ON-FARM COMPARISONS OF CARBON UPTAKE AND PARTITIONING TO ROOTS IN SIMPLE AND COMPLEX PASTURE MIXTURES

R. Howard Skinner, Matt A. Sanderson, Benjamin F. Tracy[1]

Abstract

Forage yield on pastures is a function of net photosynthetic inputs (photosynthesis minus respiration) and the partitioning of those inputs between above- and below-ground tissues. While many studies have looked at aboveground productivity of pastures, much less information is available on canopy photosynthetic rates, or on root production and distribution in the soil profile. As part of an on-farm study to compare dry matter yield of 2-, 3-, and 11-species forage mixtures, we measured net canopy photosynthesis on 7 to 8 dates from early-April to early-October in 2000-2002. We also measured root distribution to a depth of two feet in mid-September each year. Net photosynthetic rate did not differ significantly among mixtures although there was a trend towards greater net photosynthesis as the number of species increased, especially during the summer (June through August). The 11-species mixture also had greater root biomass than the other two mixtures and roots were distributed deeper in the soil profile as the number of species in the mixture increased. Deeper rooting depth could improve productivity during summer drought by increasing access to available soil moisture.

Introduction: Reduced forage production on pastures during periods of summer drought presents a significant risk to producers. Research suggests that productivity can be improved by increasing the number of plant species within the community (Tilman, 1999). Benefits from increased species diversity are often greatest under harsh environmental conditions and have been associated with; 1) improved utilization of scarce resources (Spehn et al. 2000), 2) facilitation of the growth and survival of one or more species by a companion species (Bertness, 1998), or 3) an increased probability of including the most productive species as the total number of species increases (Wardle, 1999). Forage yield is a function of net photosynthetic inputs (photosynthesis minus respiration) and of the partitioning of those inputs between above- and below-ground tissues. Root production during moisture stress can be particularly important because enhanced rooting can increase access to deep soil moisture. While many studies have looked at aboveground productivity, much less information is available on canopy photosynthetic rates and on root production and distribution in the soil profile. This study compared net photosynthesis rates during the growing season (April to October) and root distribution to a depth of 2 ft for three pasture mixtures containing 2, 3, or 11 forage species. We hypothesized that canopy photosynthesis and root biomass would increase as mixture complexity increased.

Materials and Methods: Three forage mixtures were compared under haying and grazing management on a farm in Berks County, eastern Pennsylvania. Soil at the farm is a Weikert-Berks shaly silt loam. This soil is well drained, contains a high amount (10 to

[1] Research plant ecophysiologist and agronomist, USDA-ARS Pasture Systems and Watershed Management Research Unit, Building 3702, Curtin Road, University Park, PA 16802-3702; Assistant Professor, Dept. Crop Sci., Univ. Illinois, Urbana, IL.

50%) of coarse rock fragments, and has a low water-holding capacity. Soil pH was 6.4 and available P and K levels to a 6-in. depth averaged 79 and 127 lb/acre, respectively. The producer applied lime at 2000 lb/acre in spring 2000. An automated weather station at the site recorded rainfall, air temperature, and soil moisture.

Two 1-acre paddocks of 2- and 11-species mixtures (Table 1) were no-till planted with a Tye Pasture Pleaser drill (Tye Co., Lockney, Texas) on 28 August 1997. The previous crop was winter wheat. Glyphosate [N-(phosphonomethyl) glycine] was applied to the wheat stubble at 1.0 lb a.i./acre two weeks before planting. The producer custom hired the planting of the 3-species mixture, but the establishment procedures were essentially the same. We selected two 1-acre paddocks of this planting for monitoring. In May 1999, we installed one 20 x 20-ft grazing exclosure in each treatment paddock. The area inside the exclosure was used to emulate a three-cut (late May, July, and August) hay management scenario. The area inside the exclosure was fertilized with 36 lb N/acre in April of each year to emulate the N that was recycled to the grazed areas from dung and urine of the heifers.

The paddocks were not grazed in 1998, but were cut twice for hay. Beginning in 1999 and continuing into 2002, each paddock was stocked with 45 to 60 Holstein dairy heifers for a 1- to 2-day period on a 30 to 45-day rotation interval. Grazing started in late April and ended the first week of October each year. All of the paddocks on the farm were cut for hay once in late May or June each year of grazing.

Net canopy photosynthesis was measured at mid-day (10:00 am to 2:00 pm EST) on 7 to 8 dates from early-April to early October in 2000, 2001, and 2002 using a LI-6400 open-path photosynthesis system combined with a 16 ft^3 plexiglass canopy chamber. Measurements were generally taken every 3 to 4 wk. Seasonal estimates of photosynthetic rates were obtained by grouping readings taken in April and May (spring), June through August (summer) and September and October (fall). In September of each year, root biomass and distribution were determined by taking four 2 inch-diameter by 2 ft-deep soil cores from each pasture. Roots were washed free of soil and ashed at 1000° F, and root dry weight expressed on an ash-free basis.

<u>Results and Discussion:</u> Neither mixture complexity (P = 0.37) nor harvest strategy (grazed vs. cut) (P = 0.43) had a significant effect on overall mid-day photosynthetic rates, although a trend existed for photosynthesis to increase with increasing number of species in the mixture (6.8, 7.2, and 7.9 $\mu mol\ m^{-2}\ s^{-1}$ for the 2-, 3-, and 11-species mixtures, respectively). Differences among mixtures were least in the spring (<5%) and greatest in the summer where photosynthesis in 3- and 11-species mixtures was 50% greater than in the 2-species mixture (Table 2). A significant year by season interaction for photosynthetic rate was also found (Table 3). When averaged across mixtures, photosynthetic rate was always greatest in the spring whereas summer and fall rates did not differ from each other. The greatest spring and fall photosynthetic rates occurred in 2000 with the lowest rates in 2001. In contrast, the greatest summer photosynthetic rate occurred in 2001, which was relatively cool and wet, and the lowest in 2002, when severe drought developed.

The 11-species mixture had greater root biomass than the other two mixtures (Table 4) and root distribution extended deeper into the soil profile as mixture complexity increased. In the 2-species mixture, 73% of root biomass was found in the top 2 inches of the soil profile compared with 59% in the 3-species and 48% in the 11-species mixture. At the same time, the 12-24 inch layer contained 4, 8 and 12% of total root biomass in the 2-, 3-, and 11-species mixtures, respectively. The 3- and 11-species mixtures originally contained the deep-rooted species, alfalfa and chicory. However, chicory disappeared from the mixtures before root data were collected and alfalfa generally averaged < 20% of aboveground biomass during the 2000-2002 growing seasons (Sanderson et al., this proceedings). The deeper rooting profile with increased species diversity appeared to be related as much to a redistribution of grass roots within the soil profile as it was to inclusion of the deep-rooted species. Harvest strategy had no effect on total root biomass (P=0.59) or on distribution within the soil profile. The top 2 inches contained 60% of total root biomass when plots were cut compared with 58% under grazing.

Averaged across the three years that photosynthetic rate and root biomass were measured, forage yield was 35% greater (data not shown) and root biomass in September 30% greater in the 11- vs. the 2-species mixture. At the same time, there was only a 16% difference in mid-day photosynthetic rate. Obviously, differences in mid-day net photosynthesis were not sufficient to account for the increased production that was observed with the 11-species mixture. Several reasons could account for the discrepancy between mid-day net photosynthesis and biomass production. First, net canopy photosynthesis also includes soil respiration which possibly could have been greater in the 11-species mixture, masking the true increase in photosynthesis. However, in a companion study, we found no effect of mixture complexity on canopy respiration (unpublished data) suggesting that differences in respiration were not responsible for reducing observed differences in net photosynthesis. Second, drought stressed plants often have similar photosynthetic rates compared with non-stressed plants early in the day, while afternoon rates are significantly reduced by drought (Baldocchi et al., 1983) . It is possible that the deeper root distribution and greater access to water with the 11-species mixture reduced the level of stress and allowed that mixture to maintain afternoon photosynthesis at rates that were comparatively greater than the 16% improvement over the 2-species mixture that was observed at mid-day. Finally, including more species in the mixture could have extended the growing season by including species that green up sooner in the spring. Extending the length of the growing season could increase total productivity without requiring any increase in photosynthesis.

Although interesting trends were observed, our results showed no significant effect of mixture complexity on mid-day canopy photosynthetic rates, despite a 35% increase in forage yield in the 11- compared to the 2-species mixture. The most complex mixture did have increased root production, and depth of rooting increased as mixture complexity increased. Greater root biomass combined with deeper penetration into the soil profile should improve forage production during periods of drought stress by improving access to water in deeper soil layers that would not otherwise be available.

Literature cited:

Baldocchi, D.D., S.B. Verma, N.J. Rosenberg, B.L. Blad, A. Garay, and J.E. Specht. 1983. Influence of water stress on the diurnal exchange of mass and energy between the atmosphere and a soybean canopy. Agron. J. 75:543-548.

Bertness, M.D. 1998. Searching for the role of positive interactions in plant communities. TREE 13:133-134.

Spehn, E.M., J. Joshi, B. Schmid, M. Deimer, and C. Korner. 2000. Above-ground resource use increases with plant species richness in experimental grassland ecosystems. Func. Ecol. 14:326-337.

Tilman, D. 1999. The ecological consequences of changes in biodiversity: a search for general principles. Ecol. 80:1455-1474.

Wardle, D.A. 1999. Is "sampling effect" a problem for experiments investigating biodiversity-ecosystem function relationships? Oikos 87:403-407.

Table 1. Composition of three forage mixtures planted in 1-acre pastures on a farm in Berks County, PA.

<u>2-Species Mixture</u>	<u>11-Species Mixture</u>
Pennlate orchardgrass	Pennlate orchardgrass
Will white clover	Will white clover
	Puna chicory
<u>3-Species Mixture</u>	Saratoga smooth bromegrass
Pennlate orchardgrass	Barcel tall fescue
Alfagraze alfalfa	Matua prairiegrass
Puna chicory	Paddock meadow bromegrass
	Norcen birdsfoot trefoil
	Alfagraze alfalfa
	Climax timothy
	Palaton reed canarygrass

Table 2. Seasonal differences in effect of mixture complexity on mid-day canopy photosynthetic rates for pastures in eastern Pennsylvania.

Mixture	Spring	Summer	Fall
	--------------Net Photosynthesis (μmol m^{-2} s^{-1})[a]----------------		
2-species	11.0 ± 1.0	3.7 ± 0.7	5.5 ± 0.7
3-species	10.5 ± 0.9	5.7 ± 1.1	4.9 ± 0.7
11-species	11.2 ± 0.9	5.6 ± 0.9	6.7 ± 1.0

[a]Values ± SE are averaged across harvest strategy (cut vs. grazed) and year (2000-2002).

Table 3. Annual and seasonal effects on mid-day canopy photosynthetic rates.

	Spring	Summer	Fall
	-------------Net Photosynthesis (μmol m^{-2} s^{-1})[a]-------------		
2000	12.7 ± 1.2	4.9 ± 0.7	6.7 ± 0.7
2001	9.4 ± 0.7	6.4 ± 1.0	4.0 ± 0.8
2002	10.0 ± 0.9	3.6 ± 0.8	6.0 ± 1.1
Mean	10.9 ± 0.6	5.0 ± 0.5	5.7 ± 0.5

[a]Values ± SE are averaged across harvest strategy (cut vs. grazed) and mixture complexity (2-, 3-, and 11-species).

Table 4. Root biomass distribution to a depth of 2 ft for forage mixtures of increasing species complexity.

Depth	2-species	3-species	11-species
	Ash free dry weight (lb/acre)[a]		
0-2 in	1660 a[b] (73[c])	1070 a (59)	1410 a (48)
2-6 in	340 b (15)	400 b (22)	730 a (25)
6-12 in	180 b (8)	210 b (11)	460 a (16)
12-24 in	80 b (4)	140 b (8)	370 a (12)
Total	2270 b	1820 b	2950 a

[a]Values averaged across harvest strategy (cut vs. grazed) and year (2000-2002).

[b]Means within a given row followed by the same letter are not significantly different at $P = 0.05$

[c]Values in parentheses indicate the percentage of total root biomass found in that particular soil layer. Total may not sum to 100% because of rounding error.

ON-FARM COMPARISONS OF CARBON UPTAKE AND PARTITIONING TO ROOTS IN SIMPLE AND COMPLEX PASTURE MIXTURES

R. Howard Skinner, Matt A. Sanderson, Benjamin F. Tracy[1]

Many studies have looked at above-ground productivity of managed grasslands, but much less information is available on photosynthetic inputs into the system or on the proportion of total inputs used for root production. We conducted an on-farm study to compare canopy photosynthetic rates and root production of simple and complex forage mixtures managed for hay production or grazing. Three forage mixtures (2, 3, or 11-species of grasses, legumes, and a forb) were established on 1-acre pastures on a farm in eastern Pennsylvania and grazed by dairy heifers or managed under a 3-cut hay system. Although interesting trends were observed, we saw no significant effect of mixture complexity on mid-day canopy photosynthetic rates, despite a 35% increase in forage yield in the 11- compared to the 2-species mixture. The most complex mixture had greater root production, and depth of rooting increased as mixture complexity increased. The greater rooting depth appeared to result from the inclusion of deep-rooted species in the complex mixture and from redistribution to greater depths of roots from other species. Greater root biomass combined with deeper penetration into the soil profile should improve forage production during periods of drought stress by improving access to water in deeper soil layers that would not otherwise be available.

[1] Research plant ecophysiologist and agronomist, USDA-ARS Pasture Systems and Watershed Management Research Unit, Building 3702, Curtin Road, University Park, PA 16802-3702; Assistant Professor, Dept. Crop Sci., Univ. Illinois, Urbana, IL.