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Research Article

Switchgrass (*Panicum virgatum* L.) Cultivar Adaptation, Biomass Production, and Cellulose Concentration as Affected by Latitude of Origin

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Ten cultivars of switchgrass (*Panicum virgatum* L.) of northern and southern origins that had demonstrated adaptation to North Dakota were evaluated for biomass production, cellulose concentration, and nutritive value in the southern Canadian prairie region: Saskatchewan and Manitoba. In this region, cultivars adapted to northern latitudes present interest for biomass production. Latitude of origin of the cultivars was positively correlated to stand density ($r = 0.83$, $P < 0.01$), biomass production ($r = 0.69$, $P < 0.01$), and cellulose ($r = 0.84$, $P < 0.01$), and negatively correlated with organic matter digestibility ($r = -0.86$, $P < 0.01$) and N ($r = -0.85$, $P < 0.01$). Dacotah and ND 3743, the northern origin cultivars, were more persistent in Brandon, MB (94 to 100% stand density) and exhibited higher cellulose and hemicellulose concentrations than southern cultivars. Southern cultivars produced higher biomass than northern-origin cultivars until they suffered significant stand and biomass decline. Cave-in-Rock, the southern origin cultivar, did not persist in the third year after seeding. However, southern-adapted cultivars exhibited better nutritive value for grazing cattle. We conclude that switchgrass production in the southern Canadian prairie should utilize the USA cultivars from northern latitudes or adapted Canadian cultivars should be developed.

1. Introduction

Rising world energy demand and government policies to increase secure domestic supplies of energy in North America have created interest in ethanol for automotive fuels. Biomass crops that can be converted to ethanol biofuel by enzymatic digestion and fermentation or thermochemical conversion of plant cellulose and hemicellulose polymers to ethanol in large-scale biorefineries have been identified [1]. Switchgrass (*Panicum virgatum* L.) is a warm-season (C4) grass species native to the tallgrass prairie region of North America including the southern Canadian prairie. Generally, warm-season grass species can be moved about 300 miles north or 200 miles south of their original location [2]. This grass has been studied for lignocellulosic biomass conversion to fuel-grade ethanol in USA, but the southern Canadian prairie region is its northern limit of adaptation. Cultivation of switchgrass in this region will require cultivars adapted to northern latitudes. Northern ecotypes have a longer winter dormant period with better winter survival than southern ecotypes when grown at the same latitude [3]. The attributes of switchgrass for a biomass crop include its yield potential, longevity, water use and nutrient use efficiency, and suitability for marginal land. Switchgrass has been reported to produce excellent biomass yield in North Dakota, South Dakota, and Minnesota [4, 5] and in southern Quebec [6] but may be limited in the prairie region of Western Canada to sites south of 51°N latitude [7]. Also, only one switchgrass cultivar was evaluated in Canada [7, 8], but several cultivars have been developed or successfully cultivated in North Dakota, USA [4]. The objective of this research was to evaluate the biomass production, cellulose concentration, nutritive value for ruminant livestock, and persistence of a number of USA-adapted switchgrass cultivars at two locations in the southern Canadian prairie region.

2. Materials and Methods

2.1. Study Site Description. The experimental sites were Brandon, Manitoba (49° 50′ N, 99° 57′ W) and Swift Current, Saskatchewan (50° 16′ N, 107° 44′ W), Canada. The soil at Brandon was an Orthic Black Chernozem fine sandy loam (sandy, mixed frigid, udorthentic Haploboroll). The soil at Swift Current-dryland site was a Swinton loam, Orthic Brown Chernozem [9] or a fine, mixed, aridic Haploboroll and at Swift Current-irrigated site, it was an alluvial Rego Chernozem (clay to clay loam) [9] or alluvial typic Haplustoll. Seeds of ten switchgrass cultivars were obtained from the USDA NRCS Plant Materials Centre at Bismarck, North Dakota (Table 1). Cultivar descriptions of eight entries and nomenclature of this report can be found in Alderson and Sharp (1994) [10]. The experiment was seeded with 5.9 kg ha^{-1} (based on Pure Live Seed (PLS)) on 28 June, 1993 at Swift Current and on 11 August, 1993 at Brandon. Individual plots were 6 rows wide and 1.8 × 6 m at Swift Current and 5 rows wide and 1.5 × 6 m at Brandon. Weeds were controlled by hand at Brandon and no herbicides were used at this location. At Swift Current, weeds were controlled in the establishment year by application of Buctril M (280 g/L bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) and 280 g/L MCPA (4-chloro-2-methyl(phenoxy)acetic acid)) formulated as a emulsifiable concentrate on 9 July, 1993. In 1994, weeds were controlled with application of 2,4-D ((2,4-dichlorophenoxy)acetic acid) and Banvel (Dicamba (3,6-dichloro-2-methoxybenzoic acid)) on 27 April, 1994. Weeds were controlled in 1995 with application of atrazine (6-chloro-N-ethyl-N′-(1-methylethyl)-1,3,5-triazine-2,4-diamine) on 11 May, 1995. At Swift Current-irrigation Buctril M was applied on 12 June, 1996 and atrazine on 25 July, 1996 for weed control. The delayed spring growth initiation by switchgrass resulted in weed invasion and competition from cool-season annual weeds in every growing season at Swift Current at both sites. Foxtail barley (*Hordeum jubatum* L.) was a frequent weed problem and herbicide control varied from excellent in one year (1995) to poor in the next year (1996). At Swift Current-dryland, crested wheatgrass (*Agropyron cristatum* L. Gaertn.) was the major weed species and the application of atrazine did not control it.

Weather at Swift Current and Brandon was recorded at standard agrometerological stations within 1-2 km of the experimental locations (Table 2). Irrigation water was applied at Swift Current-irrigation to increase biomass productivity with 62 mm on 21 June, 75 mm on 29 July, 69 mm 18 August, and 75 mm on 29 August, 1994; 75 mm on 18 May, 75 mm on 31 May, 62 mm on 3 August, 62 mm on 21 August, and 62 mm on 13 September, 1995; 75 mm on 05 June, 62 mm on 7 August, and 75 mm on 21 August, 1996. No irrigation was provided at Brandon.

2.2. Data Collection. Seedling emergence was visually evaluated at Brandon on 7 September, 1993 by counting seedlings in randomly located quadrants. Stand density was ocularly estimated as a percentage of soil cover in each plot by 2 to 3 experienced observers. Due to the number of observations between 30 and 70%, it was determined that transformation of stand density data was not required prior to analysis of variance [11].

Sites were sampled in late September or as close as possible to the first frost (−3°C) of the autumn season. Forage samples were harvested in September during the study years with a flail-type forage harvester from the center 0.61 m width of each plot at Swift Current. In some plots at Swift Current where plant density of switchgrass was low, hand-clipped samples of switchgrass were harvested from 1 m^2 area within each plot. Forage samples at Brandon were harvested in late September of 1995 and early October of 1996 with a flail-type harvester from the center 0.91 m width with a stubble height of 5 cm. Fresh total plot yield was weighed and recorded. Subsamples were weighed, dried at 60°C in a forced-air oven, and reweighed to calculate dry matter (DM). Plot biomass yields were converted to DM biomass yield prior to analysis.

Additional subsamples of biomass from both sites were dried and ground to 1 mm particle size and forage nutritive value was determined in analytical laboratories at the Agriculture and Agri-Food Canada Semiarid Prairie Agricultural Research Centre in Swift Current. The low biomass production of Trailblazer at Swift Current Site 2 was insufficient for a complete set of analyses on this cultivar. Cellulose and hemicellulose concentrations were determined by standard methods [12, 13]. *In vitro* organic matter digestibility (OMD) was determined by modified technique of Tilley and Terry (1963) [14, 15]. Fistulated sheep wethers used for the collection of rumen fluid were fed a bromegrass (*Bromus inermis* L.)/alfalfa (*Medicago sativa* L.) hay diet and cared for in accordance with the Canadian Council on Animal Care guidelines [16]. Nitrogen concentration was determined following AOAC (1984) [17]. Phosphorus concentration was colorimetrically determined after the samples had been digested with sulphuric acid [18]. Calcium concentration was determined after a nitric-perchloric acid digestion [19].

2.3. Statistical Analysis. Experiments of a randomized complete block design with six replications were established at all three sites. Analysis of variance was determined with JMP software [20]. Biomass data were analyzed as a split-plot in time and space [11] with a mixed model, where replication and its interactions were random effects and cultivars, sites, and years were fixed effects. Due to the large range in biomass production data, this parameter was transformed according to the formula: $Y = \log_{10}$ (Biomass) and the resulting transformed data were analyzed. Biomass production data from each site-year were also analyzed separately as a randomized complete block experiment. The least-square cultivar means for biomass production were backtransformed to the original data scale for presentation. Cellulose concentration

Table 1: Switchgrass cultivars grown for biomass production and cellulosic concentration at Brandon, MB and Swift Current, SK, Canada in 1995 and 1996.

Cultivar	Breeding institution(s)^	Year of release	Site of origin	Latitude (°N)
Blackwell	KS AES, NRCS Manhattan KS	1934	Blackwell, OK	37
Cave-in-Rock	MO AES, NRCS Elsberry MO	1958	Cave-in-Rock, IL	37
Dacotah	ARS NRCS Bismarck ND	1989	Breien, ND	46
Forestburg	ARS NRCS Bismarck ND	1987	Forestburg, SD	44
Nebraska 28	NE AES, ARS, NRCS Lincoln NE	1935	Holt County, NE	42
Pathfinder	NE AES, ARS Lincoln NE	1953	Sites in NE and KS	37 to 43
Summer	SD AES Brookings SD	1953	Nebraska City, NE	41
Sunburst	U. of South Dakota	1998	Union County, SD	43
ND 3743	NRCS Bismarck ND	—	Upham, ND	49
Trailblazer	ARS, U. of Nebraska	1984	Sites in NE and KS	37 to 43

^AES: Agricultural Experiment station; ARS: agriculture Research Service USDA; NRCS: Natural Resource Conservation Service USDA; U. of South Dakota: University of South Dakota; U. of Nebraska: University of Nebraska; state name abbreviations as per US postal service.

Table 2: Monthly average maximum, minimum, and mean temperatures (°C) and precipitation (mm) at Brandon, MB and Swift Current, SK, Canada from 1994 to 1996 and the 30-year (1971 to 2000) means (Environment Canada 2009).

Month	Brandon				Swift Current			
	T_{max}	T_{min}	T_{mean}	Precip.	T_{max}	T_{min}	T_{mean}	Precip.
1971–2000 mean								
May	19.2	4.4	11.8	52.6	17.6	4.5	11.1	49.5
June	23.5	9.8	16.6	75.7	22	9.2	15.6	66
July	25.9	11.9	18.9	72.5	24.8	11.3	18.1	52
Aug.	25.4	10.5	18	69.2	25	10.8	17.9	39.9
Sept.	18.8	4.9	11.9	48.3	18.3	5.3	11.8	30.2
1994								
May	19.6	3.4	11.6	48.2	18	5	11.5	62.4
June	22.2	9.4	15.9	75.7	20.8	8.8	14.8	89.2
July	23.9	10.1	17	47.2	25.6	10.6	18.1	22.4
Aug.	22.9	9	16	30.8	24.8	10.3	17.6	23.2
Sept.	21.6	5.4	13.6	52.6	22.5	7.5	15	10.9
1995								
May	16.8	3	9.9	56.4	16.2	3.2	9.7	29
June	25.2	11.6	18.5	77.7	22.8	9.9	16.4	101
July	25.1	11.7	18.4	25.2	23.6	11.2	17.4	57.1
Aug.	26.2	10.6	18.4	24.6	23	10.3	16.7	107.6
Sept.	19.8	3.3	11.6	31.8	18.3	5.5	11.9	52.8
1996								
May	14.6	1.7	8.2	86.8	13.2	2.4	7.8	65
June	23.6	10.8	17.1	41	21.7	10	15.9	77.7
July	24.4	11.3	17.9	62	24.3	11.1	17.7	23.1
August	26.7	10.4	18.5	22.4	27.3	11.6	19.5	32.6
Sept.	18	5.2	11.6	57.8	15.3	5.3	10.3	105.7

and nutritive value parameters were analyzed based on means over years within each site. Pearson correlation coefficients were calculated with the multivariate option of JMP.

3. Results and Discussion

3.1. Weather. Growing season monthly temperatures from 1994 to 1996 were close to the 1971–2000 period averages [21]. Mean temperature in May was below average, especially in 1996 at both Brandon and Swift Current. Spring growth of switchgrass was not observed until June, which may be related to the cool temperatures in May at these locations. Maximum temperatures at both locations were also near the 30-year mean for each month. The winter temperatures in 1994-95 were very cold (data not shown) with extremely low temperatures for an extended period in February and March.

On average, monthly precipitation is distributed more evenly during the growing season at Brandon compared to Swift Current which has peak rainfall in June followed by drier summer months (Table 2). During this study, the variation in monthly precipitation was greater at Swift Current which is typical of this semiarid prairie location. In 1994 at Swift Current, a wetter than normal May and June periods were followed by a drier summer. In 1995, a drier May was followed by a wetter June-to-September period. In 1996, a normal spring was followed by a drier period in July and August and then a wetter than normal September.

3.2. Stand Establishment and Persistence. Seedling emergence in all plots with the exception of Blackwell switchgrass were rated as excellent. Stand establishment at Swift Current-dryland was generally adequate in 1994 with Dacotah, ND 3743, and Summer exhibiting >50% stands (Table 3). Blackwell switchgrass establishment was significantly lower than other cultivars, 13% in 1994 at Swift Current ($P < 0.05$). By the next year, however, stand density of most cultivars was not significantly different from zero. Only Dacotah and ND 3743 maintained >50% stand density at this site in 1995. There was subsequent invasion by crested wheatgrass (*Agropyron cristatum* L. Gaertn.) in the cultivars where the switchgrass plant density had declined. This cool-season grass species had been grown on the site prior to this trial and residual seed in the soil may have persisted despite tillage and herbicide control prior to and subsequent to seeding switchgrass. As a result, this site was abandoned for further data collection.

At Swift Current-irrigation, all cultivars except Blackwell had adequate establishment in 1993, the year of seeding (Table 3). By 1994, Blackwell, Cave-in-Rock, Pathfinder, Summer, and Trailblazer plants density had declined significantly ($P < 0.05$). In contrast, stand density of Dacotah, Forestburg, Nebraska 28, and ND 3743 increased from 1993 to 1994. Because stand density was recorded as a percentage of ground cover, the increase in stand density was likely due to tillering by established plants. Then by 1996, stands had declined, most below 50% levels. Only Dacotah, Forestburg, and ND 3743 stands were maintained until 1996 at this site. Plant density decline in switchgrass is generally attributed to low-temperature injury during the winter period [22]. There was period of below normal temperatures at Swift Current during January (−22.1°C; 46-year mean is −17.4) and March 1996 (−12.3°C; 46-year mean is −8.3) and drier summer months at Brandon and Swift Current in 1995 and this weather may have contributed to the plant density decline in 1995-96.

Stand density data after establishment at Brandon indicated that all stands were complete (100%) by 1994 or one year after seeding (data not shown). By the second year after seeding, however, Blackwell, Cave-in-Rock, Pathfinder, and Trailblazer stands had decreased ($P < 0.05$) at Brandon (Table 3). Dacotah, Forestbury, Nebraska 28, Summer, Sunburst, and ND 3743 switchgrasses maintained stand density in 1995 and showed little or no decline in stand density in 1996. Dacotah (98%) and ND 3743 switchgrasses (92%), in particular, maintained nearly complete stands in 1996. Likewise, Dacotah and ND 3743 switchgrass cultivars exhibited the best persistence among eight cultivars or experimental strains grown at three sites in western North Dakota [4]. Cave-in-Rock and Summer switchgrass exhibited stand density decline in western North Dakota [4] similar to our results, while Trailblazer was persistent in their study [4] unlike to the current study. In contrast, others reported no stand decline for Blackwell, Trailblazer, or Cave-in-Rock switchgrass over several years and several sites in North Dakota, South Dakota, and Minnesota [5]. Researchers concluded that switchgrass cultivars cannot be moved more than 500 km (or 5° latitude) north of their geographic origin or they suffer from winter injury [4, 23]. Nevertheless, latitudinal adaptation of switchgrass would permit moves up to 2 USDA hardiness zones or about 450 km with no impact on stand longevity [24]. Dacotah originated approximately 300 km south of Brandon, while ND 3743 originated 135 km south of Brandon, Manitoba. Forestburg originated about 680 km south of Brandon, and it exhibited a decline in plant density by 1996 at Swift Current, but had excellent persistence at Brandon. Sunburst originated about 800 km south of Brandon and exhibited persistence comparable to Forestburg. Other cultivars in this trial originated from sites further south (Table 1) and exhibited poor persistence either at Swift Current-dryland or at both Brandon and Swift Current-irrigated sites. Our results were consistent with others [24] in that a latitudinal adaptation among switchgrass cultivars limits the distance that any cultivar can be moved northward. Casler et al. [22] also reported that southern-adapted cultivars exhibited a lack of persistence when grown at northern locations and similarly northern-adapted cultivars exhibited stand decline in southern locations. These researchers concluded that switchgrass cultivars will be needed for each region to maximize biomass for bioenergy production [22]. It can be surmised from the results from the current study that the utilization of American switchgrass cultivars in western Canada should be restricted to the most northerly adapted cultivars in order to avoid plant stand decline.

3.3. Biomass Production. Biomass production was sensitive to higher-order interactions of location, year, and cultivar effects when the biomass production parameter was analyzed. However, when the transformed data were analyzed, only the location × cultivar interaction was significant as well as cultivar and location main effects. Cultivar × environment interactions for switchgrass have been reported for biomass production and other agronomic or biofuel traits in north central USA [22, 25]. Location, year, and cultivar interactions were significant in this study, but the effect of harvest date was not [25]. There was also evidence of longitudinal adaptation to locations in this study related with the longitude of the original collection site for the cultivar. In contrast, others concluded that switchgrass did not exhibit adaptive response to longitude [22].

Biomass production was affected by stand density as evidenced by the high correlation between stand density and biomass production in 1996 at both Swift Current ($R = 0.93$, $P < 0.01$) and at Brandon ($R = 0.89$, $P < 0.01$) (Table 7). There were significant biomass production differences ($P < 0.05$) among the cultivars in all three years at Swift Current and both years at Brandon (Table 4). Cultivar ranking changed from year to year, but Dacotah, Forestburg, Nebraska 28, and ND 3743 switchgrasses were higher yielding cultivars than Cave-in-Rock, Pathfinder, or Trailblazer. It has been observed in North Dakota that southern-adapted cultivars tend to produce more biomass than northern-adapted cultivars [4, 5]. The biomass production observed in the present study were 28 to 40% or 60 to 72% lower than those reported in North Dakota [4, 5], which may be related to drier summer observed at the study locations, especially in Brandon, MB. In addition, these biomass observations are lower than cool-season perennial native grass species in this region of Western Canada [7] and suggest that switchgrass is not competitive with those species as a potential biomass for biofuel crop [8]. The biomass results of the current study confirm that southern-adapted switchgrass cultivars produce higher biomass than northern-adapted cultivars until they suffer significant stand decline with their biomass productivity declining sharply. Especially, this trend could be seen in Nebraska 28 stand density and yield changes from 1994 to 1996 at Swift Current-irrigation.

Biomass production of switchgrass at Brookings South Dakota was highly correlated with tiller density, number of phytomers per tiller, and mass per phytomer [26]. High-yielding cultivars in Wisconsin and South Dakota, such as Cave-in-Rock, had larger tillers with more and larger phytomers than early maturing and lower yielding cultivars, such as Dacotah. Biomass production differences between sites are attributed to variation in reproductive tiller density because reproductive tiller mass was five times greater than that of vegetative tillers [26]. Although these variables were not determined in the current study, we observed that southern-adapted cultivars neither maintained tiller density over time (lack of persistence discussed above) nor developed the height reported for this species in the mid-west USA locations. This suggests that low phytomer and tiller mass and possibly low reproductive tiller numbers were limiting biomass production in these southern-adapted cultivars.

3.4. Cellulose Concentration. Cellulose concentration was highest for Dacotah at Swift Current and for ND 3742 switchgrass at Brandon ($P < 0.05$) (Table 5). Cave-in-Rock exhibited the lowest cellulose concentration at both locations ($P < 0.05$). There was no significant difference among the switchgrass cultivars for hemicellulose concentration at Swift Current ($P > 0.05$). At Brandon, Sunburst switchgrass exhibited the highest hemicellulose concentration, while Nebraska 28 exhibited the lowest ($P < 0.05$). Dacotah and ND 3743 contained the highest neutral detergent fiber (NDF) concentrations at both sites while Cave-in-Rock had the lowest ($P < 0.05$) (Table 6). The NDF concentration is a prediction of forage intake by ruminants [27], so these results suggest that northern-adapted switchgrass cultivars would be consumed less by beef cattle than southern-adapted cultivars.

Cave-in-Rock switchgrass exhibited the highest organic matter digestibility (OMD) while Dacotah switchgrass had the lowest OMD at both locations ($P < 0.05$) (Table 6). As well, Cave-in-Rock switchgrass was the highest in N concentration at both sites ($P < 0.05$). Dacotah switchgrass meanwhile had the lowest N concentration at Swift Current, while Dacotah and ND 3743 had the lowest N concentrations at Brandon ($P < 0.05$). There was no significant difference in P concentration among switchgrass cultivars at Swift Current ($P > 0.05$). At Brandon, highest P concentration was found in Cave-in-Rock switchgrass, whereas the lowest P concentration was in Dacotah and ND 3743 ($P < 0.05$). All the observed P concentrations were greater than the 1.0 g kg^{-1} required for beef cattle diets [28]. Furthermore, Dacotah and ND 3743 exhibited the highest Ca concentrations (Table 5), while either Cave-in-Rock (Swift Current) or Sunburst (Brandon) had the lowest ($P < 0.05$). Only Dacotah and ND 3743 exhibited sufficient Ca concentration to satisfy the requirement of beef cattle at a minimum of 6.0 g kg^{-1} level [28]. Forage from all other switchgrass cultivars would require mineral supplementation to avoid Ca deficiency.

3.5. Relationship to Latitude. Variation in latitude of origin was positively correlated with stand density and cellulose concentration but negatively correlated with OMD digestibility and N concentration. Correlation between latitude of origin and biomass production, P concentration, or Ca concentration depended on the location. The correlation between latitude of origin and plant density in 1996 differed between Brandon and Swift Current (Figure 1). Several cultivars that exhibited mediocre stand density at Brandon did not persist at Swift Current. A generally linear relationship of switchgrass yield with latitude was found in south central US environments [2]. Cultivars from higher latitude of origin in USA, such as Dacotah and ND 3743 had greater plant density, cellulose, and Ca concentrations, but lower OMD, N, and P concentrations than cultivars from southern latitudes. This suggests that plant breeders will need to select switchgrass cultivars for adaptation at northern latitudes to improve feed-stock availability for ligno-cellulosic production and conversion to biofuels. Similarly, other studies concluded that regional cultivars of switchgrass, rather than broadly adapted cultivars, will

Table 3: Stand density (%) of ten switchgrass cultivars at Swift Current, SK and Brandon, MB, Canada.

Cultivar	Swift Current					Brandon	
	Dryland		Irrigation				
	1994	1995	1993	1994	1996	1995	1996
Blackwell	13	0	5	0	3	20	29
Cave-in-Rock	42	0	41	0	1	27	10
Dacotah	59	51	43	81	89	99	100
Forestburg	36	15	43	57	44	99	89
Nebraska 28	49	14	32	55	15	99	91
Pathfinder	41	0	48	0	1	57	49
Summer	51	2	48	12	1	96	86
Sunburst	45	1	33	37	23	87	82
ND 3743	53	56	40	69	58	100	94
Trailblazer	40	1	32	0	1	37	27
$LSD_{0.05}$	16	20	15	19	18	25	10

Table 4: Mean biomass production of ten switchgrass cultivars grown at Swift Current-irrigated, SK and at Brandon, MB, Canada.

Cultivar^	Swift Current			Brandon	
	1994	1995	1996	1995	1996
	Mg ha^{-1}				
Blackwell	0.03	0.68	1.19	1.42	0.21
Cave-in-Rock	0.03	0.37	0.07	0.96	0.07
Dacotah	1.19	7.63	9.41	3.53	0.98
Forestburg	0.88	9.22	3.95	4.12	0.89
Nebraska 28	0.80	9.45	0.91	3.67	0.52
Pathfinder	0.04	0.55	0.27	2.55	0.52
Summer	0.13	1.28	0.12	3.73	0.85
Sunburst	0.35	4.71	1.03	3.81	1.14
ND 3743	0.50	5.38	2.79	3.09	0.89
Trailblazer	0.00	0.30	0.17	1.04	0.23
$LSD_{0.05}$	0.36	1.26	2.40	1.50	0.36

^Mean values were backtransformed to the original data scale after analysis of variance on $\log_{10}$ transformed values. Probability of the cultivar effect was determined from transformed data analysis of variance. LSD values were calculated from analysis of variance error term of original scale data.

Table 5: Mean cellulose and hemicellulose concentration of ten switchgrass cultivars grown at Swift Current, SK and at Brandon, MB, Canada.

Cultivar	Cellulose		Hemicellulose	
	Swift Current	Brandon	Swift Current	Brandon
	g kg^{-1}			
Blackwell	282	288	288	266
Cave-in-Rock	249	283	285	266
Dacotah	312	330	293	275
Forestburg	306	298	300	296
Nebraska 28	307	294	300	262
Pathfinder	274	290	284	274
Summer	285	311	301	288
Sunburst	293	313	302	302
ND 3743	306	342	289	291
Trailblazer	—	285	—	270
$LSD_{0.05}$	10	12	ns	16

ns: not significant at $P = 0.05$.

Table 6: Mean organic matter digestibility (OMD), neutral detergent fiber (NDF), N, P, and Ca concentration of ten switchgrass cultivars grown at Swift Current, SK and at Brandon, MB, Canada.

Cultivar	OMD		N		P		NDF		Ca	
	Swift Current	Brandon	Swift Current	Brandon	Swift Current	Brandon	Swift Current	Brandon	Swift Current	Brandon
	$g\ kg^{-1}$									
Blackwell	579	549	18	11	2.3	2.3	588	559	4.55	5.27
Cave-in-Rock	612	563	21	13	2.2	2.6	537	551	3.74	5.49
Dacotah	521	443	12	6	2.7	1.5	629	612	6.05	7.05
Forestburg	524	503	15	8	2.4	1.9	621	602	4.62	5.64
Nebraska 28	527	507	15	8	2.5	1.9	624	558	4.26	5.93
Pathfinder	590	534	21	10	2.7	2.1	579	565	4.38	5.40
Summer	562	499	17	8	2.4	2.0	592	603	4.30	5.93
Sunburst	546	490	16	7	2.2	1.6	612	621	3.97	4.60
ND 3743	537	446	14	6	2.6	1.5	616	647	6.13	6.22
Trailblazer	—	560	—	12	—	2.5	—	557	5.42	5.73
$LSD_{0.05}$	13	24	1	1	ns	0.4	13	14	0.43	0.73

ns: not significant at $P = 0.05$.

Table 7: Pearson correlation coefficients for mean values of traits of 10 switchgrass cultivars at Brandon, MB (above the diagonal) and at Swift Current, SK (below the diagonal), Canada.

Trait	Latitude	Stand	Yield	Cellulose	Hemicellulose	OMD	N	P	Ca
Latitude	—	0.83**	0.78**	0.89**	0.57	−0.92**	−0.88**	−0.88**	0.52
Stand	0.83**	—	0.89**	0.75**	0.56	−0.90**	−0.97**	−0.91**	0.43
Yield	0.60	0.93**	—	0.77**	0.82**	−0.86**	−0.92**	−0.91**	0.17
Cellulose	0.80**	0.73*	0.63*	—	0.55	−0.96**	−0.87**	−0.88**	0.51
Hemicellulose	0.30	0.13	0.07	0.56	—	−0.53	−0.60	−0.60	−0.22
OMD	−0.80**	−0.73*	−0.63*	−0.98**	−0.66*	—	0.96**	0.96**	−0.55
N	−0.82**	−0.84**	−0.75**	−0.93**	−0.53	0.94**	—	0.98**	−0.34
P	0.53	0.50	0.50	0.47	−0.24	−0.36	−0.34	—	−0.34
Ca	0.78**	0.85**	0.76**	0.64*	−0.15	−0.56	−0.70*	0.69*	—

*, **correlation coefficient is significant at $P < 0.05$ and $P < 0.01$, respectively.

be needed for biomass production for biofuel conversion [22]. However, if switchgrass cultivars are required for grazing, then improved forage quality could be selected by incorporating genetic sources from southern latitudes that will have later maturity and higher forage quality. Our results support others' conclusions [22, 24] that latitude of origin influences switchgrass longevity and cellulose concentration and this effect of latitude is more important at the limits of a cultivar's adaptation. Swift Current and Brandon represent the most northern environments where some of these switchgrass cultivars have been tested.

Variation in stand density among the cultivars was positively correlated with biomass production, cellulose concentration, and Ca concentration but negatively correlated with OMD and N concentrations (Table 7). Dacotah and ND 3743 switchgrasses were more persistent and exhibited the highest cellulose concentrations but had the lowest OMD and N concentrations ($P < 0.05$). Blackwell, Cave-in-Rock, and Trailblazer switchgrass were less persistent and had the lowest cellulose concentrations and the highest OMD and N concentrations ($P < 0.05$). Cellulose concentration was correlated with latitude of cultivar origin similarly at Swift Current and Brandon (Figure 2).

Biomass production was correlated with cellulose (Table 7). Biomass production was greater in earlier maturing, northern-adapted cultivars such as Dacotah and ND 3743. As others have stated, biomass production is correlated with a larger proportion reproductive tillers that have large and numerous phytomers [22, 26]. In the present study, southern-adapted cultivars tended to remain vegetative in the two study sites due to the shorter growing season.

As expected, cellulose concentration was negatively correlated with OMD, N, and Ca concentrations, but at Swift Current only (Table 7). Hemicellulose concentration was also negatively correlated with OMD concentration at Swift Current. Meanwhile, OMD was positively correlated with cultivar differences in N concentration (Table 7). Nitrogen concentration was positively correlated with P concentration at Brandon as has been reported for other grasses such as timothy (*Phleum pratense* L.) [29]. The relationship between latitude of origin and OMD digestibility differed between Brandon and Swift Current (Figure 3). Finally, the current

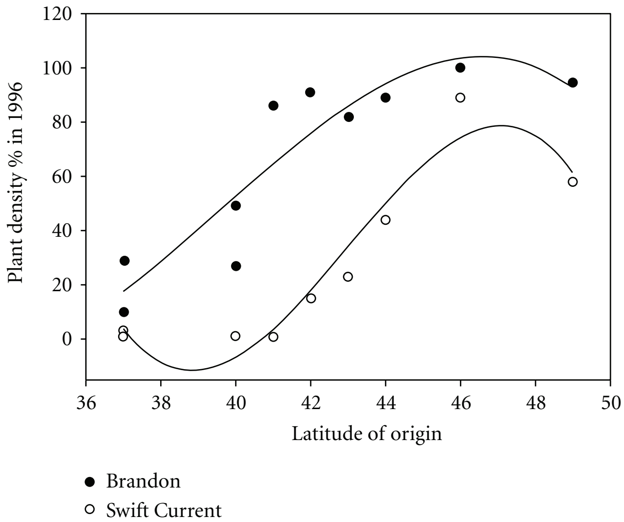

Figure 1: Effect of latitude of origin for 10 switchgrass cultivars on plant density in 1996 at two locations in the southern prairie region of western Canada. The cubic regressions are significant at Brandon ($P < 0.01$, $R^2 = 0.76$) and at Swift Current ($P < 0.001$, $R^2 = 0.90$).

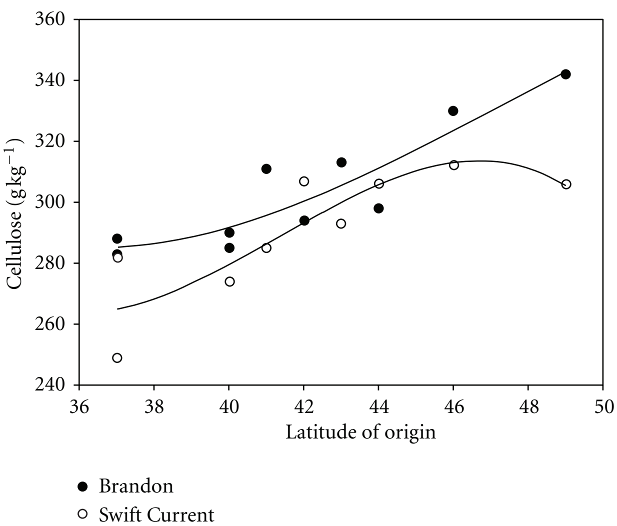

Figure 2: Effect of latitude of origin for 10 switchgrass cultivars on mean cellulose concentration at two locations in the southern prairie region of western Canada. The cubic regressions are significant at Brandon, MB, ($P < 0.01$, $R^2 = 0.75$) and nearly significant at Swift Current, SK, ($P < 0.06$, $R^2 = 0.61$), Canada. Y, g kg^{-1} = 334.3 − 3.61X.

study indicated that Dacotah and ND 3743 switchgrasses were more mature and lower in OMD at Brandon than at Swift Current.

The regression results in Figures 1–3 indicate that different responses were evident at Swift Current and Brandon despite their similarity in latitude (50° 16′ versus 49° 50′, resp.). However, elevation also contributes to climatic conditions and Swift Current is 416 m higher than Brandon. If the correlation to latitude is adjusted to account for the elevational difference between the two testing sites, then site differences are removed and one regression equation can explain the results from both sites (data not shown).

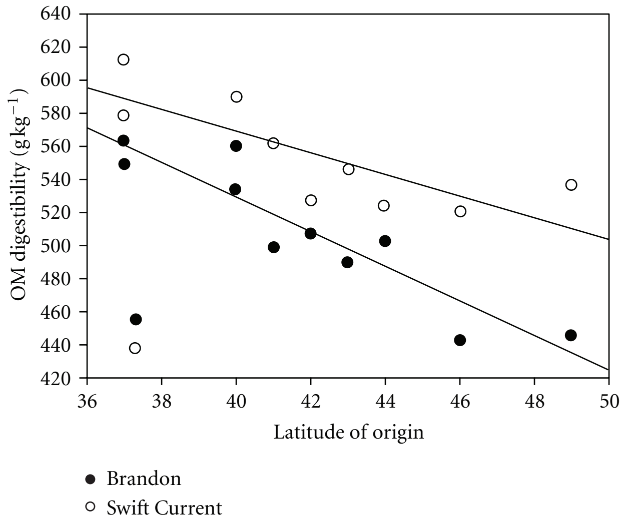

Figure 3: Effect of latitude of origin for 10 switchgrass cultivars on organic matter digestibility (OMD) concentration at two locations in the southern prairie region of western Canada. The linear regressions are significant at Brandon, MB, ($P < 0.001$, $R^2 = 0.83$) and at Swift Current, SK, ($P < 0.001$, $R^2 = 0.83$), Canada. Y, g kg^{-1} = 437.6 + 7.8X.

4. Conclusions

Switchgrass cultivation will be more successful in Manitoba and possibly southeastern Saskatchewan which border on the tallgrass prairie. Further west in the mixed grass prairie region typified by Swift Current, switchgrass productivity will be limited by winter temperatures. There may be a longitudinal adaptation required for successful cultivation of this species in the mixed prairie region but as the current study revealed it is highly related to latitudinal adaptation. Only switchgrass cultivars from northern latitudes in USA possess sufficient hardiness to be successfully cultivated on the southern Canadian prairies. Sustainable Canadian switchgrass biomass production will require the development of cultivars adapted to Canadian conditions that would exhibit superior stand longevity such as that exhibited by northern-adapted cultivars in North Dakota. Cellulose concentration for switchgrass biomass conversion to ethanol was highest in the most northern-adapted cultivars likely because they had progressed further in phenological development. Cellulose production per hectare will be a function of both yield and cellulose concentration, so plant breeding to develop Canadian cultivars for energy production should focus on earlier maturity germplasm. The higher OMD observed for cultivars from southern latitudes (Figure 3) indicated that plant breeding for a potential grazing cultivar of switchgrass would favour the use of germplasm from southern-adapted cultivars.

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