Seedling Development of Chicory and Plantain

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ABSTRACT

Chicory (*Cichorium intybus* L.) and plantain (*Plantago lanceolata* L.) are perennial herbs for pastures. Knowledge of growth and development of these species is needed to develop appropriate management practices. We compared growth and development of chicory and plantain during establishment in growth chamber, greenhouse, and field studies. 'Grasslands Puna', 'La Certa', and 'Forage Feast' chicory and 'Ceres Tonic' and 'Grasslands Lancelot' plantain seedlings were destructively sampled weekly for 7 wk in the growth chamber and greenhouse beginning 8 to10 days after planting (DAP). The number and mass of leaves and roots (primary, lateral, basal, and adventitious; growth chamber only) were recorded. In the field, leaf development was measured during spring and fall of 1997, whereas leaf and root development were measured during spring of 1999. Puna chicory developed a larger root mass than plantains, whereas plantains had greater root length than chicory. Plantains developed 8 to 10 adventitious roots on the hypocotyl, but the chicory cultivars developed only one or two. Plantain and chicory developed only one or two basal roots per plant. Primary and lateral roots dominated the root systems of both species. Leaf development in fall 1997 was slower than in spring with only two leaves forming on each species by 49 DAP in fall compared with six to seven leaves during spring in the field. Across environments (except fall), seedlings developed three to four leaves by 40 to 50 DAP. Our data suggest that development of three to four leaves is required for successful establishment of chicory and plantain seedlings.

PERENNIAL cool-season grasses predominate in the pastures and haylands of the northeastern USA (Baylor and Vough, 1985). Growth of these grasses follows the well-known bimodal distribution of rapid growth in late May and early June and a *summer slump* during July, August, and early September. Farmers would like forage crops to fill in the *summer slump* period and to extend the grazing period in the fall. Grasslands Puna chicory has been investigated as an alternative pasture herb because of reported drought tolerance and production in summer (Collins and McCoy, 1997; Jung et al., 1996; Li et al., 1997; Volesky, 1996). It has high digestibility and a low fiber concentration, which are desirable for growing and lactating ruminants (Turner et al., 1999). Newer varieties of chicory are now available, but information on their use and productivity is limited.

Plantain (buckhorn plantain, narrow leaf plantain, ribwort, ribgrass) commonly occurs as an occasional weed in temperate pastures (Grime et al., 1990). Older reports describe it as deep rooting, drought resistant, and a palatable pasture plant (Foster, 1988; Ivins, 1952; Sagar and Harper, 1964). Recently, domesticated cultivars of plantain have been selected for pasture production in New Zealand (Rumball et al., 1997; Stewart, 1996). The ecology of natural populations of plantain and its biology as a weed have been researched (Kuiper and Bos, 1992; Bassett, 1973). Apart from older reports in the scientific literature, the forage value of plantain is relatively unknown.

The concept of complex pasture plant mixtures, or *herbal leys*, has received renewed attention. In New Zealand, pastures seeded to a complex mixture of species (18 to 26 species consisting of cool-season grasses and legumes along with several pasture herbs including chicory and plantain) yielded more dry matter under sheep grazing than did simple perennial ryegrass (*Lolium perenne* L.)–white clover (*Trifolium repens* L.) mixtures (Ruz-Jerez et al., 1991; Daly et al., 1996). The increased production resulted from greater forage growth during the summer, contributed mainly by the forb component (mostly chicory). In Scotland, trials with several mixtures of forbs, grasses, and white clover under low-input management for hay production showed that plantain and chicory competed well with grasses (Fisher et al., 1996). Chicory and plantain are grown in monocultures for specialty pastures in New Zealand (Alan Stewart, Pyne Gould, Guiness LTD., personal communication, 1999). Research from North America indicates that chicory persists in mixtures with other cool-season forages and increases late season herbage production (Belesky et al., 1999; Kunelius and MacRae, 1999).

Establishing new pastures from seed is risky. Rapid development of leaf mass and area and establishment of a critical root mass and number are necessary to ensure seedling survival. Knowledge of the growth and development of new forages is necessary for developing appropriate management practices and in formulating potential species mixtures for pasture seedings. The objective of this research was to develop fundamental information on the growth and development of chicory and plantain during establishment.

MATERIALS AND METHODS

Greenhouse and Growth Chamber Trials

In the greenhouse, five seeds of Grasslands Puna chicory and Ceres Tonic and Grasslands Lancelot plantain were planted 1 cm deep in 5-cm diameter by 21-cm deep containers filled with potting soil (Scotts–Sierra Horticultural Products Co., Marysville, Ohio). Seedlings were thinned to one per container soon after emergence. Containers (105 of each entry) were planted on 24 Jan. 1997 and entries were grouped into five replicates with 21 containers of each entry per replicate. The experimental design was a randomized complete block. Beginning 10 DAP, three containers per replicate of each entry were sampled destructively each week for 7 wk. Temperature in the greenhouse varied from 23 to 41°C during

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Abbreviation: DAP, days after planting.

the day and 13 to 24°C at night. Relative humidity ranged from 10 (day) to 100% (night). Natural light was supplemented (but the natural daylength was not extended) with artificial light from 400-W lamps providing 260 μmol photosynthetic photon flux density (PPFD) $m^{-2}s^{-1}$ at plant height during the experiment. Red/farred light ratio of the supplemental light was 1.61 compared with 1.31 for natural light levels.

Grasslands Puna, La Certa, and Forage Feast chicory and Ceres Tonic and Grasslands Lancelot plantain were compared in the growth chamber. The same planting and establishment procedures were used for the growth chamber experiment, except that the 15 individual containers of each entry that were sampled each week were considered individual replicates. Because of the number of containers, three growth chambers were used and treatments were blocked by chambers and within chambers. Beginning 8 DAP on 9 Feb. 1998, 15 containers (replicates) of each entry were sampled destructively weekly for 7 wk. Temperatures in the growth chambers were maintained at 25°C during the day and 15°C during the night. Daylength was set at 16 h and relative humidity ranged from 50 to 70%. Light in the chambers was provided by a mixture of incandescent and fluorescent bulbs at 216 μmol photosynthetic photon flux density (PPFD) m^{-2} s^{-1} with a red/farred light ratio of 1.6. Plants were watered daily in both experiments and no additional nutrients were added.

At each destructive sampling in each experiment, the number of leaves per plant were counted, plants were removed from the container, and the soil was washed from the roots in cold running water. Root length was measured from the cotyledonary node to the tip of the longest root. Shoots and roots were separated at the cotyledon node and dried at 55°C for 48 h to determine dry weight. For the growth chamber trial, roots were classified as primary (taproot), lateral, basal, or adventitious as described by Stofella et al. (1979) and Zobel (1991) and the number of roots in each category were counted and recorded. The primary root is the first root to emerge from the seed. Lateral roots arise from pre-existing roots and develop from the pericycle. In our study, lateral roots occurred only on the primary root. Basal roots arise from the transition area between the junction of the hypocotyl and the primary root. Adventitious roots arise from nonroot tissue or from nonpericyclic tissue on older roots. In our study, adventitious roots occurred on the hypocotyl above the basal roots and just below the soil surface.

The greenhouse experiment was analyzed as a randomized complete block design with five replicates (averages of three containers per replicate). Separate analyses of variance were conducted for each sampling date. Preplanned orthogonal comparisons were used to compare treatment means at each sampling date. The comparisons were (i) Puna chicory vs. the average of Tonic and Lancelot plantain and (ii) Tonic vs. Lancelot. The growth chamber experiment was analyzed as a randomized complete block. Separate analyses were conducted for each sampling date and preplanned orthogonal comparisons were used to compare treatment means. The comparisons were (i) the average of chicory vs. the average of plantain, (ii) Lancelot vs. Tonic, (iii) Puna vs. other chicory, and (iv) Forage Feast vs. La Certa chicory. In both experiments, least squares means along with the standard error were plotted against sampling date to illustrate seedling development.

Field Studies

Two field studies were conducted at the Russell E. Larson Agricultural Research Center near Rock Springs, PA to determine seedling developmental patterns. Soil at the site was a Hagerstown silt loam (fine, mixed, semiactive, mesic Typic Hapludalfs). Soil tests indicated a pH of 6.3, 59 kg ha^{-1} of available P, and 220 kg ha^{-1} of available K. No fertilizer was applied in 1997 or 1999. In the first field study in 1997, Tonic and Lancelot plantain and Puna, Forage Feast, and La Certa chicory were seeded with a plot drill in 5- by 6-m plots on 16 May in a clean tilled seedbed. Plantain was seeded at 11 kg ha^{-1} and chicory at 4.5 kg ha^{-1}. The seeding was repeated on 19 September on an adjacent site with the same species, cultivars, and cultural methods except that plot size was 2- by 3-m.

Seedling emergence was monitored weekly for both plantings. Seedlings in all plots had emerged by 28 May for the spring planting and 29 September for the fall planting. Thirty seedlings were selected at random in each plot at 21, 37, 47, 61, and 74 DAP for the spring seeding and 17, 24, 31, 35, 42, and 49 DAP for the fall seeding. The number of fully expanded leaves was counted on each selected seedling. The arithmetic average of the 30 observations per plot was calculated for the mean leaf development stage.

A second field study was planted on 28 Apr. 1999 with the same species and cultivars used in 1997. The field site was adjacent to the spring and fall 1997 plantings. Plot size and cultural methods were the same as for the fall 1997 planting. Seedlings had emerged in all plots by 8 May. Fifteen seedlings were dug to a 30-cm depth from each plot at 19, 26, 34, 47,

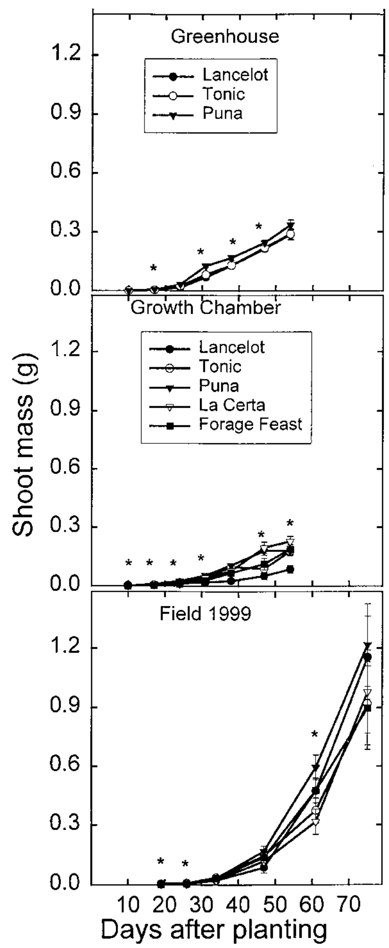

Fig. 1. Shoot mass of Tonic and Lancelot plantain and Puna, La Certa, and Forage Feast chicory in greenhouse, growth chamber, and field experiments. Individual data points are the least squares means ± standard error of 15 observations in each experiment. Asterisks indicate dates with significant differences among treatments.

and 75 DAP. The number of leaves per plant and shoot mass was determined at each harvest. Root length and mass were measured at 19, 34, and 75 DAP. Root type (primary, basal, adventitious, or lateral) and number were determined at 19 and 34 DAP. Only lateral roots were counted at 75 DAP.

The experimental design for each study was a randomized complete block with five blocks (replicates). Mean leaf number was regressed on DAP. Categorical terms were included in the model to test differences in regression parameters among cultivars. When a cultivar by regression parameter interaction was significant ($P < 0.05$), differences between pairs of cultivars were assessed by computing *P*-values for *t*-tests between all possible pairs and then adjusting the *P*-values to account for multiple comparisons. Adjustments were made with either the Tukey method, for intercepts, or the stepdown Sidak approach for linear and quadratic regression coefficients (SAS Institute, 1998). Data for root mass and number were analyzed by harvest date and preplanned orthogonal comparisons were used to compare treatment means. The comparisons were (i) the average of chicory vs. the average of plantain, (ii) Lancelot vs. Tonic, (iii) Puna vs. other chicory, and (iv) Forage Feast vs. La Certa chicory. Least squares means along with the standard error were plotted against sampling date to illustrate trends.

RESULTS AND DISCUSSION

Leaf Development

Chicory and plantain both had epigeal seedling emergence, meaning that the hypocotyl elongates during emergence and pulls the cotyledons and shoot apex above ground. Plantain produced two long (about 3 to 5 cm), narrow cotyledons that resembled emerging grass coleoptiles.

Puna chicory seedlings had a slightly greater ($P < 0.05$) shoot mass than Lancelot or Tonic plantain seedlings up to 47 DAP in the greenhouse, but not at the last two sampling dates (Fig. 1). In the growth chamber, Lancelot plantain seedlings had less ($P < 0.05$) shoot mass than other entries. The chicory cultivars did not differ ($P > 0.05$) in shoot mass in the growth chamber. Shoot mass of Tonic plantain was greater ($P < 0.05$) than Lancelot plantain at 19 and 26 DAP in the field during spring 1999, but cultivars did not differ after 26 DAP. The chicory and plantain cultivars did not differ ($P > 0.05$) in shoot mass at the end of the field experiment in spring 1999.

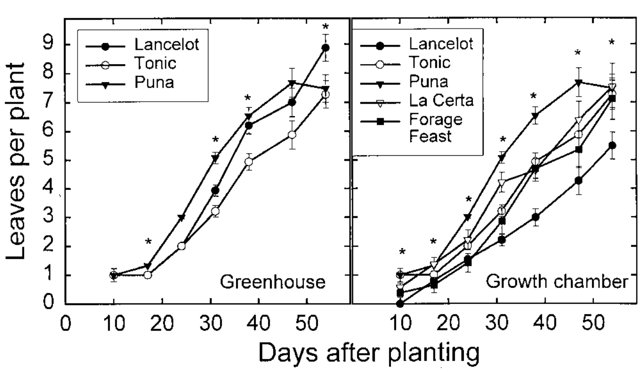

Fig. 2. Leaf development of Tonic and Lancelot plantain and Puna, La Certa, and Forage Feast chicory in greenhouse and growth chamber experiments. Individual data points are the least squares means ± standard error of 15 observations in each experiment. Asterisks indicate dates with significant differences among treatments.

Puna chicory and Lancelot plantain had more ($P < 0.05$) leaves per plant than Tonic plantain at early sample dates in the greenhouse and growth chamber (Fig. 2). Lancelot plantain developed the most ($P < 0.05$) leaves by the last date in the greenhouse and during spring 1999 in the field (Fig. 3), but not in the growth chamber. Puna chicory had more ($P < 0.05$) leaves than other entries at most sample dates in the growth chamber. All species and cultivars had developed three to four leaves by 30 to 40 DAP in the greenhouse and growth chamber.

Leaf development pattern of both species and cultivars in the field was similar in the spring and fall 1997 (Fig. 3a,b). During spring 1997, development was linear up to 65 DAP with no difference ($P > 0.05$) among species or cultivars. Seedlings developed six to seven

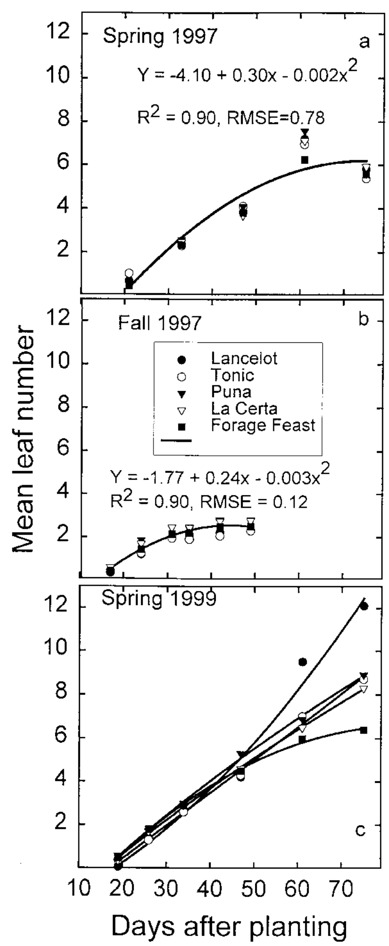

Fig. 3. Leaf development of Tonic and Lancelot plantain and Puna, La Certa, and Forage Feast chicory in field plots at Rock Springs, PA plotted against days after planting in spring (May to July; 3a), fall (September to November; 3b) 1997, and spring 1999 (May to July; 3c). Each data point is the mean of five replications. Regression lines and equations in spring and fall 1997 apply to all data. RMSE = root mean square error. Individual regression equations for spring 1999 were: Lancelot plantain, $Y = -2.68 + 0.115x + 0.001x^2$; Tonic plantain, $Y = -2.68 + 0.155x - 0.00003x^2$; Puna chicory, $Y = -2.68 + 0.181x - 0.0004x^2$; La Certa chicory, $Y = -2.68 + 0.173x - 0.0004x^2$; Forage Feast chicory, $Y = -2.68 + 0.198x - 0.001x^2$. For all equations, $R^2 = 0.99$ and RMSE = 0.39.

Table 1. Monthly rainfall and average temperature at Rock Springs, PA during 1997 and 1999.

Month	Air temperature			Rainfall		
	1997	1999	30-yr avg	1997	1999	30-yr avg
	°C			mm		
April	7.6	9.0	8.7	28	94	74
May	11.9	15.1	14.8	100	37	92
June	19.4	19.2	19.5	59	104	101
July	20.9	22.9	21.8	61	61	91
August	19.1		20.9	171		80
September	15.4		16.8	122		83
October	10.2		10.6	13		72
November	3.1		5.0	87		84

leaves per plant in spring 1997, which was similar to greenhouse results for Lancelot, Tonic, and Puna. Seedling leaf development in fall 1997 was curvilinear and much slower than in spring with only two leaves developing on any entry by 49 DAP (Fig. 3b). Species and cultivars did not differ ($P > 0.05$) in developmental rate. Mean temperature during the fall was much lower than in spring (Table 1), which along with decreasing daylengths may account for differences in leaf development between spring and fall. Total rainfall was similar in spring and fall. Visual observations of the plots in spring 1998 indicated that the fall-planted seedlings did not survive the winter, which suggests that seedlings need more than two fully expanded leaves for winter survival.

During spring 1999, leaf development of all entries was similar up to 50 DAP (Fig. 3c). Lancelot developed a greater number of leaves (12) in spring 1999 than spring (7 leaves) or fall (2 leaves) of 1997, possibly due to the higher temperatures in spring 1999 compared with 1997 (Table 1). Forage Feast had fewer ($P < 0.05$) leaves than other chicory cultivars at 75 DAP. All species and cultivars had developed three to four leaves by 40 to 50 DAP in spring of 1997 and 1999.

Root Development

In the greenhouse, Puna chicory had the greatest root mass ($P < 0.01$) at all but the first sample date (Fig. 4). Lancelot and Tonic plantain did not differ ($P > 0.05$) in root mass. Differences among entries were much smaller in the growth chamber than the greenhouse but the relative ranking of chicory and plantain was the same. Puna also had the greatest root mass ($P < 0.05$) in the field and all chicory cultivars had greater root mass than plantains at 74 DAP in spring 1999.

Puna chicory and Tonic plantain developed a longer root ($P < 0.01$) than Lancelot plantain by the third sampling date in the greenhouse (Fig. 4). The longest root of each entry had reached the bottom of the containers by about 38 DAP and root length did not change after that. Tonic had a greater ($P < 0.05$) root length than Lancelot plantain by the last sampling in the growth chamber and the field, whereas the chicory cultivars did not differ ($P > 0.05$) in root length.

Analysis of root types in the growth chamber and field revealed significant differences between species. The plantains developed several adventitious roots on the hypocotyl, whereas the chicory cultivars developed

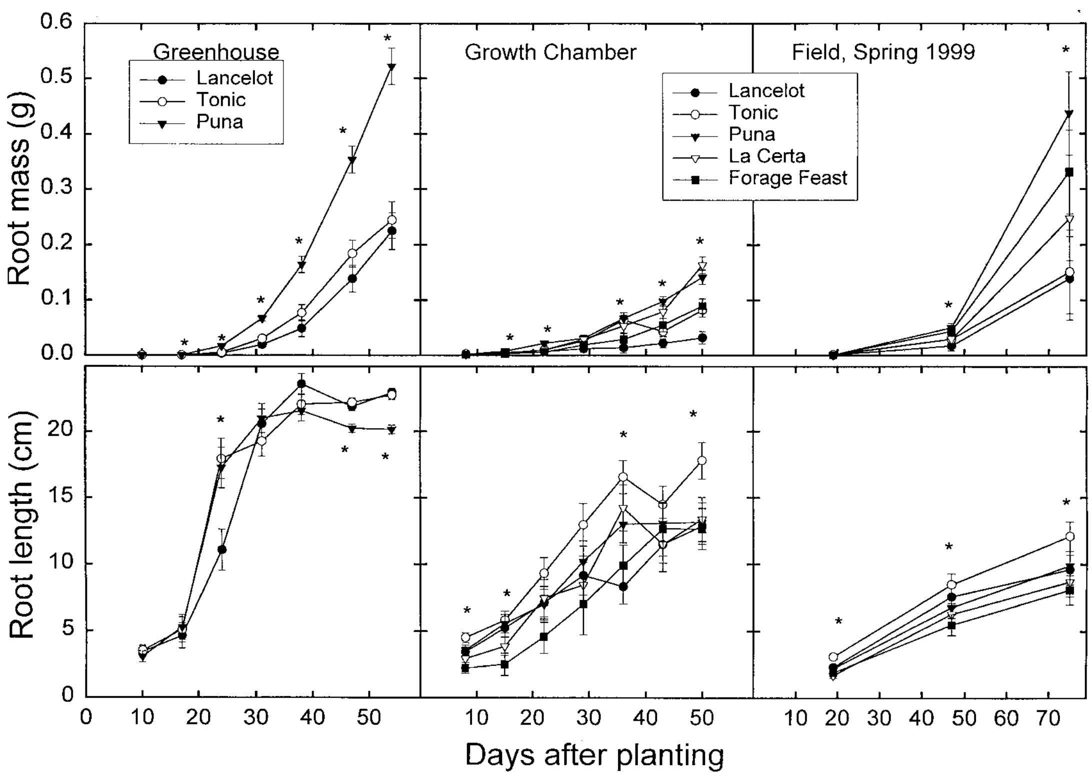

Fig. 4. Root development of Tonic and Lancelot plantain and Puna, La Certa, and Forage Feast chicory in greenhouse, growth chamber, and field experiments. Data for root length are for the longest single root. Individual data points are the least squares means ± standard error of 15 observations in each experiment. Asterisks indicate dates with significant differences among treatments.

only one or two adventitious roots during seedling development (Fig. 5). It is not clear if roots on the hypocotyl function in water or nutrient uptake or simply provide structural support for the seedling (Zobel, 1991). Only one to two basal roots developed on any cultivar or species.

The primary and lateral roots dominated the root system for each species. Chicory maintained a dominant primary root (primary root diameter averaged 4.7 mm in the growth chamber and 5.5 mm in the field) with many laterals during seedling development. The dominant primary root of chicory probably contributed to its greater root mass (Fig. 4). Plantain had a less dominant primary root (diameter averged 2.1 mm in the growth chamber and 3.1 mm in the field) than chicory and the lateral roots tended to form a more fibrous system. In natural populations of plantain, the primary root is replaced by a series of adventitious and lateral roots early in development (Sagar and Harper, 1964). In our experiment, the plantains developed more ($P < 0.05$) lateral roots than the chicorys during the first half of the growth chamber trial, but not in the latter half of the trial. Tonic plantain had more lateral roots than Lancelot, whereas the chicory cultivars did not differ ($P > 0.05$) in the number of lateral roots in the growth chamber. Species and cultivars did not differ ($P > 0.05$) in number of lateral roots at 34 DAP in the field. The primary and lateral roots in dicots are primarily responsible for water and nutrient uptake early in establishment (Zobel, 1991). Differences in root numbers, mass, and length may result in differences among species and cultivars in stress tolerance of the seedlings during establishment (Klepper, 1992).

There were differences among environments in plant growth and development. At about 50 DAP, shoot and root mass were lower and roots were longer in the greenhouse than in the growth chamber and field (Fig. 1 and 4). Differences in light levels, air temperature, and soil moisture probably accounted for these discrepancies. Light levels and temperatures were lower in the growth chamber than in the greenhouse. Plant containers were watered daily in the controlled environments, whereas the field experiments relied on natural rainfall.

The differences in seedling size among species and cultivars did not seem to be related to seed mass. Seed mass of Puna, La Certa, and Forage Feast chicory was 0.75, 1.19, and 1.57 mg seed^{-1}, respectively, whereas seed mass of Lancelot and Tonic plantain was 1.45 and

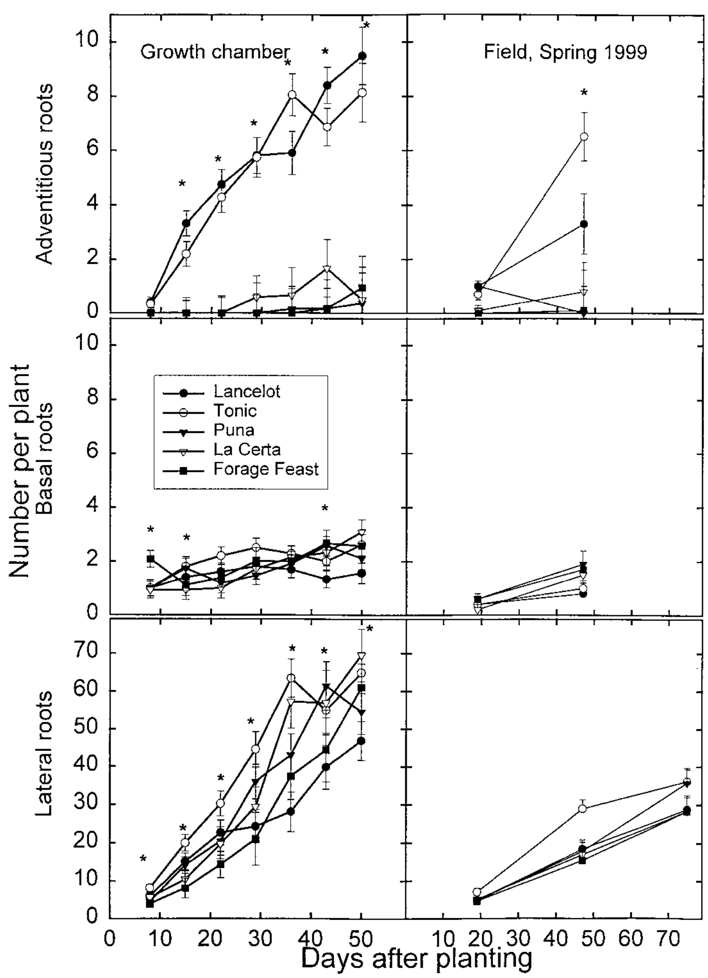

Fig. 5. Number of adventitious, basal, and lateral roots of Tonic and Lancelot plantain and Puna, La Certa, and Forage Feast chicory in the growth chamber and field. Individual data points are the least squares means ± standard error of 15 observations in each experiment. Asterisks indicate dates with significant differences among treatments.

2.19 mg seed^{-1}, respectively (averages of four replicate determinations on lots of 100 seed of each entry).

SUMMARY AND CONCLUSIONS

The chicory cultivars developed similarly in leaf number, shoot and root mass, and root morphology in the greenhouse, growth chamber, and field, indicating that the cultivars had similar establishment capabilities. The plantains differed among growth environments mainly for leaf number and shoot mass. Across environments, seedlings generally developed three to four leaves by 40 to 50 DAP. Root length and number were increasing rapidly during this time.

Perennial grasses are considered successfully established when four to six leaves and at least two adventitious roots have developed (Ries and Svejcar, 1991). We are not aware of similar establishment criteria for chicory and plantain. Our results showed that both chicory and plantain developed three to four leaves with a root system capable of supporting this leaf mass by 40 to 50 DAP in central Pennsylvania. Development was slower in the fall and a longer time would be required for seedlings to develop to this size in the fall.

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