Productivity of Forage Cultivars of Chicory and Plantain in the Northeast Region of the United States

A Thesis in Agronomy by María E. Labreveux

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ABSTRACT

Summer growth of cool season species in the Northeast USA is reduced due to a combination of high temperature and drought. This reduced growth generates an imbalance in the offer of forage, and the use of alternative species is presented as a solution. The objectives of these studies were to evaluate forage cultivars of chicory (Cichorium intybus L.) and plantain (Plantago lanceolata L.) for their annual as well as seasonal productivity and nutritive value when grown in the NE USA, and to evaluate physiological and morphological responses when subjected to water shortage or elevated temperatures. A first grazing experiment was carried out in 1998 evaluating several chicory and plantain cultivars. Chicory cultivars (Forage Feast, L.E. Lacerta, Grasslands Puna), plantain cultivars (Grasslands Lancelot and Ceres Tonic) and Pennlate orchardgrass were subjected to a combination of frequency (three or five-week rest period) and intensity (50 or 150-mm stubble height) of grazing. Puna chicory and Lancelot plantain had similar dry matter (DM) yields to Pennlate orchardgrass over spring (6511, 7357 and 7240 kg ha\(^{-1}\), respectively), whereas over the summer Puna chicory and Ceres Tonic plantain equaled the yield of Pennlate (3354, 3168, 3888 kg ha\(^{-1}\), respectively). Frequently grazed plots produced less DM during the summer than infrequently grazed plots (1669 vs. 4448 kg ha\(^{-1}\), \(p<0.001\)). However, herbage from frequently grazed plots exhibited higher crude protein (CP, 225 g kg\(^{-1}\)) and \textit{in vitro} true dry matter digestibility (IVTDMD, 890 g kg\(^{-1}\)) but similar neutral detergent (NDF, 348 g kg\(^{-1}\)) concentration than infrequently grazed plots (CP= 189 g kg\(^{-1}\), IVTDMD= 855 g kg\(^{-1}\), NDF= 374 g kg\(^{-1}\)). In 2000 and 2001, Puna chicory, Lancelot plantain and Pennlate orchardgrass were tested when subjected to a variable frequency of grazing during the summer. Spring yields of Puna chicory were higher than those of Pennlate orchardgrass (5740 vs. 3610 kg ha\(^{-1}\) - average over year-, respectively, \(p<0.05\)), whereas summer DM yield of Puna chicory was either higher (5362 vs. 2893 kg ha\(^{-1}\) for Puna chicory and Pennlate orchardgrass in 2000, respectively, \(P<0.05\)) or similar (3368 and 3605 kg ha\(^{-1}\) Puna chicory and Pennlate orchardgrass in 2001, respectively). Yield of Lancelot
plantain decreased greatly from 2000 to 2001 as a consequence of low plant survival, which was 25 percent of the initial stand by the end of the study. During the springs of 2000 and 2001, the CP concentration of Puna chicory, Lancelot plantain and Penllate orchardgrass were similar (174, 161 and 165 g kg⁻¹, respectively), whereas during the summers Puna chicory CP concentration was higher than that of Penllate orchardgrass and Lancelot plantain (199, 179 and 168 g kg⁻¹, respectively, P<0.05). The NDF concentration of the forbs was lower than that of orchardgrass during spring (379 vs. 484 g kg⁻¹, respectively, P<0.001) and summer (338 vs. 497 g kg⁻¹, respectively, P<0.001). The IVTDMD of Puna chicory over the spring (872 g kg⁻¹) was similar to that of orchardgrass (864 g kg⁻¹), but higher than Lancelot plantain (740 g kg⁻¹). Over the summer Puna chicory had the highest digestibility (899 g kg⁻¹). The composition of the herbage of the three species differed significantly between seasons and among cultivars. Puna chicory had lower leaf to stem ratios than Penllate orchardgrass during both seasons; nevertheless, Puna chicory IVTDMD was higher than that of orchardgrass. Nutritive value of Lancelot plantain was similar or slightly lower than that of Penllate orchardgrass. Their herbage composition however, differed significantly.

The summer growth of cool season forages is reduced due to a combination of high temperatures and water shortage. A two year experiment was designed to compare the effect of two soil water availability conditions. Well-watered plots received water every week to maintain soil at or close to field capacity, while stressed plots received water every 3 wk in 2000 and 5 wk in 2001 near State College, PA. All plots were mowed at the beginning of the drying cycle. Puna chicory dry matter (DM) yield was not affected by the watering treatment applied in 2000 or 2001. Even though water stressed plants had a significantly lower leaf area index (LAI, 4.2 vs. 2.7 and 3.1 vs. 2.5 on watered and stressed plots in 2000 and 2001, respectively, P<0.05), it did not affect dry matter accumulation, and a slightly lower specific leaf area (SLA, 33.8 vs. 30.0 m² kg⁻¹ and 24.5 vs. 21.9 m² kg⁻¹ watered and stressed plots in 2000 and 2001, respectively) may have compensated to maintain yield. Water stress did not affect physiological functions. Average photosynthesis rates during 2000 and
2001 were close to 12 \( \mu \text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1} \). The effect of water treatment on DM yield of Lancelot plantain was masked by low plant survival during 2000.

With the objective of quantifying morphogenetic and physiological traits of chicory (Grasslands Puna and Forage Feast) and plantain cultivars (Grasslands Lancelot and Ceres Tonic) when subjected to elevated day temperatures, a controlled environment study was carried out. Plants were grown in PVC pipes over 7 wk (2 + 5 wk acclimation and experimental period, respectively) in growth chambers set to either 25/15°C or 30/20°C day/night temperatures. Eight plants per species were harvested each week and separated into shoot and root components. Single leaf gas exchange was measured on 10 plants per species at 2 wk and 5 wk. Dry matter (DM) allocation between root and shoot of chicory and plantain (RSMR: root to shoot mass ratio) differed between species at 4 wk (0.52 vs. 0.27 for chicory and plantain, respectively, \( P<0.01 \)), when chicory plants had a larger amount of DM allocated to the primary root than plantain (0.3 vs. 0.2 g in 3 wk, respectively, \( P<0.1 \)). Both species produced similar amounts of shoot DM at each harvest but it was allocated to different structures. At 5 wk, chicory had allocated 5.3 g to the main axis and 2 g to daughter rosettes, while plantain had allocated 1.9 g to the axis and 5.3 g to daughter rosettes (\( P<0.001 \) and \( P<0.01 \) for main axis and tiller comparison respectively). Neither the morphological nor the physiological aspects evaluated for chicory and plantain were affected by temperature. Single leaf photosynthesis at 5 wk was higher on plantain than on chicory (13.3 and 17 \( \mu \text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1} \), respectively, \( P<0.01 \)).

These studies demonstrated that Puna chicory can produce annual and seasonal yields similar to or greater than those of orchardgrass making it a viable alternative forage species for the Northeast US. Puna chicory can withstand relatively long periods without rainfall and its use in pastures of the NE USA could be beneficial. Both chicory and plantain did not exhibit signs of reduced shoot or root growth rates due to high temperatures and any morphological or physiological difference between species did not however, confer an advantage or disadvantage when grown in temperatures above
optimum. However, the low winter survival of plantain limits its potential use as a forage species in the region.
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CHAPTER 1

INTRODUCTION

Although the Northeastern region of the US is characterized as temperate continental with no dry season and cool summers, grazing farm operations often experience forage shortages during the summer. Forage shortage in this region may be caused by an uneven distribution of rainfall during the growing season, an increase in evapotranspiration demand due to higher temperatures during the summer, or a combination of edaphic, climatic, plant and animal factors. While climatic and edaphic conditions cannot be controlled, the best combination of plant and animal operations can be chosen that will maximize sustainable farm profits.

One of the first decisions to be made in a grazing animal operation is the selection of forage species to be planted based on factors such as soil properties and animal needs. The selection of pasture species and variety will determine the amount and distribution of forage over the year. The most widely selected pasture species in the northeastern states of the USA are cool-season species that can tolerate cold winters and have high quality forage. However, cool-season forage species produce most of their dry matter during the spring, early summer and fall seasons, and, with few exceptions, they have low tolerance to stressful summer conditions.

Summer stress is often associated with plants receiving insufficient water or rainfall. Even when soil water is abundant however, plants can experience short periods of stress during the day when high temperatures occur. In fact, water stress in cultivated species classified as mesophytic (land plants that grow in an environment with moderate amounts of moisture) is the most common type of plant stress (McKersie and Leshem; 1994). However, within cultivated mesophytic species there are differences in their capacity to cope with stress and maintain acceptable yields. Hurvitz (1958) proposed a classification system for cultivated species according to their comparative degree of drought tolerance. In this system, chicory (Cichorium intybus L.) was classified as having a high level of drought tolerance. Chicory has been bred for many different
purposes including its use as a forage species. If this drought tolerance character found on chicory bred as root crop was transmitted to forage cultivars, it would make it a desirable species to be grown in areas such as the Northeast USA.

Forage cultivars of chicory are promoted for their high quality forage, and high liveweight gains and voluntary feed intake in deer, sheep and cattle (Barry, 1998; Kusmartono et al., 1996; Clark et al., 1990; Rumball, 1986). However, their stand persistence after four years is considerably reduced (Li et al., 1997) and should be taken into account in future studies.

Another perennial forb that has considerable tolerance to drought and summer heat is plantain (*Plantago lanceolata* L.) (Sagar and Harper, 1964). This perennial herb of the family *Plantaginaceae* has a broad distribution in grasslands throughout the temperate world and is highly palatable to grazing animals, providing mineral-rich forage (Fraser and Rowarth, 1996). Plantain grows on a wide range of agricultural soils (Stewart, 1996), consequently its utilization for pasture purposes could improve forage availability during the summer on soils of lower quality. However, its adaptability to the conditions in the Northeast USA, with hot summers and very cold winters, has not yet been tested.

Most available information on grazed chicory and plantain pastures are related to the forage productivity and quality of these species while grown under climatic conditions less severe than those encountered in the NE region of the USA. Little is known regarding the effect of climatic factors on the mechanisms that determine growth, development and forage accumulation in chicory (Sanderson and Elwinger, 2000; Li et al., 1998) or plantain (Calviere and Duru, 1995). The objectives of this study were to determine the effect of temperature and water availability on forage yield of chicory and plantain, and to evaluate forage productivity of these species in Pennsylvania when subjected to grazing.
Grazing in the Northeast USA. Balancing forage supply and demand.

Management of pastures on a grazing animal operation is very complex. The objective of pasture management is the simultaneous achievement of several goals including: i) the production of high quality, high nutritive forage ii) maintenance of forage production for as long as possible during the growing season iii) reduction of losses through plant tissue senescence and iv) maintenance of plant density (Hogdson, 1990). The balance between forage supply and efficient plant resource utilization would need to be met while maintaining acceptable levels of animal productivity and ensuring sustainability of the system (Mayne et al., 2000).

Because a large proportion of the forage produced in temperate regions is provided by cool season grass species the supply of herbage is unevenly distributed during the year. Cool season forages grow best under moderate temperatures (20 - 25 °C). Following the variations in temperature and triggered by reproductive development, forage production of these species peaks during the spring and reaches its minimum during the summer. In the fall growth increases slightly before the plants become dormant during winter (Parsons and Chapman, 2000). An efficient use of the crop depends on harvesting at times of surplus and conserving feed for the winter. However, many times, grazing farmers in the northeastern USA have to utilize part of the surplus to supplement pasture production during the summer of the same growing season reducing the supply of conserved forage for the winter.

One option to alleviating the shortage of forage in the summer is to use annual forage crops such as rape, turnip, kale (Brassica spp. L.), forage sorghum (Sorghum bicolor L.), and maize (Zea mays L.), which produce significant amounts of forage during the summer. There is however, the required cost and labor of re-establishment, which could make them less desirable. Among perennials the number of utilized species is limited, with alfalfa (Medicago sativa L.), which has the highest quality and productivity levels
as well as the best yield over the summer, being the best choice (Lacefield, 1998). However, optimum growth of alfalfa stands requires good soil conditions and as a result, only 37% of the hay acreage in the northeast can be utilized to grow alfalfa (PDA 2000). Orchardgrass (Dactylis glomerata L.) and reed canarygrass (Phalaris arundinacea L.) have lower summer yields than alfalfa but have a wider tolerance to variable or poor soil conditions.

The complexity of grazing animal operations derives from the need to balance forage supply with animal nutritional demands at any given time. The forage provided by cool season grasses is highly seasonal generating a summer forage shortage and although annual crop supplementation is possible, perennial forms are more desirable.

The difficulty for researchers and farmers is to find alternative perennial forages capable of surviving the cold winters of the northeast, maintaining even dry matter production during the summer and tolerating moderate soil quality. With the number of forage germplasms available in the seed banks of the world exceeding fifty thousand, finding an alternative perennial forage, while a daunting task, is possible (Harrison and Pearce, 2000).

**Forage cultivars of chicory and their potential for grazing pastures.**

Chicory is a perennial herb of the Asteraceae family (group of the compositae), that grows as a rosette, has broad leaves and a long thick taproot. This species has been bred for multiple industrial uses and, in the past 25 years, genotypes with excellent forage qualities have been developed for pasture purposes (Lancashire, 1978). It is suggested that chicory can attain good summer growth rates and maintain a good water status due to the characteristics of its roots (Barry, 1998). Data available for the Northeast USA concerning productivity of chicory and orchardgrass suggests that when chicory pastures are cut 3 times in their growing season they can achieve dry matter yields between 5 and 7.5 Mg ha⁻¹, which represents 1.5 to twice as much productivity as orchardgrass (Hall, 1994; Hall and Jung, 1994). A similar yield relation was found by Jung et al. (1996); when orchardgrass and chicory stands
were cut at 3 intervals, the annual yield of chicory was higher than for orchardgrass. However, neither of these reports related productivity of chicory and summer performance.

The nutritional value of chicory forage is also an important advantage of the species. Holden et al. (2000) found the concentrations of organic matter (OM), acid detergent fiber (ADF), and neutral detergent fiber (NDF) of Puna chicory were lower than those of Pennlate orchardgrass. Chicory herbage also contained higher levels of Ca, Mg, Na, Fe, Cu, and Zn than orchardgrass (Jung et. al, 1996) that could potentially prevent cases of grass tetany in young cattle or adults feeding on vegetative grass. In addition, chicory forage has also been tested for ant-helmintic effects in grazing deer (Hoskin et al., 1999), although, the chemical substance that may confers this property remains unknown.

In contrast to its favorable yield and nutritive characteristics, plant persistence of forage chicory is a matter of concern. After 3 years field plots of Puna chicory decreased in yield because of a decrease in plant density (Hunter et al., 1994). Li et al. (1997) and more recently Belesky et al. (2000), reported plant stand losses of 70 and 95% by the end of the fourth year of growth, accompanied by a 50% yield reduction in the third year. Grazing and cutting strategies, however, have focused on the control of reproductive development overlooking the fact that this type of management tends to reduce the life span of some plants (Davies, 1988). Future research should focus on determining the best combination of frequency and intensity of grazing that would improve stand survival as well as quality of the available forage.

**Plantain: potential use of a forage forb in the Northeast USA pastures.**

Plantain (*Plantago lanceolata* L) is a perennial herb of the family *Plantaginaceae*, characterized by a rosette growth form with linear to linear-lanceolate leaves, and an adventitious root system (Sagar and Harper, 1964). It is broadly distributed in grasslands throughout the temperate world, and is palatable to grazing animals, providing mineral-rich forage (Fraser and Rowarath, 1996). The species is rapid to establish, grows on a wide range of
agricultural soils and can attain dry matter yields similar to orchardgrass during dry years (Stewart, 1996). Plantain is tolerant to drought and summer heat and could potentially have a uniform distribution of yield over the growing season.

“Grassland Lancelot” and “Ceres Tonic” are two commercially available cultivars of plantain. AgResearch in New Zealand selected grasslands Lancelot for its bushy growth habit and the ability to tiller strongly under close grazing by sheep (Rumball et al., 1997). Ceres Tonic was selected by Stewart (1996) because of its erect growth habit and large leaves. Tonic remains erect under a wide range of conditions whereas Lancelot can become prostrate under close grazing. Although both cultivars have similar annual yields, they differ in morphology, and seasonal productivity especially during the summer (Stewart, 1996).

Plantain and chicory grow on a wide range of agricultural soils. If chicory and plantain species are capable of growing under the environmental conditions experienced in the northeastern USA, then they may potentially be used to improve pasture summer productivity in the region. The investigation into the viability of these species for pasture systems in the NE is a difficult task, requiring that several complex questions be answered. Questions including: i) what physiological and/or morphological mechanisms make these species tolerant to summer stress in other geographical regions, ii) Do they translate to the environment in which we are testing the genotypes and iii) Would an additional stress factor such as grazing counteract these beneficial mechanisms?

**Water stress. Studying plant responses to stress through its effects on leaf area development.**

For years, researchers have studied plant characteristics and behavior under diverse environmental conditions in order to understand how they cope with stress. They have been looking into many simple characters that confer, for example, drought resistance, wishing to find traits that would allow breeders
to screen for these genotypes. However, universal characteristics of this sort probably do not exist, and even if they did, their functionality may vary from one environment to another.

When studying the capture of light and efficiency of water use, the crop’s modulation of leaf area development seems to be more influential on the achievable yield than the net assimilation rate (Lemaire et al., 1987). Several reasons are given for grain crops, specifically wheat, on how the rate of leaf area development influences water utilization over time. The rate of leaf area development determines the amount of dry matter produced up to a certain moment in time; it influences the amount of water consumed up to this point and also affects the amount of water loss from direct soil evaporation (Passioura et al., 1993). Even though most studies have been conducted with grain crops, these findings become important when studying forage species, where the harvestable portion of the crop are the leaves, because studying stress effects on leaf area development directly affects the harvestable product.

To study how environmental factors affect plant growth and leaf area development, several explanatory schemes can be utilized (Torssell, 1984). There are two different but complementary mechanistic models that consider leaf area development as a determinant variable in the model. The trophic model includes the processes of light interception, CO₂ assimilation and respiration, and partitioning among plant organs, and uses the leaf area index (leaf area per unit area of ground) as the determinant of the quantity of energy absorbed by the crop. The morphogenetic model, considers the processes of growth and development of organs, leaf appearance and number, leaf elongation and size, tillering or branching and stem elongation, which are all components of the leaf area index of the crop. The connection between these two mechanistic models is evidenced in the hypothesis described below concerning the partitioning of assimilates among the different plant organs.

Carbon assimilate partitioning has been considered on theoretical grounds, as a growth optimization process. Schulze and Chapin (1987) present the view that plants regulate partitioning so that the internal pool sizes of
carbon and nutrients remain constant even under a changing resource base. In other words, when one resource is limiting and others held constant, a variation in the internal carbohydrate concentration occurs, representing a deviation from a set-point ratio. Plants respond to this by increasing or reducing the expenditure on either shoot or root parts, thereby bringing the ratio back to the set point. This mechanism would operate when plants are subjected to a stressing factor such as water limitation or even defoliation by grazing. In the case of water limitation during the summer, we would expect to observe stimulation of root growth accompanied by a reduction in leaf area growth with an increase in the specific weight of those leaves to maintain an internal carbon-to-nutrient balance. This general scenario is based on the theoretical economic argument that plants should adjust allocation so that all resources equally limit growth. Furthermore, under changing resource availability, plants adjust their root to shoot ratio to maximize growth rate and the mechanism for this compensation would be related to the internal ratio of carbon to nutrients (Bloom et al., 1985).

Under the morphogenetic model, plant responses to environmental stress are a result of the changes in the growth of different plant parts to efficiently use limiting resources. Especially important are the reduction in tissue loss (life span of organs) and the conservation of the resources that most strongly limit growth. In response to drought, plants would hypothetically reduce transpiration rates by partial stomatal closure thus, reducing water loss more than photosynthetic carbon gain and consequently increasing water use efficiency (carbon gain per unit of water transpired) (Lemaire et al. 1987). Also, more tolerant individuals within a species would tend to increase leaf and root longevity, reducing resource demand and achieving a favorable balance for growth (Grime, 1979).

Regardless of which model is used to understand the effects of stress factors on forage species productivity, differences in genotype tolerance to moderate summer stress will primarily be expressed through the most sensitive indicator, leaf area expansion. However, a genotype's ability to cope with stress may be the result of many morphological or physiological characteristics. If both
chicory and plantain are capable of tolerating summer conditions of the NE USA, the more tolerant cultivars are expected to exhibit a higher capacity to maintain leaf growth (morphogenetic response) and a good plant water status (physiological response).
REFERENCES


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(Lolium perenne)/white clover (Trifolium repens) pasture upon the growth and voluntary intake of red and hybrid deer during lactation and post weaning growth. J. Agric. Sci. 127:387-401.


CHAPTER 2

Productivity under grazing of chicory and plantain cultivars in the Northeast US
INTRODUCTION

Pastures in the northeastern USA are predominantly composed of high quality cool-season grass species. Productivity of these species follows a bimodal distribution, reaching maximum yields in the spring and minimum yields during the summer. The modality of growth of these species generates an uneven distribution of herbage supply over the growing season. Alfalfa is the best yielding temperate pasture species available. However, in lower quality soils or other situations where this legume cannot be grown, orchardgrass is the primary forage provider over the summer. The availability of options is limited and farmers could improve their pasture management with alternative crops such as forage chicory (*Cichorium intybus* L.) and english plantain (*Plantago lanceolata* L.).

Chicory was first reported as having excellent forage value under rotational grazing by Lancashire (1978). The chicory cultivar "Grasslands Puna" was released in 1985 and has been frequently used in the USA and reported as having good summer productivity (Jung et al., 1996; Volesky, 1996). It is a high quality feed, and high liveweight gains and voluntary feed intake are obtainable in deer, sheep and cattle (Barry, 1998; Kusmartono et al., 1996; Clark et al., 1990; Rumball, 1986). However, its plant stand persistence under grazing and cutting management is a concern.

Naturally occurring populations of English plantain have considerable tolerance to drought and summer heat (Sagar and Harper, 1964). Plantain has a broad distribution in grasslands throughout the temperate world, and its leaves are highly palatable to grazing animals, providing mineral-rich forage (Fraser and Rowarth, 1996). Plantain establishes rapidly, grows on a wide range of agricultural soils, and it has been reported that during dry years the species can attain dry matter yields similar to those of orchardgrass (Stewart, 1996). Two forage cultivars are available commercially, Grasslands Lancelot and Ceres Tonic. Grasslands Lancelot was selected for its bushy growth habit and the ability to tiller strongly under close grazing by sheep (Rumball et al., 1997).
Ceres Tonic was selected for its erect growth habit and large leaves (Stewart, 1996).

Forage chicory has higher potential yields than plantain (Sanderson et al., 2001), but the latter grows on a wider range of agricultural soils than chicory. Consequently the utilization of these two species for pasture purposes could improve forage availability during the summer over a wide range of soil conditions. While some reports have been generated for chicory pastures in the NE USA under non-grazing situations (Belesky et al., 2001, 2000; Holden et al., 2000; Collins and McCoy, 1997; Jung et al., 1996), most available information on grazed chicory pastures comes from climatic conditions different than those observed in the NE region of the USA (Li et al., 1997a,b; Rumball, 1997; Stewart, 1996; Ruiz-Jerez et al., 1991). Information on plantain pastures and its adaptability to the conditions of the NE USA is scarce (Sanderson and Elwinger, 2000; Sanderson et al., 2001).

Our objectives were to evaluate annual and summer productivity of different cultivars of chicory and plantain for direct feeding pastures in the northeastern USA, and to develop appropriate grazing guidelines for the region.

**MATERIALS AND METHODS**

Two field experiments were conducted at the Pennsylvania State University Haller Farm Beef Research center near State College, PA. The soil at the experimental site was a Hagerstown silt loam (fine, mixed, mesic Typic Hapludalfs). The purpose of the first experiment was to evaluate different commercially available cultivars of chicory and plantain when grown in the NE USA, to test their seasonal productivity under grazing and compare it against the performance of a traditional species used in the region. The second experiment aimed to test and develop the most appropriate grazing strategies for either species that would maximize growth rates and yield over the year and the summer in particular.
Planting conditions, treatments and experimental design

Experiment 1

The chicory cultivars Forage Feast, Grasslands Puna and INIA LE Lacerta, the plantain cultivars Grasslands Lancelot, Ceres Tonic, and Pennlate orchardgrass, were seeded in May 1997. A Hege 1000 series plot drill planter adjusted to seeding rates of 0.45 g m\(^{-2}\) for chicory and 1.1 g m\(^{-2}\) for plantain and orchardgrass was used for planting. Soil tests to a 15-cm depth in March 1998 indicated a pH of 6.3 and 93 kg ha\(^{-1}\) P, 489 kg ha\(^{-1}\) K, and 256 kg ha\(^{-1}\) Mg. No fertilizer was added at planting while nitrogen fertilization during the first production year totaled 50 kg ha\(^{-1}\) N applied on 10 April and 15 June in the form of urea. A total of 60 kg ha\(^{-1}\) P and 120 kg ha\(^{-1}\) K were applied in April. Weeds were controlled by mowing during the year of establishment.

The experimental design was a randomized complete block (four blocks) with a split plot arrangement of cultivars randomly assigned to subplots within the grazing treatments main plots. Plot size (cultivars within grazing treatment) was 12 by 14 m. The grazing treatments consisted of combinations of frequency (three and five wk rest period) and intensity (50 or 150 mm stubble residue) of grazing. Paddocks were grazed ‘frequently and severe’ (FS = 3 wk x 50 mm), ‘frequently and light’ (FL = 3 wk x 150 mm), ‘infrequently and severe’ (IS = 5 wk x 50 mm), or ‘infrequently and light’ (IL = 5 wk x 150 mm). All cultivars (subplots) within a grazing treatment (main plot) and block were grazed at the same time for an occupation period not longer than 36 h using 12 to 14 beef cow-calf pairs. Grazing began on 5 May and ended 9 September 1998. Herbage mass was measured pre and post grazing in four 0.1m\(^2\) quadrats cut to ground level with electric shears. All material was oven dried at 55 °C for 48 h and weighed. Plant and tiller counts were performed on 1 October 1997, 1 April and 12 October 1998, and 4 May 1999. A 0.6 by 0.6 m quadrat was used for chicory and plantain plants, whereas orchardgrass tillers were counted within three 0.1 m\(^2\) quadrats.
Statistical analyses of results were performed using the MIXED procedure of SAS (SAS Institute V.8.2, 2000). Results for dry matter yield were separated into spring and summer seasons and compared within each season. Pre-planned orthogonal contrasts were used for mean separation (Steel et al., 1997). Cutivars were evaluated using Pennlate orchardgrass as the ‘control’. Pre-planned cultivar comparisons were Forage Feast chicory (Fc) vs. Pennlate orchardgrass (Penn), Lacerta chicory (Lc) vs. Penn, Puna chicory (Pc) vs. Penn, Tonic plantain (Tp) vs. Penn, and Lancelot plantain (Lp) vs. Penn. Grazing treatment by cultivar means were compared for the effect of grazing treatment within each cultivar (e.g. yield of IS Puna chicory vs. yield IL Puna chicory). Overall grazing treatment effect was also compared.

**Planting conditions, treatments and experimental design**

**Experiment 2**

Based on results from exp. 1, cultivars Grasslands Puna chicory, Grasslands Lancelot’ plantain and 'Pennlate' orchardgrass were selected to be seeded on August 1999 in the same location and under similar soil conditions. Soil tests pre-planting indicated a pH of 6.5 and nutrient content of 89 kg ha\(^{-1}\) P, 325 kg ha\(^{-1}\) K, and 205 kg ha\(^{-1}\) Mg. The soil was tilled during the spring of 1999 but seeding was delayed due to drought conditions. Prior to seeding, weeds were controlled with glyphosate. A no-till seeder was used at seeding rates similar to experiment 1. Mowing controlled weeds during the year of establishment. Nitrogen fertilizer was applied at rates of 75 - 85 kg ha\(^{-1}\) N, split into 2 applications per year (May and August of 2000 and 2001). The experimental site was approximately 2.2 ha. A split block design (4 replicates) was used, with the species and 2 grazing treatments as factors. Each experimental unit was approximately 0.09 ha. Grazing treatments consisted of 2 different stubble heights left after grazing during spring and summer. The severe-severe (S/S) treatment plots were grazed to an average canopy height of 50 mm during the entire season of growth, while the severe-moderate (S/M)
plots were grazed to 50 mm stubble height over spring and 100 mm during the summer. Timing to grazing was determined through bi-weekly monitoring of canopy height. Grazing began when canopy height reached 250 mm on orchardgrass and chicory plots and 200 mm on plantain plots. Height monitoring was done with a meter stick and height was defined as that of the first vegetative leaf touching the measuring device. Twenty-five readings were made on each plot. The number of animals per paddock at each grazing event was adjusted in order to limit the grazing period to no longer than 28 h. Grazing commenced on 26 May, 2000 and 5 May, 2001. After the first grazing, chicory plots were mowed to a height of 100 mm to reduce variability in stubble height or remove reproductive stems. In general, between 7 and 10 beef cow-calf pairs were used to graze the plots to a 100 and 50 mm stubble respectively. Total time for grazing the entire experiment (rotation time) was approximately 10 days. Plant counts were made 3 times over the growing season, in May, August and October. Biomass samples were taken pre and post grazing. At each sampling date, two 1.6 m² areas were cut of which 0.53 m² was kept for separation into components, another 0.53 m² was kept for dry matter estimation and the rest of the sample was immediately weighed. Samples to estimate dry matter were taken put into an oven at 55°C for 48h and then weighed.

Statistical analyses of results were performed using MIXED procedure of SAS (SAS Institute V.8.2, 2000) based on guidelines to analyze a split-block presented by Steel et al. (1997) and Litell et al. (2000). A combined analysis over the years was performed and results were compared within seasons. Treatment means of herbage quality and herbage components were separated using pre-planned orthogonal contrasts (Steel et al. 1997). Cultivar comparisons were made using Pennlate orchardgrass as control. Pre-planned contrast for cultivar comparisons were Puna chicory vs. Pennlate orchardgrass and Lancelot plantain vs. Pennlate orchardgrass. Grazing effect was tested over the summer applying the contrasts S/S grazing vs. S/M grazing. Pre-planned contrast for year comparison was 2000 vs. 2001.
RESULTS AND DISCUSSION

A variety of weather conditions were observed over the period of this study (Table 1). While the region was not experiencing a drought, there were periods of excessive dryness in September 1998, July and September 2000 and June through August 2001, with August 2001 the most stressful of the three. The variability in weather conditions had a pronounced impact not only on the amount of forage produced but also on its distribution over the growing season. In addition to the impact of varying weather conditions, the amount of forage produced was affected by plant density.

Pasture productivity and cultivar comparison - Experiment 1

Herbage productivity of chicory and plantain cultivars during 1998 is presented in Table 2. During spring 1998 both cultivar and grazing treatment were statistically significant (P= 0.0015 and 0.04, respectively), although the interaction of main effects was not (P= 0.45). Pennlate orchardgrass, Puna chicory and Lancelot plantain had the highest yields (724.0, 651.1, 735.6 g m\(^{-2}\), respectively); whereas Forage Feast chicory, Lacerta chicory and Tonic plantain had lower yields than orchardgrass (627.7, 570.9, 570.0 g m\(^{-2}\), respectively). On average, the yield of FS plots were lower than for FL, and IS plots (Table 3). Neither frequency nor intensity of grazing alone were responsible for the lower yields, however, the combination of 3-week grazing frequency and 50-mm stubble height appeared too stressful on all cultivars.

During summer 1998, main effects were significant (grazing treatment and cultivars, P < 0.001) but not their interaction (P= 0.51). Regardless of the intensity, frequently grazed plots yielded significantly less than their counterparts grazed every 5 wk, the difference in average yield being more than two-fold (166.9 vs. 444.8; P < 0.001). All cultivars yielded less than Pennlate orchardgrass (Table 2). Forage Feast and Lacerta chicory and Lancelot plantain
yielded between 30 and 40% less, whereas the Puna chicory and Tonic plantain yielded 10 to 20% less than the orchardgrass.

Results of this one-year experiment showed that during the spring, chicory and plantain cultivars are able to undergo either 3-week or 5-week grazing events as long as there was either enough leaf area remaining for regrowth or the rest period was long enough to achieve maximum accumulation. During the summer, a longer resting period was required to achieve maximum yields. Energy for regrowth, if sufficient regrowth buds are present, is either provided by photosynthetically active tissue or it is derived from reserves, the latter having a slower initial regrowth rate and consequently requiring a longer resting period to achieve maximum tissue accumulation. Strategies for grazing orchardgrass should leave a 100-mm stubble height to prevent productivity losses such as those observed in spring 1998. However, this grazing strategy is not necessarily applicable to plantains and chicories since their “morphology” is different. These results add more detail in terms of differential seasonal grazing management to those found under clipping conditions (Sanderson et al., 2001) and to the findings for Puna chicory (Belesky et al., 1999; Li et al., 1997a; Volesky, 1996) that suggest a 5 week interval between cuttings to attain maximum yields. The risk of a grazing strategy allowing long resting period during the spring is the partitioning of reserves to reproduction. In the case of chicory, a taller stubble can also lead to a non-desirable canopy structure with regrowth occurring from buds left on the flower stalk instead of those coming from the crown (Li et al., 1998).

**Dry matter yields in 2000 and 2001 – Experiment 2**

During the springs of 2000 and 2001 the average DM productivity of Puna (5842 and 5638 kg ha\(^{-1}\) for 2000 and 2001, respectively, Table 4) was significantly higher than that of Pennlate orchardgrass (3638 and 3582 kg ha\(^{-1}\) for 2000 and 2001, respectively, P < 0.05). Lancelot plantain had a higher dry matter yield than Pennlate orchardgrass in spring 2000 (5401 vs. 3638 kg ha\(^{-1}\)
for Lancelot plantain and Pennlate orchardgrass, respectively, $P<0.05$), but a year later Lancelot plantain and Pennlate orchardgrass had similar DM productivities (3294 vs. 3582 kg ha$^{-1}$ for Lancelot plantain and Pennlate orchardgrass, respectively).

During summers of 2000 and 2001, grazing treatment did not significantly affect pasture productivity of any of the cultivars under study. In 2000, summer productivity of Puna chicory was higher than that of Pennlate orchardgrass (5363 vs 2893 kg ha$^{-1}$, respectively, $P<0.05$). However, in 2001, summer yield of chicory and orchardgrass was similar (3368 vs. 3606 kg ha$^{-1}$, respectively). Drier weather conditions during summer 2001 had a major effect on the length of the re-growth period and the number of grazing cycles for Puna chicory (Table 5). Puna chicory showed stunted growth during the periods of high transpiration demand (beginning of July until mid-August), remaining latent until rain occurred (data not shown), which resulted in 1 less harvest cycle in the 2001 when compared to 2000. This result could explain the lower Puna chicory yields observed in 2001 when compared to 2000.

Summer dry matter yield of Lancelot plantain was similar to that of orchardgrass in 2000 (2817 vs. 2893 kg ha$^{-1}$ for Lancelot plantain and Pennlate orchardgrass, respectively), but significantly lower in 2001 (2817 vs. 3606 kg ha$^{-1}$ for Lancelot plantain and Pennlate orchardgrass, respectively, $P<0.05$). The significant plant death registered on Lancelot plantain plots explained the reduction in yield for summer 2001. This reduction in yield could not be attributed exclusively to drier weather conditions during 2001 but to the inherent lack of winter tolerance of this plantain cultivar (Skinner and Gustine, 2002).

**Pasture density and plant death**

The number of plants per square meter of each species and cultivar in experiment one was not significantly affected by the grazing treatment (Figure 1). Nevertheless, plant density during the grazing period declined significantly.
Puna and Forage Feast chicory, Lancelot plantain, and Pennlate orchardgrass losses were between 25 and 45% of their initial stand. Highest losses occurred in Lacerta with an 80% density reduction, while Tonic plantain lost only 20%. Plant counts taken after the winter of 1999 showed that Ceres Tonic plantain had the lowest tolerance to cold weather. While winter killed 50% of Lancelot plantain’s stand, Tonic plantain lost 95% of its stand making it the least suitable plantain cultivar for the northeastern region of the USA. Because of the near total loss of the Tonic plantain stand, this experiment was not continued into 1999. Although the traditional thought that carbohydrate reserves are responsible for the likelihood of surviving winter kill has been questioned (Cunningham and Volenec, 1998), results that link ecotype characters to winter hardiness exist. Among the genotypes used for the development of Ceres Tonic plantain, breeders used materials coming from the Mediterranean region of Portugal (Stewart, 1996). Robson (1967) suggested that continental ecotypes of tall fescue (Festuca arundinacea Schreb.) were more winter hardy than their Mediterranean relatives. Mediterranean ecotypes when grown in temperate regions had higher autumn yields but low persistence, presumably related to a lower base temperature and winter dormancy.

The fact that pure stands of chicory and plantain lose a considerable number of plants has been mentioned in the literature (Li et al., 1997a, 1997b, and 1998; Stewart, 1996) and can be a potential problem for their use as perennial pastures. These losses can be either intrinsic to the genotype or be caused by the interaction of multiple stresses; grazing, drought and heat stress, and this question remained unanswered after our 1998 trial.

In 2000 and 2001, an attempt was made to reduce the stress interaction to a minimum by grazing only when the pastures reached a defined canopy height, using an adaptation of the method proposed by Bircham and Hodgson (1983). During experiment two, the number of Puna chicory and Pennlate orchardgrass plants lost were much lower than during experiment one (Figure 2). For these entries, losses did not exceed 8% and were not affected by the intensity of grazing during the summer. Nevertheless, the number of Lancelot
plantain plants per square meter was reduced between 50 and 60%. Similar losses were also observed in a clipping study, reinforcing our findings that Lancelot plantain has decreased survivability in the northeastern USA (Sanderson et. al., 2001).

The initial density of plants of Lancelot plantain in May 1998 (experiment one) and May 2000 (experiment two) was 425 vs. 375 plants m⁻², slightly higher for experiment one than experiment two, yet the final number after 1 year (one over winter), was approximately 125 plants m⁻² in both experiments. This means that the grazing strategy had little or no effect on the winter survival of this cultivar. Plant density losses continued over the second grazing year in experiment two to unviable minimum values of 48 plants m⁻². Results over these 3 grazing seasons leave little hope for any improvement in plantain survival caused by changes in the utilization strategy. Studies of the demography of Plantago lanceolata suggest a half-life length of two years on both closely and undergrazed pastures, but it is also reported that the largest portion of losses occurs during the first year of life and losses after this term are not age-related (Kuiper and Bos, 1992).

Puna’s initial density on the other hand, was similar for both grazing strategies (100 plants m⁻²), but after 1 year plant density in experiment one had dropped to 50 plants m⁻² while in experiment two the average density remained the same (100 plants m⁻²). This suggests that grazing strategy does influence the survival rate of Puna chicory in a 2-year old pasture. Losses at the end of the second grazing season were 35%, leaving an average density of 69 plants m⁻², well above the minimum viable of 25 plants m⁻² proposed by Li et al. (1997b) and similar to the density obtained by them on a 2-year pure stand pasture.

Pennlate’s density loss during the first year in both experiments differed significantly. While in Exp. 1 losses were close to 50%, in Exp. 2 losses were nil and remained this way over the second year of grazing. Changes in Pennlate tiller density were taken as a measure of stress imposed by each grazing strategy. Our results suggest that a canopy-height based strategy allows for
better control of the stress imposed and consequently improves pasture persistence.

**CONCLUSIONS**

Our results suggest that Puna chicory as a pure stand would be a good complement to Pennlate orchardgrass pastures to improve forage availability during the summer. The rest period of both cultivars differed significantly during dry summers limiting the grazing strategy to be used. It was also found that a plant based grazing strategy was more appropriate to minimize plant losses in Puna chicory. Finally, neither Grasslands Lancelot nor Ceres Tonic plantain are appropriate cultivars to be used in the NE region of the USA due to lack of winter tolerance.
REFERENCES


Table 1: Monthly air temperature (°C) and accumulated rainfall (mm) during 1998, 2000 and 2001, near State College, PA, 16801.†

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean temperature</th>
<th>Accumulated rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>17.6</td>
<td>16.7</td>
</tr>
<tr>
<td>June</td>
<td>19.1</td>
<td>20.6</td>
</tr>
<tr>
<td>July</td>
<td>21.2</td>
<td>20.2</td>
</tr>
<tr>
<td>Aug.</td>
<td>21.1</td>
<td>20.2</td>
</tr>
<tr>
<td>Sept.</td>
<td>19.0</td>
<td>16.2</td>
</tr>
<tr>
<td>Oct.</td>
<td>11.7</td>
<td>11.9</td>
</tr>
</tbody>
</table>

† Source: http://pasc.met.psu.edu/PA_climatologist/index.php
Table 2: Expt. 1- Seasonal productivity of chicory, plantain and orchardgrass cultivars under grazing during 1998. †

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Spring 1998</th>
<th>Summer 1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feast (Fc)</td>
<td>6237</td>
<td>2452</td>
</tr>
<tr>
<td>Lacerta (Lc)</td>
<td>5709</td>
<td>2802</td>
</tr>
<tr>
<td>Puna (Pc)</td>
<td>6511</td>
<td>3354</td>
</tr>
<tr>
<td>Plantain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lancelot (Lp)</td>
<td>7356</td>
<td>2688</td>
</tr>
<tr>
<td>Tonic (Tp)</td>
<td>5700</td>
<td>3168</td>
</tr>
<tr>
<td>Orchardgrass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pennlate (Penn)</td>
<td>7240</td>
<td>3888</td>
</tr>
</tbody>
</table>

Comparisons ‡ Significance

- Fc vs. Penn: * *
- Lc vs. Penn: * *
- Pc vs. Penn: NS NS
- Lp vs. Penn: NS *
- Tp vs. Penn: * *
- S.E.: 348 201

* Significant at the 0.05 probability level.
† Productivity calculated as accumulated dry matter yield of target species (green tissue and flowers) averaged over 4 grazing treatments.
‡ Pre-planned comparisons: cultivar means comparisons vs. Pennlate orchardgrass.
Table 3: Expt. 1 - Seasonal productivity of chicory, plantain and orchardgrass during 1998. Grazing treatment effect.†

<table>
<thead>
<tr>
<th>Grazing treatment</th>
<th>Spring 1998</th>
<th>Summer 1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequent Severe (FS)</td>
<td>5451 b, l</td>
<td>1644 c</td>
</tr>
<tr>
<td>Frequent Light (FL)</td>
<td>7066 a</td>
<td>1694 c</td>
</tr>
<tr>
<td>Infrequent Severe (IS)</td>
<td>6847 a</td>
<td>4295 b</td>
</tr>
<tr>
<td>Infrequent Light (IL)</td>
<td>6485 ab</td>
<td>4602 a</td>
</tr>
<tr>
<td>S.E.</td>
<td>350</td>
<td>258</td>
</tr>
</tbody>
</table>

† Productivity calculated as the average accumulated dry matter yield of target species (green tissue and flowers).
‡ Within columns, grazing treatments means followed by the same letter are not significantly different according to Tukey’s w test (p <0.05).
Table 4: Expt.2 - Seasonal productivity of Puna chicory, Lancelot plantain and Pennlate orchardgrass during 2000 and 2001 under grazing. †

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Spring</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Severe</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td><strong>-------- kg DM ha⁻¹ --------</strong></td>
<td></td>
<td>S v. M‡</td>
</tr>
<tr>
<td><strong>2000</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Puna chicory (Pc)</td>
<td>5842</td>
<td>5031</td>
</tr>
<tr>
<td>Lancelot plantain (Lp)</td>
<td>5401</td>
<td>2429</td>
</tr>
<tr>
<td>Pennlate orchardgrass (Penn)</td>
<td>3638</td>
<td>2761</td>
</tr>
</tbody>
</table>

Contrast §

- Pc vs. Penn: * * *
- Lp vs. Penn: * NS NS
  SE

**2001**

| Puna chicory                         | 5638   | 3231   | 3504     | NS       |
| Lancelot plantain                    | 3294   | 1043   | 1007     | NS       |
| Pennlate orchardgrass                | 3582   | 3390   | 3821     | NS       |

Contrast §

- Pc vs. Penn: * NS NS
- Lp vs. Penn: NS * *
  SE

* Significant at the 0.05 probability level.
† Productivity calculated as the average accumulated dry matter yield of target species (green tissue and flowers).
‡ Grazing treatment mean pre-planned orthogonal contrast S vs. M.
§ Cultivar mean pre-planned orthogonal contrasts against Pennlate.
Table 5: Expt. 2 - Average number of grazing cycles for Puna chicory, Lancelot plantain and Pennlate orchardgrass pastures over a two year grazing experiment.

<table>
<thead>
<tr>
<th>Year</th>
<th>Puna chicory</th>
<th>Lancelot plantain</th>
<th>Pennlate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2001</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>
Figure 1: Expt. 1 - Density of chicory (a) and plantain cultivars (b) under razing condition from fall 1997 until spring 1999.
Figure 2: Expt. 2 - Density of Puna chicory and Lancelot plantain plants (a), and orchardgrass tillers (b) during 2000 and 2001.
CHAPTER 3

Nutritive value of chicory and plantain herbage under grazing
INTRODUCTION

Productivity of pastures in the northeastern USA follows the bimodal distribution observed on cool-season forage species where minimal yields occur over the summer. Reduced yields over the summer pose a problem to grazing farmers. The introduction of alternative forage varieties is being suggested as a possible solution to increase forage production over the summer, and crops such as forage chicory (*Cichorium intybus* L.) and English plantain (*Plantago lanceolata* L.) are being considered for this purpose.

Chicory was first reported as having an excellent forage value under rotational grazing by Lancashire (1978). The chicory cultivar "Grasslands Puna" was released in 1985 and has been frequently used in the USA, and is reported to have good summer productivity (Jung et al., 1996; Volesky, 1996). It is suggested that this cultivar has similar or higher digestibility than mixed pastures of perennial ryegrass and white clover (Hoskin et al., 1999) and similar or higher digestibility than birdsfoot trefoil (Min et al., 1997; Fraser and Rowarth, 1996). It has also been suggested that faster rumen degradation and rates of passage through the digestive tract improve voluntary feed intake and subsequently the growth rate of deer grazing chicory (Kumarstono et al., 1997). Other chicory cultivars such as Forage Feast and INIA Lacerta are available on the market however, little information is known regarding their performance in the NE USA.

*Plantain* sp. has a broad distribution in grasslands throughout the temperate world and occurs naturally in contrasting environments (Haeck, 1992). It can also grow in a wide range of agricultural soils (Stewart, 1996). Two forage cultivars of *Plantago lanceolata* L., Grasslands Lancelot and Ceres Tonic, were selected for their upright growth habit and larger leaves than the naturally occurring types (Rumball et al., 1997, Stewart, 1996). The leaves of plantain cultivars are highly palatable to animals and have a similar digestibility to perennial ryegrass and birdsfoot trefoil pastures (Fraser and Rowarth, 1996).
A drawback of chicory and plantain is their capacity to bolt over the entire growing season, which could undermine their potential use under grazing conditions. The objectives of these studies were to evaluate chicory and plantain cultivars under different grazing systems and to assess the nutritive value of their herbage when grown in the NE USA.

**MATERIALS AND METHODS**

Two field experiments were conducted at the Pennsylvania State University Haller Farm Beef Research center near State College, PA. The soil at the experimental site was a Hagerstown silt loam (fine, mixed, mesic Typic Hapludalfs). The purpose of the first experiment was to evaluate different commercially available cultivars of chicory and plantain when grown in the NE U.S.A., to test their nutritive value as forages under grazing and compare it against the performance orchardgrass, a traditionally used species in the region. The second experiment aimed to test and develop the most appropriate grazing strategies for either species that would ensure potential growth (companion paper) and nutritive values over the year, particularly in the summer when forage is scarce.

**Experiment 1: Planting conditions, treatments and experimental design**

Chicory cultivars Forage Feast, Grasslands Puna and INIA LE Lacerta, and plantain cultivars Grasslands Lancelot and Ceres Tonic, as well as Pennlate orchardgrass, were seeded in May 1997. A Hege 1000 series plot drill planter adjusted to seeding rates of 4.5 kg ha\(^{-1}\) for chicory and 11 kg ha\(^{-1}\) for plantain and orchardgrass was used for planting. Soil tests to a 15-cm depth in March 1998 indicated a pH of 6.3 and 93 kg ha\(^{-1}\)P, 489 kg ha\(^{-1}\) K, and 256 kg ha\(^{-1}\) Mg. No fertilizer was added at planting. Nitrogen fertilization in 1998 totaled 50 kg ha\(^{-1}\) N applied on 10 April and 15 June in the form of urea. Additionally, on 10
April 60 kg ha\(^{-1}\) P and 120 kg ha\(^{-1}\) K were applied. Mowing was used to control weeds during the year of establishment.

The experimental design was a randomized complete block (four blocks) with a split plot arrangement of cultivars randomly assigned to subplots within the grazing treatments main plots. Plot size (cultivars within grazing treatment) was 12 by 14 m. The grazing treatments consisted of combinations of frequency (three and five wk rest period) and intensity (50 or 150 mm stubble residue) of grazing. Paddocks were grazed ‘frequently and severe’ (FS = 3 wk x 50 mm), ‘frequently and light’ (FL = 3 wk x 150 mm), ‘infrequently and severe’ (IS = 5 wk x 50 mm), or ‘infrequently and light’ (IL = 5 wk x 150 mm). All cultivars (subplots) within a grazing treatment (main plot) and block were grazed at the same time for an occupation period not longer than 36 h using 12 to 14 beef cow-calf pairs. Grazing began in 4 May and ended 9 September 1998. Herbage mass was measured pre and post grazing in four 0.1m\(^2\) quadrats cut to ground level with electric shears. One of four pre-grazing biomass samples was separated into target and non-target species. All material was oven dried at 55 °C for 48 h and weighed. Target species material was ground through a 2 mm Willey mill screen (Thomas-Willey) and re-ground to pass a 1 mm screen in a UDY mill (UDY Corp., Colorado). Nutritive value estimates were performed by the Crop Quality Laboratory at Penn State University using a near infra-red reflectance spectroscope (model 6250, NIRSystems, Silver Spings, MD) to predict crude protein, fiber fractions and digestibility. A calibration set of 100 samples was selected using CENTER and SELECT computer software (ISI Software, Port Matilda, PA; Shenk and Westerhaus, 1991) and used to test the calibration equation. Calibration samples were analyzed for total crude protein (CP = combustion N x 6.25; AOAC method 99.03, 1990), neutral detergent fiber analysis (NDF_Ankom; Van Soest, 1967; modified for using ANKOM) and in vitro true dry matter digestibility (IVTDMD_Ankom; Tilley and Terry, 1963; modified for ANKOM technology). Crude protein analyses was performed by the Agricultural Analytical Laboratory at Penn State University. Calibration statistics for CP estimation were SECV = 1.07, Bias = -0.20, SEC(C) =1.07, RSQ
= 0.959 (where SECV is the standard error for cross validation, SEC(C) is the standard error for calibration uncorrected for bias). Calibration statistics for NDF_Ankom estimation were SECV = 2.76, Bias = -0.75, SEC(C) =2.62, RSQ = 0.937. Calibration statistics for NDF_Ankom estimation were SECV = 2.76, Bias = -0.75, SEC(C) =2.62, RSQ = 0.94. Calibration statistics for IVTDMD_Ankom estimation were SECV = 1.85, Bias = negligible, SEC(C) =1.85, RSQ = 0.94.

Statistical analyses of results were performed using the MIXED procedure of SAS (SAS Institute V.8.2, 2000). Results for herbage quality were analyzed for three dates in 1998, 5 May (spring), 8 August (mid-summer), 22 September and 5 October on frequently and infrequently grazed plots respectively (considered late-summer). Pre-planned orthogonal contrasts were used (Steel et al., 1997). Cultivars were evaluated using Pennlate orchardgrass as the ‘control’. Pre-planned cultivar comparisons were Forage Feast chicory (Fc) vs. Pennlate orchardgrass (Penn), Lacerta chicory (Lc) vs. Penn, Puna chicory (Pc) vs. Penn, Tonic plantain (Tp) vs. Penn, and Lancelot plantain (Lp) vs. Penn. Grazing treatment by cultivar means were compared for the effect of grazing treatment within each cultivar (e.g. yield of IS Puna chicory vs. yield IL Puna chicory). Overall grazing treatment effect was also compared. Pre-planned grazing treatment comparisons were frequent vs. infrequent, severe vs. light, and all four grazing treatments combinations.

**Experiment 2: Planting conditions, treatments and experimental design**

Grasslands Puna chicory, Grasslands Lancelot plantain and Pennlate orchardgrass were seeded on August 1999 in a different field with similar soil type at the Haller Beef Research Farm. Soil tests prior to planting indicated a pH of 6.5 and nutrient content by Mehlich 3 of 89 kg ha⁻¹ P, 325 kg ha⁻¹ K, and 205 kg ha⁻¹ Mg. The plot area was tilled during the spring of 1999 but seeding was delayed due to drought conditions. Before seeding, weeds were controlled with glyphosate. Seeding rates were similar to those used on Experiment 1. Mowing controlled weeds during establishment.
Nitrogen fertilizer was applied at a 75 - 85 kg ha\(^{-1}\) rate, split into two applications per year (May and August of 2000 and 2001). The experimental site was approximately 2.2 ha and each experimental unit was 0.09 ha. A split block design (four blocks) was used. Two grazing intensity treatments were tested to control reproductive development and were defined by the post grazing stubble height left during spring and summer. The ‘severe’ (SS) treatment plots were grazed down to an average canopy height of 50 mm during the entire season of growth, while the ‘severe-moderate’ (SM) plots were grazed to a 50 mm stubble height over spring and 100 mm during the summer. The grazing cycle was defined by the time required by each pasture to reach a 250 mm of canopy height in the case of orchardgrass and chicory and 200 mm for plantain plots. Residual height was measured once or twice over the occupation period, which never exceeded 36 hs. Two canopy height measurements were taken over the rest period to establish time to grazing. Pre-grazing herbage samples were taken from a 2-m section of one row and separated into components, leaves, flower stalks, dead leaves, stubble and weeds. All samples were oven dried at 55°C for 48h and weighed. Leaf area was determine on green leaves with a planimeter (Model Li-Cor 3000, Li-cor Inc., Lincoln, NE), and leaf area index (LAI, m\(^2\) m\(^{-2}\)) was estimated. This green leaf sample was oven dried and weighed separately to estimate specific leaf weight (SLA, cm\(^2\) g\(^{-1}\)). All weighed leaves and flower stalks were kept and ground for nutritive value assessment, which was estimated as described for Exp. 1. Results were separated into spring (May to July) and summer (mid July to beginning of October) and analyzed within seasons.

Statistical analyses of results were performed using MIXED procedure of SAS (SAS Institute V.8.2, 2000) based on guidelines to analyze a split-block presented by Steel et al. (1997) and Litell et al. (2000). A combined analysis over the years was performed and results were compared within seasons. Treatment means of herbage quality and herbage components were separated using pre-planned orthogonal contrasts (Tilley et al. 1998). Cultivar comparisons were made using Pennlate orchardgrass as a control. Pre-planned contrasts for cultivar comparisons were Puna chicory vs. Pennlate orchardgrass and Lancelot
Results and Discussion

Herbage nutritive value of different chicory and plantain cultivars.

Experiment 1

Differences in nutritive value between cultivars of chicory, plantain and Pennlate orchardgrass were observed in 1997, the year of establishment, and in 1998 (Table 6). The differences in nutritive value were more apparent at the beginning than at the end of the grazing season. In spring 1998, the chicory cultivars had an average CP concentration of 217 g kg⁻¹ while orchardgrass had 173 g kg⁻¹ (p<0.05). Among the plantains, however, only Tonic had a higher CP than Pennlate orchardgrass (210 vs. 173 g kg⁻¹, respectively, P<0.05). Crude protein concentration of Tonic plantain remained above 200 g kg⁻¹ throughout the grazing season, while that of Lancelot plantain fluctuated and was 194 g kg⁻¹ on average. In the summer harvests of 1997 and 1998 (average of mid and late summer harvests), the CP of chicory and plantain cultivars was 181 and 204 g kg⁻¹, respectively, whereas Pennlate orchardgrass had a CP concentration of 155 and 198 g kg⁻¹ in the same periods (P>0.05).

Jung et. al (1996), found no differences in the CP concentration of Puna chicory and Pennlate orchardgrass herbage when grazed frequently over a two year period (230 g kg⁻¹ for both species averaged over 1992 and 1993). Belesky et al. (2000) reported N concentration values ranging from 22 to 35 g kg⁻¹ at fertilization levels of 0 to 480 kg ha⁻¹ N. These values correspond to CP concentrations of 137 and 219 g kg⁻¹ respectively, which suggests that the N fertilization rate of 70 kg ha⁻¹ yr⁻¹ used in this study was sufficient to obtain adequate concentration of CP in Puna chicory. In addition, Belesky et al. (2000) and Collins and McCoy (1997) report that plant density of Puna chicory is
reduced with higher N fertilization rates, suggesting that there is no added benefit to increasing the amount of N used on chicory pastures.

The NDF concentration in chicory and plantain herbage was significantly lower than that of Pennlate orchardgrass in the year of establishment and the year following establishment (Table 6). Average NDF concentrations of 260 g kg$^{-1}$ were observed in the year of establishment but increased to values above 300 g kg$^{-1}$ in the following year. The highest values were observed in May 1998 when the average fiber concentration of chicory, plantain and orchardgrass was 381, 391 and 545 g kg$^{-1}$, respectively.

The NDF values reported by Holden et al. (2000) for Puna chicory and Pennlate orchardgrass under a variety of cutting intensities suggest that management levels had no effect on the NDF concentration of herbage, but differences were significant between the two species. The NDF values for Puna chicory and Pennlate orchardgrass were reported to be 207 g kg$^{-1}$ and 506 g kg$^{-1}$ respectively, both lower than those observed in this study. However, under clipping conditions, NDF concentrations obtained on a companion study for chicory and plantain herbage were slightly higher than in this study; the average NDF concentration for this study in May 1998 of Puna and Feast chicory and Lancelot and Tonic plantain was 468 and 497, respectively.

The IVTDMD of the three chicory cultivars was on average between four and six percent higher than that of Pennlate orchardgrass in the spring and in late summer of 1998 (896 and 905 vs. 863 and 853 g kg$^{-1}$, respectively, P<0.05). However, IVTDMD did not differ in Mid-summer (894 vs. 885 g kg$^{-1}$, respectively), which was due to an increase in the IVTDMD of the orchardgrass rather than a decrease in the digestibility of chicory dry matter. McCoy et al. (1997) report differences in IVTDMD of different strata of Puna chicory pastures, but they were lower than 750 g kg$^{-1}$ at least five percent lower than the values observed in this study under grazing.

The IVTDMD of plantain cultivars was not higher than that of Pennlate orchardgrass in any of the harvest dates (857 vs. 867 g kg$^{-1}$ average over the year, respectively). Levels of cellulose tend to be higher in grasses than in
dicots, which may limit dry matter intake but not necessarily its digestibility (Minson, 1990). Estimated values of IVTDMD for naturally occurring species of plantain of 804 g kg\(^{-1}\) have been reported (Derrick et al., 1993), but no reports have been found concerning the nutritive value of Plantago sp. under grazing conditions.

The frequency and intensity of grazing (Table 7) had a significant effect on the CP concentration and the IVTDMD in herbage grown over mid and late summer of 1998. Protein concentration of herbage produced in August and the September-October harvests of 1998 was significantly affected by the frequency and intensity of grazing. The frequency with which the pastures were grazed in mid-summer had a more prominent effect on the CP concentration of herbage than did the intensity. The difference between grazing every 3 wk or every 5 wk was almost 20\% (229 vs. 189 g kg\(^{-1}\), P<0.01). Similar to the findings in this study, Holden et al. (2000), reported that the more frequently clipped plots exhibited a higher CP concentration than the less frequently harvested (225, 166 and 149 g kg\(^{-1}\) on the frequent, moderate, less frequent harvest, respectively; average over 1992 and 1993).

The IVTDMD of herbage from chicory, plantain and orchardgrass was particularly lower when the plots were grazed every 5 wk to a stubble height of 150 mm (Table 7). The average herbage IVTDMD of frequently grazed plots was 890 g kg\(^{-1}\), four percent higher than the IVTDMD of infrequently grazed pastures (P<0.05). However, this difference occurred only over mid-summer of 1998.

**Herbage nutritive value of Puna chicory and Lancelot plantain - Experiment 2**

The CP concentrations in spring (average over both years of study) of Puna chicory and Lancelot plantain were similar to those of orchardgrass (174, 161 and 165 g kg\(^{-1}\), respectively; Table 8). However, over the summer Puna chicory herbage had a higher CP than that of Pennlate orchardgrass (191 vs.
179 g kg\(^{-1}\), \(p<0.05\), while CP of Lancelot plantain was similar to that of orchardgrass as in Exp.1. The NDF concentrations of the forbs was constantly lower than in orchardgrass herbage (383, 375 and 484 g kg\(^{-1}\) for Puna chicory, Lancelot plantain and Pennlate orchardgrass, respectively, \(p<0.001\) in both comparisons). Finally, IVTDMD of Puna chicory herbage over the spring (872 g kg\(^{-1}\)) and summer (899 g kg\(^{-1}\)) was slightly higher than that of Pennlate orchardgrass (864 and 865 g kg\(^{-1}\) over spring and summer, respectively), which was higher than that of Lancelot plantain (740 and 773 g kg\(^{-1}\) over spring and summer, respectively).

Leaf to stem ratios (L/S, Table 9) of Puna chicory and Lancelot plantain herbage in spring 2001 were one half the ratio in 2000 (2.94 for both species in 2000 and almost 1.5 in 2001, \(p<0.001\) for year comparison). Over the summer, Puna chicory’s L/S ratio was less than a quarter in 2001 of what was observed in 2000 (3.8 vs. 14.3 over 2001 and 2000, respectively \(p<0.05\)), while the L/S ratio of the plantain herbage between years was similar (10.6 on average between 2000/01). The composition of the herbage of Pennlate orchardgrass over the spring was also different between years, but the relation was opposite. The proportion of leaves over stems was 4.4 during 2000 and 25.0 during 2001 (\(p<0.05\)), while over the summer the herbage was composed of leaves only.

Comparisons of the nutritive value of herbage between 2000 and 2001 can be related to the developmental stage of the pastures and, to a lesser extent, to weather conditions being more stressful over 2001 (Table 10). However, there was no year by species interaction suggesting that regardless of the differences in herbage composition between years and seasons, the relationship between species remained the same. It was observed that during the spring, the nutritive values of the three species in 2001 was significantly lower than in 2000 (CP: 183 vs. 150 g kg\(^{-1}\), \(p<0.01\); NDF: 392 vs. 435 g kg\(^{-1}\), \(p<0.05\); IVTDMD: 846 vs. 804 g kg\(^{-1}\), \(p<0.05\); on 2000 and 2001, respectively). In the summer however, these differences disappeared.

The nutritive values of most forage species vary over time. This variation can be associated to reproductive stages, maturity of plant parts (Buxton et al.,
1985) and, in the case of grazed pastures, the effect of treading and dung and urine depositions (Minson, 1990). Reproductive stages of Pennlate orchardgrass are early in the spring while chicory and plantain may flower later in the spring and summer (Castellano-Cantero, 1997; Stewart, 1996). It is possible that differences in the timing to reproductive development are associated with nutritive values observed since most differences occurred over the spring between the forbs and orchardgrass.

CONCLUSIONS

Nutritive value of chicory and plantain cultivars was evaluated over a three year period and under a range of grazing frequencies and intensities. Frequency of grazing, rather than intensity, had an effect over the nutritive value of both the plantain and chicory cultivars, for which a rest period no longer than 5 wk was more advantageous. In general, Puna chicory and Lancelot plantain herbage had an NDF concentration lower than that of orchardgrass, but had a similar protein concentration. The digestibility of the herbage of Puna chicory and Lancelot plantain varied over the years, and in the last two years of study Lancelot plantain exhibited a lower digestibility than orchardgrass, while Puna chicory had similar or even higher herbage IVTDMD than the grass. Puna chicory herbage had a higher IVTDMD and lower NDF concentration than Pennlate orchardgrass over the summer, which would confer an advantage for farmers over this season improving both dry matter intake and digestible energy of pastures. This advantage is not masked by the tendency of the chicory species to bolt over the entire grazing season.
REFERENCES


Hoskin, S.O., T.N. Barry, P.R. Wilson, W.A.G. Charleston, and J. Hogdson. 1999. Effects of reducing anthelmintic input upon growth and faecal egg and larval counts in young farmed deer grazing chicory (Cichorium intybus) and perennial ryegrass (Lolium perenne)/white clover (Trifolium repens) pasture. J. Agric. Sci. 132:335-345.


Min, B.R., T.N. Barry, P.R. Wilson, and P.D. Kemp. 1997. The effects of grazing chicory (Cichorium intybus) and birdsfoot trefoil (Lotus corniculatus) on venison ad velvet production by young red and hybrid deer. NZ J. Agric. Res. 40:335-347.


Table 6: Nutritive value of chicory, plantain and orchardgrass under different grazing treatments in the year of establishment and during 1998 (Exp. 1).

<table>
<thead>
<tr>
<th>Species / Cultivar §</th>
<th>Summer 1997 †</th>
<th>Spring 1998</th>
<th>Mid-Summer 1998</th>
<th>Late-Summer 1998</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CP‡ NDF</td>
<td>CP NDF IVTDMD</td>
<td>CP NDF IVTDMD</td>
<td>CP NDF IVTDMD</td>
</tr>
<tr>
<td>Chicory</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feast</td>
<td>160 255</td>
<td>212 399 892</td>
<td>211 321 922</td>
<td>216 277 935</td>
</tr>
<tr>
<td>Lacerta</td>
<td>143 240</td>
<td>221 384 892</td>
<td>201 350 878</td>
<td>169 371 847</td>
</tr>
<tr>
<td>Puna</td>
<td>166 251</td>
<td>214 361 905</td>
<td>207 328 882</td>
<td>220 291 932</td>
</tr>
<tr>
<td>Plantain</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lancelot</td>
<td>150 284</td>
<td>179 391 849</td>
<td>216 347 795</td>
<td>188 288 870</td>
</tr>
<tr>
<td>Tonic</td>
<td>131 264</td>
<td>210 390 872</td>
<td>219 312 873</td>
<td>203 283 884</td>
</tr>
<tr>
<td>Orchardgrass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pennlate (Penn)</td>
<td>155 538</td>
<td>173 545 863</td>
<td>198 510 885</td>
<td>197 529 853</td>
</tr>
<tr>
<td></td>
<td>SE 4.9 5.8</td>
<td>5.5 11.0 7.9</td>
<td>12.9 18.4 21.3</td>
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<td>Contrasts</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Feast vs. Penn</td>
<td>NS * * * *</td>
<td>NS * NS</td>
<td>NS * * *</td>
<td>NS * * *</td>
</tr>
<tr>
<td>Lacerta vs. Penn</td>
<td>NS * * * *</td>
<td>NS * NS</td>
<td>* * NS</td>
<td>NS * NS</td>
</tr>
<tr>
<td>Puna vs. Penn</td>
<td>NS * * * *</td>
<td>NS * NS</td>
<td>NS * *</td>
<td>NS * NS</td>
</tr>
<tr>
<td>Lancelot vs. Penn</td>
<td>NS * NS *</td>
<td>NS * NS</td>
<td>NS * NS</td>
<td>NS * NS</td>
</tr>
<tr>
<td>Tonic vs. Penn</td>
<td>NS * * NS</td>
<td>NS * NS</td>
<td>NS * NS</td>
<td>NS * NS</td>
</tr>
</tbody>
</table>

* Significant at the 0.05 probability level.
† Dates correspond to 10 July 1997, and in 1998 to 4 May, 24 Aug., and 9 Sept. or 5 Oct. on frequently and infrequently grazed plots, respectively.
‡ CP, crude protein; NDF, neutral detergent fiber; IVTDMD, in vitro true dry matter digestibility. Data are average of chicory, plantain and orchardgrass cultivars.
§ Data are average of herbage yield over four grazing treatments and 4 replicates (n=16)
¶ Pre-planned orthogonal contrasts.
Table 7: Nutritive value of herbage as affected by grazing treatment in three different dates over 1998 (Exp. 1).

<table>
<thead>
<tr>
<th>Grazing treatment ‡</th>
<th>Spring 1998</th>
<th>Mid-Summer 1998</th>
<th>Late-Summer 1998</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CP†</td>
<td>NDF</td>
<td>IVTDMD</td>
</tr>
<tr>
<td>Frequent Severe</td>
<td>206§</td>
<td>415</td>
<td>878</td>
</tr>
<tr>
<td>Frequent Light</td>
<td>201</td>
<td>404</td>
<td>884</td>
</tr>
<tr>
<td>Infrequent Severe</td>
<td>199</td>
<td>424</td>
<td>872</td>
</tr>
<tr>
<td>Infrequent Light</td>
<td>200</td>
<td>405</td>
<td>881</td>
</tr>
<tr>
<td>SE</td>
<td>9.5</td>
<td>11.3</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Contrasts #

- Frequent vs. Infrequent: NS NS NS ** NS * NS NS NS NS
- Light vs. Severe: NS NS NS * NS * NS NS NS NS
- Frequency* Intensity: NS NS NS NS NS NS NS NS NS

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.
† CP, crude protein; NDF, neutral detergent fiber; IVTDMD, in vitro true dry matter digestibility. Data are average of chicory, plantain and orchardgrass cultivars.
‡ Frequent grazing occurred at 3-wk intervals and infrequent at 5-wk intervals. Under severe intensity a 50-mm stubble height was left while under slight grazing intensity a 150-mm stubble was left.
§ Data are average of herbage yield Puna, Feast and Lacerta chicory, Lancelot and Tonic plantain and Pennlate orchardgrass, and four replicates (n=24)
# Pre-planned orthogonal contrasts.
Table 8: Herbage quality of grazed Puna chicory, Lancelot plantain and Pennlate orchardgrass during 2000 and 2001 (Exp. 2).

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Spring</th>
<th></th>
<th>Summer</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CP †</td>
<td>NDF</td>
<td>IVTDMD</td>
<td>CP</td>
</tr>
<tr>
<td>Puna chicory</td>
<td>174</td>
<td>383</td>
<td>872</td>
<td>199</td>
</tr>
<tr>
<td>Lancelot plantain</td>
<td>161</td>
<td>375</td>
<td>740</td>
<td>168</td>
</tr>
<tr>
<td>Pennlate orchardgrass</td>
<td>165</td>
<td>484</td>
<td>864</td>
<td>179</td>
</tr>
<tr>
<td>SE</td>
<td>5.9</td>
<td>14.0</td>
<td>17.8</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Contrasts ‡

- Puna vs. Pennlate: NS *** NS * *** **
- Lancelot vs. Pennlate: NS *** *** NS *** ***

*, **, *** Significant at the 0.05, 0.01 and 0.001 probability levels.

† CP, crude protein; NDF, neutral detergent fiber; IVTDMD, in vitro true dry matter digestibility. Data are average of chicory, plantain and orchardgrass cultivars.

‡ Cultivar mean pre-planned orthogonal contrasts against Pennlate (p < 0.05).
Table 9: Leaf to stem ratio of Puna chicory, Lancelot plantain and Pennlate orchardgrass under grazing during 2000 and 2001 (Exp. 2).

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Puna chicory</td>
<td>Lancelot plantain</td>
</tr>
<tr>
<td>Leaf-stem ratio ‡</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>2.94a§</td>
<td>2.94a</td>
</tr>
<tr>
<td>2001</td>
<td>1.52a</td>
<td>1.43a</td>
</tr>
<tr>
<td>SE</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>2000 vs. 2001</td>
<td>***</td>
<td>***</td>
</tr>
</tbody>
</table>

*, *** Significant at the 0.05 and 0.001 probability level, respectively.
† No reproductive stems were observed in Pennlate orchardgrass over the summer.
‡ Data are average of two grazing intensity treatments, severe / severe treatment grazed to 50 mm over both seasons, and severe/moderate intensity grazed to 100 mm over the summer.
§ Different letters within years denote significant differences among species (orthogonal contrast chicory vs. orchardgrass or plantain vs. orchardgrass, P< 0.05).
Table 10: Variability of herbage nutritive value of grazed chicory, plantain and orchardgrass cultivars over a two year study (Exp. 2).

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CP†</td>
<td>NDF</td>
</tr>
<tr>
<td>Year</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>183‡</td>
<td>392</td>
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<tr>
<td>2001</td>
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<td>435</td>
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<tr>
<td>SE</td>
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<td>1.04</td>
</tr>
</tbody>
</table>

Contrast §

| 2000 vs. 2001 | **            | *            | *            | NS | NS | NS     |

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.
† CP, crude protein; NDF, neutral detergent fiber; IVTD, in vitro true dry matter digestibility. Data are average of chicory, plantain and orchardgrass cultivars.
‡ Data are average of herbage yield of Puna chicory, Lancelot plantain and Pennlate orchardgrass, two grazing treatments, four replicates and two (spring) or three (summer harvest.
§ Pre-planned orthogonal contrasts.
CHAPTER 4

Response to Water Deficit of Grasslands Puna Chicory and Grasslands Lancelot Plantain
INTRODUCTION

Summer growth of cool season forages in the Northeast USA is reduced as a consequence of a combination of high temperatures and drought. Although the region is considered temperate and humid, periods without rainfall can last from a few weeks to over a month. Recent years have seen longer periods of drought (Jain et al., 2002). Herbage production decreases during the summer, generating an imbalance between the needs of the grazing animal and herbage availability. Among the species used for pastures, alfalfa produces the highest yields over the summer compared to other forages, but its production is limited to the best quality soils. Thus, there is a need for alternative forage species that remain active over the summer and that can be grown in a variety of soil conditions.

In the past 15 yr, several chicory (Cichorium intybus L.) and narrow leaf plantain (Plantago lanceolata L.) cultivars have been bred as forage crops, and some of them have been reported to be summer tolerant (Rumball et al., 1997; Stewart, 1996). Grasslands Puna chicory and Grasslands Lancelot plantain were bred and tested for summer tolerance in New Zealand where their performance in comparison to orchardgrass (Dactylis glomerata L.) was considered promising (Stewart, 1996; Moloney and Milne, 1993). These cultivars are now being marketed in the northeastern USA as alternative pasture species. Very little information is available concerning the summer herbage productivity of Lancelot plantain and Puna chicory in this region (Labreveux et al., 2001; Sanderson et. al, 2001; Belesky et al., 1999). In addition, the mechanisms that allow these species to tolerate or avoid water deficit stress and/or high temperature have not been investigated. Studies of root chicory suggested that under mild water stress its taproot allowed for the exploitation of water at greater soil depth maintaining root yield. However, aboveground biomass yield was very sensitive to stress (Schittenhelm, 1999). Studies of natural stands of P. lanceolata suggested that their mechanisms to
cope with drought stress involved midday stomatal closure and maintenance of plant water status (Woldendort and Smit, 1992).

The characteristics required for a species to succeed under drought stress will vary with the climatic conditions under which the species is grown. Growth characters related to drought tolerance are easier to identify for plants growing in a Mediterranean climate than for those growing in a temperate region such as the NE USA. Drought periods in temperate climates are less predictable than in Mediterranean climates (Whitmore, 2000). Among temperate agricultural species, avoidance rather than tolerance to drought are more common mechanisms, since tolerance to drought, such as tolerance to desiccation or osmotic adjustment, is generally correlated with lower productivity (Hall, 2001; McKenzie et al., 1999). In order to improve herbage availability over the summer, avoidance strategies in forage crops should involve the capacity to explore deep sources of water (Volaire et al., 1998) and/or minimize water loss by reducing transpiring leaf area. However, the extent of the reduction in transpiring leaf area should not limit herbage productivity (Durand et al., 1989). The objectives of this study were to evaluate the performance of forage cultivars of chicory and plantain when subjected to drought cycles, and shed light on the attributes of these two species that might allow them to remain active over the summer in the NE USA.

**MATERIALS AND METHODS**

**Study site and seeding conditions**

Two rainout shelters at the Russell E. Larson Agriculture Research Center near State College, PA, were used to create soil water depletion cycles for Grasslands Puna chicory and Grasslands Lancelot plantain. An adjacent field plot was used as a control treatment where the same cultivars had adequate
levels of water available during the entire growing period. The soil at the site was a Murril silt loam. Analysis of soil (Mehlich 3) prior to seeding in September 1999, indicated a pH of 6.2, 102 kg ha\(^{-1}\) P, 307 kg ha\(^{-1}\) K, and 319 kg ha\(^{-1}\) Mg. The area was tilled and cultivars were seeded with a Carter seeder into 16 m\(^2\) plots at a seeding rate of 4.5 kg ha\(^{-1}\) for Puna chicory and 11 kg ha\(^{-1}\) for Lancelot plantain.

**Treatment description - 2000**

From July to September of 2000, three 3-wk soil water depletion cycles (Stressed treatment) were imposed on those plots located within the rain shelters. Plots in the adjacent uncovered field received abundant water every week from irrigation and ambient rainfall to maintain the soil at field capacity (Watered treatment). A sprinkler system was installed to water individual plots in both the rainout shelters and the uncovered field plots. The stress treatment was watered to field capacity once every 3 wk. Volumetric soil water content was measured weekly between 1000 and 1400 h from which water requirements for future irrigation were assessed. Volumetric soil water content was monitored with a Troxler nuclear gauge (Troxler Electronic Laboratories Inc. Research Triangle Park, NC). Access tubes were installed on two replicates of each water treatment and species. The soil cores removed during the installation of the access tubes were used to calibrate the nuclear gauge. The soil cores were divided into 10-cm segments, weighed, oven-dried at 100 °C for 72 h and re-weighed to determine gravimetric soil water content. The relationship between estimated and measured soil water was \(Y = 19.7 + 0.42x\).
r=0.952, p<0.0001). Soil data necessary for further calculations such as bulk density and water content at field capacity and permanent wilt were available for the site from analysis performed at the time the rainout shelters were constructed. Average volumetric soil water content at field capacity (-0.03 MPa) for a depth of 0 – 30 cm and 30 – 60cm of soil was 0.32 m$^3$ m$^{-3}$ (volume of water per volume of soil) in both cases. These values at permanent wilt (-1.5 MPa) were 0.15 and 0.20 m$^3$ m$^{-3}$ for the first and second 30 cm of the soil profile, respectively.

At the beginning of each 3-wk growth cycle, plots were mowed to a stubble height of 70-mm, after which both stressed and well-watered plots were watered. Three weeks later, productivity, as well as morphological and physiological parameters were assessed. Herbage clippings together with plant counts were taken from four 30 x 30 cm quadrats cut to 70-mm. Three quadrat samples were oven-dried for 48 h at 65 °C and weighed. The remaining quadrat sample was separated into stems, weeds, and green and dead leaves. Leaf area was determined on green leaves with a planimeter (Model Li-3000, Li-Cor Inc., Lincoln, NE). Plant parts were oven-dried at 65 °C for 48 h and weighed.

Physiological characteristics measured were related to single leaf gas exchange traits and pre-dawn water potential. Leaf gas exchange was measured with a Li-Cor 6400 (Li-Cor Inc, Lincoln, NE) open system portable gas analyzer on the last fully extended leaf of eight plants per sub-plot, ten recordings being taken per leaf from 1100 to 1400 h. Water potential was measured before sunrise with a pressure chamber (PMS Corvallis, OR) on four young fully extended leaves per subplot (Turner, 1981).
Soil water depletion cycles during 2000 spanned from mid July to the beginning of October. The first cycle was started on 14 July and was harvested on 28 July, the second cycle started on 7 August and was harvested on 25 August, and lastly the third cycle ran from 11 September until 2 October.

**Treatment modifications applied in 2001**

During 2001, the experiment was repeated with some modifications. Due to a poor winter survival, plant density of Lancelot plantain was low and consequently dropped from the experiment. In addition, the drought cycles imposed on Puna chicory plots were increased to 5-wk. Samples for dry matter yield determination and physiological trait measurements were taken 3 wk and 5 wk into the drying cycle. After 5 wk of regrowth all plots were mowed to a 7-cm stubble height to begin a new cycle. Morphological and physiological traits were measured during 2001 using the protocol from the previous year; however, pre-dawn water potential was not measured.

During 2001, the cycles ran from 2 May until 12 July as the final harvest (5 wk) with an intermediate harvest (3 wk) on 29 June. The second cycle was started on 16 July, was sampled after three weeks on 2 August, and the final harvest was made on 22 August. Soil and air temperature for both years was recorded with a weather station located 200 m from the experimental site (Table 11).


**Statistical analyses**

The experimental design was completely random with 4 replications and a split-plot arrangement of treatments. Water treatments were whole plots and species were subplots. Data were analyzed using a repeated measures mixed model (The MIXED Procedure, SAS Version 8.2, SAS Inc.) with watering cycles as the repeated factor. The five error terms (replicates, replicates by week interaction, replicates by cycle interaction, replicates by water by cycle interaction, and the residual) were modeled as random effects; water treatment, species, and watering cycles were treated as fixed effects. Covariance structures for the repeated measure analyses were modeled by either compound symmetry or heterogeneous compound symmetry depending on which structure resulted in the most efficacious model (Littell et al., 1996). A compound symmetry structure has constant variance and covariance for all watering cycles, while a heterogeneous compound symmetry structure allows different variance and covariance for each cycle or pair of cycles. Pre-planned comparisons were performed using Tukey’s procedure (Steel et al., 1997). Pre-planned comparisons were well-watered vs. stressed, Puna chicory vs. Lancelot plantain, the species by water treatment interaction, and the effect of cycles within a species by water treatment interaction.
RESULTS AND DISCUSSION

Description of soil water content

Well watered control plots, from here on referred to as well-watered or simply watered, were maintained near field capacity, which was estimated to be 0.32 m$^3$ m$^{-3}$ for both the first and second 0.30 m of the soil profile. Volumetric soil water content (VWC) of watered Lancelot plantain plots was on average over the season 0.30 m$^3$ m$^{-3}$ (Figure 3). Soil water depletion cycles were observed in the first 0.30 m of soil in the stressed treatment plots. In this layer, VWC after watering was close to 0.30 m$^3$ m$^{-3}$ and decreased to 0.2 m$^3$ m$^{-3}$ after 3 wk.

Volumetric soil water content of well-watered Puna chicory plots (Figure 4) was more variable and slightly lower than that of Lancelot plantain plots. The water content in the first 0.30 m of soil varied between 0.25 and 0.30 m$^3$ m$^{-3}$, but at the depth of 0.30 to 0.60 cm it remained above 0.30 m$^3$ m$^{-3}$ on average. As observed in Lancelot plantain plots when subjected to drought, cycles of water depletion were evident in the first 0.30 m of the profile. Both the maximum and minimum observations were lower in Puna chicory than in Lancelot plantain plots. Maximum readings after watering in the first 0.30 m layer were 0.25 m$^3$ m$^{-3}$, and minimum readings reached values of 0.17 m$^3$ m$^{-3}$. In the 0.30 to 0.60 m depth, average VWC was 0.27 m$^3$ m$^{-3}$. Similar results were observed during 2001 when Puna chicory pastures were subjected to 5 wk of drought. Watering cycles and VWC changes for 2001 are presented in Figure 5.

Dry matter yields and plant density. Experiment 1

Herbage mass of Puna chicory and Lancelot plantain varied over time (Table 12); effects differed between each of the three 3-wk water cycles (water treatment*species *watering cycle interaction, P < 0.01). During the first watering cycle, stressed plants of Puna chicory produced 61 g m$^{-2}$, half as much dry matter (DM) as their well watered counterparts, which produced 128 g m$^{-2}$
(P < 0.01). During the second and third watering cycles this difference diminished. Stressed chicory plants produced 127 g m\(^{-2}\) during the second cycle whereas well watered chicory produced 191 g m\(^{-2}\). During the third cycle the yields of stressed and watered plots were 74 vs. 61 g m\(^{-2}\), respectively (P>0.05). The differences observed between water treatments in the first cycle could be the result of an acclimation period during which stressed Puna chicory plants allocated a larger amount of carbohydrates to the production and growth of roots over shoots (Onillon et. al, 1995) until taproots reached beyond the first 0.30 m of depth were water availability was high and near field capacity.

Lancelot plantain responded to the water treatments differently than Puna chicory. During the first two growing cycles, stressed plants yielded more than watered ones (Table 12). On average, well watered plants yielded 38 and 67 g m\(^{-2}\) during the first and second cycle, respectively, while the stressed plots yielded 69 and 145 g m\(^{-2}\) (difference not significant for the first cycle and P <0.01 over the second cycle). The lower yield of well-watered plots was associated with a significant loss in plant density (Figure 6). Plant losses of the Plantago lancelolata cultivars Lancelot plantain and Ceres tonic grown in the northeastern US have been well documented (Labreveux et al., 2001; Sanderson et al., 2001), and are associated with winter kill (Skinner and Gustine, 2002).

On the last watering cycle, which took place from mid September to 1 October, yields of chicory and plantain were similar regardless of the water treatment applied. Plant density at this point was similar for all species and treatments with an average density of 65 plant m\(^{-2}\) (Figure 6). Although plant density of Puna chicory was 50 to 60% of the initial stand this is an appropriate plant density to sustain adequate DM yields, (Sanderson et al., 2001; Labreveux et al., 2001; Collins and McCoy, 1997). However, a stand of 65 plants m\(^{-2}\) does not appear to be sufficient to achieve potential Lancelot plantain yields as it was observed under grazing conditions (Chapter 1).

Plant density loss was observed on all plots regardless of watering levels or species. But, well-watered plantain plots lost more than two thirds of its plant stand (180 to 48 plants m\(^{-2}\)) within the first 7 wk of starting the
experiment, while during the same period the stand density of stressed Lancelot plantain decreased only by one third, from 150 to 100 plant m\(^{-2}\). Although plant loss was not as dramatic as for the plantain, well watered chicory plots lost more plants over the first 3 wk of the experiment than stressed chicory plots did (decrease from 180 to 120 plants m\(^{-2}\) and from 125 to 110 plants m\(^{-2}\) in well watered vs. stressed plots, respectively). Plant losses of Puna chicory could also be attributed to winter kill (Skinner and Gustine, 2002) as well as to a natural thinning of the plant stand over time (Castellano-Cantero, 1997; Li et al., 1997a; McCoy and Collins, 1997), while winter kill is the main factor affecting the decrease in plant density of Lancelot plantain. In this study we observed a lower thinning of plots subjected to drought stress, which suggest an association between stress imposed and a delay in death of plantain plants.

**Leaf growth and leaf area**

Leaf area index (LAI), was reduced by water stress in Puna chicory (Table 14). Leaf area index of Puna chicory under water stress was 2.7, one and a half times smaller than its LAI of 4.2 on well watered plots that reached 4.2 (P<0.05). The specific leaf area (SLA) of stressed chicory plants, although not statistically significant, was also reduced by ten percent when compared to well watered plants (33.8 and 30.0 m\(^2\) kg on watered and stressed plants, respectively). Increases in leaf weight as a consequence of drought stress have been reported for forage grass species, and have been related to an increase in the accumulation of sugars at the expense of structural carbohydrates (Durand et al., 1989). Leaf growth and leaf area development are considered to be among the first indicators of drought stressed forage species (Elbersen and West, 1996; Lemaire et al., 1987;) as well as in grain crops such as sorghum (Borrell et. al, 2000) and corn (Stone et. al, 2001). At higher levels of stress, physiological functions are altered, stomatal conductance is reduced, and evaporation might not be sufficient to maintain leaf temperature which may result in an increase in heating, and decreased photosynthesis (Hall, 2001). Maintenance of green
leaf area is essential to sustain radiation interception and carbon assimilation during critical periods of crop growth (Borrell et al., 2000), but a reduction of one and a half units, from 4.2 to 2.7, in the LAI of Puna chicory plots did not seem to affect its yield, suggesting that intercepted radiation was not significantly reduced. Carbon assimilation in turn was not affected either. Photosynthesis levels of watered and stressed plants of Puna chicory indicate that the drought conditions imposed did not significantly affect carbon assimilation (12 vs. 10 µmol CO₂ m⁻² s⁻¹ on watered and stressed treatment respectively, P>0.05).

The LAI of Lancelot plantain plants was similar in watered and stressed conditions (LAI 1.4, SE= 0.4; Table 14). This apparent lack of response to stress in Lancelot plantain seems to be better explained by the reduction in plant density mentioned previously than by physiological reasons. A significant response was observed in the values of SLA of stressed and watered plants of Lancelot plantain. The same increase in weight at the expense of leaf area expansion observed in chicory plants was evident in plantain. The SLA on watered plots was 23 m² kg⁻¹, one third larger than the values for the stressed plants (15 m² kg⁻¹, P<0.05). On average the SLA of Puna chicory was almost 70% higher than that of Lancelot plantain (31.9 vs. 19.2 m² kg⁻¹, respectively, P<0.001). The SLA of a species is positively correlated with its relative growth rate, or the efficiency of production of new tissue per unit of existent tissue, and it is related to the habitat in which the species developed (Poorter, 1992; Dijkstra and Lambers, 1986). Puna chicory must then have a higher potential rate of growth than Lancelot plantain, regardless of the water availability in the soil.

The stress imposed on both species did not reach critical levels to reduce physiological activity. Photosynthesis, stomatal conductance and leaf temperature remained similar regardless of the watering level or species. However, average photosynthesis rates of Puna chicory were lower than that of Lancelot plantain (11 vs. 14 µmol CO₂ m⁻² s⁻¹, respectively, P<0.05). This
difference was also observed in controlled environmental conditions and under 30/20 °C day/night temperatures (Chapter 5).

Pre-dawn leaf water potential of Puna chicory plants was not affected by the watering level (-0.16 vs. -0.23 MPa in watered and stressed plants, respectively, P>0.05). Plantain, when subjected to water stress, exhibited a pre-dawn leaf water potential which was 90% lower than when receiving adequate amounts of water (P<0.001), reaching levels of -0.7 MPa. Although the water potentials do not appear to be low, there is evidence that differences in pre-dawn potentials are correlated with midday water stress. For example, pre-dawn leaf water potential of water stressed tall fescue pastures have been reported to be between -0.6 and -0.9 MPa 3 wk after the last rainfall, depending on the nitrogen fertilization level; while leaf water potentials of well-watered plants were above -0.2 MPa (Onillon et al, 1995). Pennypacker et al. (1990) reported pre-dawn water potential values of well watered alfalfa plants as -0.3 MPa while stressed plants had a water potential of -0.5 MPa. In both reports, mid-day water potential of stressed plants was lower than that of well watered ones and was correlated to the above ground biomass produced.

These results together with results of stomatal conductance and photosynthesis rates measured at midday, suggest that both Puna chicory and Lancelot plantain posses mechanisms to cope with the stress and maintain physiological functions by varying morphological characteristics such as leaf area and specific leaf weight before reducing yield.

**Productivity of Puna chicory in 2001. Experiment 2**

In 2001, plant density of Lancelot plantain was below 10 plants m⁻² in the best of cases, and at worst, no plants were left regardless of the watering treatment applied the previous year (data not shown). These observations do not support the theory that acclimation to drought can improve winter survival (Skinner and Gustine, 2002).
Herbage DM yields of Puna chicory during 2001 and for both water levels were lower than the previous year (107 g m\(^{-2}\) in 2000 vs. 68 and 82 g m\(^{-2}\) in 2001 after 3 or 5 weeks, respectively; Table 15). This may have been due to a decrease in the number of plants m\(^{-2}\) (Figure 7). Although Li et al. (1997a), suggest a critical density for Puna chicory of 25 plants m\(^{-2}\), this number of plants does not suffice to maintain herbage productivity from year to year as was observed in other studies (Labreveux et al., 2001; Sanderson et al., 2001).

Herbage DM yield of Puna chicory over a 5 wk growing cycle did not seem to be affected by the watering level imposed. Time to maximum herbage accumulation however, differed between growing cycles. During the first growing cycle maximum DM accumulation on both water treatments was reached after three weeks. This result coincided with the suggestions made by Clark et al. (1990) under clipping and Li et al. (1997b) under grazing conditions that well watered Puna chicory can achieve maximum DM yields after a 3 wk regrowth interval.

The results observed for the second growing cycle illustrate a different scenario and suggest that a different harvest management may need to be applied on stressed Puna chicory pastures. Herbage productivity of Puna chicory after three and five weeks of growth were similar in the well watered plots (55 g m\(^{-2}\) and 70 g m\(^{-2}\) 3 and 5 wk interval respectively, P>0.05). This means that maximum accumulation had been reached after 3 wk. However, accumulated growth on stressed plants after 3 wk was only 31 g m\(^{-2}\), less than half of that achieved 2 wk later, when accumulated yield was 69 g m\(^{-2}\) (P<0.05). A similar response was observed on grazed Puna chicory pastures. The growth rate during a dry summer was lower than during a less stressful year, prolonging the time elapsed to reach maximum accumulation of herbage estimated as canopy height (Chapter 2).

Plant density of Puna chicory plots continued to decrease during 2001 and was not affected by the water treatment imposed. The average density was 50 plants m\(^{-2}\), similar to the counts obtained under grazing or clipping
experiments after two years of growth (Labreveux et al., 2001; Sanderson et al., 2001).

**Morphological and physiological responses of Puna chicory during 2001**

Although total DM produced was not affected by the water stress imposed, leaf expansion was. Well watered plots had an average LAI of 3.1 while the LAI of stressed plots was 2.5 ($P < 0.05$; Table 15). The leaf area expanded per unit weight is the key morphological parameter to explain the plants ability to maintain productivity at a reduced total leaf area. The SLA on well water plots was 24.5 m$^2$ kg$^{-1}$ while on stressed Puna chicory plants this feature was only 21.9 m$^2$ kg$^{-1}$ ($P < 0.05$), 12% lower than on watered chicory plants.

As expected from the results of the previous year, drying stress imposed over a three week period did not affect physiological activity of Puna chicory, and no effects were found even after a five-week water stress period. Photosynthesis levels remained around 12 µmol CO$_2$ m$^{-2}$ s$^{-1}$, similar to the 11 µmol CO$_2$ m$^{-2}$ s$^{-1}$ from the previous year, and leaf temperatures (35 °C) and stomatal conductance (258 ppm CO$_2$) were not altered by water stress either.

**CONCLUSIONS**

In forage species where the target organs to be harvested are leaves, it is important to find species or cultivars that will be able to cope with water stress without reducing leaf productivity. When subjected to intermediate periods without water, Grasslands Puna chicory and Grasslands Lancelot plantain maintained their herbage production by reducing leaf expansion, which reduces evaporative surface, but without reducing their specific leaf weight. Their physiological activity was not affected by water stress and consequently they maintained adequate levels of photosynthates. The use of these species in the NE USA pastures could improve productivity over the summer since Puna
chicory and Lancelot plantain remain active over this season. Unfortunately, the lack of tolerance to winter conditions of the region of Grasslands Lancelot plantain makes it unsuitable for perennial pastures.
REFERENCES


Table 11: Average soil and air temperature during 2000 and 2001 near State College, PA 16801

<table>
<thead>
<tr>
<th>Month / Year</th>
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<th>2000</th>
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</tr>
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<td></td>
<td>°C</td>
<td>°C</td>
<td>°C</td>
<td>°C</td>
</tr>
<tr>
<td>April</td>
<td>8.8</td>
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<td>10.0</td>
</tr>
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<td>17.8</td>
<td>17.7</td>
<td>16.2</td>
<td>16.1</td>
</tr>
</tbody>
</table>

† Monthly average soil temperature at 5 cm depth. Source: [http://www.wcc.nrcs.usda.gov/scan/pennsylvani/pennsylvania.html](http://www.wcc.nrcs.usda.gov/scan/pennsylvani/pennsylvania.html)
‡ Monthly average air temperature. Source: [http://pasc.met.psu.edu/PA_climatologist/](http://pasc.met.psu.edu/PA_climatologist/)
Table 12: Herbage accumulation of Puna chicory and Lancelot plantain in 2000 when subjected to two water regimes.

<table>
<thead>
<tr>
<th>Species</th>
<th>Water treatment</th>
<th>Cycle 1</th>
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<td></td>
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<td>g m⁻²</td>
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<td>191</td>
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<td>Puna chicory (Pc)</td>
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<td>11.5</td>
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<tr>
<td></td>
<td>Watered</td>
<td>38.2</td>
<td>66.8</td>
<td>61.6</td>
</tr>
<tr>
<td>Lancelot plantain (Lp)</td>
<td>Stressed</td>
<td>68.6</td>
<td>146</td>
<td>57.5</td>
</tr>
<tr>
<td>W vs. S</td>
<td>NS</td>
<td>§</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>11.5</td>
<td>20.6</td>
<td>14.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pc vs. Lp</td>
<td>*</td>
<td>§</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>7.70</td>
<td>14.2</td>
<td>9.60</td>
<td></td>
</tr>
</tbody>
</table>

*, **, § Significant at $P \ 0.05, 0.001,\ or\ 0.10$, respectively.

† Species mean is averaged across water treatment and cycle. Water mean is averaged across species and cycle.

‡ Watered and stressed plots were watered every wk and every 3 wk respectively.
Table 13: Herbage accumulation of Puna chicory in 2001 when subjected to two water regimes.

<table>
<thead>
<tr>
<th>Cycle / week</th>
<th>Herbage mass</th>
<th>Cycle 1</th>
<th>Cycle 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Water †</td>
<td></td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Watered (W)</td>
<td>93</td>
<td>96</td>
<td>55</td>
</tr>
<tr>
<td>Stressed (S)</td>
<td>92</td>
<td>94</td>
<td>31</td>
</tr>
<tr>
<td>W vs. S</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>SE</td>
<td>15.2</td>
<td>15.2</td>
<td>9.5</td>
</tr>
</tbody>
</table>

† Watered and stressed plots were watered every wk and every 3 wk respectively.

‡ Herbage mass 3 wk and 5wk significantly different (P<0.05).
Table 14: Leaf area index (LAI) and specific leaf area (SLA), Photosynthesis, leaf temperature and stomatal cavity CO2 concentration (Ci) of Puna chicory and Lancelot plantain pastures subjected to different water levels during 2000.

<table>
<thead>
<tr>
<th>Species</th>
<th>Water treatment</th>
<th>LAI m² kg⁻¹</th>
<th>SLA µmol CO₂ m⁻² s⁻¹</th>
<th>Photosynthesis µmol CO₂ m⁻² s⁻¹</th>
<th>Leaf temperature °C</th>
<th>Ci µmol l⁻¹</th>
<th>Water Potential --- MPa ---</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watered</td>
<td>4.2</td>
<td>33.8</td>
<td>12.0</td>
<td></td>
<td>27.1</td>
<td>257.2</td>
<td>-0.16</td>
</tr>
<tr>
<td>Stressed</td>
<td>2.7</td>
<td>30.0</td>
<td>10.4</td>
<td></td>
<td>28.1</td>
<td>237.2</td>
<td>-0.23</td>
</tr>
<tr>
<td><strong>W vs. S</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td><strong>SE</strong></td>
<td>0.4</td>
<td>1.61</td>
<td>1.07</td>
<td></td>
<td>0.55</td>
<td>19.14</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>Pc</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Watered</td>
<td>1.4</td>
<td>23.0</td>
<td>14.9</td>
<td></td>
<td>27.5</td>
<td>272.1</td>
<td>-0.39</td>
</tr>
<tr>
<td>Stressed</td>
<td>1.4</td>
<td>15.3</td>
<td>12.4</td>
<td></td>
<td>27.6</td>
<td>226.4</td>
<td>-0.74</td>
</tr>
<tr>
<td><strong>W vs. S</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NS</td>
<td>NS</td>
<td>***</td>
</tr>
<tr>
<td><strong>SE</strong></td>
<td>0.4</td>
<td>1.61</td>
<td>1.15</td>
<td></td>
<td>0.58</td>
<td>19.99</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>Lp</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pc vs. Lp</strong></td>
<td>***</td>
<td>***</td>
<td>*</td>
<td></td>
<td>NS</td>
<td>NS</td>
<td>***</td>
</tr>
</tbody>
</table>

*, ***, † Significant at P 0.05, 0.001, or 0.10, respectively.

‡ Species mean is averaged across water treatment and cycle. Water mean is averaged across species and cycle.

‡ Watered and stressed plots were watered every wk and every 3 wk respectively.
Table 15: Leaf area index (LAI), specific leaf area (SLA), single leaf photosynthesis rate, leaf temperature and leaf internal CO\textsubscript{2} concentration (Ci) of Puna chicory plants subjected to different water levels during 2001.

<table>
<thead>
<tr>
<th>Water</th>
<th>LAI</th>
<th>SLA</th>
<th>Photosynthesis</th>
<th>Leaf temperature</th>
<th>Ci</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m\textsuperscript{2}kg\textsuperscript{-1}</td>
<td>µmol CO\textsubscript{2}m\textsuperscript{-2}s\textsuperscript{-1}</td>
<td>°C</td>
<td>µmol l\textsuperscript{-1}</td>
<td></td>
</tr>
<tr>
<td>Water †</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Watered (W)</td>
<td>3.1</td>
<td>24.5</td>
<td>12.4</td>
<td>35.2</td>
<td>268</td>
</tr>
<tr>
<td>Stressed (S)</td>
<td>2.5</td>
<td>21.9</td>
<td>11.8</td>
<td>34.9</td>
<td>247</td>
</tr>
<tr>
<td>SE</td>
<td>0.4</td>
<td>1.0</td>
<td>0.6</td>
<td>1.0</td>
<td>8.7</td>
</tr>
<tr>
<td>W vs. S</td>
<td>*</td>
<td>*</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

* Significant at $P = 0.05$.
† Watered and stressed plots were watered every wk and every 3 wk respectively.
Figure 3: Volumetric soil water content (VWC) of Lancelot plantain plots in 2000 under two watering regimes. Stressed plot watered every 3 wk (white arrows) and well-watered watered every week. Black arrows indicate harvest dates. Errors bars indicate two standard errors. A, VWC at field capacity (-0.03 MPa) at 0 to 0.3 m and 0.3 – 0.6 m, B, permanent wilt (-1.5 MPa) at 0.3 to 0.6 m, and C, permanent wilt at 0 to 0.3 m.
Figure 4: Volumetric soil water content (VWC) of Puna chicory plots in 2000 under two watering regimes. Stressed plot watered every 3 wk (white arrows) and well-watered watered every week. Black arrows indicate harvest dates. Errors bars indicate two standard errors A, VWC at field capacity (-0.03 MPa) at 0 to 0.3 m and 0.3 – 0.6 m, B, permanent wilt (-1.5 MPa) at 0.3 to 0.6 m, and C, permanent wilt at 0 to 0.3 m.
Figure 5: Volumetric soil water content (VWC) of Puna chicory plots in 2001 under two watering regimes. Stressed plot watered every 5 wk (white arrows) and well-watered watered every week. Harvest dates (black arrows) were on 3 and 5 wk. Errors bars indicate two standard error. A, VWC at field capacity (-0.03 MPa) at 0 to 0.3 m and 0.3 – 0.6 m, B, permanent wilt (-1.5 MPa) at 0.3 to 0.6 m, and C, permanent wilt at 0 to 0.3 m.
Figure 6: Plant density of Puna chicory and Lancelot plantain plots in 2000 under two watering regimes. Stressed plots received water every 3 wk and weekly well-watered plots. Errors bars indicate two standard errors.
Figure 7: Plant density of Puna chicory plots in 2001 under two watering regimes. Well-watered and stressed plots received water weekly and every 5 wk, respectively. Errors bars indicate two standard errors.
CHAPTER 5

Response of Chicory and Plantain forage cultivars to elevated day temperatures.
The seasonal distribution of dry matter of temperate pasture species follows a bimodal distribution which results into forage shortage over the summer. In recent years forage cultivars of chicory (Cichorium intybus L.) and English plantain (Plantago lanceolata L) have been introduced to the Northeast USA and have been marketed as summer tolerant species. It has been suggested that chicory and plantain remain active during the summer when most cool-season grasses and legumes go dormant. Studies in mixed pastures containing chicory or plantain cultivars indicate that improved summer productivity is related to a proportionally higher productivity of forbs over the other species within the pasture (Fisher et al., 1996). It has also been suggested that mixed pastures containing Puna chicory in their mix could have higher nutritive values over the summer (Belesky et al., 2000; Chapter 3).

Phenotypical expression of tolerance or avoidance depends on the climate areas, soil conditions, etc (Whitmore, 2000). Most of the commercially available forage cultivars of chicory (Rumball, 1986) and plantain (Stewart, 1996) have been developed in New Zealand, and there is little information concerning their growth and development under summer weather conditions prevailing in the NE USA. There is also little information to document their ability to cope with summer stress factors.

High temperatures and low water availability often stress forage plants during the summer. High day temperatures can have direct and indirect inhibitory effects on plant growth. High temperature can damage the photosynthetic apparatus of plants and can increase evaporative demand causing a more acute water stress (Hall, 2001). There is evidence of temperate species that can tolerate wide temperature ranges (Bowen, 1991). Avoidance mechanisms including dormancy are more common among crops and cool-season grasses (Volaire et al., 1998). There is limited published information regarding how chicory and plantain respond to temperature and
moisture conditions common during a summer stress period. The objective of the study was to quantify morphogenetic and physiological characteristics of different cultivars of chicory and plantain when growing under optimal and supra-optimal temperatures in a controlled environment.

**MATERIALS AND METHODS**

**Seedling establishment, acclimation period.**

Seeds of chicory (Grasslands Puna and Forage Feast) and plantain (Ceres Tonic and Grasslands Lancelot) were germinated in PVC containers (10 cm diameter by 30 cm depth) filled with Mapleton sand (sand 98.6%, silt 0.5%, clay 0.9%). The containers were put under mist in a greenhouse for approximately 1 week at air temperatures between 20-25°C. After germination, seedlings were thinned to three per container, kept in the greenhouses for another week and thinned to 1 plant per container. At the end of the second week plants were moved to the growth chambers set at 25/15 °C day/night temperatures where plants were allowed to acclimate for an additional week.

**Temperature treatments and watering description.**

At the end the 3rd week, growth chambers were randomly set to the treatment day/night temperatures of 25/15 and 30/20 °C, and plants were grown for a period of 5 weeks. This procedure was repeated 3 times (8/27/99 to 10/22/99; 1/6/00 to 3/9/00; 2/28/00 to 4/27/00) and each period was considered a replicate (block) in time (randomized complete block). The two temperature treatments were randomly assigned to the chambers in each repetition.

Quantum flux density at plant level in the growth chamber was 750-850 µmol PPFD m⁻² s⁻¹ provided by high-pressure sodium and metal halide lamps, with a red/far red light ratio of 3.4 - 3.6. Relative humidity in the chambers ranged from 50 - 70%. Plants in the growth chambers were watered with 1/4-
strength Hoagland’s solution for the first 2 weeks and then a 1/2-strength solution was applied thereafter. Nutrient solution was applied through a drip irrigation system (on/off dribble tubes) twice daily.

The amount of water required to reach field capacity in the containers was calculated. After filling the PVC containers with dry sand their weight was recorded (dry weight) and placed under water sprinklers and weighed every 1/2 hour until maximum ”wet” weight was achieved. The difference between ”wet and dry weight” was considered the minimum amount of water required to irrigate per day. This quantity was increased by 10 % to ensure drainage and to prevent accumulation of salts in the growing medium. In addition, before re-filling the nutrient solution container, pots were flushed with distilled water first and then watered with nutrient solution. Nutrient solution was located inside the growth chamber to prevent differences in ambient and irrigation water temperature.

**Root and shoot sampling.**

One hundred and sixty plants were harvested per replicate. Four plants per cultivar and per treatment were harvested every week during five weeks. Those plants were separated into components (shoot, root). Shoots were separated into main axis, tillers and stems. Leaves of the main axis were measured individually to determine area with a planimeter (Model Li-3000, LI-COR, Lincoln, NE) on weeks 3 and 5 (35 and 56 days after planting). Number and position in the axis of leaves, tillers and stems were also recorded. The root component was washed to remove growing medium and stored in a solution of 25% ethanol 75% distilled water. Roots of plants from the 1st, 3rd and 5th week of harvest were separated into taproot and fine root and analyzed separately. Root length, average diameter and distribution of the categories of root diameter were measured by computerized analysis using winRHIZO software (Regent Instrument Inc., Quebec, Canada). The software was installed on a computer coupled to a flatbed scanner with a transparency tray adapter. Roots were
stained with neutral red (Sigma Chemical Co. St. Louis, MO, USA at rates of .025g l⁻¹ distilled water) for approximately 2 to 4 h. After staining, the roots were rinsed to remove adhering stain not incorporated into the roots and spread in the transparent tray containing a thin layer of degasified water. A flatbed scanner was used to generate a digital image of the roots, which was then analyzed using the aforementioned software. Image acquisition was set on an automatic threshold using Lagarde's method. Root density of the sample was lower than 0.3 mm root length per mm² of tray surface. Fine roots of the 1st week of sampling were small enough to meet this requirement. A subsample was taken for fine roots harvested during the 3rd and 5th week. All shoot and root components were oven dried at 60°C for 48 h and then weighed. All root samples were then ashed at 500°C for a minimum of 4 h to correct dry weights for growing medium remaining.

Additional non-destructive measurements were taken. Leaf gas exchange was measured with an open system infrared gas analyzer model Li 6400 (Li-Cor Inc, Lincoln, NE) on the last fully extended leaf. Five plants per cultivar were selected during the 2 and 5 weeks (35 and 56 DAP respectively) of growth. Ten recordings were taken per leaf.

**Statistical Analysis**

Data were analyzed using the MIXED Procedure of SAS (SAS Inst. V.8, 1997), and separate analyses were conducted for each sampling date. Pre-planned comparisons of means were performed using Tukey’s w test (Steel et al., 1997). Data of cultivars were pooled within species and means of Puna and Feast chicories were compared against means of Tonic and Lancelot plantains. Comparisons consisted of 1) chicory vs. plantain; 2) Day temperature treatment: 30 °C vs. 25 °C; 3) Interaction of species by temperature: chicory 30 °C vs. chicory 25 °C, and plantain 30 °C vs. plantain 25 °C. Significant difference was considered at an alfa 0.05 but P-values below 0.10 were indicated.
RESULTS AND DISCUSSION

Total biomass of chicory and plantain plants was similar during the 5-week harvest period and was not significantly affected when grown under a day temperature of 30°C vs. 25°C (Figure 7). In neither of the root or shoot fractions was there evidence that the plants were reaching a maximum accumulation of tissue or a reduction in growth rate, even after the onset of leaf senescence at 49 days after planting (DAP). By the end of the sampling period, whole plant DM weight of chicory plants was 13.4 g, of which 7 g were allocated to shoot and the remaining 6.4 g to roots. Plantain whole plant weight was 12.6 g, 7.5 g allocated to shoots and 5.1 g to roots.

The DM allocation between root and shoot of chicory and plantain (RSMR: root to shoot mass ratio) (Table 16) up to 42 DAP remained similar, with average values of 0.56 and 0.78, respectively (P>0.10). But, RSMR can change drastically during a season of growth as it was observed in Smyrnium perfoliatum L., a species in the same family of chicory (Lux et al., 1993). Later during the growing cycle, RSMR differed between the species and was greater for chicory than for plantain. The ratio 49 DAP was 0.52 and 0.27, and 56 DAP it was 0.91 and 0.68 for chicory and plantain plants, respectively (P <0.01 and 0.10 after 49 and 56 DAP, respectively). This corresponded with the timing at which differences between primary root weights between species become evident (Table 17)

Root mass and partitioning into components.

Chicory is characterized by having a thick and long taproot (Rumball, 1986), whereas plantain, P. lanceolata in particular, has a perennial main root (Soekarjo, 1992). Over the first 28 DAP, a larger proportion of DM was allocated to fine roots than to the primary root or main axis; this ratio being 5 to 1 between fine and main axis root weight for both species (Table 17). There were
no differences between the two species until 42 DAP (P<0.10) when chicory reached a taproot weight of 0.34 g, increasing its dry weight by more than 400-fold in 14 d. At this time, plantain individuals had increased their primary root weight by more than 300-fold to 0.19 g. The fine to primary root ratio was 2.5:1 for chicory and remained at this value throughout the following harvest while the ratio for plantain was 1.5:1 and increased to 20:1 during the same time period.

There were no differences between species in the total amount of DM allocated to roots; however, the allocation between different root components differed greatly. Theoretically, different root structures have different functions, but when grown under a non-limiting environment different root structures can perform similar tasks. Brouwer (1981) analyzed the function of adventitious and seminal roots and their importance in maintaining growth of maize plants. He found that when adventitious roots are removed by clipping, the seminal root of maize plants remained functional and supported similar levels of growth to plants with a complete root system. The larger taproot of chicory plants may imply an advantage for exploring deeper soil strata in the search for water but fine roots may have the ability to occupy a larger volume of the profile. However, under drying conditions soils become harder to penetrate and larger diameter roots can produce larger forces and be advantageous (Fitter, 1996; Bennie, 1996). Another advantage of a larger taproot is that water resistance to transport is a direct function of root radius, with a higher radius resulting in lower resistances (Oertli, 1996). Consequently, if fine and tap roots are located in a soil horizon where water is still available, water will flow more easily through the taproot than through the fine roots supplying a larger amount of the available water to the shoot.

Fine root weight 28 DAP and one week into the temperature regimes, was greater in chicory than plantain (0.039 and 0.030 g, respectively, P<0.10). During the subsequent harvest, the weight increased 2.5 times to similar levels of 0.99 and 0.75 g for chicory and plantain respectively. Two weeks later the biomass allocated to this fraction of roots reached 4.6 g in chicory and 4.8 g in
plantain, which represents an increment in weight of 25 to 29 mg of DM per day.

The total length of fine roots increased considerably with time and did not differ between species. A 10-fold increase in length occurred between 28 and 42 DAP (from approximately 6 to 70 and 66 m, for chicory and plantain respectively). Over the following 2 wk the increases in root length were smaller, but still high, with a five and seven-fold increase for chicory and plantain, respectively. The final fine root length of these species 56 DAP was 374 and 468 m under what could be considered close to optimal water and nutrient growing conditions and regardless of the temperature of growth.

Specific root length (SRL) is the ratio between length and weight of fine roots and is an estimate of the benefit over costs of fine root construction. The range of SRL for both species did not differ and ranged from 22 to less than 10 m kg⁻¹ (data not shown). High SRL or low root tissue densities are associated with fast growing species and may be related to faster root proliferation but a shorter life span (Ryser and Lambers, 1995).

Fine roots are very important in nutrient acquisition and exploration of large volumes of soil (Fitter, 1996). The distribution of fine roots according to increasing diameter ranges had similar patterns on each of the three weeks analyzed (Figure 9). The sum of length of all diameter classes corresponds to the total fine-root length. The total length increased over time, but the distribution remained fairly constant (Table 17). A greater proportion of the roots had very small diameters, in the range of a tenth to half a millimeter. The variability of the amount of roots within these ranges was also higher than that of larger diameters. The average diameter to describe fine and coarse roots is arbitrary and dependant on the species and growing conditions, but usually a limit of 1 or 2 mm is used (Eissenstat, 1991). In the case of chicory and plantain grown under our growing conditions it seems likely that the limit should be considered 1 mm or less.

The diameter of roots is also important in determining building costs. Smaller diameters have a lower initial cost of production but have a high
respiration rate. Larger diameters have higher initial cost and since they have longer life spans maintenance respiration in the long term is higher (Eissenstat, 1997) and this in turn may be higher at higher temperatures. The average diameter of fine roots was the only trait that was affected by the different regimes of temperature and this response differed between species and with time (Table 18). Root diameter of chicory and plantain plants 28 DAP was similar and did not differ between growing temperatures (average of 0.66 and 0.63 mm for chicory and plantain respectively, SE = 0.02 and N = 24). Two weeks later, the average diameter of fine roots of chicory plants was 0.70 mm while that of plantain 0.66 mm (P<0.001). Over the next harvest (56 DAP), with plants having been grown at different day/night temperatures for 5 weeks, the average root diameter of chicory grown under 25/15 °C was 10% higher than when grown under a 30/20 °C regime (0.69 and 0.63 mm at 25/15 °C and 30/20 °C, respectively, P<0.05). However, the diameter of fine roots of plantain was not altered by the temperature at which plants grew (0.63 and 0.64 mm at 25/15 °C and 30/20 °C, respectively), marking a difference in the response of these two species to temperatures above 25 °C. Also, the differences between species observed at 42 DAP remained 56 DAP; chicory roots had larger diameters than plantain roots (P<0.05). Root diameter of perennial ryegrass in the field also varied with time and was 0.4 and 0.25 mm in summer and winter respectively (Mathew et al., 1991), suggesting that roots produced over the summer may have a larger diameter to ensure a better water supply to the root but also that chicory and plantain have thicker roots than ryegrass.

**Shoot mass and partitioning into components.**

Shoot composition of both species differed along the 5-week growing period in a controlled environment (Figure 9). Both species produced similar amounts of DM at each harvest but it was allocated to different structures. This difference was evident 42 DAP (P<0.01) when the weight of the main axis of chicory was 1.6 g while only 0.4 g were allocated to daughter rossettes. DM of
the main axis (not including reproductive stems) and daughter rosettes of plantain fit a ratio of 1:1 weighing approximately 0.7 g each. This ratio increased for chicory from 4:1 to almost 6:1 in the following 14 days while plantain’s dropped to 0.8:1. Forty-nine DAP, the weight of the main axis of chicory and plantain plants was 3.1 g and 1.4 g respectively (P<0.01), while the amount allocated to auxiliary born daughter rosettes was 0.7 g and 2.1 g (P<0.05). At the end of the experimental growing period the allocation pattern between species was almost opposite, chicory allocated 5.3 g to the main axis and 2 g to daughter rosettes, while plantain allocated 1.9 g to the axis and 5.3 g to daughter rosettes (P<0.001 and 0.01 for main axis and tiller comparison respectively).

Chicory plants did not produce any reproductive structures since the species does not usually flower until the second year after planting (Rumball, 1986). However, plantain, at long day length, has a continuous production of stems that develop on axillary buds while apical meristems remain vegetative (Kuiper and Bos, 1992; Soekarjo, 1992). Plantain plants grown in this experiment began flowering 49 DAP or 4 weeks into the growth chamber conditions. At this time tiller appearance stopped as they increased in size and weight. There were eight daughter rosettes on average, which occupied both cotyledonary sites up to the axillary bud of leaf six (data not shown). The average number of daughter rosettes on chicory plants 49 DAP was 3 and had increased by only 1 unit 7 d later. The appearance of chicory daughter rosettes in contrast to plantain did not follow any apparent pattern of site filling.

Reproductive stems also appeared from meristematic tissue in leaf axils of plantain taking the place of daughter rosettes (Kuiper and Bos, 1992). The number of flowers on plantain individuals increased from three, 49 DAP, to six, 56 DAP and were filling all continues axillary sites from leaf 7 up to leaf number 13. Although the number of flowers increased, their proportion of shoot biomass was only about 3%.
Leaf area development and single leaf physiological activity.

Chicory and plantain differed significantly among the parameters that describe their growth habits such as LA, SLA, photosynthesis, etc. (Table 19). These differences have been observed under water stressed and dense canopy conditions, and lead us to conclude that they are inherent to the species and not the growing conditions (Chapter 4). Total leaf area 35 DAP was 50% higher in chicory than in plantain (0.013 vs. 0.008 m² plant⁻¹, respectively, P<0.05). However, 21 days later, when tiller DM equaled the DM of chicory’s main axis, their plant leaf area was not different (0.082 10⁻³ vs. 0.152 m² plant⁻¹, respectively).

With similar total leaf area per plant, it could be assumed that both species intercepted a similar amount of radiation. Considering both are C₃ species, they could have similar efficiencies of radiation conversion. However, single leaf photosynthesis results reveal that at 35 and 56 DAP plantain had a 30% higher photosynthesis rate than chicory, a response also observed under dense canopy and varying water supplies (Chapter 4). Single leaf photosynthesis levels 35 DAP were 13.3 and 18.3 µmol CO₂ m⁻² s⁻¹ for chicory and plantain respectively (P<0.01), while 56 DAP the same level was observed on chicory, with plantain having a rate of 17 µmol CO₂ m⁻² s⁻¹ (P<0.01). Temperature did not affect photosynthetic rate for either of the species tested.

Higher concentration of CO₂ in the stomatal cavity (Cᵢ: internal CO₂ concentration) are associated with greater photosynthesis levels per unit mass but also with lower water use efficiencies (Gutschick, 1997). The Cᵢ of chicory leaves 35 DAP was 254 µmol l⁻¹ while in plantain it was 264 µmol l⁻¹ (P<0.01). Twenty one days later the Cᵢ values for chicory leaves had significantly dropped by about 7% (P<0.05) and were lower than that of plantain leaves (238 vs. 259 µmol l⁻¹, respectively, P<0.001).

If radiation interception was similar in chicory and plantain but plantain had higher levels of photosynthesis, why then did they produce the same amount of whole plant DM? There are several uninvestigated parameters that
could account for the losses that may be related to species differences in root diameter (Table 18) and allocation to primary roots (Table 17). Chicory had higher primary root mass and slightly coarser roots. These fractions require a higher investment of photosynthates for construction but have a lower turnover, while fine roots have a higher turnover rate and consequently higher photosynthates requirement for growth respiration (Eissenstat, 1997).

Some indicators of the growth strategies utilized by different species and related to their capacity to exploit available resources are leaf area ratio (LAR), specific leaf weight (SLA), and leaf weight ratio (LWR) (Poorter, 1990). The LAR of chicory was 40% higher than that of plantain 35 DAP (P<0.05), but 2 wk later the values were not significantly different although variability was fairly high (7.2 vs. 15.7 m² kg⁻¹ for chicory and plantain respectively, SE = 5.51). The SLA of both species 35 DAP was similar, 2.4 and 2.6 m² kg⁻¹ for chicory and plantain respectively. However, at 56 DAP chicory’s SLA was lower than that of plantain (2.6 vs. 9.4 m² kg⁻¹ respectively, P<0.10). Finally, LWR differed at both 35 and 56 DAP and was higher for chicory. Chicory LWR was 0.74, 35 DAP while plantain was 0.56 (P<0.001). Two weeks later the values on both species had dropped, as is expected on plants of a bigger size, but the differences between species were even bigger (chicory had a LWR of 0.42 and plantain 0.20 (P<0.001)). Other species within the Apiacea family (family to which chicory belongs) such as Smyrnium perfoliatum, exhibited high values of SLA (56.8 m² kg⁻¹), LAR (12.6), LWR (0.221) and Shoot to root (6.781), typical of fast growing and competitive species (Lux et al., 1993)

There is a positive correlation between SLA, LWR, and LAR with the relative growth rate (RGR) of species, and RGR has been associated with species growth strategies (Grime and Hunt, 1975). That is, slow-growers being stress-tolerators and fast growers being capable of exploiting resources more rapidly (Grime, 1979). Both chicory and plantain would be classified within a fast-growing group of species but chicory has slightly higher values of LWR suggesting it would be a better competitor in a mixed pasture.
CONCLUSIONS

Summer stress is caused by a combination of soil water depletion and high temperatures occurring more or less simultaneously. Our objective was to determine the response of chicory and plantain forage cultivars to temperature conditions commonly occurring in the NE US. Cool-season grass species used in the region exhibit a reduction in their growth rate or dormancy in response to high temperatures, but surprisingly chicory and plantain did not exhibit signs of reduced shoot or root growth rates. Not even a reduction in leaf expansion, commonly consider a first symptom of stress. We could assume then that these two species are tolerant to day temperatures of at least 30°C. Although chicory and plantain evolved in different environments, both are fast growing species that have similar productivity levels. They differ though on their allocation of DM. Chicory has a larger primary root (tap root) than plantain, and allocated greater DM to a main axis than to shoot daughter rosettes. They also differ in that plantain has higher levels of carbon assimilation than chicory. However, these physiological and morphological differences did not confer an advantage or disadvantage when grown in temperatures normally occurring in the NE USA. Change in growth patterns in response to summer conditions will be a result of water stress or an interaction of water availability and temperature stress but not to temperature alone.
REFERENCES


Table 16: Root to shoot mass ratio (RSMR) of single chicory and plantain plants when grown under controlled environment over a 5 week period.

<table>
<thead>
<tr>
<th>Days after planting</th>
<th>Chicory</th>
<th>Plantain</th>
<th>SE †</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RSMR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>0.58</td>
<td>0.78</td>
<td>0.23</td>
<td>NS</td>
</tr>
<tr>
<td>35</td>
<td>0.28</td>
<td>0.32</td>
<td>0.05</td>
<td>NS</td>
</tr>
<tr>
<td>42</td>
<td>0.82</td>
<td>1.24</td>
<td>0.42</td>
<td>NS</td>
</tr>
<tr>
<td>49</td>
<td>0.52</td>
<td>0.27</td>
<td>0.06</td>
<td>**</td>
</tr>
<tr>
<td>56</td>
<td>0.91</td>
<td>0.68</td>
<td>0.11</td>
<td>§</td>
</tr>
</tbody>
</table>

** Significant at \( P = 0.01 \) or 0.10, respectively.
† Standard error of the comparison between means of chicory and plantain
Table 17: Length and weight per plant of fine and primary roots of chicory and plantain at 28, 42 and 56 days after planting in a controlled environment. †

<table>
<thead>
<tr>
<th>Species</th>
<th>Length</th>
<th>Fine root</th>
<th>Primary root</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m</td>
<td>g</td>
<td>g</td>
</tr>
<tr>
<td>Chicory</td>
<td>28</td>
<td>42</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>6.7</td>
<td>70</td>
<td>374</td>
</tr>
<tr>
<td>Plantain</td>
<td>28</td>
<td>42</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>6.5</td>
<td>66</td>
<td>468</td>
</tr>
<tr>
<td>SE</td>
<td>0.8</td>
<td>11</td>
<td>185</td>
</tr>
<tr>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>§</td>
</tr>
</tbody>
</table>

* Significant at $P = 0.05$, ** Significant at $P = 0.001$, respectively.
† Fine roots after removing tap root or main pivotal root.
‡ Fine roots after removing primary root.
Table 18: Average diameter of fine roots of chicory and plantain when grown under two different temperatures

<table>
<thead>
<tr>
<th>Species</th>
<th>Temperature</th>
<th>Diameter †</th>
<th>Diameter †</th>
<th>Diameter †</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°C</td>
<td>Days after planting</td>
<td>Days after planting</td>
<td>Days after planting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>28</td>
<td>42</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>mm</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Chicory</td>
<td>25/15 (O)</td>
<td>0.62</td>
<td>0.70</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>30/20 (H)</td>
<td>0.69</td>
<td>0.70</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>O vs. H</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>*</td>
</tr>
<tr>
<td>Plantain</td>
<td>25/15 (O)</td>
<td>0.64</td>
<td>0.64</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>30/20 (H)</td>
<td>0.61</td>
<td>0.67</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>O vs. H</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Chicory vs. Plantain</td>
<td>NS</td>
<td>***</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

*, ***, Significant at \( P =0.05, 0.001 \), respectively. NS, not significant.

† Average diameter of roots after removing tap root or main pivotal root
Table 19: Leaf area development, single leaf physiological activity and growth indicator related to leaf area of chicory and plantain grown in growth chambers.

<table>
<thead>
<tr>
<th>Leaf area per plant</th>
<th>LAR †</th>
<th>LWR ‡</th>
<th>SLA ¶</th>
<th>Photo-synthesis</th>
<th>Leaf internal CO₂ (Ci)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Days after planting</td>
<td>35</td>
<td>56</td>
<td>35</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>m²</td>
<td>m² kg⁻¹</td>
<td>kg kg⁻¹</td>
<td>M² kg⁻¹</td>
<td>µmol CO₂ m⁻² s⁻¹</td>
</tr>
<tr>
<td>Chicory</td>
<td>0.013</td>
<td>0.082</td>
<td>17.1</td>
<td>7.20</td>
<td>0.74</td>
</tr>
<tr>
<td>Plantain</td>
<td>0.008</td>
<td>0.152</td>
<td>12.5</td>
<td>15.7</td>
<td>0.56</td>
</tr>
<tr>
<td>SE</td>
<td>0.002</td>
<td>0.039</td>
<td>1.34</td>
<td>5.51</td>
<td>0.03</td>
</tr>
<tr>
<td>P</td>
<td>*</td>
<td>NS</td>
<td>*</td>
<td>NS</td>
<td>***</td>
</tr>
</tbody>
</table>

*, **, ***. § Significant at P =0.05, 0.01, 0.001, or 0.10, respectively.
† Leaf area ratio = leaf area plant / whole plant weight
‡ Leaf weight ratio = leaf weight / whole plant weight.
¶ Specific leaf area = leaf area / leaf weight.
§ Significant differences between weeks on the Ci of chicory, P <0.05
Figure 8: Plant biomass accumulation and partitioning between shoot and root of chicory and plantain during a 5-week growth period under controlled environment conditions (bars indicate one standard error).
Figure 9: Partition between components of the shoot of chicory and plantain over a 5-week growth period under controlled environment conditions (bars indicate one standard error).
Figure 10: Distribution of root diameter of single plants of chicory and plantain when grown in a controlled environment and under two summer temperatures.
CHAPTER 6

SUMMARY AND CONCLUSIONS
Productivity and response of chicory and plantain to grazing conditions and summer stress

When raising cattle under grazing conditions in the Northeast USA several problems are encountered. One of these problems is balancing the offer and the demand of forage over the most commonly used pasture species. The overall objective of this study was to evaluate two species, *Cichorium intybus* L. and *Plantago lanceolata* L., for the feasibility of using these forage species to improve summer productivity in the NE USA. These species are not commonly used in this region, but have the potential to improve summer forage availability in other regions of the USA and abroad. Several forage cultivars of these species are being marketed to farmers. Grasslands Puna, Forage Feast, and INIA LE Lacerta are among the chicorys, and Grasslands Lancelot and Ceres Tonic are the two available plantain forage cultivars. Assessing the suitability of each one of these genotypes to the NE USA soil and climatic environment and defining grazing management practices were among the goals.

The performance of Puna chicory was somewhat constant, it had the highest yield among the chicory cultivars both during the spring (6511 vs. 6277, 5709 kg ha⁻¹ for Puna, Feast and Lacerta chicory, respectively) and the summer (3354 vs. 2452 and 2802 kg ha⁻¹ for Puna, Feast and Lacerta chicory, respectively) of 1998. It had higher of similar yields than those attainable by Pennlate orchardgrass during the summer of 2000 (5363 vs. 2893 kg ha⁻¹, respectively) and 2001 (3368 vs. 3606 kg ha⁻¹, respectively), while its spring yields were consistently higher than for orchardgrass (5740 vs. 3610 kg ha⁻¹, average yield during 2000 and 2001 for Puna chicory and Pennlate orchardgrass, respectively).

Plant losses were registered on all chicory and plantain cultivars. Losses of Lancelot and Tonic plantain were most likely related to low tolerance to winter temperatures. However, plant losses would be observed both after the winter and during the growing season. Puna chicory registered the highest plant density when compared to Feast and Lacerta chicorys during 1998.
Nevertheless, plant density of Puna chicory reached 50% of the initial plant stand or less than 50 plants m\(^{-2}\) after two years of study, which could compromise its use in perennial pastures.

No grazing treatments in particular applied during this three-year study had an effect over plant persistence, nutritive value, or herbage productivity during the summer of chicory, plantain or orchardgrass. Nevertheless, the grazing strategies applied yielded a range of practical management guidelines to utilize chicory, plantain and orchardgrass. The frequency of grazing applied during 1998 had an effect on yield of all species, particularly during the summer (1670 vs. 4450 kg ha\(^{-1}\), observed on pastures grazed every three or five weeks, respectively). The protein concentration and digestibility of herbage during the summer of 1998 however, was higher when pastures were grazed every three weeks than grazed every five weeks. The results of dry matter accumulation of Puna chicory and Lancelot plantain under water stress suggested that the minimum length of the regrowth period should be of three weeks, but during a stressful period such as during the summer a regrowth period of five weeks would be recommended.

**Nutritive value of chicory and plantain under grazing**

In most crop cultivar evaluations, dry matter yield is the most practical response parameter to be measured in order to assess performance under a variety of growing conditions. In the case of forage species however, determination of the nutritive value of the genotype-grazing management complex was important. Reports indicated that chicory and plantain could produce reproductive structures during the entire growing season; consequently assessments of the effects of the different grazing strategies applied over their reproductive stages, and their impact over the nutritive value of the herbage were of particular interest.

The nutritive value of chicory was similar between cultivars. The concentration of fiber (in the form of neutral detergent fiber – NDF) ranged from
360 to 400 \text{g kg}^{-1} \text{ during the spring of 1998, and decreased to concentrations below 300 \text{g kg}^{-1} \text{ at the end of the summer of 1998. Concentrations of crude protein (CP) of the herbage of Puna, Feast and Lacerta chicorys was not particularly high nor was it different than that of Pennlate orchardgrass. The exception occurred at the beginning of the spring in 1998 when the average CP of the chicorys was 215 \text{g kg}^{-1} \text{ while that of Pennlate orchardgrass was only 173 g kg}^{-1}. Digestibility of the herbage of Puna chicory was significantly lower than that of Pennlate orchardgrass during both studies. In late summer of 1998 and the 2000/2001 period the IVTDMD (\textit{In Vitro} true dry matter digestibility) of Puna chicory was 932 and 899 digestibility \text{g kg}^{-1}, respectively. During that same period the IVTDMD of Pennlate orchardgrass was 853 and 865 \text{g kg}^{-1}, respectively. Digestibility of Puna chicory was lower than that of Pennlate orchardgrass even though the proportion of leaf to stems in the herbage harvested was much higher in the grass than in the chicory during the spring and summer of 2000 and 2001.

The nutritive value of Puna chicory herbage was higher than that of Pennlate orchardgrass and Lancelot plantain. It had a lower NDF concentration than orchardgrass herbage and higher digestibility which could allow for a higher dry matter intake and energy digested. The NDF and CP concentration of Lancelot plantain and Puna chicory herbage were similar, however its digestibility during the spring and summer of 2000/2001 differ. The IVTDMD of Lancelot plantain in the spring (740 \text{g kg}^{-1}) and summer (773 \text{g kg}^{-1}) was even lower than for orchardgrass (864 and 865 average for the spring and summer of 2000/2001, respectively).

\textbf{Morphological and physiological response of chicory and plantain to elevated temperatures and cycles of water shortage}

Plant responses to summer stress are very complex due to the interaction of several factors such as temperature and soil and air moisture. For most temperate species, growth temperatures above 25°C reduce growth rate.
Shortage of water may reduce the rate of growth as well and even affect physiological functions depending on the extent of the water deficit. However, plant responses vary greatly and other than the fact that *Plantago* as a species is widely distributed in arid zones or that chicory has an extensive root system, very little was known about their morphological or physiological responses to temperature and water stress.

When subjected to several soil water depletion cycles Puna chicory plants would produced similar amounts of dry matter than those plants that were frequently watered. The yield of Puna chicory plants was not affected by the water stress applied. The plants reduced their transpiring leaf area from a leaf area index (LAI) of 4.2 to 2.7 in 2000 and from 3.1 to 2.5 in 2001, but at the same time maintained productivity by increasing the weight of individual leaves. The specific leaf area (SLA, or the weight per area of leaf tissue) of stressed Puna chicory plants in 2000 and 2001 was 10% lower than in well watered plants.

A strategy similar to that of Puna chicory was observed on Lancelot plantain plants. The SLA of well-watered plants was 23 m² kg⁻¹, significantly higher than that of stressed plants (15.3 m² kg⁻¹). The LAI of plantain plots however, did not differ between water treatments. This result was related to losses in plant density observed on all plantain plots that were higher in the well-watered treatment plot affecting LAI results.

Plants of Puna chicory and Lancelot plantain were not affected in their physiological functions by water deficit. Photosynthesis rates, although different between species, were similar in stressed and well-watered plants. Average single leaf photosynthesis rate of Puna chicory was 11.7 µmol CO₂ m⁻² s⁻¹ and 13.7 µmol CO₂ m⁻² s⁻¹ for Lancelot plantain. Species differences in photosynthesis rate were also observed under optimal and supraoptimal temperatures, but no temperature effect was registered on either species.

Single plants of chicory and plantain when grown under controlled environment conditions can produce similar amounts of biomass. The differences are registered on the mass allocation to different shoot and root
structures. Chicory and plantain roots may weigh the same, but chicory plants have a larger proportion of biomass allocated to a thick primary root (tap root) while plantain plants have a larger fine root mass. Similarly, chicory has a larger shoot main axis while plantain has a larger proportion of axillary born rosettes.

**GENERAL CONCLUSIONS**

Puna chicory and Lancelot plantain have the potential to cope with the summer conditions registered in the Northeast USA. Elevated temperatures do not affect either their morphological development or their physiological activity. Puna chicory has a deep tap root that allows it to explore deep water sources even after extended periods without rainfall. In addition, both cultivars adjust the leaf area expanded per unit leaf weight to reduce transpiring area but without reducing dry matter productivity. However, thinning of the plant stand of chicory may limit its use in perennial pastures. Lancelot plantain exhibited a reduced persistence that may be related to low tolerance to winter temperatures which compromises its use in the northeastern USA.
VITA

María Labreveux was born in Buenos Aires, Argentina, in 1972 from a French journalist and an Argentine Professor of social sciences. She grew up in Buenos Aires during the years of dictatorship and saw the rising of democracy in Latin America in the ’80’s. In 1978, her family moved to Brighton, UK, where she received her first lessons about living in a different culture and learning a language other than her native Spanish and the French she learned from her grandparents during the summers she spent in France. In 1981, she spent her first year in an American school in Gainesville, where her mother was invited to teach at the University of Florida.

In 1990, she started a six-year program on agricultural sciences at the University of Buenos Aires, Argentina. As an extra curricular activity, she performed as student representative in the University’s government. In addition, during school brakes, she left to experience life in Central Asia; Pakistan, Afghanistan, India, Uzbekistan, Tajikistan, were among the countries she visited. It was there that she first experienced the realities of war, hunger and devastation; but also, she discovered the beauty of nomadic cultures that live in an era still untouched by technology, cars and fast food.

In 1996, after the completion of her degree, she enrolled in a MSc program on animal production and pasture ecophysiology at the University of Mar del Plata, Argentina. She finished her degree in 1998 and moved to the United States to begin a PhD program in Agronomy, spending four years learning about the problems encountered by grazing animal operations in the Northeast US. She was a teaching assistant in an introductory soils class, which gave her the opportunity to not only enhance her knowledge of natural systems, but to contribute to the learning experience of students and inspire those that, much like herself years earlier, would see a PhD as unattainable. Once again, she performed as a graduate student representative of the Crop and Soil Science Department and for the Latin American Student Association at PSU. Of all the lessons she has learned about agronomic systems, the comprehensive lies in how differences found in production systems have their roots in cultural experiences.

Maria plans to continue her learning experiences in the US and abroad. She and her husband hope to be able to utilize the skills they have obtained to help those in this world who have not been as fortunate as they.