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Is There a Role for Biodiversity in Temperate Pastures?

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Short title: Biodiversity in temperate pastures

1 **ABSTRACT**

2 Globally, biodiversity refers to the broad array of genetic material, species, and ecosystems that
3 make up the natural world. Pasture ecosystems can be highly biodiverse, with a complex array of
4 organisms contributing to proper ecosystem functioning. Within the broad range of biodiversity
5 in pastures, plant species diversity may be the most amenable to manipulation or management.
6 Postulated benefits of plant species diversity in experimental grasslands include greater and more
7 stable primary production along with more efficient nutrient use. Most information on the
8 potential benefits of increased plant diversity comes from studies of synthesized grasslands that
9 have not included domestic grazing animals. Some research in pasture ecosystems suggests that
10 greater plant species diversity benefits herbage productivity and resistance to weed invasion.
11 Little research has been done that has examined effects of plant species diversity on primary and
12 secondary productivity at larger (pasture) scales. Species identity, abundance, and their spatial
13 distribution across the landscape are critical features in pasturelands. Managing for high forage
14 species diversity may be most appropriate for grazing lands highly variable in soils, landscapes,
15 and climate.

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18 Key words: grazing ecosystem, forages, diversity, ecosystem function, ecosystem services
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1 Biodiversity is a key feature of properly functioning ecosystems including temperate forage
2 and grazing lands. Biodiversity refers to the broad array of genetic material, species, and
3 ecosystems that make up the natural world including their variability and interactions. On a
4 global scale, the earth's biodiversity encompasses 1.75 million described species from viruses to
5 vertebrates and the habitats they occupy (Alonso et al. 2001). Conservation of the earth's
6 biodiversity has important implications to ecosystem functions (habitat, biological, or system
7 properties or processes of ecosystems; Costanza et al. 1997) and the goods and services humans
8 derive from them (Table 1).

9 Some ecological research indicates that increased plant biodiversity increases primary
10 production in grasslands and benefits other ecosystem functions such as nutrient retention and
11 resistance to weed invasions. These results and concepts have been extrapolated to management
12 of forage and pasturelands (e.g., Tilman et al. 1999; Minns et al. 2001). It is not clear, however,
13 whether the results and concepts of basic ecological biodiversity studies apply to managed forage
14 and grazing lands.

15 Early research on pasture management seemed to advocate relatively complex mixtures of
16 grasses and legumes (Foster 1988). During the 1950's however, the emphasis of pasture
17 management shifted to monocultures of grasses maintained by N fertilizers or simple mixtures of
18 grasses and legumes (e.g., one of each) and management of those mixtures to maintain the
19 legume component (Blaser et al. 1952; Donald 1963). Forage and pasture management research
20 since that time has focused on monocultures or simple forage mixtures.

21 Pasture management in temperate regions is moving beyond the traditional concerns of
22 optimizing the quality and quantity of herbage for animal production. New challenges in pasture
23 management include such cross-cutting issues as sustainability, reduced inputs of fertilizers and

1 pesticides, soil protection, C sequestration, resistance to invasion by alien plants and insects, and
2 the aesthetic value of the landscape (West 1993; Krueger et al. 2002). It is within this context
3 that increased biodiversity may play an important role.

4 The objectives of this paper are to (i) discuss the role of biodiversity in temperate
5 pasturelands, (ii) consider the evidence for ecosystem benefits of increased plant species
6 diversity in temperate grazing lands, and (iii) consider whether it is worth managing for
7 increased plant species diversity.

8 **PASTURE BIODIVERSITY**

9 A rough sketch of the potential diversity of insects, invertebrates, fungi, animals, and
10 plants can be assembled from the literature. For example, an examination of northern Ireland
11 grasslands shows a range of plant and insect species depending on the level of management and
12 inputs (Table 2). Generally, biodiversity decreased as management intensity increased. Semi-
13 natural pastures in Sweden had a broad range of plants, insects, and birds (Table 3). Several
14 surveys of insects, invertebrates, and plants in the pastures of the northeastern US also reveal a
15 highly complex ecosystem (Table 4). The biomass of different organisms at different trophic
16 levels in temperate grasslands indicates the level of biodiversity in grassland food webs (Table
17 5).

18 Thus, pastures can be very diverse ecosystems, but many components of this biodiversity
19 cannot be easily managed or directly manipulated for management purposes. Research has
20 shown that management practices can influence insect and soil animal abundance and diversity
21 (Bardgett and Cook 1998; Kruess and Tsharntke 2002). Plant species diversity, however, may be
22 the component of biodiversity most amenable to management. This paper will focus on plant
23 species diversity because of its central role in primary production in the pasture ecosystem.

Plant Species Diversity in Pastures

Plant species diversity refers to the number of species (species richness, number per unit area) and their relative abundance (evenness, an estimate of species distribution within a community) in a defined area. Ecologists use various indices that combine these two measures to describe diversity in plant communities. Spatial scale strongly influences plant species diversity in that: i) species richness increases with the area sampled, and ii) small-scale (alpha) diversity varies independently from large-scale (beta) diversity. Evaluating species richness without taking into account evenness and spatial scale effects could underestimate the importance of diversity in pasture ecosystems.

On the surface, pasturelands may appear uniform with a homogeneous mixture of plant species. Closer examination, however, reveals a complex temporal and spatial structure of both species and species richness in pastures (Parsons and Dumont 2003). Plant species richness in traditionally managed grasslands (i.e., species-rich ancient grazing lands such as chalk grassland and heathland) in northwest Europe ranged from 50 to 60 species 100 m^{-2} , whereas more intensively managed grasslands contained 10 to 20 species 100 m^{-2} (Peeters and Janssens 1998).

Early research on the ecology of prairie in Alberta and Saskatchewan revealed more than 100 species of grasses, forbs, shrubs, and sedges (Coupland 1950). More recently, Hill et al. (2000) extended this early work and analyzed the geographic distribution of native and introduced plants in southern Alberta as a baseline against which to compare changes in vegetation resulting from future climate or management-induced changes.

Diverse pasture mixtures were emphasized in the conversion of cleared land in Saskatchewan. Aspen parkland in Saskatchewan was cleared and seeded to complex mixtures of grasses and legumes [e.g., smooth brome (*Bromus inermis* Leyss), creeping red fescue

1 (*Festuca rubra* L.), alfalfa (*Medicago sativa* L.), alsike clover (*Trifolium hybridum* L.), white
2 clover (*Trifolium repens* L.)] before the 1970's; whereas since that time simple mixtures of
3 smooth brome grass and alfalfa have been sown (McCartney 1993; Bittman et al. 1997). In
4 eastern Canada, most of the common cool-season forage legumes and grasses [e.g., birdsfoot
5 trefoil (*Lotus corniculatus* L.), white clover, red clover (*Trifolium pratense* L.), smooth
6 brome grass, timothy (*Phleum pratense* L.), orchardgrass (*Dactylis glomerata* L.)] are used in
7 different combinations for pastures depending on the landscape, climate, and soil resources
8 (Petit, 1993; Papadopoulos et al., 1993). Others have emphasized the appropriate use of
9 complex forage mixtures in Canadian pastures (Clark et al., 1993).

10 **PLANT DIVERSITY AND PASTURE ECOSYSTEM FUNCTION**

11 The principal ecosystem functions (defined as biological system properties or processes
12 of ecosystems) include primary productivity, nutrient cycling, and decomposition. Many of these
13 ecosystem functions provide ecosystem services of value to humans (Table 1; Costanza et al.
14 1997). Although we might be focused primarily on productive output in managed grasslands, the
15 ecosystem goods and services provided by grazing ecosystems must be considered as well (Table
16 1).

17 Reported benefits of plant diversity in grasslands include: increased primary production;
18 greater ecosystem stability in response to disturbance; reduced invasion by exotic species, and
19 greater nutrient cycling and retention (Fridley 2001). Although there is some consensus that plant
20 diversity benefits grassland ecosystem function, there are reports that indicate no general benefit
21 of increased plant diversity and highly productive agricultural systems often rely on low plant
22 species diversity (Huston et al. 2000; Wardle et al. 2000). The studies indicating benefits for

1 plant diversity suggest that managing for increased plant species diversity on pasturelands could
2 increase forage yield, improve yield stability, and reduce soil nutrient losses.

3 **EVIDENCE FOR DIVERSITY EFFECTS IN PASTURELAND**

4 Many of the studies on diversity effects in grasslands were done with several nonagronomic
5 species in small plots that were clipped and not grazed. Thus, the results from these types of
6 experiments are difficult to extrapolate to pastures. In this section, I discuss some of the evidence
7 for plant diversity effects on primary and secondary productivity, ecosystem stability, resistance
8 to invasion, and nutrient cycling in pastures. I then discuss some of the mechanisms involved.

9 **Complex Forage Mixtures and Primary Productivity**

10 One of the principal benefits ascribed to increased plant diversity in grassland systems has
11 been increased primary productivity. In early applied research on complex forage mixtures,
12 studies in Connecticut USA found no significant trend in yield with increasing seeded species
13 richness (Brown and Munsell 1936). Research with combinations of cool-season grasses and
14 legumes containing 1 to 7 species in clipped and grazed plots under irrigation in Utah, however,
15 indicated a positive relationship between herbage yield and seeded species richness (Bateman
16 and Keller 1956).

17 Research in Ontario, Canada concluded that mixture complexity per se was not as important
18 as the use of strategically selected and appropriately managed complexity (Clark 2001). In New
19 Zealand, pastures seeded with a mixture of 10 to 23 species of cool-season grasses and pasture
20 herbs and grazed by sheep yielded more herbage than simple grass-legume mixtures (Ruz-Jerez
21 et al. 1991; Daly et al. 1996). Greater herbage production of the complex mixtures resulted from
22 summer growth of legume and forb components.

1 Bullock et al. (2001) compared the productivity of what they considered a species-poor
2 mixture (6 to 17 species of grasses, forbs, and a legume) with a species-rich mixture (25 to 41
3 species) in small plots under hay management at six sites during 4 yr in southern England. There
4 was no difference in herbage yield between the mixtures in Year 1; however, the species-rich
5 mixture yielded up to 42% more herbage than the species-poor mixture during Years 2 to 4.

6 We compared three forage mixtures (2, 3, or 11-species) on-farm in replicated 0.4-ha
7 pastures grazed by dairy heifers or managed under a 3-cut hay system for four years. The
8 complex mixture yielded more forage dry matter than the two-species mixture, but this
9 difference was due to the inclusion of a few highly productive forage species (Fig. 1, Sanderson
10 et al. 2004a). The primary advantage of the three- and 11-species mixtures resulted from the
11 inclusion of chicory (*Cichorium intybus* L.) and alfalfa, both deep taprooted species, on the
12 drought-prone soil. A disadvantage was that nearly one-half of the planted species did not persist
13 beyond four years in the complex forage mixture. Similar results were obtained in a grazed
14 small-plot trial that compared 13 forage mixtures (combinations of 2, 3, 6, or 9 species) under
15 management-intensive grazing. The six- and nine-species mixtures yielded more forage than the
16 two- and three-species mixtures; however, the principal cause for greater yields was the inclusion
17 of red clover (Deak et al. 2004).

18 Other field-plot studies have shown no benefit to forage production from highly complex
19 forage mixtures (e.g., Zannone et al. 1983; Tracy and Sanderson 2004b). Several studies in the
20 New Zealand hill country reported inconsistent evidence of production responses to forage
21 species richness (Nicholas et al. 1997; Dodd et al. 2003, White et al. 2004). In those studies, the
22 environment (site, fertility, slope) influenced herbage yield more than species diversity (Dodd et
23 al. 2003).

1 The contrasting results from studies conducted with different forage species,
2 environments and management conditions should not be surprising. Taken together, these studies
3 suggest that in a stable environment with few limitations to production herbage yield might be
4 maximized from a low diversity stand composed of species well adapted to that environment. As
5 environmental heterogeneity and functional expectations increase (i.e., more items from the list
6 in Table 1) pastureland sustainability might be maximized from more complex mixtures.

7 **Grazing Animal Productivity on Diverse Pasture Mixtures**

8 There are few studies on how biodiversity affects animal performance even though grazing
9 animals have a key role in affecting plant species diversity in grazing lands (Rook and Tallwin,
10 2003). On New Zealand high-country grazing lands species richness and evenness were weakly
11 associated with sheep carrying capacity (Scott, 2001). Grazing research with lactating dairy cows
12 in the mid 1960's indicated that there was no benefit to planting a complex mixture of grasses
13 and legumes for grazing (Table 6; Wedin et al. 1965).

14 More recent dairy grazing research demonstrated that milk production per cow did not differ
15 among simple (orchardgrass-white clover) and complex swards (three to nine species of grasses,
16 legumes, and chicory; Soder et al. 2004; Sanderson et al. 2004b; Table 7). Forage production per
17 hectare (and by extrapolation, animal production per hectare) was greater on complex forage
18 mixtures compared to the simple grass-legume mixture during a dry year (2002) but not during a
19 wet year (2003). As in the on-farm work described above, less than one-half of the species
20 planted in the complex mixtures were present by the third year, indicating that species presence
21 was not very stable in these mixtures. Future research in this area should focus on grazing trials
22 that measure animal productivity, behavior, and selection on a range of species mixtures so that
23 practical recommendations can be made for grazing management.

Ecosystem Stability

Another tenet of plant biodiversity theory in grasslands is that increased diversity contributes to the stability of ecosystems. Tracy and Sanderson (2004b) in a small-plot study with mixtures of up to 15 species of legumes, forbs, and grasses found that complex forage mixtures did not improve forage yield or yield stability. Most of the mixtures decreased in species number during the 3-yr study and became dominated by perennial grasses.

Research on New Zealand high-country grazing lands showed that species richness and evenness were weakly associated with the stability of sheep production (coefficient of variation in annual carrying capacity; Scott 2001). Stability (measured as the coefficient of variation in seasonal herbage production) of temperate grazing lands in southern Australia was not related to species richness (Kemp et al. 2003).

Nicholas et al. (1997) reported a high coefficient of variation (CV) for low numbers of species, and a decreasing CV as species number increased; evidence of reduced risk from species-rich grasslands. Thus, the evidence is lacking for a clear-cut effect of plant species diversity on the stability of managed grazing lands.

Invasion by Exotic Species (Weeds and Pests)

Greater plant diversity in grassland ecosystems has been thought to contribute to resistance to invasion by weeds and pests. Tracy et al. (2003) reported that weed abundance decreased in experimental pasture mixtures as the evenness of forage species increased. In addition, species composition of the mixture affected weed abundance as mixtures based on tall fescue (*Festuca arundinacea* Schreb.) had fewer weeds in the soil seed bank and aboveground vegetation than did mixtures based on smooth brome grass. Similar results were found in a series of greenhouse,

1 field, and survey experiments with cool-season pasture species in the northeast (Tracy and
2 Sanderson, 2004a).

3 **Diversity and Nutrient Cycling in Forage Plant Communities**

4 Aboveground diversity influences nutrient cycling through microbial decomposition of plant
5 litter. In complex pasture plant communities, the litter of different plant species intermingles and
6 decomposes together. Research results concerning plant diversity effects on litter decomposition
7 in experimental systems have been conflicting [e.g., positive effects (Bardgett and Shine 1999);
8 no effects (Wardle et al. 1997), or mixed results (Hector et al. 2000)].

9 Increasing the diversity of grassland plant communities may increase nutrient retention. Soil
10 nitrate levels, both within and below the rooting zone, were reduced as the number of plant
11 species increased in growth chamber studies and in tallgrass prairie communities (Naeem et al.
12 1994; Tilman et al. 1996). For example, increasing the diversity of non-leguminous species
13 grown with legumes in grassland mixtures could help reduce nitrate leaching species while still
14 benefiting production through N fertilization (Scherer-Lorenzen et al. 2003).

15 **Mechanisms to Explain Diversity Effects in Forage Plant Communities**

16 There is limited evidence for plant diversity benefits in temperate pasturelands. However,
17 there has been even less research regarding the mechanisms underlying these responses in forage
18 and grazing lands. Mechanisms proposed to explain the observed responses to plant diversity in
19 experimental grasslands include: (i) the “sampling effect”, resulting from the greater chance of
20 including more productive species in highly diverse plant communities; (ii) facilitation, whereby
21 the presence of one species increases the growth or survival of another species; (iii) niche
22 differentiation/niche separation, or greater coverage of habitat caused by a wider range of species
23 traits in a more diverse community; and (iv) the “insurance effect”, where a highly diverse plant

1 community is buffered from environmental extremes by having some species that are tolerant of
2 different stresses and thereby stabilize productivity (Fridley 2001).

3 **Sampling Effect**

4 The sampling effect refers to when mixtures overyield simply because of the greater
5 probability of including an adapted, high-yielding plant species in a species-rich mixture. In
6 some studies, the dominant influences on herbage accumulation were related to the presence of
7 particular species rather than the number of species (Dodd et al. 2003). Generally, when higher-
8 yielding species were included in species-rich mixtures, yields increased.

9 **Facilitation**

10 Facilitation is when one plant species alters the environment in a way that benefits a
11 neighboring species. For example, neighbors near species that lift water hydraulically from deep
12 in the soil profile can use a significant proportion of that water resource, effectively ameliorating
13 the adverse effects of drought for shallow-rooted species. Growing deep and shallow rooted
14 grassland species in mixture may result in greater nutrient extraction from deeper soil layers by
15 the deep-rooted species than would normally be observed in monoculture (Berendse 1982).

16 Neighboring plants can also favorably alter other environmental conditions. Shading by
17 larger plants can lower soil temperature, reducing heat stress effects while also reducing
18 evapotranspiration leading to improved leaf water relations of smaller neighboring species. In a
19 New Zealand study, deferred grazing of perennial ryegrass-white clover pastures during the
20 summer resulted in increased herbage accumulation which, in turn, led to lower soil
21 temperatures, increased soil moisture and improved white clover survival compared to
22 conventionally grazed pastures (Harris et al. 1999).

1 White clover growing in a complex mixture with chicory had improved leaf water
2 relations and greater relative growth rate than similar white clover grown only with bluegrass
3 (Skinner et al. 2004). They hypothesized that hydraulic lift, whereby chicory may have
4 redistributed water from deep in the soil to the surface layer making it available to shallow-
5 rooted species such as white clover. Research is underway to test the hydraulic lift hypothesis.
6 The main conclusion was that the presence of a deep-rooted species was more important than
7 simply species richness in affecting herbage productivity in a stressful environment.

8 **Niche Differentiation**

9 Niche differentiation refers to different plant species coexisting by exploiting resources
10 differently, either in time or space. For example, different plant species may obtain soil nutrients
11 through different rooting depths or strategies. Or, species may differ in phenology and have
12 different periods of peak growth.

13 **Insurance Effect**

14 Diversity theory suggests that greater plant diversity buffers plant communities from
15 environmental extremes. By having some species that are tolerant of different stresses, complex
16 mixtures act to ensure and thereby stabilize productivity. For example, the productivity of
17 grazing lands during summer drought may be improved by sowing a percentage of pastures to
18 warm-season grasses (Skinner et al. 2004) or by planting multi-species mixtures that include
19 some of the more drought resistant cool-season grasses and forbs (Lucero et al. 1999).

20 Interactions among species within complex mixtures may also improve the ability of normally
21 drought-sensitive species to maintain production under stressful conditions.

22

CONCLUSIONS AND RECOMMENDATIONS

1
2 Is there a role for biodiversity in temperate pastures? Clearly biodiversity plays a role in the
3 proper functioning of temperate pasture ecosystems. Perhaps a more relevant question should be
4 “can biodiversity or components of biodiversity (e.g. plant species diversity) be managed to
5 influence ecosystem functions to benefit the output of pasture ecosystem goods and services?”
6 Some research suggests that greater plant species diversity benefits herbage productivity and
7 resistance to weed invasion. Despite these positive results, it must be remembered that
8 management for increased plant species diversity is not simply a numbers game. Species
9 identity, abundance, and their spatial distribution across the landscape are critical features in
10 pasturelands. Managing for high forage species diversity may not be appropriate for a highly
11 productive, stable environment where the main objective is maximum forage production. Most
12 temperate pasturelands, however, are highly variable in soils, landscapes, and climate and often
13 fulfill multiple functions for producers (e.g., animal production and resource protection). It is in
14 these situations where greater plant diversity may be most beneficial.

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- 13

1 Table 1. Ecosystem goods and services provided by pasturelands (adapted from Costanza et al. 1997).

Ecosystem service	Ecosystem function	Example
Gas regulation	Regulation of atmospheric chemical composition	CO ₂ /O ₂ balance
Climate regulation	Regulation of global temperature, precipitation and other biologically mediated climatic processes at global or local levels	Greenhouse gas regulation
Disturbance regulation	Capacitance, damping, and integrity of ecosystem response to environmental fluctuations.	Storm protection, flood control, drought recovery, or other aspects of habitat response to environmental variability mainly controlled by vegetation structure
Water regulation	Regulation of hydrological flows.	Provisioning of water for agriculture or industrial processes or transportation
Water supply	Storage and retention of water	Provisioning of water by watersheds, reservoirs, and aquifers
Erosion control	Retention of soil within an ecosystem	Prevention of soil loss by erosional processes..
Soil formation	Soil formation processes	Weathering of rock and the accumulation of organic material
Nutrient cycling	Storage, internal cycling, processing and acquisition of nutrients	N fixation, N and P or other nutrient cycles.
Waste treatment	Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds	Waste treatment, pollution control, detoxification
Pollination	Movement of floral gametes	Provisioning of pollinators for the reproduction of plant populations.
Biological control	Trophic-dynamic regulations of populations	Keystone predator control of prey species, reduction of herbivory by top predators
Refugia	Habitat for resident and transient populations	Nurseries, habitat, for migratory species, regional habitats for locally harvested species or overwintering grounds
Food production	The portion of gross primary production extractable as food	Production of fish, game, crops
Raw materials	The portion of gross primary production extractable as raw materials	Production of fuel, forage
Genetic resources	Sources of unique biological materials and products	Medicine, genes for resistance to pathogens and pests, ornamental species
Recreation	Providing opportunities for recreational activities	Eco-tourism, sportfishing, hunting
Cultural	Providing opportunities for non-commercial uses	Aesthetic, artistic, educational, spiritual, and or scientific values of ecosystems.

2

1 Table 2. Plant and insect biodiversity in northern Ireland grasslands (McAdam 1998).

Grassland type	Plants	Beetles	Spiders
No. of species per habitat			
Wet grassland	110	28	30
Unimproved grassland	104	27	47
Hay meadow	91	28	30
Limestone grassland	84	26	33
Heather moorland	70	34	42
Woodland	58	25	38
Improved grassland	42	22	18

2

1 Table 3. Biodiversity in semi-natural pastures of south-central Sweden (Soderstrom et al. 2001).

Group	Species richness	Total species
	#/pasture	
Vascular plants	130	341
Butterflies	18	29
Bumble bees	6	11
Dung beetles	8	14
Ground beetles	18	70
Birds	21	57

2

1

2 Table 4. Biodiversity of pastures and conservation grasslands in the northeast USA.

Group	Number of species	Source
Herbaceous plants	268	Goslee and Sanderson, unpublished data, 2004
Herbaceous plants	280	Adler et al. 2003
Soil seedbank	54	Tracy and Sanderson 2000
Beetles	275	Byers et al. 2001
Soil macroinvertebrates	2-18	Byers and Barker 2000

3

4

1

2 Table 5. Biomass of several classes of organisms in an ungrazed temperate grassland (Pimental

3 et al. 1992).

Group	kg fresh wt ha ⁻¹
Plants	20,000
Fungi	4,000
Bacteria	3,000
Arthropods	1,000
Annelids	1,320
Protozoa	280
Algae	200
Nematodes	120
Mammals	1.2
Birds	0.3

4

5

1 Table 6. Milk production of dairy cows grazing N-fertilized grass or two grass-legume mixtures
 2 in Minnesota (adapted from Wedin et al. 1965).

Treatment	Carrying		
	capacity	MilkProduction	
	Animal days ha ⁻¹	kg cow ⁻¹ day ⁻¹	kg ha ⁻¹
Grass+N ^z	325	17.1	4733
Simple mixture ^y	300	16.8	4233
Complex mixture ^x	301	15.8	3789

3

4 ^zSmooth brome grass and orchard grass received 450 kg N ha⁻¹ yr⁻¹ in three applications during
 5 year 1 and 235 kg ha⁻¹ yr⁻¹ in two applications during year 2.

6

7 ^yAlfalfa, white clover, smooth brome grass, and orchard grass.

8

9 ^xAlfalfa, red clover, alsike clover, white clover, smooth brome grass, orchard grass, timothy,
 10 meadow fescue, and reed canary grass.

11

1 Table 7. Milk production and dry matter intake of dairy cows grazing four different species
 2 mixtures (adapted from Soder et al. 2004).

Forage mixture	Milk yield ^z	Herbage intake ^z	Dry matter yield	
			2002	2003
	kg cow ⁻¹ d ⁻¹		kg ha ⁻¹	
Two species ^y	34.1	12.9	4800	9000
Three species	35.3	12.1	7400	9900
Six species	34.4	12.1	7900	11300
Nine species	34.3	11.4	7500	9000

3 ^zData are means of four grazing periods in each of two years.

4 ^yTwo-species mixture = orchardgrass and white clover; three-species mixture = orchardgrass,
 5 white clover, and chicory; six species mixture = orchardgrass, red clover, chicory, tall fescue,
 6 Kentucky bluegrass, and birdsfoot trefoil; nine-species mixture = orchardgrass, red clover,
 7 chicory, tall fescue, Kentucky bluegrass, birdsfoot trefoil, perennial ryegrass, alfalfa and white
 8 clover.

9

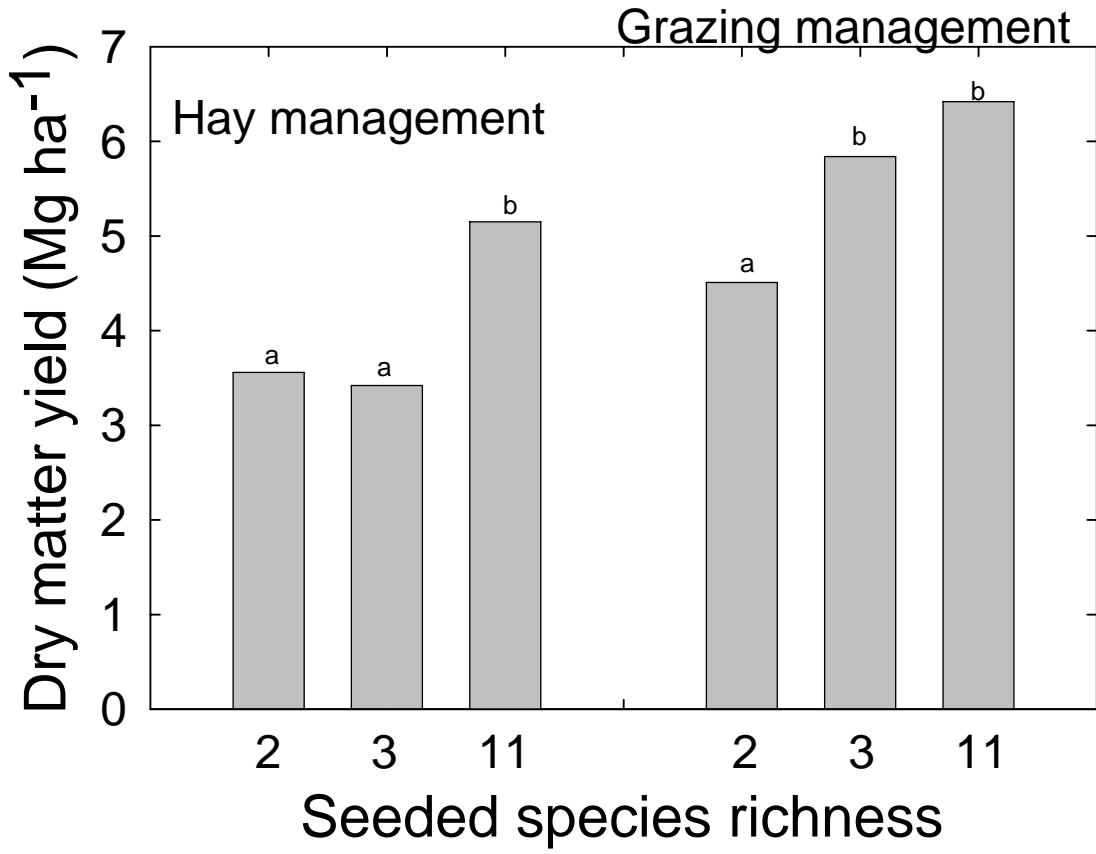
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2

3 Fig. 1 Dry matter yields of three forage mixtures under grazing in southeastern PA. Two 0.4 ha
4 pastures of a two-species (orchardgrass-white clover), three species (orchardgrass, alfalfa,
5 chicory), and an 11-species mixture [orchardgrass, alfalfa, chicory, white clover, red clover,
6 birdsfoot trefoil, prairiegrass (*Bromus wildenowii*), meadow brome (*Bromus biebersteinii*
7 Roemer & J.A. Schultes), reed canarygrass (*Phalaris arundinacea* L.), perennial ryegrass,
8 timothy (*Phleum pratense* L.), and tall fescue] were planted in the autumn of 1997. The soil was
9 a Weikert [Loamy-skeletal, mixed, active, mesic Lithic (Typic) Dystrudepts]. Pastures were
10 grazed by Holstein dairy heifers during 1999 to 2002. Paddocks were stocked with 45 to 60
11 Holstein dairy heifers for a 1- to 2-d period of stay on a 30 to 45-d rotation interval. Grazing
12 started in late April and ended the first week of October each year. Paddocks were cut for hay
13 once in June of 1999 and 2000. Data are averages of two replicate pastures and four years. Bars
14 with similar letters do not differ ($P < 0.05$). Data from Sanderson et al. (2004a).

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Fig. 1