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Harvest and Nitrogen Management of Three Perennial Grasses as Biomass Feedstock in Subarctic Alaska

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ABSTRACT. High energy costs in high-latitude regions have generated interest in the feasibility of bioenergy cropping. The goal of this study was to determine the nitrogen (N) response and best harvest regime for biomass production of three perennial, cool-season grass species—tufted hairgrass (*Deschampsia caespitosa* (L.) P. Beauv.), slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners), and smooth bromegrass (*Bromus inermis* Leyss)—at two locations in central Alaska. Maximum dry matter yields were 11.3 Mg ha^{-1} for smooth bromegrass, 8.1 Mg ha^{-1} for tufted hairgrass, and 8.0 Mg ha^{-1} for slender wheatgrass, but yields varied greatly among years. We found a linear N response in most cases, with highest yields at the 100 kg N ha^{-1} application rate. Yields for the double-harvest regime usually did not vary significantly from those of the fall harvest, but spring harvest sometimes reduced yields dramatically. Biomass in the spring harvest was usually dry enough not to require additional drying for storage. Results of this study indicate it may be possible to produce grass biomass yields high enough for use as bioenergy feedstocks in central Alaska, but questions remain about the best management practices and the economics of growing bioenergy crops in Alaska.

Key words: biomass energy, harvest timing, nitrogen application rate, smooth bromegrass, tufted hairgrass, slender wheatgrass

RÉSUMÉ. Les coûts élevés de l’énergie en haute latitude incitent les gens à se pencher sur la faisabilité d’entreprendre des cultures bioénergétiques. L’objectif de cette étude consistait à déterminer la réponse à l’azote et le meilleur régime d’exploitation pour la bioproduction de trois espèces de graminées vivaces en saison fraîche, soit la deschampsie cespiteuse (*Deschampsia caespitosa* (L.) P. Beauv.), l’élyme à chaumes rudes (*Elymus trachycaulus* (Link) Gould ex Shinners) et le brome inerme (*Bromus inermis* Leyss), à deux endroits du centre de l’Alaska. Le rendement maximum de matière sèche était de 11,3 tm ha^{-1} dans le cas du brome inerme, de 8,1 tm ha^{-1} dans le cas de la deschampsie cespiteuse et de 8,0 tm ha^{-1} dans le cas de l’élyme à chaumes rudes, bien que les rendements aient connu d’importantes variations d’une année à l’autre. Nous avons trouvé une réponse linéaire à l’azote dans la plupart des cas, les rendements les plus élevés étant ceux de la dose d’application de 100 kg N ha^{-1}. Le rendement du régime à double récolte ne variait généralement pas beaucoup du régime à récolte d’automne, bien que les récoltes du printemps donnaient parfois un rendement considérablement réduit. De manière générale, la biomasse de la récolte du printemps était suffisamment sèche pour ne pas avoir besoin d’être asséchée davantage avant d’être stockée. Les résultats de cette étude indiquent qu’il peut être possible de produire des rendements en biomasse suffisamment élevés à partir de graminées pour être utilisés comme charge bioénergétique dans le centre de l’Alaska, mais cela dit, il y a toujours lieu de répondre aux questions portant sur les pratiques de gestion exemplaires et le caractère économique des productions bioénergétiques en Alaska.

Mots clés : bioénergie, calendrier des récoltes, dose d’application de l’azote, brome inerme, deschampsie cespiteuse, élyme à chaumes rudes

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INTRODUCTION

Perennial bioenergy crops, if managed properly, can provide a renewable source of energy and may sequester carbon into the environment (Scharlemann and Laurance, 2008; Tilman et al., 2009; Georgescu et al., 2011). They may also provide cheaper energy than is currently available in regions where fossil fuels are expensive. Energy crops have been little studied in subarctic North America, but because of the extremely high price of petroleum fuels in Alaska and northern Canada, especially in remote communities (ADCCED, 2013; McDonald and Pearce, 2013), there is interest in use of bioenergy, including lignocellulosic biomass. Much of the research on perennial grasses for use as bioenergy crops has been on warm-season (C4) species, some of which have very high biomass and energy-yield potential (Lewandowski et al., 2003b; Heaton et al., 2004; Haque et al., 2009). These species are typically not adapted

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to high-latitude environments; however, work done with a few C3 species in northern areas of Europe and the United States indicates high biomass yield potential for these crops when they are managed as bioenergy crops under favorable conditions (Landström et al., 1996; Lewandsowksi et al., 2003b; Kryževičienė, 2006; Lehtomäki et al., 2008; Sanderson and Adler, 2008). Important questions about yield potential, appropriate plant species, economic feasibility, and best management regimes must be answered before decisions can be made on whether to grow energy crops in subarctic regions. Research on use of various native and non-native grasses and woody species as potential biomass crops is currently underway in central Alaska. This paper focuses on harvest and nitrogen fertilizer management for grass biomass production in central Alaska.

Forage crop producers in Alaska usually make two harvests each year, one in late June or early July and another in August or early September. A recent study (Sparrow and Masiak, 2008) showed that delaying the fall harvest of smooth bromegrass (*Bromus inermis* Leyss) improves subsequent-year yields. However, late autumn weather, with poor drying conditions and high probability of snow, limits the window for harvest and field drying of hay crops during that period. Studies in other regions have shown that delaying grass biomass harvest until spring of the next growing season results in decreased in-field moisture and improves the quality of the crop for bioenergy purposes, but sometimes it also results in large yield losses (Landström et al., 1996; Adler et al., 2006).

Soil nitrogen is often a major limiting factor for growth of crops, but nitrogen fertilizer is expensive in Alaska. Thus, proper fertilizer management is critical. Current fertilizer recommendations for grass forage crops in Alaska call for 120 to 150 kg N ha^{-1} depending on location, grass species, and yield goal (Jahns, 2009). One goal of bioenergy cropping is to reduce inputs, especially those requiring energy (Downing et al., 1995; Heaton et al., 2004), such as synthetic fertilizers.

The purpose of this study was to determine the most efficient N level and harvest time for biomass production of three perennial, cool-season grass species: tufted hairgrass (*Deschampsia caespitosa* (L.) P. Beauv.), slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners), and smooth bromegrass. Tufted hairgrass and slender wheatgrass are both indigenous to most of Alaska and northern Canada; smooth bromegrass is an introduced, long-lived, forage grass commonly used in the region.

METHODS

Sites and Experimental Design

This experiment was conducted at the University of Alaska Fairbanks Experiment Farm (64˚49′ N, 147˚52′ W) in Fairbanks, Alaska, and the Delta Junction Field Research Site (64˚00′ N, 145˚43′ W) near Delta Junction, Alaska. At both locations, the experiment was carried out over three harvest years (a harvest year is defined as a growing season plus the spring harvest in the following calendar year), from the 2008 growing season through spring 2011 at Fairbanks and from the 2009 growing season through spring 2012 at Delta Junction. Experiments at both locations were performed on stands established in 2005 and originally used for other studies, so the plots were not laid out as a complete factorial experiment. We therefore analyzed each species separately. At Fairbanks, all grasses were grown on Tanana silt loam (classified under the U.S. soil taxonomy system as coarse-loamy, mixed, superactive, subgelic Typic Aquiturbels). At Delta Junction, all plots were located on soils mapped as Volkmar silt loam (coarse-silty over sandy or sandy-skeletal, mixed, superactive Aquic Haplocryepts), but the smooth bromegrass plots were located about 1.5 km from the other plots in an area made slightly wetter by capture of drifting snow in winter. Within each species, plots were laid out in a randomized complete block design with four replications. All plots received annual applications of ammonium phosphate at 22 kg P ha^{-1} and potassium sulfate at 41 kg K ha^{-1}.

Nitrogen and Harvest Treatments

Each plot received an annual nitrogen treatment at one of three application rates (10, 50, and 100 kg N ha^{-1}). Treatments were applied as ammonium phosphate and urea in the spring of each year. Harvest treatments consisted of a double harvest regime, a single fall harvest, and a spring harvest (plots harvested in spring of the year subsequent to growth). For the double-harvest regime, the midsummer harvest was done in early to mid-July, when the grasses were fully headed. The fall harvests for both single and double regimes took place in mid-September. Spring harvests were made in early May, as soon as the soil was dry enough so that wheel traffic would not cause serious compaction and before the plants began spring growth. In central Alaska, snow is typically gone and soils are dry enough for traffic by early May, although unusually late winter-like weather can delay field operations until mid to late May. Harvest was done with a flail mower set to cut at a 10 cm height. At Fairbanks in fall 2009, some of the smooth bromegrass plots were harvested by hand clipping from 1 m^2 areas because the harvester malfunctioned. Separate samples were hand-harvested for ash analysis because of possible soil contamination produced with the machine-harvested samples. Samples were weighed immediately upon harvest and then subsampled for determination of water content. Samples were dried at 60˚C for water content determination, and ash was determined following heating in a muffle furnace at 550˚C for 7 hours.

Statistical Analysis

Repeated measures ANOVA was used to determine the effects of harvest time and N rate on yields across years.

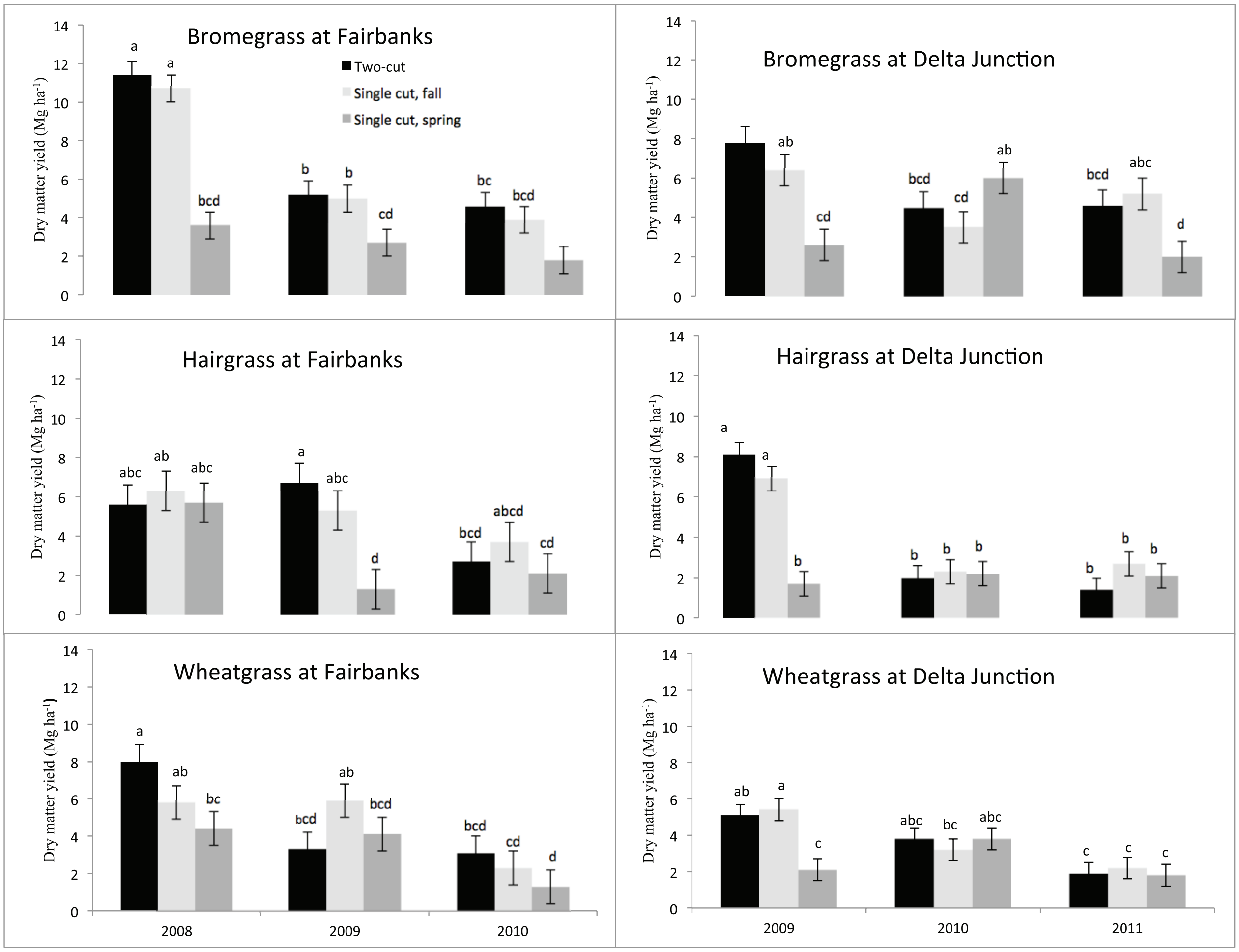

FIG. 1. Dry matter yields for smooth bromegrass, tufted hairgrass, and slender wheatgrass as affected by harvest management regime at two locations in central Alaska. Vertical lines represent standard errors. Means with the same letter within a grass species and location are not significantly different (Tukey's HSD pairwise comparison test).

Each location was analyzed separately. When significant ($p < 0.05$) harvest treatment effects were found, we used Tukey's HSD test to compare means. When ANOVA indicated significant N rate effects, we used polynomial contrasts to determine whether the effects were linear or non-linear.

RESULTS

Harvest Date

We found a significant harvest date × year interaction for yield of each grass species at each location. Dry matter (DM) yields generally decreased at both locations from the first year to the last year of the study (Fig. 1), although differences between some years were not significant. For all of the grasses, little regrowth followed the midsummer harvest. Smooth bromegrass DM yields at Fairbanks ranged from 1.9 Mg ha^{-1} for the spring harvest in year three to 11.3 Mg ha^{-1} for the double-harvest treatment in year one, while at Delta Junction they ranged from 2.0 Mg ha^{-1} for the spring harvest in year three to 7.8 Mg ha^{-1} for the double-harvest treatment in year one. Smooth bromegrass DM yields were never significantly different between the double-harvest treatment and the single fall harvest; however, yields for the spring harvest were significantly and sometimes drastically lower than the single fall harvest, except in 2010 (Fig. 1). For tufted hairgrass, dry matter yields at Fairbanks ranged from 1.3 Mg ha^{-1} for the spring harvest in year two to 6.7 Mg ha^{-1} for the double-harvest treatment in year two, while at Delta Junction they ranged from 1.4 Mg ha^{-1} for the double-harvest treatment in year three to 8.1 Mg ha^{-1} for the double-harvest treatment in year one. Yields among harvest treatments within a harvest year did not differ significantly except at Fairbanks in year two and at Delta junction in year one, when the spring harvest produced much lower yields than the other two harvest treatments (Fig. 1). Slender wheatgrass DM yields at Fairbanks ranged from 1.3 Mg ha^{-1} for the spring harvest in year three to 8.0 Mg ha^{-1} for the double harvest treatment in year one, while at Delta Junction yields ranged from 1.8 Mg ha^{-1} for the spring harvest in year three to 5.4 Mg ha^{-1} for the single fall harvest in year one. At Fairbanks, the spring harvest of wheatgrass tended to produce lower yields than the other harvests, although differences from the single fall harvest were never significant. At Delta

TABLE 1. Tissue water content (g kg^{-1}) for three grasses under three harvest regimes at Fairbanks and Delta Junction, Alaska. Means with the same letter within a grass species and location are not significantly different (Tukey's HSD pairwise comparison test).

	Fairbanks			Delta Junction		
Harvest treatment	Smooth bromegrass	Tufted hairgrass	Slender wheatgrass	Smooth bromegrass	Tufted hairgrass	Slender wheatgrass
Double harvest, summer	651a	635a	627a	697a	675a	665a
Double harvest, fall	622b	626a	596a	577b	523b	415b
Single harvest, fall	548c	602a	398b	408c	505b	345c
Single harvest, spring	121d	176b	83c	122d	159c	131d
Standard error	7	26	12	15	14	17
Probability (*p*)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

TABLE 2. Grass tissue ash concentrations (g kg^{-1}) for three grasses under three harvest regimes at Fairbanks and Delta Junction, Alaska. Means with the same letter within a grass species and location are not significantly different (Tukey's HSD pairwise comparison test).

	Fairbanks			Delta Junction		
Harvest treatment	Smooth bromegrass	Tufted hairgrass	Slender wheatgrass	Smooth bromegrass	Tufted hairgrass	Slender wheatgrass
Double-harvest, summer	68.7a	72.9ab	53.4b	48.7b	69.2ab	60.5b
Double-harvest, fall	74.8a	82.0a	96.1a	85.7a	74.8a	91.6a
Single-harvest, fall	66.3a	65.8b	61.1b	39.6c	55.2b	49.5b
Single-harvest, spring	71.4a	70.0ab	62.5b	36.1c	74.1a	55.5b
Standard error	2.4	3.0	3.7	1.3	3.9	4.9
Probability (*p*)	0.122	0.017	< 0.001	< 0.001	0.012	< 0.001

Junction, yields for wheatgrass did not differ among harvest treatments except that the spring harvest produced much lower yields than the other two harvest treatments in year one.

Tissue water content showed similar trends for all three grasses at both locations. The highest water content occurred at the mid-summer harvest and decreased in all subsequent harvests, with a dramatic decrease from the fall harvest to the spring harvest (Table 1). Although we sometimes found significant year × harvest treatment interactions, the trends in all years at both locations were similar, so we presented only the harvest treatment main effect.

Ash concentration did not vary significantly among harvest treatments for smooth bromegrass at Fairbanks, but significant effects of harvest time on tissue ash were found for smooth bromegrass at Delta Junction and for other grasses at both locations (Table 2). In general, highest ash concentrations were in the double harvest fall treatment. Ash concentrations did not decrease from the single fall harvest to the spring harvest as expected but rather ash concentration increased significantly in year one in hairgrass at Delta Junction (the only case with a significant harvest treatment × year interaction).

Nitrogen Rate

All three grasses responded with yield increases as the N application rate increased (Fig. 2). While we found a significant linear response for all grasses at both sites, we found a significant non-linear response only for smooth bromegrass at Fairbanks. For tufted hairgrass at both locations, increasing the N application rate resulted in significant increases in tissue water content. At Fairbanks, the water content in hairgrass increased from 542 g kg^{-1} at the low N rate to 611 g kg^{-1} at the high N rate, while at Delta Junction, water content was 408 g kg^{-1} at the low N rate compared to 508 g kg^{-1} at the high N rate. We found the opposite response for smooth bromegrass at Delta Junction, with the water content decreasing from 476 g kg^{-1} at the low N application rate to 410 g kg^{-1} at the high N rate. Ash concentration in tissue tended to decrease with increasing N rate in smooth bromegrass and tufted hairgrass at both locations (Table 3).

DISCUSSION

The 2008 growing season (1st year of the study at Fairbanks) was much wetter than both the 2009 and 2010 growing seasons (Table 4) and the long-term average, which may help explain the high yields in 2008. However, the high-yielding 2009 growing season at Delta Junction was slightly drier than the long-term average. Growing season temperatures for all years at both locations were slightly warmer than the long-term average except for the 2008 growing season at Fairbanks, which experienced near normal temperatures. These were fairly old stands, and we noticed substantial stand deterioration during the course of the study, especially for the indigenous species. Thus, the stands may have lost yield potential as a result of aging during the course of the study.

Our results indicate a potential for fairly high yields for these grasses and compare favorably to yields reported for cool-season grasses in other regions (Landström et al., 1996; Kryževičienė, 2006; Lehtomäki et al, 2008). However, the large interannual variation in yields is troubling and indicates we need to improve our understanding of yield determinants.

These results indicate little or no total annual yield advantage to harvesting twice during a growing season versus harvesting once in the fall. Conditions in Alaska in fall

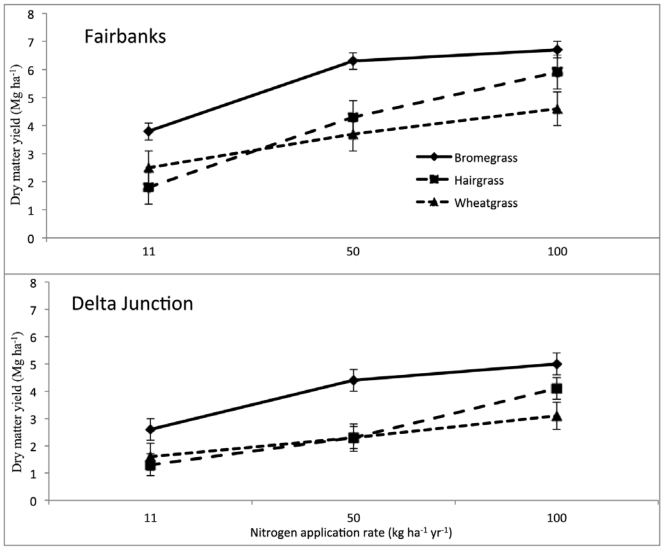

FIG. 2. Dry matter yield as affected by nitrogen application rate for smooth bromegrass, tufted hairgrass, and slender wheatgrass at two locations in central Alaska. Vertical lines represent standard errors.

are usually not conducive to field drying as the weather is usually cool and often rainy, while mid-summer weather is more likely to allow field drying. High water content decreases the value of biomass because it decreases heating efficiency and increases costs of drying and hauling (Lewandowski and Kicherer, 1997; Zethræus, 1999). Field drying would provide an advantage in terms of reduced costs. Yields for grasses allowed to stay in the field and harvested in spring were not always lower than fall harvested biomass, but generally, when the total biomass was high, we found a rather dramatic decrease in yield (Fig. 1). In some cases, well over half of the biomass was lost from the single fall harvest to the spring harvest. Other studies (Landström et al., 1996; Lewandowski et al., 2003a; Adler et al., 2006) have also reported rather large decreases in harvestable yield for over-wintered grasses, but not as dramatic as those we found in some years. Yield decreases have been attributed to loss of leaf material and to lodging of biomass (resulting in inability of harvest equipment to recover it) (Lewandowski et al., 2003a; Adler et al., 2006). Adler et al. (2006) reported larger losses in heavy snow years in Pennsylvania. In our study, total seasonal snowfall was near average in all years of the study. We did not determine leaf-to-stem ratios in this study, but we did note large amounts of lodged biomass, especially when fall yields were high. In a few cases, we hand-harvested the biomass remaining after machine harvesting in spring and indeed found that a large proportion (sometimes more than one-half) of the biomass remained (data not shown). Spring-harvested biomass always contained significantly less water than biomass harvested the previous fall. Grass water content should be 180 – 220 g kg^{-1} for good storage without loss of quality (Henning and Wheaton, 1993; Wilcke et al., 1999) and below about 230 g kg^{-1} for good combustion quality (Zethræus, 1999). Water content greater than about 200 g kg^{-1} can interfere with milling (Miao et al., 2011). All of the grasses had water content well above this level for the fall harvest, but had reached safe water content by the time of the spring harvest. Similar results were reported in northern Sweden (Landström et al., 1996). Thus, if the problem with large loss of yield could be solved, harvesting in spring would have the advantage of reducing drying costs.

Tissue ash concentrations were fairly high but within the range reported by other authors for cool-season grasses (e.g., Landström et al., 1996; Burvall, 1997; Lewandowski et al., 2003b; Dien et al., 2006). While it is difficult to define a critical value for ash in biomass, high ash concentrations cause lower heating efficiency for direct combustion, higher operating costs due to problems with slagging and fouling of the combustion chamber (Lewandowski and Kicherer, 1997), and increased air pollution (Launhardt and Thoma, 2000). Surprisingly, we found no dramatic decrease in ash concentration from fall harvest to spring harvest as reported by numerous other authors (Landström et al., 1996; Burvall, 1997; Lewandowski et al., 2003a; Adler et al., 2006). This loss has been attributed to loss of leaves, which tend to be higher in ash than stems (Landström et al., 1996; Lewandowski and Kicherer, 1997), and to leaching losses over winter, especially in wet climates. Since central Alaska has cold, dry winters and little rainfall in spring, there is little opportunity for leaching losses from tissues over winter. The lack of loss of ash also indicates little leaf loss in our grasses. At Delta Junction, the increase in ash in some grasses in spring compared to fall harvest for the first harvest year was probably due to blowing dust becoming trapped on the grass. The Delta Junction area experiences strong winter and early-spring winds, and the plots were near a fallow field that served as a source of blowing soil.

While three N application rates are not enough to establish a good N rate response curve, the fact that we found

TABLE 3. Grass tissue ash concentrations (g kg^{-1}) for three grasses under three nitrogen application rates at Fairbanks and Delta Junction, Alaska.

	Fairbanks			Delta Junction		
Nitrogen application	Smooth bromegrass	Tufted hairgrass	Slender wheatgrass	Smooth bromegrass	Tufted hairgrass	Slender wheatgrass
10 kg ha^{-1}	91.4	84.1	73.3	59.7	76.1	64.4
50 kg ha^{-1}	71.9	76.4	65.2	38.4	59.8	52.0
100 kg ha^{-1}	62.0	65.2	61.0	34.3	54.9	47.0
Standard error	4.7	3.5	4.8	2.1	2.8	5.2
Probability (p)	< 0.001	0.013	0.241	< 0.001	0.001	0.101

TABLE 4. Monthly growing season temperatures (˚C) and precipitation (mm) at Fairbanks and Delta Junction, Alaska, during the study period.

Fairbanks growing season temperatures

Month	2008 Monthly temperature	2008 Departure from long-term mean	2009 Monthly temperature	2009 Departure from long-term mean	2010 Monthly temperature	2010 Departure from long-term mean	Long-term mean monthly temperature
Apr	−1.1	−0.4	0.6	1.3	4.4	5.1	−0.7
May	10.0	0.8	11.1	1.9	12.2	3.0	9.2
Jun	15.6	0.2	15.6	0.2	15.6	0.2	15.4
Jul	16.1	−0.8	19.4	2.5	17.2	0.3	16.9
Aug	12.8	−1.0	12.8	−1.0	15.6	1.8	13.8
Sep	8.3	0.8	9.4	1.9	8.3	0.8	7.5

Fairbanks growing season precipitation

Month	2008 Monthly temperature	2008 Departure from long-term mean	2009 Monthly temperature	2009 Departure from long-term mean	2010 Monthly temperature	2010 Departure from long-term mean	Long-term mean monthly temperature
Apr	32	24	2	−6	7	−1	8
May	13	−2	2	−13	6	−9	15
Jun	53	17	39	3	34	−2	36
Jul	105	57	1	−47	79	31	48
Aug	68	17	68	17	37	−14	51
Sep	15	−8	14	−9	30	7	23
Total	286	105	126	−55	193	12	181

Delta Junction growing season temperatures

Month	2008 Monthly temperature	2008 Departure from long-term mean	2009 Monthly temperature	2009 Departure from long-term mean	2010 Monthly temperature	2010 Departure from long-term mean	Long-term mean monthly temperature
Apr	0.6	1.5	2.2	3.1	0.6	1.5	−0.9
May	9.4	1.2	10.6	2.4	10.0	1.8	8.2
Jun	13.3	−0.5	13.3	−0.5	13.9	0.1	13.8
Jul	18.3	2.6	15.6	−0.1	14.4	−1.3	15.7
Aug	11.7	−1.3	14.4	1.4	11.7	−1.3	13.0
Sep	7.8	0.9	6.7	−0.2	8.9	2.0	6.9

Delta Junction growing season precipitation

Month	2008 Monthly temperature	2008 Departure from long-term mean	2009 Monthly temperature	2009 Departure from long-term mean	2010 Monthly temperature	2010 Departure from long-term mean	Long-term mean monthly temperature
Apr	3	−5	17	9	4	−4	8
May	45	22	21	−2	4	−19	23
Jun	54	−12	94	28	53	−13	66
Jul	25	−44	45	−24	73	4	69
Aug	49	1	30	−18	36	−12	48
Sep	15	−13	31	3	7	−21	28
Total	191	−51	238	−4	177	−65	242

strong linear trends but usually non-significant non-linear responses of dry matter yield to N rate indicates that we had not reached near the maximum potential N response. We would expect decreasing response to N as the N rate approached the rate needed for maximum response (Troeh and Thompson, 1993). Most of the research on yield response to N in dedicated bioenergy grass crops has been done with warm-season grasses, and results have been highly variable, with some authors reporting no response and others reporting positive yield responses up to ~ 200 kg N ha^{-1} (Wullschleger et al., 2010). Cool-season grasses also may respond to high rates of N, even in high-latitude environments. For example, Landström et al. (1996) found that reed canarygrass yields in northern Sweden were considerably higher when 200 kg N ha^{-1} was applied compared to 100 kg N ha^{-1}.

We found that the N rate did not significantly affect the tissue water content for fall-harvested slender wheatgrass at either location, whereas increasing the N rate from 10 kg ha^{-1} to 100 kg ha^{-1} for tufted hairgrass resulted in water content increase of about 12% at Fairbanks and almost 20% at Delta Junction (data not shown). This finding may indicate delayed maturity under the higher N rates. Interestingly, smooth bromegrass at Fairbanks showed a decrease in tissue water content with increasing N rate. It is not clear why this response occurred. As expected, tissue ash concentrations decreased with increasing N rate, although the effect was not significant for wheatgrass (Table 3). Numerous other authors have also reported decreases in grass tissue ash concentrations with increasing N rate (e.g., Landström et al., 1996; Lewandowski and Kicherer, 1997; Sparrow and Panciera, 2005; Mulkey et al., 2006).

CONCLUSIONS

Results of this study indicate it is possible to produce grass biomass yields high enough to make farming grasses as feedstock for bioenergy feasible in subarctic Alaska. Questions still remain as to best management practices for optimum yield, quality, and persistence. Spring harvest, which was the only treatment that resulted in optimum tissue water contents, is not likely to be feasible because of loss of yield, and late fall harvest still contained high amounts of tissue moisture. Thus, the best option may be to harvest in mid-summer when field drying is possible. Nitrogen rates higher than those used in this study (100 kg N ha^{-1}) may increase yields, but we do not yet know whether they would be economically feasible considering the high cost of nitrogen fertilizer in the region. We did not have enough information to determine production costs for grasses grown as biomass crops, and we do not know what price grass biomass as an energy feedstock might bring in Alaska, as there is currently no market. Thus, we were unable to determine the economic feasibility of growing grass biomass in Alaska.

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