Chapter 4

Biomass Production in Northern Great Plains of USA – Agronomic Perspective

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1. Introduction

The development of biofuel is an important measure to meet America's energy challenges in the future. In the 2007 Energy Independence and Security Act, the U.S. government mandates that 136 billion liters of biofuel will be produced by 2022, of which 60 billion liters will be cellulosic ethanol derived from biomass [1-3]. Currently, ethanol is one of the biofuels that has been developed extensively. In the U.S., initial efforts for ethanol production were focused on fermentation of sugars from grains (especially maize). However, there have been criticisms for ethanol production from maize because of low energy efficiency, high input cost and adverse environmental impacts [4-5]. Biofuels from biomass feedstocks are more attractive because biomass is a domestic, secure and abundant feedstock. There are at least three major benefits for using biofuels. The very first benefit is national energy security. To reduce the reliance of imported oil for transportation, alternative energy options must be developed. Economically, a biofuel industry would create jobs and ensure growing energy supplies to support national and global prosperity. Environmentally, producing and using more biofules will reduce CO_2 emission and slow down the pace of global warming and climate change.

There are several sources of biomass feedstocks in forest and agricultural lands. The agricultural resources for biomass include annual crop residues, perennial crops, and miscellaneous process residues and manure [2, 3, 6]. Among the agricultural sources, the dedicated biofuel crops based on perennial species have been considered to the future of the biofuel industry and are the focus of intense research [2, 3, 6-8]. In addition, perennial biofuel crops also can provide other environmental and ecological benefits such as improving soil health, providing wild life habitat, increasing carbon sequestration, reducing soil erosion and enhancing water conservation [2, 9]. A key factor for meeting the government's goal is the development of biomass feedstocks with high yield as well as ideal quality for conversion to liquid fuels and valuable chemicals [2-3, 6-8,10].

The Northern Great Plains (NGP) of USA has been identified as an important area for biomass production. In particular, North Dakota is ranked first in potential for producing perennial grasses and other dedicated biofuel crops among the 50 states [10]. With about 1.2 million ha of CRP (Conservation Reserve Program) land and over 2.8 million ha of marginal land that are not suitable for cropping, the state has great potential for liquid biofuel production from biomass crops such as perennial grasses [11]. Before the great potential for biofuel production can be realized, questions still remain for developing management practices and their economic and environmental benefits for biofuel crops, such as appropriate species in certain areas, biomass yield potential and quality, harvesting scheduling (e.g., annual vs. biennial harvest), and effects on soil health and carbon sequestration.

In this paper, we review the current research progress for developing perennial biofuel crops in the NGP, primarily based on long-term field studies. We start to briefly discuss the species selections for biofuel crops in the USA and Europe. Then, we focus on development of crop management strategies for high yield as well as ideal quality. Finally, some possible environmental and ecological benefits from perennial biofuel crops are briefly discussed.

2. Appropriate species for biofuel crops

2.1. Ideal biomass crop for biofuels

There are mainly three goals to develop biomass crop for biofuels: (1) maximizing total biomass yield per year; (2) maintaining sustainability while minimizing inputs; (3) maximizing the fuel production per unit of biomass. To achieve the above goals, an ideal biomass crops should have some attributes as followings: high photosynthesis efficiency (e.g., C4 plants), long canopy (green leaf) duration, low inputs, high water-use efficiency, winter hardiness, no known pests and disease, noninvasive, and uses of existing farm equipment [2]. Based on above criteria, perennial forage crops would be ideal candidates for biofuel crops. The primary purpose for growing perennial crops for biomass production is reducing input and maintenance costs. Economically, using perennial species is more cost effective than annual ones, given the current high costs of fertilizers, pesticides (mainly herbicides) and operation fuels, and low values of lands for growing biomass crops.

2.2. Species for potential biofuel crops

Over the years, many species have been or being evaluated for potential of biofuel crops in the USA and Europe, in which the perennial grasses are dominant (Tables 1 and 2) [12]. In the USA, switchgrass was determined as a model species. In Europe, miscanthus, reed canarygrass, giant reed and switchgrass were chosen for more extensive research programs [12]. In addition, legume species and mixture of multi-species also been evaluated as bioenergy crops [5,13].

2.2.1. Switchgrass and miscanthus

Switchgrass and miscanthus are two dominant species reported in literatures for potential biofuel crops. Switchgrass, a C4 perennial grass, has been designated by the U.S. DOE as primary bioenergy crop and has been extensively studied for over two decades. Several reviews have addressed current research and development issues in switchgrass, from biology and agronomy to economics, and from production to policies [6, 14-18]. The attributes of switchgrass for biofuel production included high productivity under a wide range of environments, suitability for marginal and erosive land, relatively low water and nutrient requirements, and positive environmental benefits [17]. For biofuel purpose, switchgrass can be used to produce ethanol [2, 7, 18]. It also can be used as combustion to co-fire with coal in power plant for electricity. Currently, switchgrass production in southern Iowa is mainly used for combustion [19].

Miscanthus is another C4 tall perennial grass originated in East Asia and has been studied extensively throughout the Europe from the Mediterranean to southern Scandinavia [20]. Comparing with other C4 species (such as maize), miscanthus is more cold tolerance and winter hardy in temperate regions of Europe. It also has a low requirement of nitrogen fertilizer and pesticides. In general, miscanthus has a very high biomass yield potential when it is well established. Lewandowski et al. (2000) [20] reported that the irrigated miscanthus yield can be as high as 30 Mg/ha, and yield under rainfed conditions ranged from 10 to 12 Mg/ha. When compared biomass production in US for switchgrass and Europe for miscanthus, the average yield of miscanthus (22 Mg/ha) was twice as much as the average yield of switchgrass (10 Mg/ha), given the similar temperature, nitrogen and water regimes [21]. A side-by-side study in Illinois showed that average biomass yield in miscanthus (30 Mg/ha) can be 3 times as much as switchgrass (10 Mg/ha) [22]. Compared to switchgrass, miscanthus may require higher input costs because it must be established using rhizome cuttings, which delays full production until the second or third year [20, 21]. In Europe, the primary use of miscanthus biomass is for combustion because of the ideal chemical composition [20]. However, little information is known for the conversion of ethanol from miscanthus.

2.2.2. Reed canarygrass and alfalfa

In addition to switchgrass and miscanthus, two other species, reed canarygrass and alfalfa, have also been studied considerably for biofuel crops. Reed canarygrass is a C3 grass commonly used for hay and grazing in temperate agricultural ecosystems, and can yield 8-10 Mg/ha in the Midwest of USA and northern Europe [6, 12]. Similar to switchgrass, reed canarygrass is difficult to establish and normally has a low yield in the seeding year [6].

Alfalfa, one of the oldest forage crops in the world, has traditionally been used as high quality forage. However, alfalfa may also have some values for biofuel feedstock [13]. In an alfalfa biomass energy production system, the forage could be fractionated into stems and leaves. The stems could be processed to generate electricity or biofuel (ethanol), and the leaves could be sold as a supplemental protein feed for livestock. Currently, researchers in Minnesota are conducting experiments to select dual-use alfalfa varieties and developing management systems [13

English name	Scientific name	Photosynthetic pathway	Yields reported Mg DM/ha/year
Crested wheatgrass	*Agropyron desertorum* (Fisch ex Link) Schult.	C3	16.3
Redtop	*Agrostis gigantea* Roth	C3	Not available
Big bluestem	*Andropogon gerardii* Vitman.	C4	6.8-11.9
Smooth bromegrass	*Bromus inermis* Leyss	C3	3.3-6.7
Bermudagrass	*Cynodon dactylon* L.	C4	1.0-1.9
Intermediate wheatgrass	*Elytrigia intermedia* [Host] Nevski.	C3	Not available
Tall wheatgrass	*Elytrigia pontica* [Podp.] Holub.	C3	Not available
Weeping lovegrass	*Eragrostis curvula* (Schrad.) Nees .	C4	6.8-13.7
Tall Fescue	*Festuca arundinacea* Schreb.	C3	3.6-11.0
Switchgrass	*Panicum virgatum* L.	C4	0.9-34.6
Western wheatgrass	*Pascopyrum smithii* (Rydb.) A. Love	C3	Not available
Bahiagrass	*Paspalum notatum* Flugge.	C4	Not available
Napiergrass (elephant grass)	*Pennisetum purpureum* Schum.	C4	22.0-31.0
Reed canary grass	*Phalaris arundinacea* L.	C3	1.6-12.2
Timothy	*Phleum pratense* L.	C3	1.6-6.0
Energy cane	*Saccharum* spp	C4	32.5
Johnsongrass	*Sorghum halepense* (L.) Pers.	C4	14.0-17.0
Eastern gammagrass	*Tripsacum dactyloides* (L.) L.	C4	3.1-8.0

Table 1. The 18 perennial grass species that were screened by the US herbaceous energy crop research program [12].

2.2.3. Others

Compared to the above four widely studied species, many other species for potential biofuel crops are more regional specific and related to local climatic conditions. In the southern region of the U.S., subtropical and tropical grasses such as bermudagrass and napiergrass have been evaluated as biomass crops [6]. In southwestern Quebec, Canada, a short growing season environment, Madakadze et al. (1998) [23] evaluated 22 warm-season grasses in 5 species (sandreed, switchgrass, big bluestem, Indian grass and cordgrass). They found that the most productive entries were cordgrass and several entries of switchgrass. Switchgrass from high latitude tended to produce less biomass. The sandreed showed little potential for forage or biomass production. This study was conducted using space-planted nursery conditions and these data represent individual plant potential. Thereafter, their studies were only focused on switchgrass under solid sward conditions [23-25].

English name	Scientific name	Photosynthetic pathway	Yields reported Mg DM/ha/year
Meadow Foxtail	*Alopecurus pratensis* L.	C3	6-13
Big Bluestem	*Andropogon gerardii* Vitman	C4	8-15
Giant Reed	*Arundo donax* L.	C3	3-37
Cypergras, Galingale	*Cyperus longus* L.	C4	4-19
Cocksfoot grass	*Dactylis glomerata* L.	C3	8-10
Tall Fescue	*Festuca arundinacea* Schreb.	C3	8-14
Raygras	*Lolium* ssp.	C3	9-12
Miscanthus	*Miscanthus* spp.	C4	5-44
Switchgrass	*Panicum virgatum* L.	C4	5-23
Napier Grass	*Pennisetum purpureum* Schum	C4	27
Reed canary grass	*Phalaris arundinacea* L.	C3	7-13
Timothy	*Phleum pratense* L.	C3	9-18
Common Reed	*Phragmites communis* Trin.	C3	9-13
Energy cane	*Saccharum officinarum* L.	C4	27
Giant Cordgrass/	*Spartina cynosuroides* L.	C4	9
Salt Reedgrass			5-20
Prairie Cordgrass	*Spartina pectinata* Bosc.	C4	4-18

Table 2. Perennial grasses grown or tested as energy crops in Europe [12].

3. Biofuel crops in Northern Great Plains (NGP)

3.1. Species and biomass yields

In NGP, species evaluated for biofuel crops include switchgrass, big bluestem, Indian grass, tall wheatgrass, intermediate wheatgrass, wild rye, alfalfa and sweet clover [11, 26-33]. Switchgrass still remains in most of the studies in NGP. In South Dakota, switchgrass has been evaluated under both conventional farmland and CRP land, and the biomass yield ranged from 2 to 11 Mg/ha [28-30]. In North Dakota, cultivars of switchgrass have been tested in western and central areas in small research plots (Dickinson and Mandan) and biomass yield ranged between 2 to 13 Mg/ha, depending on cultivar [26-27]. In another site (Upham), biomass yield of switchgrass ranged from 2.4 to 10.8 Mg/ha [32]. In an on-farm scale trial, switchgrass yield ranged from 4.6 to 9.9 Mg/ha in Streeter and Munich [8, 34].

For selecting species for biofuel crops, switchgrass still has more advantages than any other species. This is because: (1) the species has been studied extensively in the US in last two decades and the germplasm pool is larger than other species; (2) it is a warm season species and has greater water use efficiency and drought resistance; (3) it is native to North America and there are no concerns about the invasiveness; (4) there are many environmental benefits for growing switchgrass.

Switchgrass plot following the 2011 harvest at Central Grasslands Research Extension Center, Streeter, ND. Photography by Rick Bohn.

In addition to species, environmental factors (e.g., precipitation, temperature, soil type etc.) have large effects on yield and quality in biofuel crops. To address the interactions of species and environment, a ten-year long-term study was initiated and established in 2006 to evaluate ten cool and warm season grasses and mixtures across North Dakota [11]. The 10 entries of species and mixtures were shown in Tables 3. These grasses/mixtures were grown in six environments in five locations across North Dakota. Among the five locations, long term growing season precipitation varies from 318 mm at Williston in the west to 431 mm at Carrington in the east. In general, western ND has a semi-arid environment but eastern ND is more humid [11, 35].

Initial biomass yield data indicated Basin and Altai wildrye showed lower biomass yields than either switchgrass or wheatgrass species (Table 4). Tall wheatgrass and intermediate wheatgrass performed well across environments in North Dakota. In contrast, performance of switchgrass was largely related to environment, particularly the seasonal precipitation. For dryland conditions, studies are still needed to address both establishment and persistence of switchgrass in the future.

Harvesting perennial grasses plots in fall 2007, Streeter, ND.

Entry	Species/mixtures
1	Switchgrass (Sunburst)
2	Switchgrass (Trailblazer or Dakota)
3	Tall wheatgrass (Alkar)
4	Intermediate wheatgrass (Haymaker)
5	CRP Mix [Intermediate wheatgrass (Haymaker) + Tall wheatgrass (Alkar)]
6	CRP Mix [Intermediate wheatgrass (Haymaker) + Tall wheatgrass (Alkar) + alfalfa + Yellow sweetclover]
7	Switchgrass (Sunburst) + Tall wheatgrass (Alkar)
8	Switchgrass (Sunburst) + Big Bluestem (Sunnyview)
9	Switchgrass (Sunburst) + Altai Wildrye (Mustang)
10	Basin Wildrye (Magnar) + Altai Wildrye (Mustang)

Table 3. Species/mixtures of perennial grasses in ten entries used for biomass study across five locations in North Dakota (names in parenthesis are cultivars) [11].

3.2. Chemical composition

Chemical composition of biomass feedstock affects the efficiency of biofuel production and energy output. The major parts of the chemical composition in the perennial biomass feedstocks are lignocellulose including cellulose, hemicellulose, and lignin; and mineral elements such as ash [3, 36-38]. Biomass may be converted into energy by direct combustion or by producing liquid fuels (mainly ethanol) using different technologies. For converting cellulosic biomass into ethanol, the conversion technologies generally fall into two major categories: biochemical and thermochemical [3, 37, 38]. Biochemical conversion refers to the fermentation of carbohydrates by breakdown of feedstocks. Thermochemical conversion includes the gasification and pyrolysis of biomass into synthetic gas or liquid oil for further fermentation or catalysis. Currently, the U.S. Environmental Protection Agency (USEPA) listed six conversion categories from different companies for ethanol from biomass [3]. Different conversion technologies may require different biomass quality attributes. For ethanol production from biochemical process (fermentation), ideal biomass composition would contain high concentrations of cellulose and hemicellulose but low concentration of lignin [37-38]. While for gasification-fermentation conversion technology, low lignin may not be necessary. For direct combustion and some thermochemical conversion processes, high ash content can reduce the effectiveness and chemical output [3, 37-38].

Entry	Hettinger	Williston-dryland	Williston-irrigated	Minot	Streeter	Carrington
	Mg/ha					
1	0.0 c†	0.2 c	13.0 ab	5.2 cde	4.0 c	12.1 ab
2	0.0 c	0.7 bc	9.6 cd	2.9 e	4.3 c	13.7 a
3	3.4 a	2.2 a	11.2 bc	10.1 a	7.4 a	10.5 bcd
4	1.8 abc	2.7 a	9.2 cd	7.4 bc	6.0 b	10.1 cd
5	3.4 a	2.5 a	10.1 cd	9.4 ab	7.6 a	9.6 d
6	4.0 a	1.8 ab	8.7 d	8.5 ab	5.8 b	10.3 bcd
7	2.0 abc	2.2 a	12.8 ab	9.4 ab	8.3 a	11.4 bc
8	0.0 c	0.7 bc	11.2 bc	4.7 de	3.6 c	12.1 ab
9	0.0 c	0.7 bc	14.3 a	5.8 cd	3.6 c	11.4 bc
10	0.9 bc	0.7 bc	9.0 d	5.8 cd	3.4 c	9.0 d
Mean	**1.5**	**1.4**	**10.9**	**6.9**	**5.4**	**11.0**
LSD (0.05)	**2.5**	**1.3**	**2.0**	**2.2**	**1.8**	**1.1**

†In each column, values followed by the same letter were not significantly different based on LSD test at P=0.05.

Table 4. Biomass yields in ten entries with different species/mixtures of perennial grasses harvested in 2007 at five locations in North Dakota (the species/mixture for each entry is shown in Table 3) [11].

Among the perennial grasses for biofuel production, chemical composition of switchgrass has been investigated in many studies [19, 29-31, 35, 39]. There is little information in the lignocellulose contents in other species such as tall and intermediate wheatgrass when they are harvested at fall as biomass feedstocks because these species have been mainly used as forage. As with yield, biomass composition is affected by genetic and environmental factors as well as by management practices such as nitrogen (N) fertilization and harvest timing. In a study in the southern Iowa, both yield and quality traits were different among 20 switchgrass cultivars. The high yielding cultivars generally had low ash content [19]. In NGP, we reported the chemical composition of the above 10 perennial grasses and mixtures shown in Table 3 in 2007 harvest. The contents of neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), hemicellulose (HCE), cellulose (CE) and ash were determined. Biomass chemical composition was affected by environment and species/mixtures, and their interaction. Biomass under drier conditions had higher NDF, ADL and HCE contents but lower CE contents. Tall and intermediate wheatgrass had higher NDF, ADF and CE but lower ash contents than the other species and mixtures. Switchgrass and mixtures had higher HCE. Tall wheatgrass and Sunburst switchgrass had the lowest ADL content. Biomass with higher yield had higher cellulose content but lower ash content. Combining with higher yields, tall and intermediate wheatgrass and switchgrass had optimal chemical compositions for biomass feedstocks production (Table 5) [35]. In another study in NGP, Karki et al. (2011) showed that tall wheatgrass had similar composition to switchgrass and has potential for ethanol production [39].

Entry	NDF	ADF	ADL	HCE	CE	Ash
	-- g/kg --					
1	733.4 bcd[†]	475.1 c	116.0 e	258.4 bcd	359.1 cd	79.2 ab
2	736.8 bcd	468.5 cd	139.1 bc	268.3 ab	329.4 f	81.2 a
3	792.6 a	535.2 a	116.3 e	257.4 bcd	418.9 a	68.8 de
4	753.5 b	507.1 b	154.5 a	246.4 d	352.6 de	71.3 cde
5	753.6 b	503.8 b	145.9 ab	249.8 cd	358.1 d	70.7 cde
6	745.5 bc	518.0 ab	140.4 bc	227.5 e	377.6 bc	69.5 cde
7	781.9 a	515.9 b	121.3 de	266.1 abc	394.6 b	64.3 e
8	736.8 bcd	459.9 cd	132.5 cd	276.9 a	327.4 f	73.9 bcd
9	723.7 cd	456.2 d	124.7 de	267.1 ab	331.5 f	74.8 abcd
10	715.4 d	461.9 cd	124.2 de	253.5 bcd	337.7 ef	76.3 abc
Mean	**747.3**	**490.2**	**131.5**	**257.1**	**358.7**	**73.0**
LSD (0.05)	**23.6**	**18.6**	**12.5**	**16.9**	**18.9**	**7.1**

[†]In each column, values followed by the same letter were not significantly different based on LSD test at P=0.05.

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin;

HCE: Hemicellulose (NDF-ADF); CE: Cellulose (ADF-ADL).

Table 5. Biomass compositional parameters in different species/mixtures averaged across six environments (the species/mixture for each entry is shown in Table 3) [35].

3.3. Mixture of multiple species

From a long-term sustainability perspective, the reliance on a single species of perennial crops (monoculture) for biomass production may be risky because of less diversity and more chance to prone to certain pests and diseases. Mixture of multiple species may overcome some problems encountered in monoculture crops. In terms of dedicated biofuel crops such as switchgrass and miscanthus, most previous and current studies are focused on monoculture. Little information is known about the mixture of multiple species and their productivity as compared to monoculture.

In ecology studies, the benefits of mixtures of species over monocultures in terms of sustainability and biodiversity have been recognized in both annual and perennial species [6, 40, 41]. For biofuel purpose, specifically, Tilman et al. (2006) argued that the mixtures of different perennial grasses are more stable, more reliable and more productive than monoculture. Also, the mixtures are more environmentally friendly in terms of energy inputs and greenhouse gas emission. From agronomic standpoint, growing mixtures of multiple species in a large farm scale will face challenges such as selecting species, seeding methods, seeds costs, harvesting and so on. In addition, biomass feedstock quality will be an important factor when considering harvesting mixtures.

4. Management strategies for perennial biofuel crops

4.1. Establishment

Many perennial warm season grasses such as switchgrass are difficult to establish [17]. In an on-farm scale study, net energy value of switchgrass is largely determined by the biomass yield in established year [8]. Therefore, improving crop establishment is a very important step to successfully manage biofuel crops. There are many factors affecting establishment of perennial grasses; however, soil moisture and temperature are the most important ones, and many management practices are related to maintenance of adequate moisture and optimum temperature for seedling development and growth.

Seeding rate (pure live seeds): Typically recommended seeding rate in the US is 4-10 kg/ha for switchgrass based on the review of Parrish and Fike (2005) [17]. Sedivec et al. (2001) provided a detail recommendation for grass varieties for ND, ranging from 2 to 24 lb/ac, depending on species or varieties [42].

Seeding depth: The seeding depth may vary with soil types. However, seeding depth of grasses is generally shallower than cereal crops. For switchgrass in NE, seeding depth ranged from 1.5 cm to 3.0 cm in silt loam soil [43]. In SD, Nyoka et al. (2007) recommended not seeding deeper than 2.5 cm regardless of soil type [44].

Seeding date: Seeding date is largely determined by soil temperature and moisture. For warm season grasses, the ideal temperature for seed germination is between 20-30 oC if no dormancy [44, 46]. In SD, the recommended seeding date is early May to mid-June [44]. In VA, the planting date for switchgrass is much later than for corn but similar to that for millet or sorghum-sudangrass. In conventionally prepared seedbeds, June 1-15 was recommended [47]. In NE, study showed that planting switchgrass in mid-March can significantly increase seedling size as compared to late April and May [48]. Under NGP conditions, early seeding may provide benefit in terms of adequate soil moisture [48]. However, low soil temperature may be a factor for limiting germination and emergence of warm season grasses.

Timing an appropriate seeding date is also important for weed control. In a study conducted in Mississippi, Holmberg and Baldwin (2006) seeded switchgrass monthly from April to October and found that the months with minimum weed biomass were April and June. In addition, rainfall is also a very important factor for determining weed suppression for seeding switchgrass [49].

Seeding methods: switchgrass and other warm season grasses can be seeded under both conventional and no-till conditions. The ideal condition for conventional seeding should be a smooth, firm, clod-free soil for optimum seed placement with drills or culti-packer seeders [44]. The seedbed should be firm enough for good seed-soil contact and a consistent seeding depth [44, 47]. Since switchgrass requires warm weather for seeding, water loss during tillage could be a problem under dry and warm days. As a result, conventional seeding may not be ideal [47].

No-till helps to conserve soil moisture, requires less time and fuel, and eliminates the soil crusting frequently encountered in conventional seedbed [47]. In the literature, the results of comparison of conventional and no-till planting for warm season grass establishment are controversial. However, no-till planting frequently showed advantages over conventional tillage, in terms of soil and water conservation [17].

The warm season grasses can be seeded by drilling as well as broadcasting. For broadcasting method, cultipacking or rolling the seedbed after broadcasting is required to ensure that seeds are sufficiently covered by soil and to improve seed-to-soil contact [44].

Seed size (seed mass): Seed size varies considerably within cultivars as well as seedlots of a single cultivar [50]. In general, seed size is linearly related to seed mass or weight in many grasses and cereal crops. Large seeds normally have advantage over small seeds for germination and emergence [51], and seedling development [52]. Switchgrass seedlings grown from larger seeds developed adventitious roots more quickly than those from small seeds [52]. Even the seedling size associated to seed size was only evident at early stage [53], Vogel (2000) still suggested that selection of populations with larger seeds may improve seedling establishment in switchgrass [18].

Seedling vigor: Seedling establishment can be quantified by a more general term, seedling vigor. Greater seedling vigor refers to larger seedling size, greater ground cover and higher biomass at early stage. In addition to environmental factors, seedling vigor is believed to the single most important trait controlled by genetic variability in establishment capacity of perennial forage crops. Many researchers have used some measure of seedling vigor as a selection criterion to improve establishment capacity, while others have used more indirect measures, such as seed mass or germination rate [54]. As mentioned in the above, seed size is positively related to seeding vigor. However, other factors are also related to seedling vigor. For example, studies in cereal crops in Australia showed that embryo size significantly contributed to seedling vigor in barley [55]. In spring wheat, high protein content also contributed to seeding vigor.

Others: Application of arbuscular mycorrhizal fungi (AMF) has been shown to be effective for enhancing seedling yield and nutrient uptake in switchgrass [56-58]. Hanson and

Johnson (2005) showed that soil PH affected switchgrass germination and the optimum PH is 6.0 [46].

4.2. Weed control during establishment

Weed competition is often a major cause of establishment failure in grasses [16, 17, 44]. Although the weed species varies from region to region and even between nearby locations, perennial forbs and warm-season grass species provide the most severe competition for warm season crops like switchgrass [17].

Application of herbicides generally provides very effective weed control. In switchgrass and other warm season grasses, atrazine has been used almost universally as both pre- and post-emergence herbicides for improving establishment [17]. However, atrazine is only labeled for roadside and CRP lands in some states, not for large area of switchgrass except for a special use in Iowa [17]. Alternatively, switchgrass was companion-planted with corn or sorghum-sudangrass using atrazine [59-60].

There are several other chemicals showing to be effective for controlling weed during switchgrass establishment. For pre-emergence application, Mitchell and Britton (2000) [61] used metolachlor for control of several warm season annual grasses. Chlorsulfuron and metsulfuron showed some efficacy in switchgrass [62]. For post-emergence application, imazapyr, sulfometuron, quincloric, 2, 4-D and dicamba have been reported or recommend for weeds control in switchgrass and other warm season grasses [17, 44]. Non-selective herbicides (e.g, glyphosate and paraquat) have been used to prepare seedbeds for no-till plantings for establishing grasses. In addition, Buhler et al. (1998) listed a few more herbicides that showed potential to provide selective weed control to improve establishment of perennial warm season grasses [63].

Herbicides are generally effective and largely available in the market. However, many herbicides are not currently registered for perennial crops for biomass production [16, 63, 71]. As a result, weed control during the establishment year can not be solely relied on chemical applications. Other control methods must be adopted to achieve the best weed control. Buhler et al. (1998) reviewed weed management in biofuel crops and provided several non-chemical control options. These options include timing seeding date, tillage and cropping practices, using companion crops and clipping. Ultimately, the best weed management strategy will be the integration of various options [63].

The overall goal of non-chemical options for weed control is to create an environment that favors to crop growth and development but disfavors weeds. A typical example is manipulation of seeding date to minimize the weed competition, by changing the relative emergence of crop and weed. In general, if crops emerged earlier than weeds, they would have advantage to acquire resources. Therefore, seeding crops before the weeds emergence is an effective way to avoid weeds pressure.

Several other management practices have been successfully used to increase crop competitive ability. In western US, Canada and Australia, increasing seeding rate has been an effective measure to suppress wild oat in barley and spring wheat [64-66]. Using large seeds also provided competitive benefit in sparing wheat against wild oat [67. 68]. Choosing cultivars with more competitive ability also provided benefit to weed control during establishment stage.

4.3. Nitrogen (N) management and N use efficiency

Like any other crops, optimizing biomass yield and maintaining quality stands require fertilizer inputs for biofuel crops. Currently, nitrogen (N) remains the primary fertilizer used in biofuel crops; therefore, most studies just consider the N application. Although some perennial species such as swithgrass and miscanthus are tolerant to low soil fertility conditions, studies showed that biomass yield responded to N application [16, 69]. Lemus et al. (2008) used 4 N rates (0, 56, 112 and 224 kg/ha) in switchgrass southern Iowa. They found that N application generally improved the biomass yield but the yield response declined as N level increased [19].

The amount of N fertilizer required for any biofuel crop is a function of several factors including yield potential of the site, cultivar, management practices, soil types, and so on. Therefore, the optimum N rate can vary from place to place. For example, a study in Texas using lowland switchgrass cultivar 'Alamo' determined that the optimum N rate was 168 kg/ha [70]. In another study in CRP land of NGP, however, the N rate of 56 kg/ha was optimum for upland switchgrass cultivars [30]. Gunderson et al. (2008) [71] summarized the response of biomass yield of upland switchgrass cultivars to N fertilizer rate. They showed that switchgrass yield even decreased as N rate was over 100 kg/ha (Figure 1). Among the management practices, perennial grass rotating with legume crops or mixture of grass and legumes may reduce N fertilizer inputs and improve their energy balance [71].

Some perennial grasses (e.g., switchgrass and miscanthus) can recycle N from the aboveground shoots to the crown, rhizome, and root in the fall for use in over-wintering and regrowth in the following spring [72]. This mechanism makes an efficient use and reuse of N by plant. However, there is still little information on when and how much of N recycles among plant organs, and how much the N cycling can contribute to over N balance in biofuel crops [7].

Another factor affecting crop N balance is fertilizer use efficiency and N use efficiency (NUE). Take switchgrass as an example, biomass yield varied considerably (up to 5 fold) at the same N application level (Figure 1). Certainly, N was not used efficiently at low yield level. Therefore, improving both fertilization use efficiency and NUE is very important for increasing biomass yield in biofuel crops. In addition, increased efficiency will ultimately reduce the N inputs.

4.4. Water management and Water Use Efficiency (WUE)

In NGP, soil water deficit occurs very frequently during crop growing season because of the highly variable and uneven distribution of seasonal precipitation. In general, biomass yield of switchgrass increased as the amount of seasonal precipitation increased. However, at a given seasonal precipitation level (e.g., 500-600 mm), switchgrass yield ranged from 2 to 25 Mg/ha (Figure 2) [71], indicating the importance of crop WUE and precipitation use efficiency. Ideally, the figure 2 should be converted to the biomass yield as a function of seasonal evapotranspiration (ET) or transpiration (T), not precipitation because crop yield is more closely related to ET or T. Although most field studies have included precipitation information in NGP, there is no detailed information of crop ET, transpiration and water-use efficiency (WUE). The quantification of ET and WUE in biofuel crops under various environmental conditions and management practices will lead to identify the best management strategies. Because both water and N are critical for crop growth, the interaction of water and N becomes important, particularly under dryland conditions. However, there are very few studies on the interactive effects of N and soil moisture on biomass yield and quality in biofuel crops.

4.5. Harvest management

Proper harvest management is important for biofuel crops for high yields and ideal qualities. The harvest management practices include harvest frequency, timing and stubble height. Currently, most studies for harvest management are focused on switchgrass [29, 69, 73]. Although switchgrass can be harvested in 2 times a year in south part of USA [73, 74], swithcgrass in NGP can only be harvested once a year either after anthesis (summer) or killing frost (fall). For maximizing the biomass yields and chemical compositional attributes for biofuels, harvesting in killing frost is an ideal harvest management [29]. Another harvest practice in the NGP is harvesting every other year (biennial harvest). Comparing annual harvest and biennial harvest, average annual biomass yield is generally lower for biennial harvest. The only benefit for biennial harvest is reducing machine operation cost. However, biennial harvest improved the switchgrass stand health if harvested in summer [29]. The reduction of annual biomass yield in biennial harvest was related to species and mixtures in our long-term field study. The reduction in annual biomass yield due to biennial harvesting ranged between 20 to 50 percent. In general, biomass yield of intermediate wheatgrass reduced the most in biennial harvest. However, there was one dryland site that Sunburst switchgrass + Altai wildrye had higher yield on the biennial harvest [11, 75]. Cutting height during harvest also affect biomass yield in perennial grasses. In general, lower cutting stubble resulted in higher biomass yield than higher cutting [75].

4.6. The role of biofuel crops in cropping systems

Given emerging markets for biofuels and increasing production of biofuel crops, new and improved cropping systems are needed to maintain overall productivity as well as sustainability. Introducing perennial crops to the existing cropping systems will face challenges. Boehmel et al. (2008) [76] studied annual and perennial biofuel cropping systems in Germany. They compared 6 systems: short rotation willow coppice, miscanthus, switchgrass, energy corn and 2 annual crop rotation systems (oilseed rape, winter wheat and triticale). The results showed that perennial biomass systems based on *Miscanthus*, switchgrass, or willows could be as productive as energy corn with lower energy inputs. Energy corn had the best energy yield performance but a relatively high energy input.

Anex et al. (2007) [77] proposed that the development of new biofuel crops and cropping systems, in conjunction with nutrient recycling between field and biorefinery, comprise a key strategy for the sustainable production of biofuels and other commodity chemicals derived from plant biomass. Such systems will allow N nutrient to be recovered and reduce fertilizer inputs.

Currently, little information is known how perennial crops interact with annual crops and their benefit in NGP. Perennials, however, are rarely permanent and some annual cropping or innovative combinations of annual and perennial biofuel crops strategically deployed across the farm landscape and combined into synergistic rotations may be necessary in the future. Combining annual biofuel crops such as corn and sorghum into rotations with perennial biofuel crops may benefit biofuel cropping systems [77].

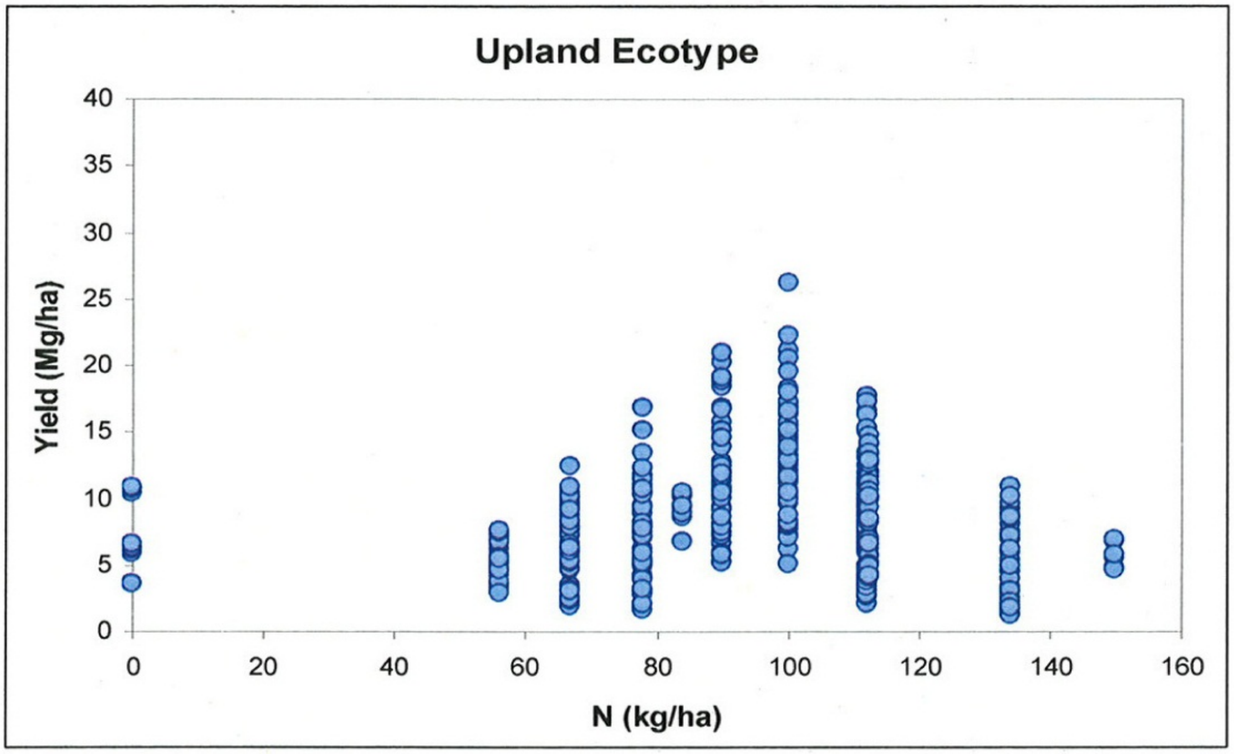

Figure 1. Biomass yield in upland switchgrass as a function of total nitrogen application during the growing season [71].

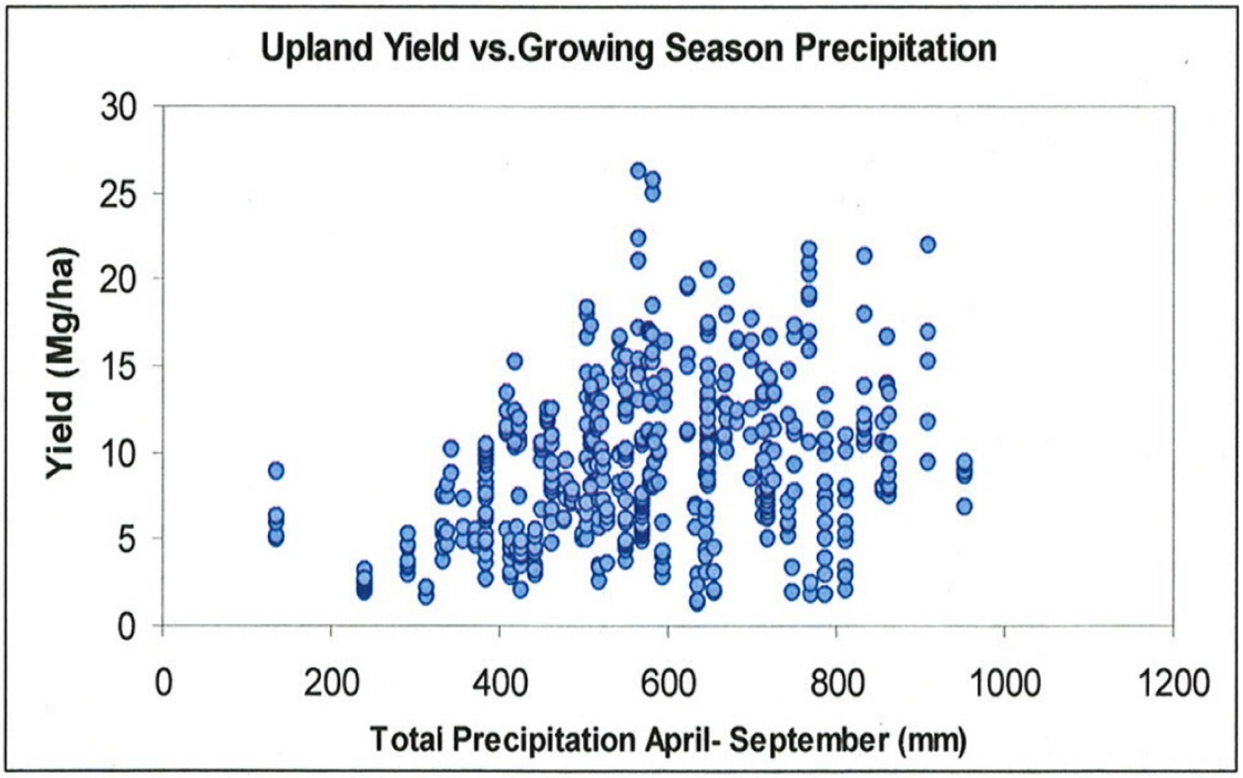

Figure 2. Biomass yield in upland switchgrass as a function of precipitation from April to September [71].

5. Ecological and environmental benefits of biofuel crops

Development of perennial biofuel crops may provide long-term sustainability on these lands by reducing soil erosion, increasing soil organic matter, reducing greenhouse gases and enhancing carbon sequestration [35]. Studies have shown that perennial crops provided many ecological and environmental benefits. Switchgrass and other warm season grasses can be used to control soil erosion, reduce runoff losses of soil nutrients, improve water quality (facilitate the breakdown or removal of soil contaminants), diversify wild life habitats and so on [17, 44]. Roth et al. (2005) [78] showed that proper managing switchgrass harvest can significantly increase grassland birds diversity. More importantly, perennial crops such as switchgrass have been shown to increase carbon sequestration and improve soil quality [9].

The environmental benefits for producing biofuel crops include high energy efficiency and reducing greenhouse gas (GHG) emission. Schmer et al. (2008) [8] evaluated the net energy efficiency and economic feasibility of switchgrass and similar crops in North and Central Great Plains. Switchgrass produced 540% more renewable than nonrenewable energy consumed. Switchgrass monocultures managed for high yield produced 93% more biomass yield and an equivalent estimated NEY than previous estimates from human-made prairies that received low agricultural inputs. Estimated average GHG emissions from cellulosic ethanol derived from switchgrass were 94% lower than estimated GHG from gasoline.

6. Future perspectives for biomass production in the northern great plains

The Northern Great Plains has over 4 million hectares of highly erodible and saline crop land. Development of perennial biofuel crops may provide long-term sustainability on these lands by reducing soil erosion, increasing soil organic matter, reducing greenhouse gases and enhancing carbon sequestration. Although studies are on-going in long-term field experiments, the best management practices are still needed to be developed for producers. The long-term ecological and environmental benefits are also needed to be quantified in the area.

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