.1\pm1.9^{c,d}$	$20.0\pm0.4^{b,c}$	$19.6\pm1.3^{d,e}$
3 N_{100} P_0 D_{10}	$18.7\pm1.5^{c,d}$	21.6 ± 1.8^{b}	$18.7\pm1.9^{d,e,f}$
4 N_{200} P_0 D_5	$17.4\pm1.3^{c,d}$	$17.9\pm1.0^{c,d}$	$19.7\pm2.3^{d,e}$
5 N_{200} P_0 D_{10}	$17.4\pm1.8^{c,d}$	$20.6\pm1.6^{b,c}$	15.7 ± 0.7^{f}
6 N_{400} P_0 D_5	15.9 ± 0.1^{d}	16.0 ± 1.3^{d}	$17.7\pm0.7^{e,f}$
7 N_{400} P_0 D_{10}	$17.5\pm1.4^{c,d}$	16.7 ± 1.7^{d}	$18.0\pm0.6^{e,f}$
8 N_{100} P_{50} D_5	23.2 ± 2.0^{a}	25.1 ± 0.5^{a}	$25.7\pm0.3^{a,b}$
9 N_{100} P_{50} D_{10}	$19.5\pm1.6^{b,c}$	$20.5\pm0.5^{b,c}$	$21.7\pm2.4^{c,d}$
10 N_{200} P_{50} D_5	25.0 ± 1.5^{a}	26.6 ± 1.5^{a}	$26.0\pm0.0^{a,b}$
11 N_{200} P_{50} D_{10}	24.7 ± 2.0^{a}	25.2 ± 1.7^{a}	$23.0\pm2.3^{b,c}$
12 N_{400} P_{50} D_5	25.4 ± 2.0^{a}	25.4 ± 1.9^{a}	26.3 ± 1.5^{a}
13 N_{400} P_{50} D_{10}	$22.5\pm2.4^{a,b}$	28.0 ± 1.8^{a}	$25.3\pm2.2^{a,b}$
14 N_0 P_{50}	10.0 ± 1.3^{e}	8.7 ± 0.5^{e}	7.3 ± 0.9^{g}

APPENDIX 2

TREATMENT MEANS FOR DIAMETER (mm)

Means in the same column with the same letters are not significantly different at $P < 0.05$

Treatments	Late summer	Early fall	Mid-fall
1 N_0 P_0	1.11 ± 0.12^{f}	1.41 ± 0.04^{g}	1.13 ± 0.03^{f}
2 N_{100} P_0 D_5	$1.79\pm0.07^{b,c,d}$	$3.42\pm0.23^{c,d,e}$	$3.87\pm0.22^{b,c}$
3 N_{100} P_0 D_{10}	$1.65\pm0.08^{c,d,e}$	$3.55\pm0.09^{b,c,d,e,f}$	3.37 ± 0.32^{d}
4 N_{200} P_0 D_5	$1.89\pm0.16^{a,b,c,d}$	$3.43\pm0.11^{c,d,e,f}$	$4.00\pm0.23^{a,b,c}$
5 N_{200} P_0 D_{10}	$1.59\pm0.15^{d,e}$	$3.64\pm0.26^{a,b,c,d,e}$	3.23 ± 0.15^{d}
6 N_{400} P_0 D_5	$1.92\pm0.18^{a,b,c,d}$	3.13 ± 0.21^{f}	$3.57\pm0.19^{c,d}$
7 N_{400} P_0 D_{10}	$1.89\pm0.87^{a,b,c,d}$	$3.28\pm0.22^{d,e,f}$	$3.53\pm0.07^{c,d}$
8 N_{100} P_{50} D_5	$1.96\pm0.03^{a,b,c}$	$3.93\pm0.16^{a,b}$	$4.23\pm0.26^{a,b}$
9 N_{100} P_{50} D_{10}	$1.63\pm0.09^{c,d,e}$	$3.24\pm0.11^{e,f}$	$3.93\pm0.09^{a,b,c}$
10 N_{200} P_{50} D_5	$2.02\pm0.16^{a,b}$	$3.87\pm0.08^{a,b,c}$	$4.13\pm0.15^{a,b}$
11 N_{200} P_{50} D_{10}	$1.98\pm0.15^{a,b,c}$	$3.71\pm0.10^{a,b,c,d}$	$4.13\pm0.20^{a,b}$
12 N_{400} P_{50} D_5	2.20 ± 0.24^{a}	$3.94\pm0.29^{a,b}$	4.40 ± 0.15^{a}
13 N_{400} P_{50} D_{10}	$2.05\pm0.05^{a,b}$	4.06 ± 0.20^{a}	$3.87\pm0.15^{b,c}$
14 N_0 P_{50}	$1.39\pm0.03^{e,f}$	1.37 ± 0.04^{g}	1.70 ± 0.10^{e}

APPENDIX 3

TREATMENT MEANS FOR LEAF AREA $(cm)^3$

Means in the same column with the same letters are not significantly different at $P < 0.05$

Treatment		Late summer	Early fall	Mid-fall
1	N_0 P_0	4.3±0.2[c]	3.6±0.9[d]	1.1±0.3[g]
2	N_{100} P_0 D_5	55.2±13.4[b]	66.6±7.5[b,c]	55.0±13.5[d]
3	N_{100} P_0 D_{10}	48.8±4.7[b]	69.4±3.4[b,c]	25.0±6.7[e,f]
4	N_{200} P_0 D_5	48.4±7.1[b]	50.8±7.5[b,c]	59.2±9.2[c,d]
5	N_{200} P_0 D_{10}	47.1±9.8[b]	72.2±13.4[b]	22.7±5.0[f,g]
6	N_{400} P_0 D_5	45.8±3.8[b]	40.3±8.2[c]	50.4±6.1[d]
7	N_{400} P_0 D_{10}	51.2±9.6[b]	49.2±12.2[b,c]	46.6±11.1[d,e]
8	N_{100} P_{50} D_5	89.3±13.3[a]	120.1±13.1[a]	64.5±12.1[c,d]
9	N_{100} P_{50} D_{10}	47.1±5.4[b]	56.3±8.6[b,c]	49.3±6.7[d]
10	N_{200} P_{50} D_5	109.0±22.8[a]	129.2±9.2[a]	81.0±7.2[b,c]
11	N_{200} P_{50} D_{10}	94.8±15.8[a]	110.8±13.9[a]	87.0±14.3[b]
12	N_{400} P_{50} D_5	111.2±19.3[a]	115.5±15.3[a]	119.0±11.8[a]
13	N_{400} P_{50} D_{10}	97.2±18.7[a]	132.3±21.1[a]	56.7±5.2[d]
14	N_0 P_{50}	5.7±1.8[c]	1.9±0.1[d]	2.6±1.4[g]

APPENDIX 4

TREATMENT MEANS FOR LEAF WEIGHT (gm)

Means in the same column with the same letters are not significantly different at $P < 0.05$

Treatment		Late summer	Early fall	Mid-fall
1	N_0 P_0	0.016±0.002[e]	0.001±0.003[c]	0.007±0.001[f]
2	N_{100} P_0 D_5	0.185±0.048[c,d,e]	0.227±0.026[b]	0.177±0.048[c,d]
3	N_{100} P_0 D_{10}	0.136±0.009[e]	0.225±0.010[b]	0.072±0.010[e,f]
4	N_{200} P_0 D_5	0.143±0.012[d,e]	0.175±0.023[b]	0.210±0.025[b,c,d]
5	N_{200} P_0 D_{10}	0.138±0.023[e]	0.223±0.030[b]	0.081±0.014[e]
6	N_{400} P_0 D_5	0.162±0.019[c,d,e]	0.173±0.037[b]	0.192±0.022[c,d]
7	N_{400} P_0 D_{10}	0.146±0.016[d,e]	0.165±0.036[b]	0.156±0.026[d]
8	N_{100} P_{50} D_5	0.225±0.020[b,c,d]	0.345±0.055[a]	0.198±0.039[b,c,d]
9	N_{100} P_{50} D_{10}	0.128±0.009[e]	0.172±0.027[b]	0.140±0.007[d,e]
10	N_{200} P_{50} D_5	0.298±0.060[a,b]	0.427±0.032[a]	0.247±0.019[b,c]
11	N_{200} P_{50} D_{10}	0.238±0.040[a,b,c]	0.365±0.032[a]	0.268±0.053[b]
12	N_{400} P_{50} D_5	0.310±0.038[a]	0.409±0.052[a]	0.394±0.029[a]
13	N_{400} P_{50} D_{10}	0.236±0.054[a,b,c]	0.413±0.092[a]	0.178±0.023[c,d]
14	N_0 P_{50}	0.023±0.010[f]	0.007±0.001[c]	0.010±0.003[f]

APPENDIX 7
TREATMENT MEANS FOR ROOT DEPTH (cm)
Means in the same column with the same letters are not significantly different at $P < 0.05$

Treatments		Late summer	Early fall	Mid-fall
1	N_0 P_0	16.5 ± 1.3^{e}	16.4 ± 1.5^{b}	17.7 ± 0.7^{c}
2	N_{100} P_0 D_5	22.4 ± 0.3^{a}	20.1 ± 0.9^{a}	20.7 ± 0.7^{a}
3	N_{100} P_0 D_{10}	$20.4\pm0.8^{a,b,c,d}$	20.0 ± 0.4^{a}	20.7 ± 0.3^{a}
4	N_{200} P_0 D_5	$21.0\pm0.8^{a,b}$	20.2 ± 0.3^{a}	21.0 ± 0.6^{a}
5	N_{200} P_0 D_{10}	$19.1\pm1.1^{b,c,d,e}$	20.6 ± 0.3^{a}	20.3 ± 0.3^{a}
6	N_{400} P_0 D_5	$20.5\pm1.1^{a,b,c}$	19.7 ± 0.7^{a}	20.3 ± 0.3^{a}
7	N_{400} P_0 D_{10}	$21.0\pm0.4^{a,b}$	20.9 ± 0.2^{a}	20.0 ± 0.0^{a}
8	N_{100} P_{50} D_5	$18.8\pm1.2^{b,c,d,e}$	19.6 ± 0.2^{a}	$19.7\pm0.3^{a,b}$
9	N_{100} P_{50} D_{10}	$17.7\pm0.1^{c,d,e}$	19.9 ± 0.7^{a}	$19.3\pm0.3^{a,b,c}$
10	N_{200} P_{50} D_5	$20.2\pm1.4^{a,b,c,d}$	20.2 ± 0.3^{a}	20.0 ± 0.0^{a}
11	N_{200} P_{50} D_{10}	$17.6\pm1.4^{d,e}$	19.7 ± 0.4^{a}	$19.3\pm0.3^{a,b,c}$
12	N_{400} P_{50} D_5	$21.0\pm0.3^{a,b}$	20.3 ± 0.3^{a}	20.7 ± 0.3^{a}
13	N_{400} P_{50} D_{10}	$18.6\pm0.3^{b,c,d,e}$	20.4 ± 0.4^{a}	$19.7\pm0.3^{a,b}$
14	N_0 P_{50}	17.0 ± 1.6^{e}	16.8 ± 0.9^{b}	18.0 ± 1.5^{c}

APPENDIX 8
TREATMENT MEANS FOR ROOT WEIGHT (gm)
Means in the same column with the same letters are not significantly different at $P < 0.05$

Treatment		Late summer	Early fall	Mid-fall
1	N_0 P_0	0.020 ± 0.002^{d}	0.021 ± 0.005^{e}	0.015 ± 0.003^{f}
2	N_{100} P_0 D_5	$0.067\pm0.010^{a,b}$	$0.347\pm0.060^{b,c,d}$	$0.462\pm0.062^{c,d,e}$
3	N_{100} P_0 D_{10}	$0.043\pm0.004^{b,c,d}$	$0.334\pm0.012^{c,d}$	$0.372\pm0.140^{d,e}$
4	N_{200} P_0 D_5	$0.055\pm0.007^{a,b}$	0.275 ± 0.026^{d}	$0.458\pm0.042^{d,e}$
5	N_{200} P_0 D_{10}	$0.044\pm0.009^{b,c,d}$	$0.367\pm0.090^{b,c,d}$	$0.253\pm0.054^{e,f}$
6	N_{400} P_0 D_5	$0.059\pm0.011^{a,b}$	0.225 ± 0.039^{d}	$0.489\pm0.010^{b,c,d,e}$
7	N_{400} P_0 D_{10}	$0.049\pm0.007^{b,c,d}$	0.245 ± 0.053^{d}	$0.444\pm0.132^{d,e}$
8	N_{100} P_{50} D_5	$0.051\pm0.005^{b,c}$	0.529 ± 0.010^{a}	$0.698\pm0.173^{a,b,c}$
9	N_{100} P_{50} D_{10}	$0.037\pm0.003^{b,c,d}$	0.263 ± 0.039^{d}	$0.432\pm0.048^{d,e}$
10	N_{200} P_{50} D_5	0.082 ± 0.029^{a}	0.586 ± 0.048^{a}	$0.721\pm0.058^{a,b}$
11	N_{200} P_{50} D_{10}	$0.054\pm0.010^{a,b}$	0.525 ± 0.066^{a}	0.758 ± 0.173^{a}
12	N_{400} P_{50} D_5	0.081 ± 0.016^{a}	$0.497\pm0.072^{a,b}$	0.801 ± 0.091^{a}
13	N_{400} P_{50} D_{10}	$0.064\pm0.010^{a,b}$	$0.485\pm0.067^{a,b,c}$	$0.577\pm0.037^{a,b,c,d}$
14	N_0 P_{50}	0.021 ± 0.003^{d}	0.012 ± 0.001^{e}	0.032 ± 0.014^{f}

APPENDIX 9

TREATMENT MEANS FOR TOTAL DRY WEIGHT (gm)

Means in the same column with the same letters are not significantly different at P < 0.05

Treatment		Late summer	Early fall	Mid-fall
1	N_0 P_0	0.050 ± 0.006^{d}	0.044 ± 0.010^{e}	0.034 ± 0.00^{f}
2	N_{100} P_0 D_5	$0.300 \pm 0.066^{a,b}$	$0.735 \pm 0.106^{b,c,d}$	$0.805 \pm 0.095^{c,d,e}$
3	N_{100} P_0 D_{10}	$0.221 \pm 0.017^{b,c,d}$	$0.727 \pm 0.006^{c,d}$	$0.600 \pm 0.179^{d,e}$
4	N_{200} P_0 D_5	$0.246 \pm 0.014^{a,b}$	0.575 ± 0.046^{d}	$0.854 \pm 0.081^{d,e}$
5	N_{200} P_0 D_{10}	$0.218 \pm 0.036^{b,c,d}$	$0.761 \pm 0.136^{b,c,d}$	$0.444 \pm 0.057^{e,f}$
6	N_{400} P_0 D_5	$0.263 \pm 0.035^{a,b}$	0.505 ± 0.088^{d}	$0.831 \pm 0.140^{b,c,d,e}$
7	N_{400} P_0 D_{10}	$0.227 \pm 0.026^{b,c,d}$	0.524 ± 0.108^{d}	$0.755 \pm 0.133^{d,e}$
8	N_{100} P_{50} D_5	$0.335 \pm 0.035^{b,c}$	1.146 ± 0.086^{a}	$1.187 \pm 0.237^{a,b,c}$
9	N_{100} P_{50} D_{10}	$0.207 \pm 0.014^{b,c,d}$	0.571 ± 0.065^{d}	$0.752 \pm 0.077^{d,e}$
10	N_{200} P_{50} D_5	0.475 ± 0.114^{a}	1.314 ± 0.046^{a}	$1.273 \pm 0.045^{a,b}$
11	N_{200} P_{50} D_{10}	$0.371 \pm 0.061^{a,b}$	1.151 ± 0.122^{a}	1.343 ± 0.292^{a}
12	N_{400} P_{50} D_5	0.494 ± 0.068^{a}	$1.191 \pm 0.151^{a,b}$	1.543 ± 0.158^{a}
13	N_{400} P_{50} D_{10}	$0.371 \pm 0.078^{a,b}$	$1.192 \pm 0.204^{a,b,c}$	$1.027 \pm 0.092^{a,b,c,d}$
14	N_0 P_{50}	0.065 ± 0.013^{d}	0.027 ± 0.003^{e}	0.057 ± 0.019^{f}

APPENDIX 10

TREATMENT MEANS FOR SHOOT ROOT RATIO

Means in the same column with the same letters are not significantly different at P < 0.05

Treatment		Late summer	Early fall	Mid-fall
1	N_0 P_0	1.394^{e}	1.126^{c}	1.390^{a}
2	N_{100} P_0 D_5	$3.402^{c,d}$	1.141^{c}	0.764^{b}
3	N_{100} P_0 D_{10}	$4.209^{b,c}$	$1.184^{a,b,c}$	0.704^{b}
4	N_{200} P_0 D_5	3.593^{c}	1.096^{c}	0.865^{b}
5	N_{200} P_0 D_{10}	$4.033^{b,c}$	1.140^{c}	0.834^{b}
6	N_{400} P_0 D_5	3.547^{c}	$1.246^{a,b,c}$	0.742^{b}
7	N_{400} P_0 D_{10}	$3.802^{b,c}$	$1.157^{b,c}$	0.718^{b}
8	N_{100} P_{50} D_5	5.666^{a}	$1.209^{a,b,c}$	0.750^{b}
9	N_{100} P_{50} D_{10}	$4.753^{a,b,c}$	$1.204^{a,b,c}$	0.746^{b}
10	N_{200} P_{50} D_5	$5.242^{a,b}$	$1.244^{a,b,c}$	0.779^{b}
11	N_{200} P_{50} D_{10}	6.104^{a}	$1.205^{a,b,c}$	0.788^{b}
12	N_{400} P_{50} D_5	$5.302^{a,b}$	$1.408^{a,b}$	0.932^{b}
13	N_{400} P_{50} D_{10}	$4.735^{a,b,c}$	1.436^{a}	0.767^{b}
14	N_0 P_{50}	$1.738^{d,e}$	$1.220^{a,b,c}$	0.972^{b}

APPENDIX 11

TREATMENT MEANS FOR NUMBER OF NODULES

Means in the same column with the same letters are not significantly different at P < 0.05

Treatment		Late summer	Early fall	Mid-fall
1	N_0 P_0	1.07±0.35[a,b,c]	2.53±0.29[a,b]	2.00±0.58[a,b]
2	N_{100} P_0 D_5	1.00±0.42[a,b,c]	2.33±0.71[a,b]	1.17±0.60[a,b]
3	N_{100} P_0 D_{10}	0.60±0.12[b,c]	2.20±0.78[a,b,c,d]	2.67±2.18[a,b]
4	N_{200} P_0 D_5	0.27±0.27[c]	0.40±0.40[d,e]	0.17±0.07[b]
5	N_{200} P_0 D_{10}	0.27±0.27[c]	0.60±0.12[c,d,e]	0.50±0.29[a,b]
6	N_{400} P_0 D_5	0.07±0.07[c]	0.07±0.07[e]	0.08±0.08[b]
7	N_{400} P_0 D_{10}	0.07±0.07[c]	0.00 [e]	0.38±0.06[a,b]
8	N_{100} P_{50} D_5	0.53±0.24[c]	1.60±0.81[b,c,d,e]	0.67±0.17[a,b]
9	N_{100} P_{50} D_{10}	1.8±0.50[a,b]	3.73±1.10[a]	3.67±1.67[a]
10	N_{200} P_{50} D_5	0.27±0.27[c]	0.40±0.40[d,e]	0.08±0.08[b]
11	N_{200} P_{50} D_{10}	0.80±0.70[b,c]	0.47±0.07[d,e]	1.17±0.17[a,b]
12	N_{400} P_{50} D_5	0.00 [c]	0.07±0.07[e]	0.00 [c]
13	N_{400} P_{50} D_{10}	0.00 [c]	0.20±0.12[e]	0.36±.07[a,b]
14	N_0 P_{50}	2.07±0.73[a]	2.20±0.90[a,b,c,d]	2.50±1.53[a,b]

APPENDIX 12

PERCENTAGE OF NITROGEN AND PHOSPHORUS IN LEAF, STEM AND ROOT OF 100 DAYS OLD BLACK LOCUST SEEDLINGS

Treatment		Leaf		Stem		Root	
		N%	P%	N%	P%	N%	P%
1	N_0 P_0	2.167	0.461	2.279	0.386	2.267	0.299
2	N_{100} P_0 D_5	2.845	0.105	3.947	0.163	3.899	0.134
3	N_{100} P_0 D_{10}	1.995	0.060	3.132	0.141	1.428	0.022
4	N_{200} P_0 D_5	2.302	0.035	4.325	0.190	4.534	0.194
5	N_{200} P_0 D_{10}	2.516	0.095	3.941	0.152	4.343	0.141
6	N_{400} P_0 D_5	4.289	0.146	4.895	0.212	4.689	0.180
7	N_{400} P_0 D_{10}	3.217	0.100	4.611	0.156	4.163	0.144
8	N_{100} P_{50} D_5	2.456	0.080	3.439	0.149	4.187	0.138
9	N_{100} P_{50} D_{10}	2.140	0.083	3.154	0.144	2.979	0.148
10	N_{200} P_{50} D_5	2.690	0.117	4.003	0.170	4.593	0.168
11	N_{200} P_{50} D_{10}	2.975	0.071	3.865	0.169	4.339	0.139
12	N_{400} P_{50} D_5	4.086	0.133	4.394	0.176	4.676	0.172
13	N_{400} P_{50} D_{10}	2.863	0.096	3.933	0.161	3.204	0.151
14	N_0 P_{50}	2.512	0.502	2.318	0.140	2.574	0.496

APPENDIX 13

TREATMENT MEANS FOR SHOOT LENGTH (cm)
Means in the same column with the same letters are not significantly different at $P < 0.05$

Type of container	Late summer	Mid-fall
Spencer-Lemaire	8.9 ± 1.3^{b}	8.4 ± 0.4^{c}
Ray Leach	8.7 ± 0.7^{b}	11.5 ± 0.8^{b}
Deepot	$11.0 \pm 1.0^{a,b}$	14.7 ± 1.0^{a}
Polythene bag	13.2 ± 0.9^{a}	$13.1 \pm 0.9^{a,b}$

APPENDIX 14

TREATMENT MEANS FOR DIAMETER (mm)
Means in the same column with the same letters are not significantly different at $P < 0.05$

Type of container	Late summer	Mid-fall
Spencer-Lemaire	1.10 ± 0.04^{b}	1.13 ± 0.05^{b}
Ray Leach	1.08 ± 0.10^{b}	1.68 ± 0.22^{a}
Deepot	1.10 ± 0.04^{b}	2.18 ± 0.19^{a}
Polythene bag	1.33 ± 0.09^{a}	2.25 ± 0.23^{a}

APPENDIX 15

TREATMENT MEANS FOR LEAF AREA $(cm)^2$
Means in the same column with the same letters are not significantly different at $P < 0.05$

Type of container	Late summer	Mid-fall
Spencer-Lemaire	2.07 ± 0.88^{b}	1.49 ± 0.40^{c}
Ray Leach	2.77 ± 0.31^{b}	$8.76 \pm 2.10^{b,c}$
Deepot	$4.43 \pm 1.21^{a,b}$	19.20 ± 4.17^{a}
Polythene bags	8.66 ± 2.02^{a}	$17.43 \pm 3.38^{a,b}$

APPENDIX 16

TREATMENT MEANS FOR LEAF WEIGHT (gm)

Means in the same column with the same letters are not significant atly different P < 0.05

Type of container	Late summer	Mid-fall
Spencer-Lemaire	0.013 ± 0.002^{b}	0.006 ± 0.000^{c}
Ray Leach	0.018 ± 0.001^{b}	$0.022\pm0.004^{b,c}$
Deepot	0.022 ± 0.003^{b}	0.050 ± 0.008^{a}
Polythene bags	0.044 ± 0.010^{a}	$0.038\pm0.006^{a,b}$

APPENDIX 17

TREATMENT MEANS FOR STEM WEIGHT (gm)

Means in the same column with the same letters are not significantly different at P < 0.05

Type of container	Late summer	Mid-fall
Spencer-Lemaire	0.013 ± 0.002^{a}	0.010 ± 0.001^{c}
Ray Leach	0.015 ± 0.002^{a}	$0.047\pm0.013^{b,c}$
Deepot	0.022 ± 0.003^{a}	0.061 ± 0.014^{a}
Polythene bags	0.022 ± 0.003^{a}	$0.054\pm0.009^{a,b}$

APPENDIX 18

TREATMENT MEANS FOR SHOOT WEIGHT (gm)

Means in the same column with the same letters are not significantly different at P < 0.05

Type of container	Late summer	Mid-fall
Spencer-Lemaire	0.027 ± 0.003^{b}	0.016 ± 0.001^{c}
Ray Leach	0.032 ± 0.002^{b}	$0.069\pm0.013^{b,c}$
Deepot	$0.044\pm0.005^{a,b}$	0.111 ± 0.022^{a}
Polythene bags	0.066 ± 0.014^{a}	$0.092\pm0.016^{a,b}$

APPENDIX 19
TREATMENT MEANS FOR ROOT DEPTH (cm)
Means in the same column with the same letters are not significantly different at $P < 0.05$

Type of container	Late summer	Mid-fall
Spencer-Lemaire	13.2 ± 0.3^{b}	14.2 ± 0.3^{c}
Ray Leach	18.0 ± 0.6^{a}	17.9 ± 0.3^{b}
Deepot	19.6 ± 2.1^{a}	22.6 ± 0.8^{a}
Polythene bag	$16.6\pm0.3^{a,b}$	19.7 ± 0.9^{b}

APPENDIX 20
TREATMENT MEANS FOR ROOT WEIGHT (gm)
Means in the same column with the same letters are not significantly different at $P < 0.05$

Type of container	Late summer	Mid-fall
Spencer-Lemaire	0.022 ± 0.003^{b}	0.021 ± 0.004^{b}
Ray Leach	$0.027\pm0.003^{a,b}$	$0.082\pm0.011^{a,b}$
Deepot	$0.028\pm0.004^{a,b}$	0.161 ± 0.056^{a}
Polythene bags	0.034 ± 0.003^{a}	0.124 ± 0.029^{a}

APPENDIX 21
TREATMENT MEANS FOR NODULES
Means in the same column with the same letters are not significantly different at $P < 0.05$

Type of container	Late summer	Mid-fall
Spencer-Lemaire	0.45 ± 0.45^{b}	0.35 ± 0.21^{c}
Ray Leach	$0.78\pm0.44^{a,b}$	$1.13\pm0.35^{b,c}$
Deepot	$1.70\pm1.14^{a,b}$	$3.00\pm1.03^{a,b}$
Polythene bag	2.85 ± 0.86^{a}	4.13 ± 1.07^{a}

APPENDIX 22
TREATMENT MEANS FOR TOTAL DRY WEIGHT
Means in the same column with the same letters are not significantly different at $P < 0.05$

Type of container	Late summer	Mid-fall
Spencer-Lemaire	0.048 ± 0.004^{b}	0.037 ± 0.005^{c}
Ray Leach	$0.059 \pm 0.003^{a,b}$	$0.151 \pm 0.020^{b,c}$
Deepot	$0.072 \pm 0.009^{a,b}$	$0.271 \pm 0.078^{a,b}$
Polythene bag	0.100 ± 0.017^{a}	0.217 ± 0.045^{a}

APPENDIX 23
TREATMENT MEANS FOR SHOOT TO ROOT RATIO
Means in the same column with the same letters are not significantly different at $P < 0.05$

Type of container	Late summer	Mid-fall
Spencer-Lemaire	1.33	0.68
Ray leach	1.25	0.66
Deepot	1.59	0.75
Polythene bag	1.89	0.80