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Diversifying Midwestern agriculture with perennial forages: a review of the benefits and barriers to forages in Iowa, and a genetic study of biofuel potential for reed canarygrass

by

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ABSTRACT

Following World War II, Midwestern farmers transitioned away from integrated crop and livestock production systems that included perennial forage crops toward two-crop rotations of corn and soybeans. This transition has contributed to severe environmental degradation in the region, including soil erosion and ground and surface water pollution from nutrients and pesticides. At the same time, the decrease in diversity on the farm has corresponded with a decrease in the number of Midwestern farms, and an increase in average farm size. As part of an interdisciplinary course of study in sustainable agriculture and plant breeding, this thesis addresses first the socio-political, economic, and ecological consequences and causes of decreased forage production in Iowa, and then focuses in on a breeding study related to the biofuel potential of reed canarygrass. In the first paper I review the agronomic, ecological, and economic benefits of forage incorporation into corn and soybeans rotations and then attempt to explain the socio-political reasons why forages are not grown on more Iowa farms. The second paper details an evaluation of reed canarygrass germplasm for biofuel traits. We evaluated the entire reed canarygrass germplasm collection available in the US at two locations, over two years, for biomass and quality traits. We found significant variability for yield, height, and quality traits among germplasm of both US origin and from regions around the world. Higher yields from Central and Northern-European accessions as compared to Middle-Eastern and Eastern-European accessions suggest they would be the best candidates for inclusion in a direct breeding program. All accessions contained relatively high levels of ash, indicating that reed canarygrass may work best as part of a mixture of bioenergy feedstocks

CHAPTER 1: GENERAL INTRODUCTION

Prior to World War II, Midwestern farmers routinely included forages in their cropping and livestock systems. These pastures and hay crops supplied fodder that fueled animal traction, and were a source of cash income alongside profits from grain production. Following the Second World War cheap chemical fertilizers and pesticides became widely available, and farmers transitioned away from agricultural systems that merged crop and livestock production toward two-crop rotations of corn and soybeans (Dimitri et al., 2005 and Cardwell, 1982). This shift in agricultural production has corresponded with a decrease in the number of farms in the Midwest, as well as a decrease in farm incomes (USDA, 2006). The substitution of corn and soybean rotations for systems that include perennial forage crops, along with the decoupling of crop and livestock production, has contributed to severe environmental degradation in the region, including topsoil loss and water pollution by nutrient and pesticide run-off (Hatfield et al., 1999).

Concerns about the environmental degradation caused by corn and soybean rotations, along with rapidly growing interest in and demand for biofuels made from cellulose, is starting to renew interest in forages. As part of an interdisciplinary course of study in sustainable agriculture and plant breeding, this thesis explores two aspects of forage production in the Midwest. The first is in the form of a review paper in which I examine the agronomic, ecological, and economic benefits to Iowa farmers including forages as part of their corn and soybean rotations, and then seek to discern the socio-political barriers to greater forage incorporation on Iowa farms. The second half of the thesis focuses on breeding efforts for a particular forage crop that may have potential as a source of biomass for cellulosic ethanol, reed canarygrass, in a paper reporting the results of an evaluation of reed canarygrass germplasm for biofuel feedstock potential.

Thesis Organization

The thesis is organized into four chapters. Chapter one provides a general introduction and explanation of the thesis organization. Chapter two is a paper accepted by the journal “Renewable Agriculture and Food Systems” entitled, “Benefits and barriers to forages in Iowa corn and soybean rotations.” Chapter three is a paper to be submitted to the journal “Crop Science” entitled, “Reed canarygrass germplasm evaluation for biofuel traits.” Chapter four provides general conclusions on the thesis material.

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CHAPTER 2: BENEFITS AND BARRIERS TO PERENNIAL FORAGE CROPS IN IOWA CORN AND SOYBEAN ROTATIONS

A paper accepted by *Renewable Agriculture and Food Systems*

Julia Olmstead[1] and E. Charles Brummer[2]

Abstract:

The transition away from forage-based cropping systems in Iowa to corn and soybean rotations since World War II has corresponded with degraded economic and environmental conditions in the state. Falling net incomes for farmers and concern over global warming and the effects of agriculture-related pollution on water, wildlife and human health has increased interest in diversified cropping systems. This paper reviews the benefits of diversifying Iowa corn and soybean rotations with perennial forage species such as alfalfa and red clover. Perennial forage crops improve soil quality, decrease NO_3-N leaching and soil erosion, increase carbon sequestration, and decrease pesticide and herbicide needs by controlling weed and insect pests. Forage legumes reduce N fertilizer needs for succeeding corn crops at a higher rate than soybeans, and corn crops following forages have higher yields than after corn or soybeans. Farmers who add alfalfa to corn and soybean rotations could realize significant economic gains. A simulated five-year rotation in Iowa including corn-soybeans-oats/alfalfa-alfalfa-alfalfa would result in a 24% net income increase over five years of corn-soybean-corn-soybean-corn, even with government farm support payments for the row crops. Farm policies that encourage

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commodity production create little incentive for Iowa farmers to diversify their cropping systems beyond corn and soybeans, despite the clear economic and ecological benefits. We recommend increasing federal support for conservation programs that reward environmentally beneficial farm practices such as the Conservation Securities Program and we encourage land grant universities to hire researchers interested in alternative agricultural systems.

Introduction

Prior to World War II, forage species, used for pasture, silage, and hay, were routinely included in Iowa crop rotations. By providing feed for livestock and work animals, cash income to farmers from hay sales, and crucial ecological benefits to the farming system, these multifunctional crops mitigated risk on the farm. The post-war influx of cheap, abundant chemical fertilizers and synthetic pesticides, along with a shift from animal to machine-based labor, caused a decrease in forage-based cropping sequences[1, 2], in part because farmers did not need to rely solely on forage legumes to supply nitrogen nor did they need feed for draft animals.

Since 1950, Iowa agriculture has increasingly focused on intensive corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) production, an effort that produced impressive results – corn and soybean yields nearly quadrupled and more than doubled, respectively, between 1950 and 2004[3]. Ironically, these yield increases did not represent improved welfare for Iowa farms or farmers. During the same period of time, the number of farms in Iowa decreased by more than 50% and crop prices plummeted[4]. After adjusting for inflation, average net income per Iowa farm in 2001 was 9% lower than it was in 1960, despite a more than twofold increase in the number of acres per farm[4].

Meanwhile, the environmental implications of intensive corn and soybean production are cause for concern. Runoff and artificial drainage from corn and soybean fields are well-documented causes of nonpoint source contamination of surface and groundwater bodies with sediment, nutrients (especially NO_3-N and P), and pesticides[9-13]. NO_3-N loading to the Mississippi River from agricultural operations in the Mississippi River Basin has been linked to a hypoxic zone in the Gulf of Mexico that is growing in size and severity[14]. Further, pesticide and herbicide use in corn and soybean production may have negative effects on human and wildlife health[15-17].

We hypothesize that diversifying Iowa corn and soybean rotations by including forage crops would offer farmers a way to mitigate negative environmental impacts caused by corn and soybean production while providing a lucrative source of income not dependent on government subsidization. In this paper, we review the literature on the agronomic and ecological effects of forage incorporation into Iowa and Midwestern cropping systems. We also look at the economic effect of incorporating forages into corn and soybean rotations in Iowa and assess socio-political barriers that discourage farmers from including forage species as part of their agricultural systems. Finally, we make recommendations for policy changes that would encourage the adoption of forages by corn and soybean farmers, a goal that has the potential to greatly improve not only the ecological health of Iowa waterways and soil but also the economic health of the state's farmers. Although this analysis primarily focuses on Iowa, the discussion and conclusions can likely be generalized to other agroecosystems.

Forage Production

Forage is defined as the edible part of a plant, other than the separated grain, that is generally above ground and that can provide feed for grazing animals or can be harvested for feeding[18]. In Iowa, several grass and legume species are cultivated as forages, including smooth bromegrass (*Bromus inermis* Leyss.), orchardgrass (*Dactylis glomerata* L.), switchgrass (*Panicum virgatum* L.), red (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.), birdsfoot trefoil (*Lotus corniculatus* L.), and most commonly, alfalfa (*Medicago sativa* L.)[19]. Forages can be harvested by animals in pasture-based systems or mechanically harvested throughout the growing season as silage/haylage, hay, or pellets for use as year-round livestock feed.

Precise estimates of the amount of perennial forage crops grown in Iowa are not available. Iowa has between one and two million hectares of pastureland, encompassing cropland, permanent, and woodland pastures[19]. An additional 650,000 hectares of hay were harvested in Iowa in 2004, 525,000 ha (81%) of which was alfalfa[20]. This represents 7% of Iowa's crop harvest, which also includes corn, soybeans, oats (*Avena sativa* L.) and wheat (*Triticum aestivum* L.).

Relative to corn and soybeans, perennial forage crops have high caloric and protein yields, and high output/input energy ratios. Based on energy data from production in Ohio, alfalfa yields nearly twice as many calories and protein per hectare as soybeans and more than 40% more protein than corn per hectare. The energy output/input (energy inputs include labor, machinery, fuel, fertilizers, pesticides, electricity and transportation) ratios for alfalfa, soybeans, and corn are 6.17:1, 4.15:1, and 2.5:1, respectively[21]. The relative energy efficiency of alfalfa over a corn and soybean rotation is mainly the result of the high energy cost of nitrogen fertilizer applied primarily to corn.

Agronomics

Rotational Yield Benefits

Little debate exists over the yield benefits arising from diversifying crop rotations, particularly those combining legume and grass crops in succession. A rotation of corn and soybeans yielded 10% more than continuous corn and 8% more than continuous soybeans in Minnesota, evidence for a “rotation effect”[22]. Adding perennial forage legumes, particularly alfalfa, to the system, creates more substantial benefits to corn yield, a trend that has been observed for over 50 years and in many regions of North America[23-33] (Table 1). In Minnesota, a single year of alfalfa increased succeeding corn yields by 19%[24] to 84%[22] compared to corn following corn and by 33% compared to corn following soybean[22]. Even when nitrogen is applied to the corn crop, corn following alfalfa typically yields more than corn following soybeans[34]. These studies demonstrate that rotations including at least one year of alfalfa would produce higher corn and soybean yields than the typical corn-soybean rotation. Because the preceding alfalfa crop supplies nitrogen to the corn for free, the higher yield is produced at lower input cost as well. Yield benefits conferred by alfalfa occur in sub-humid regions like the Midwest or in areas under irrigation. When water availability is restricted, alfalfa, which uses large quantities of water, can decrease subsequent corn yields[35].

Weeds Effects

In recent years, Iowa farmers have sprayed more than 95% of corn and soybean fields annually with herbicides[36]. Evidence of human and animal toxicity of the most frequently applied herbicides – atrazine for corn and glyphosate for soybeans – has raised concerns about their widespread use[15-17]. In particular, the widespread adoption of Roundup Ready® soybeans and corn has resulted in a large increase in the application of Roundup® (glyphosate), which is now present in many water samples in the Midwest[37]. Further, herbicide tolerant crops do not solve the weed control problem; resistance has developed in many weed species to herbicides like Roundup®, diminishing the value of the technology[38]. In other words, the technological fix of herbicide resistant crops is transient, requiring continual reinvigoration by more advanced technology.

In contrast, alfalfa and other forages planted in rotation with corn and soybeans offer non-chemical means of controlling weeds. When grown in monoculture, alfalfa stands decrease or eliminate populations of several weed species, including milkthistle [*Silybum marianum* (L.) Gaertn.], field bindweed (*Convulvulus arvensis* L.), white campion [*Silene latifolia* subsp. *Alba* (Mill.) Greuter & Burdet; syn. *S. alba* (Mill.) E.H.L. Krause], and common lambsquarter [*Chenopodium album* L.][39-42]. By their second-year, alfalfa stands can often be weed-free without any herbicide use[43, 44]. Without decreasing yields of succeeding crops, alfalfa has been shown to reduce weed densities to a comparable degree as herbicides[45-47]. A recent demonstration of one alternative system has shown that diversifying crop rotations to include triticale and either red clover or alfalfa is nearly as effective as herbicide use in controlling velvetleaf (*Abutlion* *theophrasti* Medik.) and foxtail (*Setaria febari* Hermm.), two of the most prevalent weed species found in corn and soybean crops in the Midwestern U.S.[48].

Soil Nutrients

All plants require nitrogen for growth. Corn, like most grass species, cannot fix its own nitrogen and must mainly rely either on synthetic fertilizer or animal manure nitrogen inputs or on nitrogen that has been fixed by a legume species planted before it. Soybeans are legumes, and hence fix nitrogen, but in quantities insufficient to fully meet the N demands of themselves or of successive corn crops. In contrast, alfalfa can fix up to nine times more N than soybeans, birdsfoot trefoil up to 4 times as much, and red clover up to 5 times more[49]. Sweetclover (*Melilotus* spp.), once widely planted throughout the Midwest and Great Plains, can produce even more N than these species[50]. The value of alfalfa for increasing soil nutrient levels has been documented since at least the time of the Roman agronomist Columella, who wrote sometime around 100 C.E. that alfalfa "dungs the land"[51]. The decomposing alfalfa crop results in more mineralizable N than either soybean or corn crops[52], further demonstrating the value of the crop in providing nitrogen for crop production.

Alfalfa's superior nitrogen fixation rate enables it to reduce the economically optimum N fertilizer rate needed for corn production by a greater magnitude than soybeans. Iowa State University recommends a reduction in the application rates of N fertilizer to corn following alfalfa by 80-85% compared to 0-25% for corn following soybeans[53]. Alfalfa in rotation with corn contributes an 18-50 kg per hectare larger nitrogen credit than soybeans, depending on the condition of the stand when rotated out of alfalfa[54]. In addition to cost savings for nitrogen fertilizer, this credit also results in a considerable reduction in the amount of nitrogen leaving the agroecosystem[33, 55, 56].

Soil Quality

Forage legumes and grasses improve soil quality as determined by multiple indicators, including improved soil organic matter (SOM) and physical properties[26, 57-65] (Table 2). Five years of continuous alfalfa increased the mean weight diameter of water-stable aggregates (an indicator of soil quality) from 1.5 to 2.3 mm and C content increased from 26 g/kg to 30 g/kg[66]. In comparison, five years of corn and fallow resulted in neither an increase nor decrease in soil quality[66]. Alfalfa, bromegrass and red clover increased soil structural quality, as indicated by a decrease in dispersable clay and an increase in wet aggregate stability, compared to continuous corn grown under either conventional and no-till conditions, which showed either no improvement or some decline in soil structural quality[57].

Ecological Benefits

Recent decades have seen growing concern over the widespread damage caused by row cropping, including soil erosion, nutrient contamination of waterways, and contribution to excess greenhouse gas emissions[33, 67, 68]. Cropping systems that reduce or mitigate these problems are essential if agricultural systems are to be environmentally sustainable in the long-term. Crop rotations that include forages can help reduce negative impacts of agriculture on the environment, as compared to rotations that only include corn and soybeans, through decreased NO_3-N leaching and water drain flows[33, 55, 56, 69] and by increased C sequestration[59, 66, 70-76] (Table 2). Additionally, forage crops can also play an important role in providing critical wildlife habitat for many species of migratory birds and small mammals[51, 77] (Table 2).

Economics

Few formal economic comparisons exist that calculate production costs and profits on Midwestern farms with corn and soybean rotations as compared to those with alternative rotations including forage crops such as alfalfa[65, 78-81]. Case study economic analyses, however, often show alternative rotation schemes to be economically competitive with, or frequently advantageous over, rotations of only corn and soybeans[65, 78, 79, 81, 82]. Additionally, a number of analyses show that forage-based livestock production systems are economically advantageous over grain-based livestock systems or row-crop systems[83, 84].

To illustrate the economic differences between a corn–soybean rotation and two alternative rotations in Iowa, we compared estimated production costs and incomes on an average-sized Iowa farm. This analysis does not pretend to be exhaustive or to take into consideration the complexity of factors influencing production costs and income on Iowa farms. Variables such as yield differences between farms, the effects of precipitation and pest stress, management differences, or the complexity and variation of incomes from government payments will affect any given farmer’s bottom line. This analysis seeks solely to compare production costs and farm incomes based on average farm size, management practices, input costs, prices, and government payments.

According to 2005 statistics from the Iowa Department of Agriculture[20], average farm size in Iowa is 143 hectares, so we set our generalized farm size equal to that figure. This analysis could be scaled up or down for other farm sizes and the income differences between the systems would change proportionally. According to 2002 statistics on land tenure rates, Iowa farmers on average rent 59% of the land they farm, so on our generalized farm we assumed 81 hectares were rented and 62 hectares were owned[85]. The cropping systems analyzed were as follows:

Conventional: corn—soybean

Alternative 1: corn—soybean—oat/alfalfa

Alternative 2: corn—soybean—oat/alfalfa—alfalfa—alfalfa

The *conventional* system, an annual corn and soybean rotation, represents the most common cropping system found in Iowa. For our purposes, we assumed that ½ of the farm was planted to each crop each year. *Alternative 1* includes an oats/alfalfa mix. Thus, in any given year, 1/3 of the farm is in corn, 1/3 in soybean, and 1/3 in oat/alfalfa; crops would be rotated year-to-year in that order on each of the thirds. Oat would be harvested for grain and the straw baled; a single alfalfa harvest would be taken one month after oat harvest. Alfalfa regrowth would be plowed down, adding value as an N fertilizer to the succeeding corn crop, but not considered in our economic analysis. For the *Alternative 2* rotation, the farm is divided into five fields, with one in corn, one in soybean, one in oat and establishing alfalfa, and two in established alfalfa in any given year. During the two post-establishment years of alfalfa production, four harvests are made each season.

Crop production costs were obtained from Iowa State University Extension estimates, which include fixed and variable expenses such as machinery and fuel, seeds, chemical inputs (including pesticides and fertilizers), labor, and land[86]. Actual crop prices were obtained from the Iowa Department of Agriculture[20] (except for the average price of oat straw, which was obtained from the *Hay and Forage Grower* website[87]) (Table 3). Government payments, including direct and counter-cyclical payments, were estimated as described below using formulas and figures provided by the Farm Services Agency of the USDA[88]. Direct Payments (DP) were estimated with the formula, DP = DP rate x base acreage x 85% x DP yield, where the DP rate was set in the U.S. Farm Bill, the base acreage is based on the historical acreage in crop production (assumed to be the entire program crop area on our generalized farm), and the DP yields are equivalent to those listed in Table 3. Counter-cyclical payments (CCP) were estimated using the formula, CCP = target price - market price x base acreage x 85% x CCP yield, where the target price was set in the U.S. Farm Bill, market prices are given in Table 3, and CCP yields are equivalent to those listed in Table 3.

Yields used in the analysis for corn, soybean, alfalfa, oat and oat straw were the average yields used to determine production costs in the Iowa State University Extension publication[86] (Table 3). These yields were used for all of the systems, despite the fact that yields may differ depending on the rotation employed as we described in earlier sections of this paper. Similarly, the various ecological benefits of a system including forage crops are not accounted in this analysis.

To make our estimates, we obtained average crop production costs and returns in each year for each system (Table 4) and calculated average net income across five years (the length of the longest rotation) from each production system. Government payments were also averaged across years. Net returns are equal to gross income (including deficiency payments when government programs apply) minus all production costs. Average net returns for the entire 5-year rotation were calculated with and without government program payments for each system (Table 5).

Profitability of the cropping systems was based on production costs, prices obtained by farmers for crops, and in some cases government program payments. Our calculations clearly show that the Alternative 2 rotation, with three years of alfalfa, is the most profitable, whether government payments are included or not. Alternative 1, with only one year of alfalfa, ranks second in profitability, both with and without government payments. The conventional system, which does not include forage, is the least profitable system, and results in a net loss without government payments.

Despite the increased costs associated with alfalfa production (which include factors such as additional machinery and labor), the price obtained for the crop makes the system with 3 years of alfalfa very profitable, 43% more than the conventional system even when including government program payments. According to our analysis, adding only one year of alfalfa to a corn-soybean rotation (Alternative 1) decreases profitability of the system compared to Alternative 2, due to the relatively high cost of alfalfa seed, costs associated with planting, and low yield of alfalfa in the establishment year.

The most profitable cropping system in our analysis contained three years of alfalfa. Prices of alfalfa vary with production levels in local markets and are not eligible for government deficiency payments. An increase in alfalfa production due to inclusion of the crop on more Iowa farms could therefore lead to depressed alfalfa prices. Future studies will need to consider the lowest prices for alfalfa at which the producer would have a net income equivalent to conventional systems, both with and without government program payments. A price sensitivity analysis could also indicate the economic feasibility of increased production levels and the need to consider new markets (other than hay) for alfalfa and other forages as production increases. One possibility could be the expansion of pasture-based livestock systems, demanded by a growing consumer sector[89] and offering many ecological services as compared to decoupled row crop and livestock systems[90]. The bottom line from our analysis showed that even without accounting the many positive externalities generated by alfalfa (or forages in general), profitability of the cropping enterprise increased with the inclusion of a forage component during the years 2001-2005.

The rapid expansion of the ethanol industry has caused a recent spike in corn prices that this economic analysis does not account for. Corn prices rose to four dollars per bushel at the end of 2006 and in early 2007[3]. Farmers have responded by increasing planned corn acreage in Iowa for 2007[91]. Although alfalfa (and most other crop) prices have risen along with corn, the high corn prices of 2006 made corn, on average, more profitable than alfalfa. To examine the change to farm income from the corn price increases, we compared net income from corn versus alfalfa, with and without government payments, on our sample farm, using 2006 average prices and government pay rates, 2006 production costs, and the same size and rented vs. owned land proportion assumptions as in our original analysis[85, 86, 88]. With government payments included in net income estimates, one year of corn in 2006 was 25% more profitable than alfalfa. When government payments were excluded, however, alfalfa was 38% more profitable than corn in 2006 (Table 6).

Barriers to Forage Incorporation

Our review of the literature and a simple cost-benefit analysis using average input costs and output crop value demonstrate numerous agronomic, ecological, and economic benefits that are being attained on Iowa farms that include forages in rotation with corn and soybeans. Why don't more farmers grow forage crops? We surmise that the combination of government policies, market dynamics, time constraints from off-farm employment, and culture has influenced the hesitancy of many farmers to diversify cropping systems.

Perhaps most importantly, U.S. agricultural policies subsidize a narrow set of commodities in Iowa including corn, soybeans and, to a limited extent, oats. USDA subsidies for Iowa farms totaled $12.5 billion between 1995-2004, with corn and soybean production receiving 83% of those dollars, while only 15% went toward conservation programs (mainly the Conservation Reserve Program)[92]. These policies are really a means of risk management, guaranteeing farmers a return on commodity crops regardless of the many uncontrollable variables that may impinge on production. Without similar risk avoidance for other crops, farmers would naturally be loath to grow them. Further, the programs essentially reward maximization of commodity production, offering little incentive for diversification of crop rotations or incorporation of perennial crops into agricultural landscapes.

Without policy incentives to encourage cropping system diversity (or at a minimum, policies that do not encourage corn and soybean production), many Iowa farmers are unlikely to take steps to incorporate forages into their cropping systems. A survey of row crop farmers in central Iowa found that 40% of respondents would be "not willing at all" to convert to a cropping system incorporating more forages. However, another 40% said they would be "somewhat willing," and 20% of respondents said they would be "very willing" to add forages. Of those who were not willing at all, reasons cited included preference for their corn/soybean rotation, the need for increased labor, and the need for new equipment. Survey respondents also cited a lack of market incentives as the most serious obstacle to adoption of more ecologically sound farming practices[93].

Until recently, the relatively low cost of synthetic nitrogen fertilizers and fuel has meant that farmers often did not view energy costs alone as a significant incentive to make changes in agricultural systems. Recent increases in non-renewable energy costs, however, may mean farmers will consider alternative crop production systems that require fewer energy inputs, such as forage-based rotations[94].

Conversely, rising energy costs may increase demands for biofuels such as corn-based ethanol and soy biodiesel. Although comprehensive economic analyses for this scenario have not yet been done, projections from the USDA and World Resources Institute show a substantial increase in corn production over the next decade to meet biofuel demands[94, 95]. Recent corn price increases fueled by ethanol demand means corn has lately become as or more profitable as alfalfa (Table 6). Corn acreage will expand in the near future, a scenario that will come with very high environmental costs. On the bright side, with the advent of ethanol from cellulose, many forage crops could be dual use—livestock feed or biofuel feedstock—and thus, could contribute in a sustainable way to a bioenergy future.

Recommendations for Change

Forages offer potential ecological, economic and agronomic benefits to midwestern agricultural landscapes and producers, and many farmers already incorporate forages into their systems. We see three possible avenues toward increasing the role of forage crops in the Midwest and throughout the country: revamped farm policies that stress conservation rather than production, a reinvigorated agricultural research paradigm that recognizes that the public interest is not always served by industry, and a more vocal forage research sector.

Without government policies that encourage alternative agricultural systems, farmers are unlikely to make changes to their crop rotations. Future farm policy should encourage diversification of agricultural landscapes and should reward environmental services provided by farmers. U.S. farm policies should support forage production for hay and pastures, which would increase the numbers of ruminant livestock on the land. Increased pasture-based livestock production could lead to higher net incomes for farmers while simultaneously decreasing N fertilizer use and soil erosion, thereby improving water quality and increasing carbon sequestration[83, 96].

We recommend increased funding and support for two programs within U.S. farm policy intended to promote agricultural biodiversity and conservation: the Sustainable Agriculture Research and Extension Program (SARE) and the Conservation Security Program (CSP). SARE is a competitive grant program for research and outreach that funds farmer, citizen and researcher driven projects, and has been shown to be effective at increasing sustainable production practices[97]. The promotion of researcher-farmer collaboration with a goal of increased diversity and sustainability on agricultural landscapes that is supported by SARE is crucial both to encourage positive changes on farms and to influence research priorities within land grant universities.

The CSP offers payments to farmers and landowners for carrying out conservation practices on working agricultural land. Unlike the Conservation Reserve Program (CRP), where the government essentially rents marginal land to establish grasses or wetlands, the CSP seeks to reward farmers whose agricultural practices provide ecological services such as soil erosion reduction and increased biodiversity. While the CRP has resulted in decreased erosion and increased biodiversity on some marginal lands, its costs have included a reduction in the number of working farms as well as reduced rural community vitality[98]. We recommend increased funding and expansion of incentive programs like the CSP that, rather than encourage increased commodity production, promote farming practices that provide both livable incomes for farmers and ecological benefits.

Secondly, because forage-related research currently attracts little funding from the agribusiness industry and is unlikely to receive substantial industry support in the future, agricultural research at the state land-grant institutions and through the USDA Agricultural Research Service needs to include a critical mass of forage scientists. Data for public sector forage breeding show that the numbers of breeders has declined by 26% across all forages and by 46% for alfalfa just in the period from 1994 to 2001[99]. Therefore, encouraging universities and the USDA-ARS to hire scientists willing to investigate the full range of alternative production systems would enable forage crops to gain a higher profile. Land grant universities need to develop alternatives that help farmers remain on the land while being economically stable and environmentally sensitive, rather than simply following the lead of industrialized agriculture. Funding for agricultural research from state legislatures is declining and research support is increasingly based on extramural funds through governmental agencies like USDA or NSF. These programs need to be crafted to enable the long-term nature of perennial forage crop research to compete successfully.

Finally, forage scientists need to do a better job of relaying the importance of their research to funding agencies, the government, and to the public. Although we often complain about the limitations constraining our field, we do not often take the initiative to write letters to the editor or to our congressional delegations supporting our field and the importance of forages to aesthetically pleasing, environmentally beneficial, and economically sustainable farming systems.

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Table 1. Corn yield following corn, soybeans or alfalfa across ten environments.

Preceding crop			Alfalfa-corn as % of corn-corn	Location	Year	Reference
Corn	Soybeans	Alfalfa				
-------------kg/ha -------------						
267	-	748	280%	IA	1948	31
1599	-	4792	300%	GA	1970	32
1670	-	5170	310%	ON	1976	25
3700	5100	6800	184%	MN	1986	27
852	-	1642	193%	PA	1988	29[1]
8709	9126	9031	104%	MN	1994	33[2]
7860	8130	9270	118%	MN	1997	23
5084	7015	7966	157%	ON	2003	30
3830	6140	7300	191%	SD	2005	24
7407	7407	9416	127%	MN	2005	26

[1] The corn yield values come from Table 1, with the comparison being corn following corn with no nitrogen application versus corn following alfalfa in 1984.

[2] Comparisons from Table 2 and crop yields in 1994, which is the only year with corn grown directly after both alfalfa and corn.

Table 2. Soil quality and ecological benefits contributed by forages

Ecological Indicator	**Data**	**Reference**
Soil organic matter (SOM)	148% greater SOM with C-S-O/A-A-A than C-S-C-S-C	26
Soil organic C (SOC)	24% greater SOC in C-C-O-A than C-S	73
Subsurface drainage	54% less subsurface drainage in A-C-C than C-S	33
Nitrogen loss	14% less NO_3-N loss in A-A-A-C-O-S than C-S	55
Nitrogen loss	37% less NO_3-N loss in A-C-C than C-S	56
Nitrogen loss	23-77% lower N loss in A-C-C than C-S	33
Wildlife habitat	18 times more wildlife in A than in a field by chance	77

C, Corn; S, Soybeans; O, Oats; A, Alfalfa

Table 3: Assumed crop yields (kg ha^{-1}) and average crop prices (US$ Mg^{-1}) for the year 2001 through 2005

	Assumed Yield[1]					Average Price[2]				
Crop	**2001**	**2002**	**2003**	**2004**	**2005**	**2001**	**2002**	**2003**	**2004**	**2005**
Corn	8467	8467	9408	9408	9408	$75	$87	$93	$75	$73
Soybeans	3024	3024	3024	3024	3024	$160	$204	$105	$186	$197
Oats	2867	2867	2867	2867	2867	$106	$123	$106	$103	$117
Oat Straw	907	907	907	907	907	$66	$66	$66	$66	$66
Alfalfa (established)	5442	5442	5442	5442	5442	$100	$94	$90	$95	$89
Alfalfa (first-year)	907	907	907	907	907	$100	$94	$90	$95	$89

[1] Kg $hectare^{-1}$.

[2] $US Mg^{-1}.

Table 4. Simulated production costs, gross returns and net returns for three cropping systems on an "average" 143 ha Iowa farm for the years 2001 through 2005.

		Cropping System		
Year		**Conventional[1]**	**Alt 1[2]**	**Alt 2[3]**
2001	**Cost**	$91,568	$84,314	$93,670
	Gross Return	$79,822	$85,479	$128,383
	Net Return	-$11,745	$1,165	$34,712
2002	**Cost**	$90,896	$83,214	$90,922
	Gross Return	$96,899	$98,416	$131,062
	Net Return	$6,003	$15,202	$40,140
2003	**Cost**	$94,786	$86,823	$95,659
	Gross Return	$117,628	$109,624	$135,245
	Net Return	$22,842	$22,802	$39,586
2004	**Cost**	$100,013	$91,887	$100,099
	Gross Return	$90,412	$91,421	$127,288
	Net Return	-$9,601	-$465	$27,189
2005	**Cost**	$105,799	$97,435	$109,177
	Gross Return	$91,471	$93,516	$124,309
	Net Return	-$14,328	-$3,919	$15,132

[1] C-S, [2] C-S-O/A , [3] C-S-O/A-A-A

C,corn; S,soybeans; O,oats; A,alfalfa

Table 5. Whole farm gross and net returns with and without government program payments for three cropping systems on an "average" 143 ha Iowa farm from the years 2001 through 2005.

	With Government Payments		**Without Government Payments**	
Cropping System[1]	**5-year Gross Returns (Rank)[2]**	**5-Year Net Returns (Rank)**	**5-year Gross Returns (Rank)**	**5-Year Net Returns (Rank)**
Conventional	$543,474 (3)	$60,413 (3)	$476,232 (3)	-$6,829 (3)
Alternative 1	$525,524 (2)	$81,852 (2)	$478,456 (2)	$34,784 (2)
Alternative 2	$674,527 (1)	$185,000 (1)	$646,287 (1)	$156,760 (1)

[1] Conventional = C-S, Alternative 1 = C-S-O/A, Alternative 2 = C-S-O/A-A-A; C, corn; S, soybean; O, oat; A, alfalfa

[2] The rank of 1 is highest value

Table 6. Whole farm gross and net returns with and without government program payments for corn vs. alfalfa on an "average" 143 ha Iowa farm in 2006.

	With Government Payments		**Without Government Payments**	
Crop	**2006 Gross Return**	**2006 Net Return**	**2006 Gross Return**	**2006 Net Return**
Corn	$204,525	$70,600	$172,352	$38,428
Alfalfa	$180,030	$53,209	$180,030	$53,209

Reed canarygrass germplasm evaluation for biofuel traits

Julia Olmstead[1], E. Charles Brummer[2], and Michael D. Casler[3]

Abstract

Reed canarygrass (RCG), a cool-season perennial forage crop that grows well in cool, wet climates, could be used as an energy crop. Despite its bioenergy potential, little breeding effort has gone into its development as an energy crop. We evaluated the entire reed canarygrass germplasm collection available in the United States for biomass, cell wall compositional traits based on fiber analysis, crude protein, and ash at two midwestern locations in 1999 and 2000. Variation among accessions was observed for all variables. Biomass yield was not correlated with acid detergent fiber (cellulose + lignin) or with acid detergent lignin, indicating good potential for developing favorable feedstocks for cofiring or for fermentation. A cluster analysis of accession based on phenotypic traits, as well as plots of principle component scores, showed that phenotypes varied somewhat among accessions from within a particular country or region as well as among regions. Accessions showed general clustering by region. Germplasm from central-, northern-, and southern-Europe tended to yield more than germplasm from the Middle East and eastern-Europe, suggesting that the former may be better suited for use in direct breeding programs. Overall, sufficient variation exists among wild and cultivated germplasm to warrant further RCG breeding work for biofuel development.

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[1] Primary author of manuscript, organized and analyzed data
[2] Co-author, collected data
[3] Co-author, collected data

Introduction

Perennial crops offer numerous positive benefits to agricultural systems, including decreased topsoil erosion and nutrient runoff (Crews, 2004; Jaynes, 2001; Olmstead and Brummer, 2007; Randall, 1997; Tolbert, 1998). For centuries, perennial herbaceous crops supplied energy to the farm in the form of fodder that fueled animal traction. These crops are once again being considered as potential energy sources. Interest in the conversion of plant biomass to fuel will likely lead to substantial increases in the acreage grown of perennial herbaceous crops in the near future.

Reed canarygrass (*Phalaris arundinacea* L.) (RCG), grown most commonly as forage, has more recently been shown to have potential as an energy crop. In Europe, after an evaluation of 20 perennial grasses for energy crop potential, RCG was one of four plants selected for further research and development, based on its promising biomass characteristics (Lewandowski et al., 2003). RCG is a cool-season, perennial, rhizomatous grass that forms tall-growing, dense stands and grows well in cool, wet climates while at the same time has excellent drought tolerance (Carlson et al., 1996). Its wide-ranging adaptability makes it relatively more productive in the summer than other cool-season species (Carlson et al., 1996). RCG produces high biomass yields, in some cases even exceeding switchgrass (Anderson et al., 1991; Wright, 1988). Reed canarygrass is considered complementary to warm-season biomass crops, as it fills a niche by growing well in cool climates or times of the year when grasses such as switchgrass or miscanthus may not perform well (Lewandowski et al., 2003).

Reed canarygrass is a member of the family *Poaceae,* genus *Phalaris* and tribe *Phalarideae*. It is native to temperate areas of the Northern Hemisphere, including regions of

Europe, Asia, and North America (Anderson, 1961). It typically grows in low-lying, wet areas such as along wetlands, creek banks, roadside ditches, lake shores, and rivers (Carlson et al., 1996). RCG has presented invasibility problems in wetlands in some regions of North America. Exotic germplasm introduced from Europe may be the cause of most invasive RCG strains, possibly due to hybridization with native North American strains (Lavergne and Molofsky, 2007). RCG is occasionally used as a forage crop in North America and to a lesser extent in Eastern Europe, Scandinavia and Japan. Finland and Sweden have recently begun growing RCG for bioenergy production and paper pulp production. In 2003, 2,700 hectares of RCG were under cultivation in Finland and 430 hectares were under cultivation in Sweden (Sahramaa, 2003).

Both tetraploid and hexaploid varieties of RCG exist, but most RCG in North America and in Europe are self-sterile allotetraploids, with large amounts of morphological variation (Lewandowski et al., 2003). Hexaploid RCG is adapted to warmer environments and is not winter dormant (McWilliam and Neal-Smith, 1962).

RCG forms deep and dense root systems that make it valuable for soil erosion control, particularly in wet areas (Carlson et al., 1996). It has been shown to grow well in areas with low fertility and poor soil quality, enabling its successful establishment on degraded areas such as surfaced-mined soils (Evanylo et al., 2005). It is efficient at capturing nitrogen, and could be used as a buffer crop or sponge crop to reduce nutrient leaching and run-off from sources such as manure and fertilizer applications, municipal waste-water effluent, or sewage sludge (Giggey et al., 1989; Marten et al., 1979; Partala et al., 2001). RCG can also serve as valuable wildlife habitat, particularly for nesting birds and small mammals (Camp and Best, 1994; Semere and Slater, 2007).

Despite its potential as a biofuel crop, RCG germplasm has not been evaluated to assess biofuel traits. In the U.S., all breeding to date has focused on forage traits – palatability, seed retention, disease resistance, persistence, and leafiness (Carlson et al., 1996). Maximum biomass *per se* has not been evaluated in available germplasm, and high yielding germplasm with poor nutritive value may have been overlooked in previous evaluations. Likewise, the concentrations of chemical constituents such as chlorine and sulfur, which are undesirable in biofuel feedstocks, have not been important considerations in past breeding efforts.

Breeding and evaluation of RCG germplasm for bioenergy and research on improved harvest schemes that maximize the bioenergy potential of the crop have been undertaken to a limited extent in Sweden, Finland, and England. In Finland, local, unimproved RCG germplasm was found to have relatively high ligno-cellulose levels and high biomass yields, and could be valuable, when used in a breeding program along with existing cultivars, for bioenergy cultivar development (Sahramaa, 2003). Swedish studies showed that early spring harvest of an over-wintered, senesced crop resulted in lower levels of undesirable mineral elements within the biomass, improved dry matter content, a greater proportion of nutrients from the plant recycled back into the soil, and easier and cheaper biomass storage, although yields were lower than autumn harvested RCG (Landstrom et al., 1996). In England similar results were found – delayed harvest reduced undesirable elements but also reduced biomass yields (Christian et al., 2006).

High biomass yield is the most important variable for biofuel crops. Biofuel conversion systems determine the desirability of high or low levels of fibers, minerals or other chemical compounds. For direct combustion and gasification systems, low minerals concentrations are desirable in the biomass source, and lignin is beneficial because of its high energy density. For ethanol fermentation, hemicellulose and cellulose yield is the priority; lignin is undesirable because of its adverse affects on bacteria. The objective of this research was to determine the overall biofuel potential of a diverse collection of reed canarygrass germplasm from which new breeding germplasm could be developed.

MATERIALS AND METHODS

Plant materials

Reed canarygrass germplasm was obtained from the USDA National Plant Introduction Station in Pullman, WA. One hundred four accessions were available for distribution when the experiment began; of those, 94 had sufficient germination to be included at both locations of the experiment (Arlington, WI and Ames, IA), seven were included only at Ames, and the remaining three were excluded due to poor germination. Of the 94 accessions, 27 were designated as cultivars in the GRIN (Germplasm Resources Information Network) system and 67 accessions represented wild or naturalized genetic material or had unknown provenance. Six additional cultivars (Bellevue, Palaton, PSC 1142, Rival, Vantage, and Venture) were included in the experiment at both locations. An additional five accessions obtained from Finland, seven germplasms developed at ISU, a germplasm collected in Iowa (Fraser, Boone Co.), and the cultivar ‘Flare’ were included only at Ames due to limited seed. Accessions were of diverse geographic origin, including North America, Europe, the Middle East, and northwestern Asia.

Experimental design and data collection

Seeds were germinated in the greenhouse and transplanted to the field in mid-July, 1998. Each plot consisted of two rows spaced 30 cm apart, with 20 plants spaced 30 cm apart in each row. Approximately 1.2 m was left between plots. The experiment was a randomized complete block design with two replications at each location.

Nitrogen was applied at 112 kg N ha^{-1} in early April in 1999, and split applied between early April and after the first harvest in 2000. Plant height was measured immediately prior to harvest as the standing height of each plot. Plots were harvested twice in 1999 and in 2000, in late May or early June and in October using a flail-type or sickle-type harvester. A subsample from each plot was taken before harvest and dried at 60ºC for four days in order to adjust plot yield to a dry matter basis. Forage yields of each plant were summed over both harvests prior to statistical analysis. Samples were also used to conduct biofuel and forage analyses as described previously (Lemus et al., 2002). For all analyses, sample values were estimated using near infrared spectroscopy (NIRS) calibrated with wet chemistry. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin fiber (ADL) concentrations were determined using the ANCOM 200 Fiber Analyzer (ANKOM Technology Corp., Fairport, NY 14450). Crude protein (CP) was determined using the micro-Kjeldahl procedure and ash was determined by combustion of a 1 g sample in a muffle furnace at 550ºC for 4 h. In-vitro dry matter digestibility (IVDMD) was also assessed as described by Sleugh et al. (2000). Coefficients of determination (R^2), standard errors of calibration, and cross-validation were 0.98, 0.65, and 1.13 for NDF; 0.98, 0.50, 0.75 for ADF; 0.97, 0.16, 0.28 for ADL; 0.99, 0.66, 1.40 for IVDMD; 0.99, 0.31, 0.58 for CP; and 0.92, 0.13, 0.23 for ash, respectively.

Statistical analyses

Analyses of variance were conducted on all variables using generalized least squares (Searle, 1971). All effects were considered random. ANOVAs were computed for each variable both at each location and across locations. The Ames only accessions were dropped from this analysis to make a balanced dataset.

Accession means were computed for each variable and averaged over harvests and years, which resulted in 40 variables (20 from each location). The 40 variables were standardized by year and harvest and phenotypic correlation coefficients between locations for each variable were generated to help interpret accession x location interactions. Accession means were also computed for each variable and averaged over harvests, years, and locations, resulting in 20 variables, which were used to generate phenotypic correlation coefficients between variables.

The 20 standardized variables were organized into principal components. The principal component scores were used for a cluster analysis using Ward’s method (Milligan, 1980). The principal components were weighted by the proportion of variance that each explained. This weighting insured that each of the 20 variables contributed equally to the cluster formation. The cluster dendrogram was truncated at 16 clusters, which explained 90% of the variation.

To examine differences in performance among germplasm from different regions of the world, entries were divided into ten regional groups based on latitude and longitude (Table 1). We used Duncan’s multiple range test to compare regional mean values for all variables.

Unless otherwise indicated, statistical significance is assessed at the 5% probability level throughout the results and discussion.

RESULTS AND DISCUSSION

Genotypic Variation and Entry x Environment Interactions

One accession (PI329243) completely died at both locations, so only 99 accessions remained for analysis. Variation between the two locations was present only for yield and variation among years was not significant for any of the measured variables (Table 2). No location x year interaction was present. Therefore, we combined data across locations and years for the analyses among regions and for the cluster analyses. Two accessions (PI206463 and PI338666) were removed from the cluster analysis due to incomplete data at all locations and years. Variation among harvests within years was present only for crude protein, but all variables except NDF showed a location x harvest interaction.

Variation among entries was observed for all variables (Table 2). Entry x location and entry x harvest interactions were significant for all variables except height and crude protein for the former. The location x entry interaction variance was equal in magnitude to the entry variance for yield, but lower than the entry variance for all other traits, and usually considerably smaller. Thus, perhaps the most important trait for bioenergy purposes shows considerable instability across locations. Entry x year interaction was only present for height. The location x harvest variance components were generally higher than entry x harvest or experimental error variance components, except for NDF and ADF (Table 2).

Phenotypic correlations

Data standardized by year and harvest, from all variables except ash, were positively and moderately-to-highly correlated between Ames, Iowa and Arlington, Wisconsin (Table 3). The correlation between the two locations for yield was low (0.36), which is logical considering the complexity of genotype by environment interactions that affect yield. The highest correlation was for winter kill (0.94). Nearly all the accessions had very good survival rates, and those that were susceptible were killed most likely by the cold winter temperatures that occurred in both locations. The overall strong correlations between the two locations for nearly all variables supported our decision to combine data for analysis.

Yield, averaged across years, harvests, and locations, was positively correlated with height and maturity, as seen in other crops (e.g., switchgrass [Lemus et al., 2002]), and had a low, positive correlation with spring vigor and IVDMD (Table 3). Yield had a negative correlation with crude protein and NDF, but was not correlated with ADF (cellulose + lignin) or ADL (lignin), two measures of biomass quality. Height, however, had a positive, medium correlation with NDF and ADF, was highly correlated with spring vigor and maturity, and negatively correlated with IVDMD, crude protein, and winter kill. A desirable biofeedstock for cofiring would have high biomass yield and high concentrations of cellulose and lignin. Thus, the lack of a negative correlation between yield and these traits is promising for breeding efforts to improve both traits concurrently. However, feedstocks used for fermentation would ideally have a low level of lignin, which interferes with efficient ethanol production, so the lack of correlation also may permit at least some improvement in lowering lignin and improving yield in these germplasms.

Cluster Analysis of Accession Means

The cluster analysis indicated that 90% of the variation among accession means could be accorded to 16 clusters (Fig. 1). The number of accessions contained in each cluster varied from a maximum of 13 accessions to two clusters containing only one accession, indicating phenotypic uniqueness of those accessions.

Other than clusters 13 and 16, which contained only one accession each, most of the clusters were geographically diverse (Table 5). Ten clusters contained accessions from at least four source countries, and all but one of the clusters with multiple accessions contained accessions from more than one country. Accessions from Russia, the former Soviet Union, and the USA were distributed throughout the dendrogram, although a large proportion of Russian accessions had R^2 values greater than 0.8 with each other in Clusters 9-12 (Fig. 1, Table 5). Accessions from some other countries were confined to certain parts of the dendrogram. For example, the three Polish accessions were clustered together in Cluster 5, and the two Austrian accessions occurred in Cluster 12. There were some patterns of clustering related to geographic origin that were visible, for example in Clusters 9-11, which primarily contained accessions from areas in Scandinavia, northern Europe, Canada and far northwestern Russia. Clusters 6-8 contained accessions of primarily Middle Eastern origin, while accessions in Cluster 5 were from north-central Europe, Canada, and the USA.

Only Cluster 2 had a mean forage yield significantly higher than the overall mean, and it was also significantly taller than the overall mean. Cluster 1 had significantly higher NDF and ADF content than the mean, was significantly taller than the overall means, and contained lower ash content than the mean. Thus, these clusters in particular may have the best biofuel feedstock potential.

Clusters 6 and 8 also contained higher NDF content than the overall mean, and cluster 13 contained significantly higher NDF and ADF content than the overall means.

Principal Component Analysis

The first three principal components (PC) explained 74% of the variance among accessions, with the first principal component accounting for 40% of the variance, the second for 22%, and the third for 12%. Two PC plots—PC1 vs. PC2 (Fig. 2) and PC2 vs. PC3 (Fig. 3)—showed overall a range of trait values among and between regions, but also some discernable groupings by region, more easily seen in Fig. 3. Accessions from Regions 3-6, from countries in or near the Middle East (Table 1), tended to aggregate in the upper right-hand corner of the plot (Fig. 3). Those accessions from Central and Southern Europe, as well as most accessions from the U.S. and Canada (Regions 1, 2, 8, and 9), fell primarily into the lower left-hand corner of the plot. The separation of these two groups of accessions based on phenotypic differences relates to the cluster dendrogram, which tended to group accessions from Middle Eastern or eastern-European countries separately from central, northern, and southern-European accessions (Fig. 1). Interestingly, accessions from Region 7, which come from unidentified locations in the Former Soviet Union, fall fairly close together near the intersection of the two groups.

Regional Sources of Variation

Overall, there was little variation among regions for the means of the measured variables (Table 4). Mean yield, averaged across years and locations, was highest for Region 1, which included eight accessions from France, Morocco, Portugal, and Switzerland.

Significant differences in mean yield only existed between Region 1 and Regions 5 (Former Soviet Union, Kazakhstan, Russia) and 10 (Australia and Argentina). Significant differences in mean height existed only between accessions from Region 7 (unspecified locations within the Former Soviet Union) and Region 10, which included one cultivar each from Australia and Argentina. Region 7 (from unspecified locations within the Former Soviet Union) differed from several other regions for the NDF, ADF, and ADL traits, but it is difficult to draw conclusions from this difference as the germplasm in Region Seven could have wide variations in geographic origins. Crude protein and IVDMD showed no variation among regions. Thus, little differentiation among accessions is noted on the basis of geographical origin alone, as suggested by the dendrogram (Fig. 1).

These data suggest several avenues forward for breeding reed canarygrass for bioenergy uses. First, the cultivated types in the USA and Canada perform well, but not better than germplasm from Europe. We don’t see any evidence that North American germplasm has superior performance compared to accessions from Europe, which does not support the hybrid vigor hypothesis of Lavergne and Molofsky (2007) that North American x European germplasm naturally hybridized in North America resulting in aggressive modern reed canarygrass germplasm. However, we did not grow these plants in natural wetland areas where the advantage of North American genotypes may be more evident. In any case, we can tap into European accessions for possible genotypes containing high yield and desirable cell wall composition.

Second, the relatively poor performance of Middle-Eastern and Central Asian germplasm suggests it cannot be useful directly in breeding programs. Possible heterosis between this germplasm and North American germplasm may be worth investigating.

Finally, and on a less enthusiastic note, ash contents vary among germplasms to an extent, but all are quite high, at 10% or more of dry matter, considerably more than desirable for cofiring applications (and probably for fermentation as well). Thus, while breeding may lower the ash content somewhat, substantial decreases seem unlikely, necessitating mixing reed canarygrass with other feedstocks.

CONCLUSIONS

Reed canarygrass is a promising source of biomass for cellulosic ethanol and other alternative energy sources. To create valuable biomass, breeders will need to increase yields while maintaining high hemicellulose and cellulose content (for fermentation) or high lignocellulose for gasification or cofiring. Until now, reed canarygrass breeding has focused exclusively on forage traits. The results in this study show that breeding in reed canarygrass for biomass traits would likely be a worthy effort and that germplasm other than the low alkaloid germplasm developed for forage production is likely to be useful in this effort. This study’s data also show that useful germplasm could be obtained from regions around the globe, as the multiple comparisons among regions showed few differences in trait values based on origin. Overall, European and North American germplasm performed better than Central Asian and Middle-Eastern germplasm, suggesting that direct breeding efforts should likely begin with germplasm from those regions. The potential for heterosis between germplasm from regions that show significant phenotypic differences, however, would mean that all of the germplasm could have a place in a breeding program. The relatively high ash content of reed canarygrass suggests that it would be best utilized as part of a mixture of cellulosic feedstocks, a situation that, as it would lead to increased diversity in agricultural systems, has its own advantages.

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Figure Legends

Fig. 1. Cluster dendrogram for 97 reed canarygrass accessions based on principal component values derived from eleven phenotypic traits averaged across two harvests per year at Ames, IA and Arlington, WI in 1999 and 2000, showing the 16 clusters that account for 90% of the phenotypic variation among accessions.

Fig. 2. Scatterplot of the relationship among accessions grouped by region of origin based on the first and second principal components derived from 11 phenotypic traits averaged across two harvests per year at Ames, IA and Arlington, WI in 1999 and 2000.

Fig. 3. Scatterplot of the relationship among accessions grouped by region of origin based on the first and second principal components derived from 11 phenotypic traits averaged across two harvests per year at Ames, IA and Arlington, WI in 1999 and 2000.

Table 1. Latitude and longitude ranges and country names for ten regional divisions of 100 reed canarygrass accessions tested at two locations in 1999 and 2000.

Region	Number of Accessions	Latitude	Longitude	Counties Included
		Degrees		
1	9	35-50	$^{-}$10-10	Swtizerland, Portugal, France, Morocco
2	21	40-60	10-25	Germany, Denmark, Sweden, Yugoslavia, Austria, Poland, Norway, Slovakia
3	7	35-45	30-55	Turkey, Iran, Russia
4	7	40-45	65-70	Kazakhstan, Uzbekistan
5	9	50-60	60-90	Russia, Kazakhstan
6	14	50-70	30-55	Former Soviet Union, Russia, Ukraine
7†	7	-	-	Former Soviet Union
8	6	$^{-}$100-$^{-}$155	40-60	US, Canada
9	17	$^{-}$70-$^{-}$100	35-50	US, Canada
10‡	2	-	-	Australia, Argentina

† Accessions originated from unknown locations within the former Soviet Union

‡ One accession each from Australia and Argentina

Table 2. Estimated variance components for 11 phenotypic traits measured on 99 reed canarygrass accessions at Ames, IA and Arlington, WI in 1999 and 2000.

		Variable										
Source of variation	df	Yield	Height	IVDMD	NDF	ADF	ADL	CP	ASH†	Winter Kill‡	Spring Vigor‡	Maturity‡
		g plant^{-1}	cm	------------------------------%-------------------------						-----------------score-------------------		
Location (L)	1	1098.6**	78.6	29.41	0	0.2	0.6	0	0**	0	0	0.7**
Entry (E)	98	175.7**	43.4**	1.1*	1**	0.6**	0*	6**	0**	326.8**	2.7**	0.6**
L X E	96	173.4**	2.7	0.7**	0.4*	0.1*	0*	0.4	0	10.4**	0.2*	0.1*
Year (Y)	1	0	0	0	1.6	3.1	0	0	0	-	-	-
L X Y	1	0	0	0	0.9	0	0	0	0	-	-	-
E X Y	97	0	32.2**	0	0	0	0	0	0	-	-	-
Harv (Yr) (H)	2	3028.7	573.4	133.8	9.1	1.9	0.6	62.1*	.16**	-	-	-
L X H	2	1031.7**	545.8**	17**	3.3	1.7**	0.4**	4.2**	0**	-	-	-
E X H	195	215.5**	19**	5.6**	4.2**	1.9**	0**	0.9**	0	-	-	-
Experiment. Error	1021	720.1	109.5	7.6	5.3	2.9	0.1	2.3	0.04	19.9	0.6	0.4

* Mean square associated with variance component was signficant at $P < 0.05$.

** Mean square associated with variance component was signficant at $P < 0.01$.

† Computed only for 2000.

‡ Computed only for 1999.

Table 3. Phenotypic correlation coefficients among variables based on mean values across two harvest per year, two years, and two locations (below diagonal), and also correlations within traits between mean values across harvests and years at Ames, IA and Arlington, WI (on diagonal).

	Yield	Height	NDF	ADF	ADL	IVDMD	CP	ASH	Winter Kill	Spring Vigor	Maturity
Yield	0.36**										
Height	0.41**	0.63**									
NDF	-0.24**	0.35**	0.46**								
ADF	-0.12	0.45**	0.92**	0.47**							
ADL	-0.01	0.42**	0.81**	0.81**	0.41**						
IVDMD	0.15*	-0.32**	-0.86**	-0.80**	-0.84**	0.41**					
CP	-0.44**	-0.73**	-0.31**	-0.43**	-0.39**	0.35**	0.53**				
ASH	0.03	-0.17	-0.28**	-0.22*	-0.24*	-0.03	0.15	0.08			
Winter Kill	-0.04	-0.29**	-0.26**	-0.19**	-0.28**	0.38**	0.23**	-	0.94**		
Spring Vigor	0.24*	0.73**	0.58**	0.46**	0.56**	-0.67**	-0.66**	-	-0.53**	0.85**	
Maturity	0.39**	0.75**	0.60**	0.57**	0.63**	-0.64**	-0.65**	-	-0.37**	0.72**	0.75**

[*] Correlation is significantly different from zero at $P < 0.05$.

[**] Correlation is significantly different from zero at $P < 0.01$.

Table 4. Means of seven phenotypic traits for 99 reed canarygrass accessions based on region of origin, averaged over two harvests per year at Ames, IA and Arlington, WI in 1999 and 2000.

Region	Number of Accessions	Yield	Height	IVDMD	NDF	ADF	ADL	CP
		(g plant^{-1})	(cm)	--------------------(%)--------------------				
1	9	179.32^{a}†	98.03^{ab}	61.77^{a}	54.28^{ab}	29.35^{ab}	3.14^{ab}	14.00^{a}
2	21	162.44^{ab}	94.04^{ab}	61.54^{a}	54.37^{ab}	29.54^{ab}	3.17^{ab}	13.98^{a}
3	7	146.84^{ab}	93.85^{ab}	60.25^{a}	55.73^{a}	30.41^{a}	3.37^{a}	13.30^{a}
4	7	163.30^{ab}	95.35^{ab}	61.89^{a}	54.18^{ab}	29.12^{ab}	3.06^{b}	13.95^{a}
5	9	141.78^{b}	93.11^{ab}	61.09^{a}	54.89^{a}	29.64^{ab}	3.17^{ab}	14.03^{a}
6	14	153.14^{ab}	95.42^{ab}	60.13^{a}	55.35^{a}	30.28^{a}	3.26^{ab}	13.54^{a}
7	7	156.52^{ab}	86.64^{b}	62.48^{a}	52.91^{b}	28.54^{b}	3.07^{b}	14.75^{a}
8	6	158.64^{ab}	96.76^{ab}	60.88^{a}	54.87^{a}	29.88^{ab}	3.25^{ab}	14.46^{a}
9	17	159.01^{ab}	94.69^{ab}	60.41^{a}	55.43^{a}	30.22^{a}	3.29^{ab}	13.91^{a}
10	2	140.56^{b}	107.68^{a}	61.42^{a}	54.98^{a}	29.99^{ab}	3.27^{ab}	13.38^{a}
Mean		158.13	94.66	61.08	54.76	29.75	3.21	13.93

† Means within columns followed by different letters are statistically different ($P > 0.05$).

Table 5: Country of origin of reed canarygrass accessions accorded to 16 clusters based on principal components derived from 11 phenotypic traits measured over two harvests per year at Ames, IA and Arlington, WI in 1999 and 2000.

Cluster	Country Composition
1	KAZ, POR, RUS, SOV, TUR, USA
2	3 USA, SLV
3	GER, 2 SOV, 5 USA, YUG
4	CAN, DEN, RUS, 2 SOV, SWE, UKR, USA, YUG
5	CAN, DEN, 2 GER, 3 POL, SLO, 3 SWI, 2 USA
6	IRA, 4 KAZ, 2 RUS, SOV, UZB
7	CAN, IRA, KAZ, SOV
8	IRA, KAZ, 2 RUS, TUR
9	DEN, GER, KAZ, NOR, 3 RUS, SWI
10	CAN, NOR, 4 RUS
11	3 RUS
12	2 AUS, 4 CAN, 3 RUS, SOV
13	USA
14	DEN, NOR, RUS
15	CAN, FRA, 2 POR, 2 USA
16	AST

†AST = Australia, AUS = Austria, CAN = Canada, DEN = Denmark, FRA = France, GER = Germany, IRA = Iran, KAZ = Kazakhstan, NOR = Norway, POR = Portugal, RUS = Russia, SLO = Slovakia, SLV = Slovenia, SOV = the former Soviet Union, SWI = Switzerland, TUR = Turkey, USA = United States, UZB = Uzbekistan, YUG = the former Yugoslavia.

Table 6: Means of seven phenotypic traits for accessions grouped into 16 clusters based on principal component scores developed from data measured on 97 reed canarygrass accessions over two harvests per year at Ames, IA and Arlington, WI in 1999 and 2000.

Cluster	No. of accessions	Yield	Height	NDF	ADF	ADL	IVDMD	ASH
		g plant^{-1}	cm	--------------------------	----------	--%--	----------	--------------------------
1	5	285	106	60	33	3.8	56	10
2	3	342	105	58	32	3.6	58	11
3	7	320	102	57	32	3.5	58	11
4	8	315	97	57	31	3.5	58	12
5	13	324	97	57	31	3.4	59	11
6	9	277	98	59	32	3.7	57	12
7	4	259	90	58	31	3.5	58	13
8	5	225	91	59	32	3.6	57	12
9	8	323	91	56	30	3.4	59	13
10	6	272	87	57	31	3.4	59	13
11	3	270	95	58	31	3.4	58	12
12	9	287	96	57	31	3.5	58	12
13	1	272	90	60	33	3.6	57	11
14	3	243	80	54	28	3.1	61	15
15	6	202	72	57	31	3.4	59	13
16	1	17	-	55	30	3.1	63	13
Mean		265	93	57	31	3	58	12
Std.Er.		10.16	2.37.	0.39	0.30	0.05	0.41	0.29

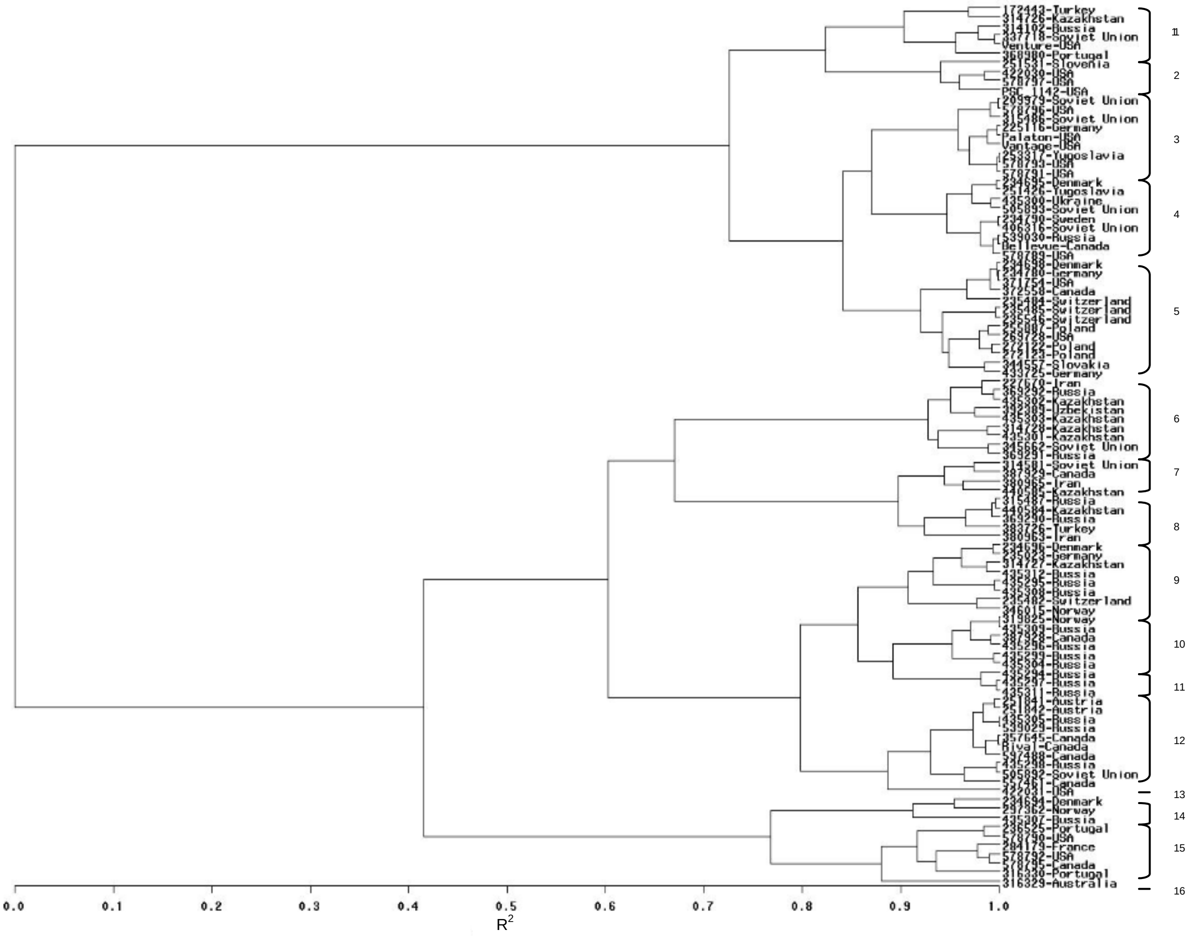
172443-Turkey
314726-Kazakhstan
314102-Russia
337718-Soviet Union
Venture-USA
368980-Portugal
251531-Slovenia
422030-USA
578797-USA
PSC 1142-USA
209979-Soviet Union
578796-USA
315486-Soviet Union
225116-Germany
Palaton-USA
Vantage-USA
253317-Yugoslavia
578793-USA
578791-USA
234695-Denmark
251426-Yugoslavia
435300-Ukraine
505893-Soviet Union
234790-Sweden
406316-Soviet Union
539030-Russia
Bellevue-Canada
578789-USA
234698-Denmark
234780-Germany
371754-USA
372558-Canada
235484-Switzerland
235485-Switzerland
235546-Switzerland
255087-Poland
269728-USA
272122-Poland
272123-Poland
344557-Slovakia
433725-Germany
227670-Iran
369292-Russia
435302-Kazakhstan
392309-Uzbekistan
435303-Kazakhstan
314728-Kazakhstan
435301-Kazakhstan
345662-Soviet Union
369291-Russia
314581-Soviet Union
387929-Canada
380965-Iran
440585-Kazakhstan
315487-Russia
440584-Kazakhstan
369290-Russia
383726-Turkey
380963-Iran
234696-Denmark
235023-Germany
314727-Kazakhstan
435312-Russia
435295-Russia
435308-Russia
235482-Switzerland
346015-Norway
319825-Norway
435309-Russia
387928-Canada
435296-Russia
435299-Russia
435304-Russia
435294-Russia
435297-Russia
435311-Russia
251841-Austria
251842-Austria
435305-Russia
539029-Russia
357645-Canada
Rival-Canada
597488-Canada
435298-Russia
505892-Soviet Union
557461-Canada
422031-USA
234694-Denmark
297362-Norway
435307-Russia
236525-Portugal
578790-USA
284179-France
578792-USA
578795-Canada
316330-Portugal
316329-Australia
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
R^2

Fig. 1.

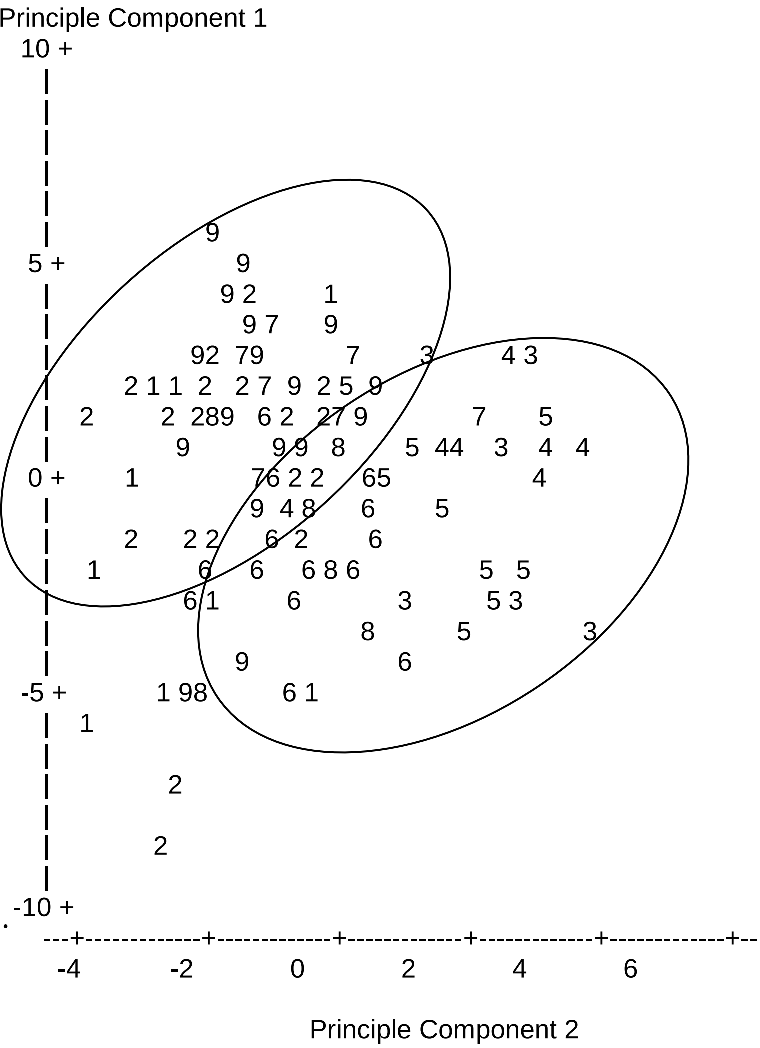
Principle Component 1
10 +
5 +
0 +
-5 +
-10 +
-4
-2
0
2
4
6
Principle Component 2

Fig. 2.

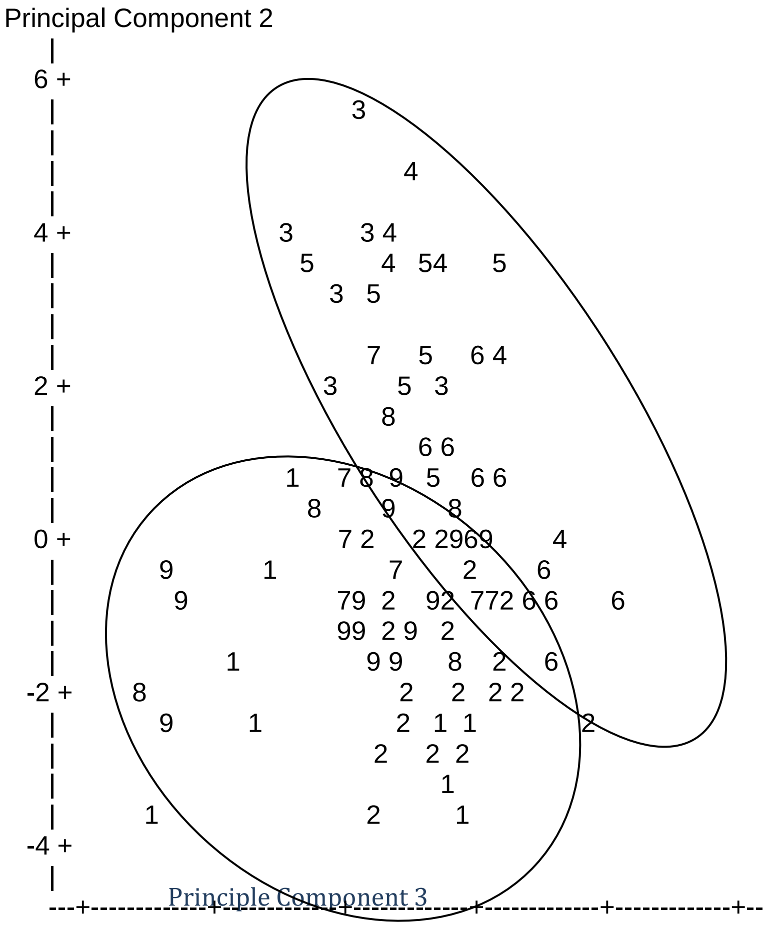
Principal Component 2
6 +
3
4
4 +
3 3 4
5 4 54 5
3 5
7 5 6 4
2 +
3 5 3
8
6 6
1 78 9 5 6 6
8 9 8
0 +
7 2 2 2969 4
9 1 7 2 6
9 79 2 92 772 6 6 6
99 2 9 2
1 9 9 8 2 6
-2 +
8 2 2 2 2
9 1 2 1 1 2
2 2 2
1
1 2 1
-4 +
Principle Component 3
-6
-4
-2
0
2
4

Fig. 3.

GENERAL CONCLUSION

Since World War II, the definition of Iowa agriculture has increasingly narrowed to just corn, soybeans, and industrial livestock production. The elegant systems of nutrient cycling and management that were achieved by integrated livestock and row-crop production have been dismantled in favor of decoupled production schemes. As Wendell Berry once put it, “when we took animals off farms and put them onto feedlots, we had, in effect, taken an old solution — the one where crops feed animals and animals’ waste feeds crops — and neatly divided it into two new problems: a fertility problem on the farm, and a pollution problem on the feedlot,” (Berry, 1996). Forage crops were once a centerpiece of the farm, providing fodder for livestock, a cash crop when harvested, and the ecological services diversified crop rotations and perennials provide.

As our extensive review of the literature unequivocally shows, returning perennial forage crops to Iowa farms (and Midwestern farms in general) would go a long way toward mitigating many of the negative environmental consequences of corn and soybean production. Ideally, forages would be added to farm systems along with livestock. But even when planted in rotation with corn and soybeans and harvested for sale as hay, forages offer multiple benefits to farmers and the environment. Perennial forages such as alfalfa reduce nutrient requirements of succeeding corn and soybean crops, improve soil quality, reduce the need for pesticides, provide wildlife habitat, decrease nutrient leaching into groundwater, and even boost yields of successive crops. Forage production could also provide a needed economic boost to Iowa farms. Our economic simulation of farm incomes with and without alfalfa included in the rotation showed that a five-year rotation including alfalfa (3 years), corn, and soybeans was 24% more profitable than a five-year rotation of only corn and soybeans, even when including government payments for the commodity crops.

While expanding forage production in Iowa and throughout the Midwest seems like a natural choice for farmers as it would be both economically and environmentally beneficial for the region, government farm policy focuses almost entirely on commodity production. Thus farmers, who take on tremendous amounts of risk with each planting, can hardly be blamed for growing what they know the government will support, even if crop prices plummet.

The best way to encourage increased forage production would be to refocus government farm subsidies away from commodities and toward supporting ecologically beneficial farm practices. Rewarding farmers who improve the environment through their agricultural practices, like by growing alfalfa and other perennial forages, could mean significant increases in agricultural diversity.

Recent interest in ethanol produced from cellulose may also play a role to encourage farmers to grow forages. While much of the focus until now has been on switchgrass, some other forage grasses may also prove to have potential as bioenergy feedstocks. Reed canarygrass, a relatively high-yielding perennial forage, performs well in climates poorly suited to switchgrass. Our evaluation showed that sufficient variation exists in available germplasm to make a reed canarygrass breeding project, with biofeedstock as a goal, worthwhile. If cellulosic ethanol were to be produced on a large-scale, a diversity of feedstocks would be necessary to avoid facing the same problems caused by monocultures of corn and soybeans.

Agricultural systems that are both environmentally and economically sustainable must be more diverse than just corn and soybean rotations. Returning forage crops to Iowa farms, either as part of systems that include livestock or as rotated crops harvested for hay or biomass, will go a long way toward improving the health of our land, water, and rural economies.

REFERENCE

Berry, Wendell. 1977. The Unsettling of America. San Francisco: Sierra Club Books.

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