Feasibility of Perennial Grass as a Biomass Feedstock in Aroostook County, Maine

Final Report

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Photo credits: We thank Paul Cyr for providing aerial photographs of central Aroostook County hay fields and grasslands. See www.paulcyrphotography.com to see more of Paul's stunning landscape, wildlife and other photos.

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Executive Summary

A grass biomass feasibility study was conducted by collaborating faculty from the University of Maine at Presque Isle, University of Maine Cooperative Extension, and Bowdoin College, and funded by the National Science Foundation grant EPS-0904155 to Maine EPSCoR at the University of Maine. Detailed study was conducted within four focal towns in central Aroostook county (Caribou, Easton, Fort Fairfield, and Presque Isle), but, many of the conclusions could be applied throughout Aroostook County. Land use analyses based on satellite imagery and ground-truthing identified over 18,000 acres of fallow or idle agricultural land within the townships, not including hayfields, pasture, and lands used for row crop production. Three years of agronomic trials yielded maximum yield of two perennial grass species in the 3.5 – 4 dry matter tons per acre, with considerable variation depending on cultivar and site characteristics such as pH, nutrients, weed pressure, and soil moisture. It is clear that perennial grasses must be managed with herbicide, wood ash or lime, and fertilizer inputs and that significant yields may not be realized until the third year post-establishment. Economic feasibility at the level of an individual farm will likely only be realized with a minimum of 250 acres at 3.5 dry tons per acre. If multiple smaller grass plots are aggregated, yields may need to be higher because of higher production and harvesting costs with custom harvesting.

Even with sufficient yields to support production costs, there is no clear market for grass biomass in the region at present, due to challenges associated with both processing and combustion of pure grass pellets. Two alternatives to a pure grass pellet are a 90% wood/10% grass pellet or a grass pellet using polyethylene as a binder – however, these options have not advanced past engineering trials. At present, the best option to yield energy from grass biomass is for farm-level whole-bale combustion systems to heat farm buildings.

Despite technological and market barriers to grass biomass production, there is considerable optimism and interest from landowners surveyed in Fort Fairfield. Thus, if these barriers can be overcome, or alternately if landowners and other stakeholders can develop alternative uses for their substantial fallow land base, this may have an economic benefit. Alternative land uses might include other energy crops such as willow, increased hay acreage, or increased food production in new sectors besides potatoes, their rotation crops, and broccoli. Thus, there may be a number of land uses that can add value to the local economy. Some of these new uses may have an environmental benefit. With significant yields of an energy crop like perennial grass, local net greenhouse gas emissions might be reduced. Conversion to reed canary grass would create some risk of establishment by this relatively invasive wetland edge species, but, little evidence of its invasiveness was found locally. New agricultural grasslands may also slightly augment wildlife habitat, including for some grassland birds and deer.

Overall, we recommend that landowners, community stakeholders, and local agricultural agencies and organizations: 1) consider grass biomass production for farm-level energy production taking advantage of USDA programs like BCAP and REAP, 2) continue to monitor technological progress on incorporation of grass into pellets or other combustion products, 3) evaluate other land uses for the region's considerable fallow land base, and 4) educate small

landowners who are not producing an agricultural product about potentially productive uses of their land and agricultural businesses with whom they could partner.

Research Objective

Since 2010, a research collaboration centered at the University of Maine at Presque Isle has been evaluating the feasibility of raising perennial grasses as a renewable feedstock in biomass energy production. This collaborative is funded by the National Science Foundation EPSCoR grant to the University of Maine's the Sustainability Solutions Initiative. Team members have included UMPI faculty Jason Johnston, Ph.D. (ecologist and team leader), David Putnam (eologist/anthropologist), Kimberly Sebold, Ph. D. (historian), and Chunzeng Wang, Ph.D. (geologist and GIS specialist). David Vail, Ph.D., Adams Catlin Professor of Economics, Emeritus of Bowdoin College has provided a variety of socioeconomic expertise. This project has expanded the initial agronomic studies by Andrew Plant, Ph.D., UMaine Cooperative Extension Associate Professor; Dr. Plant has also been part of the UMPI initiative.
The goal of this report is to provide interested citizens and stakeholders a summary of our findings. We consider the relevant stakeholders to be the individual landowners, municipalities, agricultural corporations, and agricultural or economic development organizations of Aroostook County, Maine. We have assembled this report to inform decisions about land, infrastructure and economic development initiatives, environmental opportunities and risks, processing, and marketing. Our report relies primarily on locally collected data, but also upon other reports and scientific literature. The primary goal of this research was to understand the available land base and other resources, stakeholder interest, agronomic and production considerations, transportation costs and logistics, processing, potential end uses, and ecological risks and opportunities.

I. GIS Analysis of land available for grass biomass production

A fundamental question, regarding the feasibility of producing grass as a biomass feedstock in Aroostook County, is whether there is a sufficient area of suitable land. In general, "suitable land" has fertility, drainage, and other characteristics to support adequate grass yield; it is currently not used as prime row crop land for profitable production of potatoes, broccoli and other high value crops.

Mapping Methods

Land-cover-land-use (LCLU) for the central Aroostook townships of Presque Isle, Caribou, Fort Fairfield, and Easton (Figure 1) was mapped and analyzed using a GIS (geographic information system) software called ArcGIS. The combined acreage of the four townships is 175,877. For each township a GIS database was created by using layers of data including DigitalGlobe's Precision Aerial Imagery (at 30-cm pixel size) and color infrared imagery (abbreviated as CIR; at 60 cm pixel size; both were captured in June 2011) and land-owner parcel map. High-resolution (at 2-m pixel size), LiDAR (light detection and ranging)-derived digital elevation model (abbreviated as DEM) data such as ground slope and hill-shade data released by Maine GIS Office in April 2013 were used as well, in particular when interpreting old farm fields (now presented as fallow or forest). The CIR imagery was classified into normally 16 classes based on CIR reflectance spectrum from different types of vegetation (land-cover). The classified CIR data layer provided another means to aid in determination of vegetation type in addition to direct interpretation of high-resolution, visible-light, true-color satellite imagery.

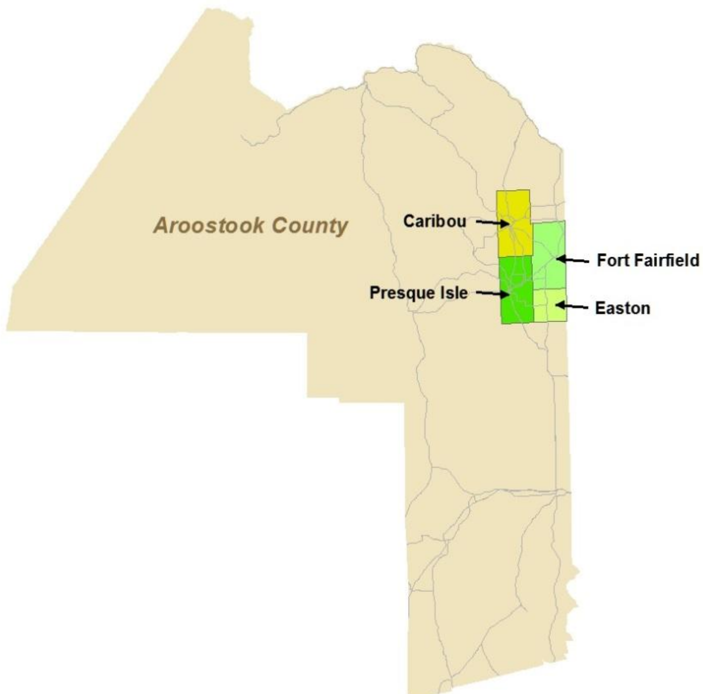

Figure 1: Map showing location of the four central Aroostook townships Presque Isle, Caribou, Fort Fairfield, and Easton where this land-use mapping project was conducted.

For each township, a polygonal feature class (a LCLU GIS file) was created and used for LCLU digitization. Utilizing all data layers to provide insight to LCLU, UMPI EPSCoR GIS team members used the on-screen digitization method in ArcMap to split land in all four townships into separate plots and assigned a land use value to each one based on interpretation of the high-resolution aerial and CIR imageries (including the classified CIR data). Land-use values/types include the following:

Cropland – including small grains, potatoes, broccoli, and rotation crops;

Forest – forest of any trees, also including tree farms and orchards;

Pasture – grassland used for animal grazing and often fenced;

Hayfield – grassland harvested for hay;

Fallow-1 – early successional grassland consisting of an array of low vegetative growth, lacking shrub and small-tree growth found in later succession, and not being used as pasture or harvested for hay. It is generally dominated by grasses and herbaceous plants, including some of or all of: timothy, ryegrass, smooth bromegrass, reed canary grass, clover, Canada thistle, goldenrod, and burdock (Figure 2a);

Fallow-2 – later successional growth of fallow-1, containing some shrubs (mostly red-osier dogwood and willows) and young trees (poplars, birch, pine, spruce) in addition to grasses and herbs (Figure 2b). Fallow-2 would become entirely forested with more years of fallow (Figure

2c)***Wetland*** – land areas saturated with water, either permanently or seasonally, including marsh, swamp, bog, and fen;
Water bodies – including lakes, ponds, and rivers/streams;
Developed – lands developed for residential, commercial, and industrial uses with man-made structures or for non-agricultural, industrial operations (such as gravel pit and rock quarry);
Wasteland – open, marginal lands with dumped rocks or waste, or with steep slope, or wet, or less fertile; they are mostly adjacent to farm fields;
Other uses – such as roadways, railways, transmission lines (they were mapped as "developed" for the townships of Fort Fairfield, Easton, and Presque Isle).

Figure 2: Examples of fallow lands. (a) Fallow-1; (b) Fallow-2; (c) Forested fallow land for at least 20 years. See the text for detailed explanation.

Pasture, hayfield, fallow-1, and fallow-2 form grassland that is the focus of our mapping efforts.

The high-precision mapping projects for both Fort Fairfield and Easton townships conducted in 2012 and 2013 were based on the DigitalGlobe high-resolution visible light and color infrared (CIR) data captured in June 2011. To make sure the mapping result was up to date, we also used Google Earth's recently released high-resolution images (15-cm pixel size; captured in September 2013) in addition to the DigitalGlobe 2011 data in mapping Presque Isle and Caribou townships between winter 2013 and summer 2014. To improve accuracy of the on-screen digitization a process called ground-truthing was intensively used. This involved visiting suspected land-use plots, in particular the grassland plots of fallow-1, fallow-2, hayfield, and pasture lands as defined by the initial on-screen digitization and interpretation. Observations were used as feedback to improve digitizing efforts in the laboratory and errors in land-use type assignment were corrected on-site using a laptop computer with ArcGIS. The land-use map for each township was thoroughly examined before it was called "completed".

Figure 3 demonstrates how a land-use map is made after CIR data classification and interpretation. Figure 4 shows how LiDAR-derived data such as DEM slope and hillshade were useful in interpretation of older fallow land and in study of historic change of cultivated land.

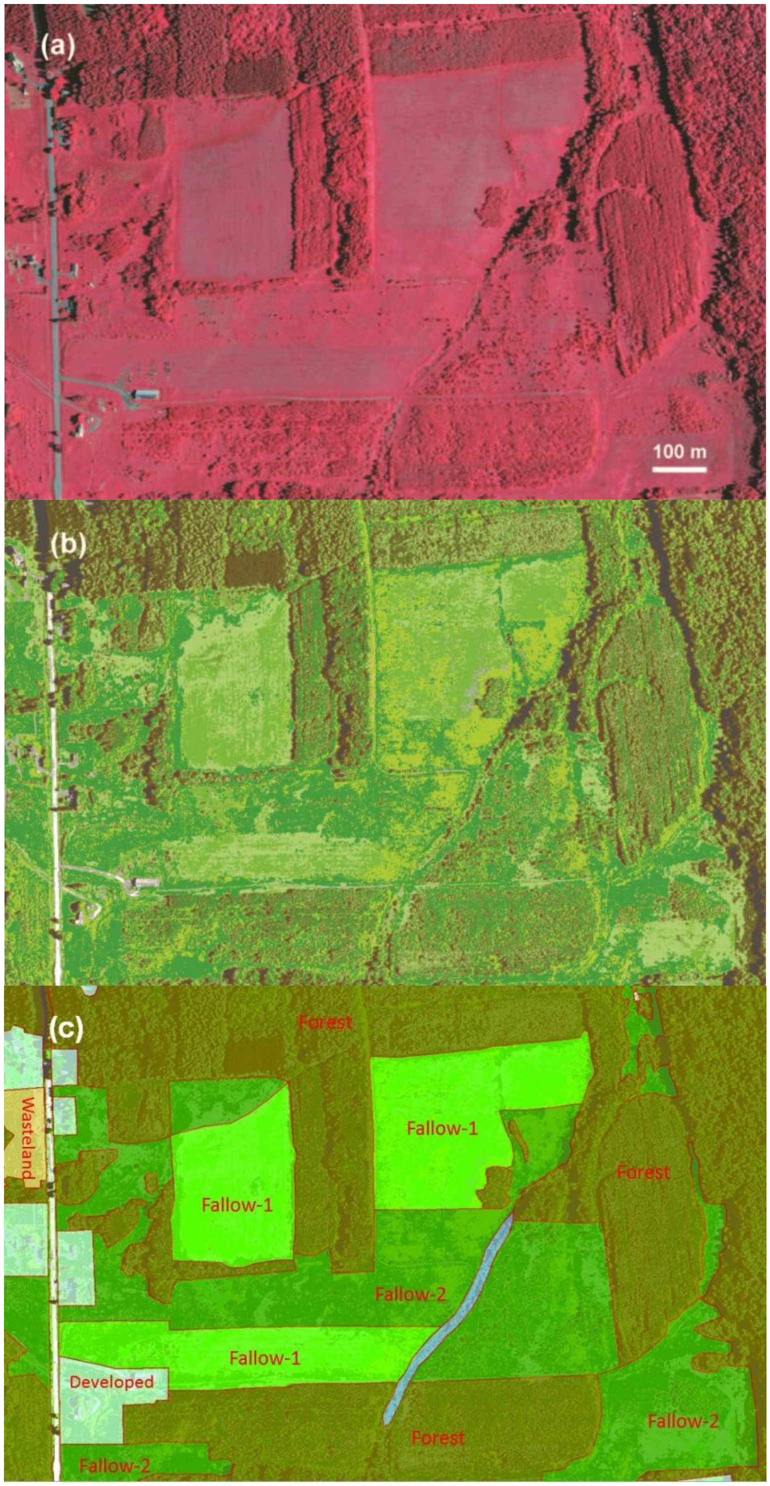

Figure 3: Sample imageries showing CIR data classification and interpretation of land use. (a) – CIR imagery; (b) – classified CIR imagery; and (c) – land-use map.

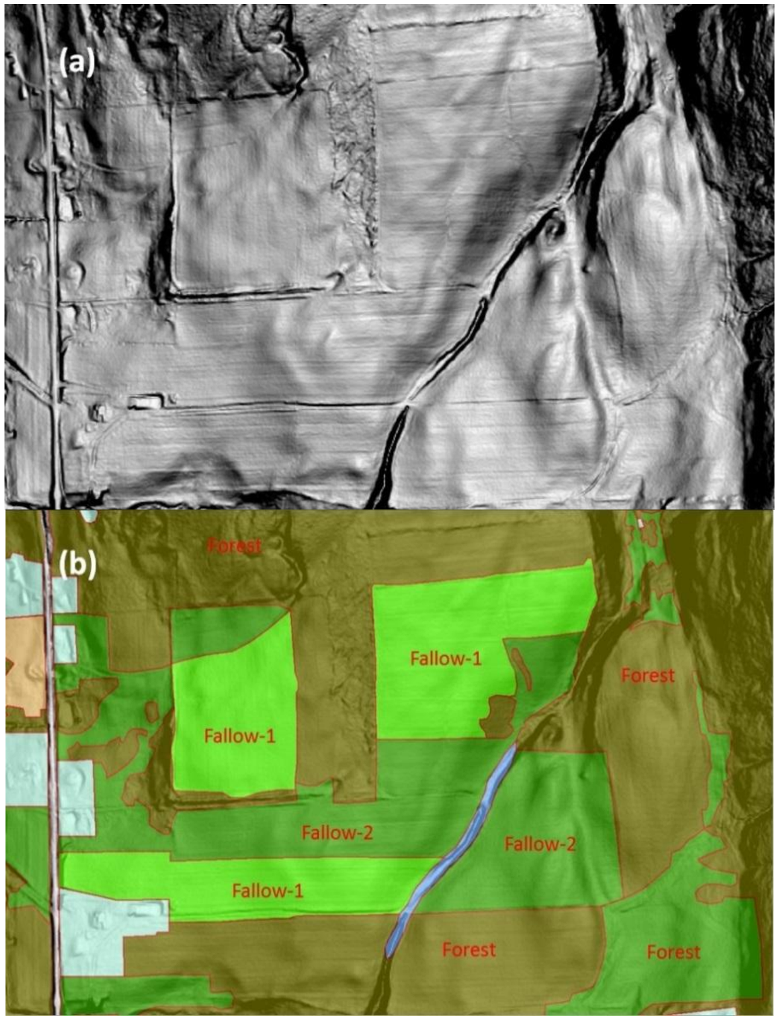

Figure 4: LiDAR-derived ground slope data layer (a) clearly reveals old cultivated land characterized by smooth surface and fine linear features as a result of long-time tilling; some of which are currently fallow-2 or completely forested as indicated in (b) and shown in Figure 2c. (a) and (b) cover the same area and have identical extent as Figure 3.

Land Area by Agricultural Land Use Type

The high-precision land-use mapping has resulted in a land-use GIS database separately developed for each township. Based on the GIS database, a land-use map was generated with ArcMap. ***Appendix A*** includes land-use maps for all the four townships. After a mapping project was immediately completed for a township, we shared the digital land-use GIS data with and printed land-use maps for our stakeholders such as Maine Farm Bureau, Maine Farmland Trust, Northern Maine Development Commission, town offices, and land management agencies to use. For example, the land-use map and data was immediately used as baseline data for town of Easton's comprehensive planning project.

The land-use GIS databases were also analyzed with ArcMap to summarize total acreage of each land-use type, total acreage of fallow-1 and fallow-2 plots over 10 acres in size, and total number of plots for each land-use type. Total acreage for cropland (Fig. 5) in Presque Isle, Caribou, Fort Fairfield, and Easton is 52,728 acres. Hayfields make up 3,059 acres, pasture comprises 1,312 acres, fallow-1 is 12,254 acres, and fallow-2 is 6,512 acres. The combined acreage of fallow-1 and fallow-2 is 18,766 which accounts for 25% of the total open lands in the four townships. The total amount of fallow-1 and fallow-2 land plots over ten acres in size is 12,033 acres, which accounts for 16% of the open lands. See ***Appendix B*** for detailed land use results for each township.

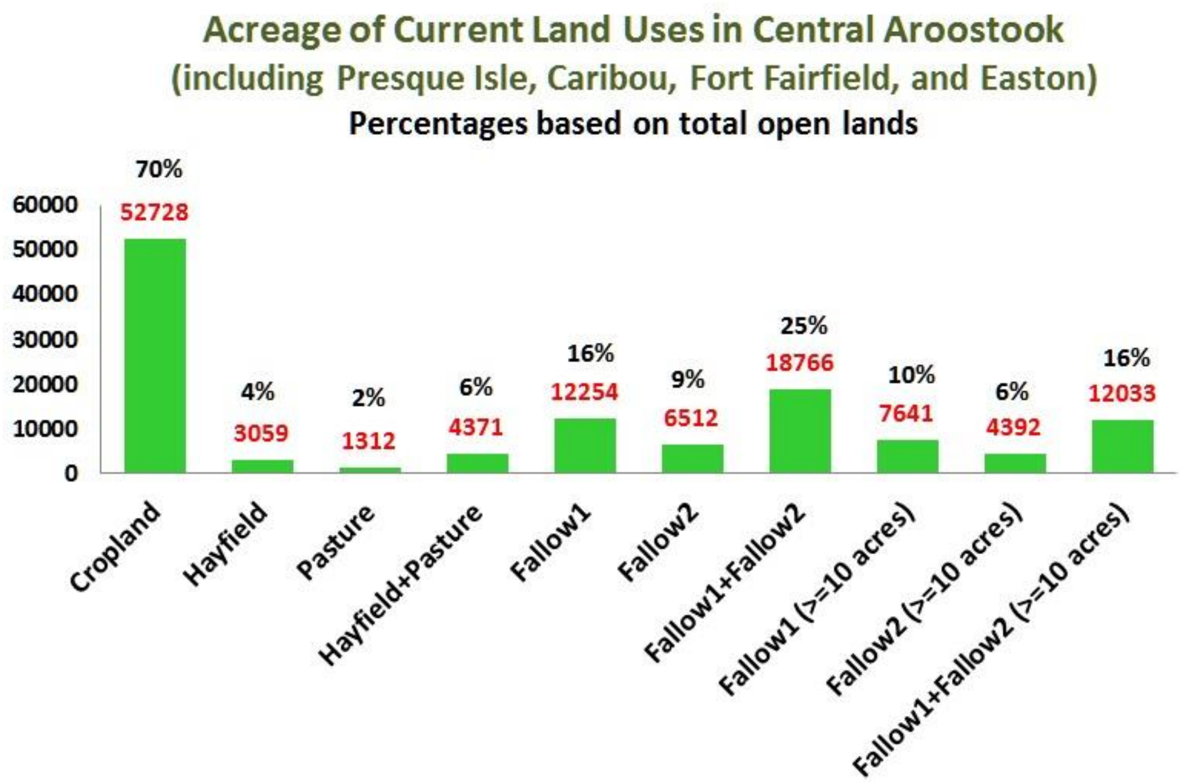

Figure 5. Land-use statistics for all the four townships combined. ("open lands" include all land uses but forests, water bodies, wetlands, wastelands, and developed)

Using ArcGIS we performed union overlay between land-use GIS data layer and the soil survey data layer obtained from Natural Resources Conservation Services (NRCS) Maine State Office in Bangor. The union overlay generated a new data layer that combines attribute data from both layers. With this new data layer we were able to use ArcGIS tools to select/extract grasslands that are located in poorly-drained or very-poorly-drained soils and to calculate their acreage. The results shown in the Table 1 clearly indicate that only a very small percentage (4.1-6.6%) of the grasslands are located in "poorly-drained" or "very-poorly-drained" soils. We also performed calculations by using ArcGIS tools on acreage of grassland that is designated/classified as "farmland of state importance" or "all areas are prime farmland" by NRCS (see Table 2). As shown in Table 2, a considerable amount (79-90%) of the grassland in each township falls in this designation/class; among this amount of the grassland, 53-87% is fallow land (fallow-1 or fallow-2).

Table 1: Acreage of grasslands with "poorly-drained" or "very-poorly-drained" soils

	Total acreage of grassland (including hayfield, pasture, fallow-1, and fallow-2)	Acreage of grassland in poorly-drained or very-poorly-drained soils	Percentage
Fort Fairfield	6,896	317	4.6%
Caribou	6,204	267	4.3%
Presque Isle	5,926	393	6.6%
Easton	4,111	168	4.1%
Total	*23,137*	*1,145*	*Average 4.9%*

Table 2: Acreage of grasslands classified as "farmland of state importance" or "all areas are prime farmland" by NRCS

	Total acreage of grassland (including hayfield, pasture, fallow-1, and fallow-2)	Acreage/percentage of grassland classified as "farmland of state importance" or "all areas are prime farmland" by NRCS	Acreage/percentage of fallow (1+2) classified as "farmland of state importance" or "all areas are prime farmland" by NRCS
Fort Fairfield	6,896	5,706 (83%)	3,804 (55%)
Caribou	6,204	5,585 (90%)	5,378 (87%)
Presque Isle	5,926	5,107 (86%)	4,498 (76%)
Easton	4,111	3,253 (79%)	2,167 (53%)
Total	*23,137*	*19,651 (average 84.5%)*	*15,847 (average 68.5%)*

In summary, land of several types is suitable for producing perennial grass as a biomass feedstock in central Aroostook County. Existing hay fields plus a substantial portion of current pasture and "fallow-1" land (in parcels larger than ten acres) would make up the core land base for grass biomass. Our farm-level economic analysis (see another chapter below) suggests that 1,000 acres or more of grassland are needed for optimum efficiency. Based on that assessment, we conclude that all four townships in our study area have an ample land base for grass biomass, assuming that effective economic incentives were in place. In particular, Easton and Fort Fairfield stand out as townships with the greatest potential for biomass grass production and, presumably, location of a centralized fuel processing facility.

II. Agronomic Trials and Management Recommendations

Research and varietal trials have been conducted at state research facilities throughout the U.S. However, both species and specific cultivars successful in one locale may not yield well in another due to differences in soil, drainage, climate and other environmental factors. Studies show large yield differences among species within the same climatic and geographic areas, but with differing soil quality (Bonos, 2008). Specifically in Northern Maine's climate, it may be that warm-season grasses such as switchgrass or *Miscanthus* would not be as well adapted as they are in southern New England states. Cool season grasses such as Reed Canary Grass would most likely fare better, but they tend to have higher ash content, which could make combustion properties less desirable (Dell-Point Technologies Inc, Personal Communication, 2008). Thus, field trials were conducted to evaluate the yield potential and ash content of a variety of cultivars of reed canary grass (*Phalaris arundinacea* L., hereafter, 'RCG') and switchgrass (*Panicum virgatum* L., hereafter 'SWG').

Plots were planted at three geographically diverse Aroostook County locations: Houlton, Caribou, and St. Agatha. Fields were selected based on growers' interest in participating and each grower selected a site deemed "marginal" in quality. The Houlton site had sloped, dry land, with good soil quality and ideal soil pH for grass production (6.0<pH<6.5). The Caribou site was characterized by poor drainage and very low soil pH. St. Agatha site was sloped, with ledge outcroppings and low soil pH.

Small plots, measuring 5'x25', were planted with Reed Canary Grass varieties or Swichgrass varieties, with or without oats as a companion crop. Oats were included on some plots to assess their weed control benefit and the potential for a harvestable crop during the establishment year (perennial grasses cannot typically be harvested economically the year they are established, so oats could hypothetically provide an interim livestock feed crop). Plot treatments consisted of 5'x25' plots for each grass variety in plots that were either fertilized on unfertilized, replicated four times in split-plot randomized complete block design. Three Reed Canary Grass varieties ('Palaton', 'Venture', and 'Marathon'), and five Switchgrass (Swg) varieties ('Cave-in-Rock', 'Shawnee', 'Carthage', 'Blackwell', and 'Dacotah') were included. RCG varieties were planted at a rate of 15 lbs/ac, and SWG varieties at a 9 lbs/ac rate. For plots including an oat companion, oats were sown over the top at a rate of 32 lbs/ac, and received nitrogen fertilization at the rate of 15 lbs/ac provided by a post-emergent broadcast of ammonium nitrate fertilizer (30-0-6).
In each year following establishment, the plots were split between fertilized/unfertilized, at a rate of 75 lbs or 0 lbs of nitrogen per acre, using ammonium nitrate (30-0-6) applied as a broadcast treatment in early spring.

Yield Data

Yields were expected to vary by year due to weather fluctuations and the fact that it takes up to three years to establish mature yields in perennial grasses. Detailed results are provided in Appendix B; here we summarize the range of yields by year, variety, fertilizer treatment, and pH. During 2010, the establishment year, data was only collected from our Caribou site and only consisted of those plots that were fertilized (75 lbs N/Ac., Ammonium Nitrate 30-0-6) in the spring, because the non-fertilized plots did not produce any harvestable yield. Yields on RCG varieties ranged from 1.46-1.57 DMT/acre and for SWG were 1.37-1.97 DMT/acre. Weed control was a significant issue at our Houlton site and at the time of harvest was considered the dominant vegetation. The cooperating grower applied a post emergent herbicide in spring of 2011 to better control this issue in subsequent years. At our St. Agatha site, lack of rainfall persisted throughout the summer leading to the decision that if harvested, it would be deleterious to the stand in future years.

In 2011, only reed canary grass accessions were harvested at our Houlton and St. Agatha sites as switchgrass plots were assessed to be in poor condition. In Caribou, all reed canary grass accessions were collected, and only one switchgrass (Blackwell) accession was collected. Spring-fertilized plots had a range in yield by variety of 0.61-3.35 DMT/acre for RCG and 1.81 DMT/acre for the single variety of SWG. Unfertilized plots had a range of 0.45-1.67 DMT/acre for RCG and 1.09 DMT/acre for the single variety of SWG.

Yields for 2012 best represent expected yields of established perennial grass plantings. Yield samples were collected from the Caribou and St. Agatha sites. The Houlton site was omitted because the cooperator harvested the site prior to yield sampling. At the Caribou site, we were able to harvest four of five switchgrass accessions. Significant yield gains were achieved in 2012 for the northern Aroostook site, which were likely the result of the combined effects of increased stand maturity and augmented soil quality. Despite 2012 being a dry year, overall the grass crop did well, likely due to early rainfall. The greatest effect upon yields at the St. Agatha site was probably the addition of wood ash as a liming agent, done by the cooperating grower at the beginning of the 2012 growing season. Measured pH of that soil rose from 5.5 in 2011 to 6.1 in 2012. Fertilized plots yielded 0.8-4.09 DMT/acre for RCG and 2.5-4.0 DMT/acre for SWG. Non-fertilized plots yielded 0-1.72 DMT/acre for RCG and 0.4-2.2 DMT/acre for SWG.

Composite samples were submitted for analysis of ash content (% DM) and energy content (BTU/lb DM), which were only measured for one year (2010) due to the expense of the analyses (Appendix B).

Conclusions from Yield Trials

Three years of yield trials demonstrate that while perennial grasses can successfully grow in northern Maine, there are many challenges. We cannot draw any definitive conclusions about the feasibility of grass biomass production in Aroostook County. Nonetheless, a few provisional conclusions seem to be justified:

First, by the third year, for some cultivars, yields of greater than 3.5 dry tons per acre were achieved. However, there is little prospect for profitable biomass grass production on truly marginal land, for instance in wet, steeply sloped and very acidic field conditions.

Second, annual nitrogen fertilizer applications are critical for reaching crop yield levels that *might* be economically feasible. However, the cost of fertilizing makes it far from a sure thing. Limestone or wood ash applications also appear to be crucial to raise yields on highly acidic soils.

Third, it is unclear whether switchgrass or reed canary grass is superior based on these agronomic trials, and there is considerable variation by cultivar within each grass species.

Finally, three years of field trials reinforce the general conclusion that several growing seasons are required for crop yields to approach levels that could be economically profitable with a sufficiently high farmgate price for biomass. Even under optimistic yield and price assumptions, it would take several years to recoup the initial establishment costs plus all annual operating expenses.

Cultivar and Management Recommendations for New and Existing Grass Stands

Whether growers decide to produce biomass with existing grass stands or replant or renovate fields, a number of key best management practices for biomass production can be recommended:

1. Species and Cultivar Selection: The most important aspect of grass species selection is for producers to know into which end-markets they want to sell. For our northern climate, cool-season grasses will provide the most consistency and ability to survive winters and achieve maturity during the short growing season. From the trials conducted in this study, we observe inconsistency in establishment and yields of the warm-season switchgrass. The one switchgrass cultivar that showed promise was cv. Blackwell.

2. Soil Preparation: Sites with good drainage and pH > 6.0 will produce best. RCG will do better than most other grasses on poorly drained sites and SWG will do comparatively better on dry sites or in dry years. The key factors for successful production will be proper soil pH and fertility. In 2011, our trials demonstrated clearly the effect of soil pH on yield potential, i.e. yields were approximately 3 times greater for plots with a pH around 6.6 versus a pH of 4.9 (Figure 6). Prior to planting, it is highly recommended that producers conduct soil tests on individual fields to assess existing soil pH and fertility.

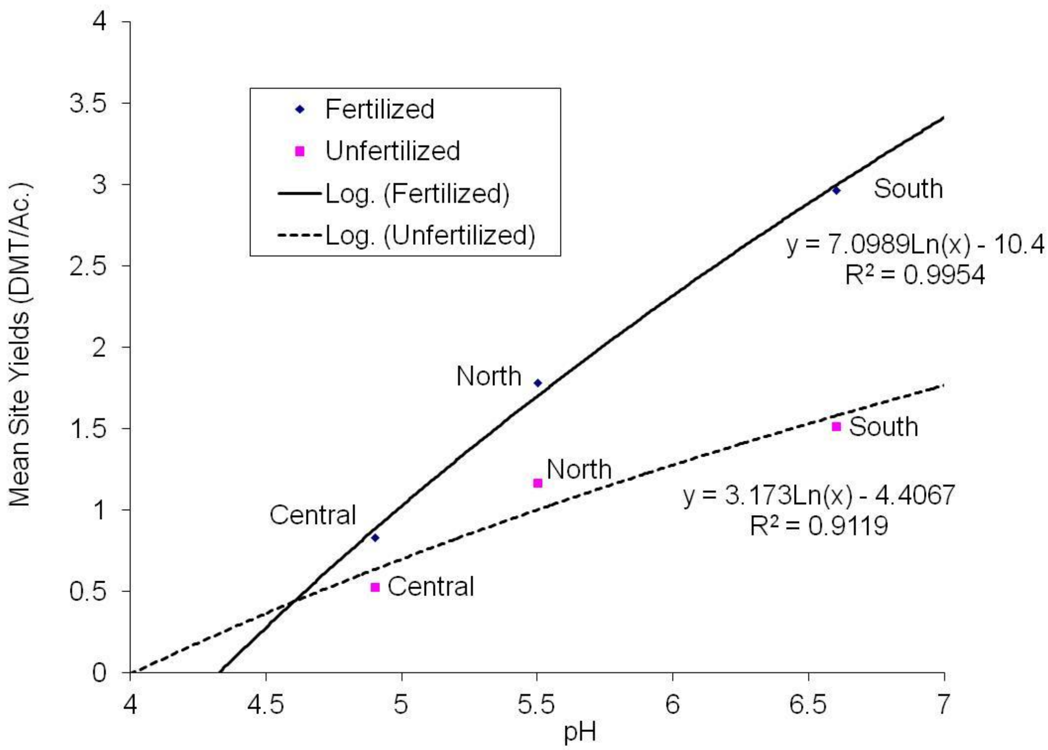

Figure 6: Mean site yields (DMT/Ac.) of reed canary grass as a function of measured soil pH at three sites in Aroostook County, ME, 2011.

3. Seeding: The best times to establish new stands or renovate existing ones are spring and late summer. To establish new stands, provide a firm seed bed and ensure good seed to soil contact. Many biomass-type grass species have proven to be difficult to establish utilizing no-till methods. They tend to be poor competitors with weeds during the first few years. Most typical forage grass species (e.g. Timothy) perform better with no-till planting than biomass grass species. If using a no-till system, be sure to suppress currently growing vegetation and residue as they will typically out-compete the newly planted grasses. Seeding rates differ depending on the type of grass planted, but they should be based upon pure-live seeding rates which accounts for the germination rate of the selected seed source.

4. Fertilization: Studies have demonstrated the responsiveness of grasses to applications of N-P-K fertilizers (Bosworth et al., 2013; Woelfel et. al., 1960; Wrobel et. al., 2009), but, too much nitrogen can lead to excessive stem length and lodging (Bosworth et al., 2013). Nitrogen fertilization is highly recommended, with a general range of recommended application between 50-75 lbs/Ac. of nitrogen. During the year of establishment, it is recommended that little to no fertilizer be used (<15lb N/Ac.).

5. Pest Management: Disease and insect pressure is minimal for forage and biomass grasses in Aroostook County. The greatest threat to yield and quality is undesirable weeds. Weed management is especially important for biomass species during the 2-3 year establishment period as they are poor competitors. Broad spectrum herbicides may be warranted prior to sowing, and/or broadleaf herbicides may be used after the year of establishment.

6. Harvesting: Harvest technology and methods for biomass grass are the same as for forage grasses. The major difference is harvest timing. Unlike forage grasses, where the optimum harvest occurs at peak above-ground nutrient density, for biomass used as a solid fuel, one should harvest at minimum nutrient density and maximum carbon content. For our area, the best approach is a single cut in late summer (August/September). Ideally, one would delay collecting the cut grass for 2-3 weeks after cutting to maximize the amount of nutrients that leach out with rainfall. At time of harvest, growers should check moisture, especially if the crop will be stored for any length of time. Moisture should be in the range of 15%-18%.

7. Storage: Many types of storage design are used by hay producers, each with its own benefits and costs. Some are inexpensive and allow more spoilage while others are more expensive but minimize spoilage. Best suggestions are to create budgets based on the local cost of materials for alternative designs and compare the lost revenue from spoilage of the different storage types. One of the most cost effective methods for our region, combining capital expense and spoilage loss, appears to be a crushed rock pad with tarpaulin (http://fyi.uwex.edu/forage/files/2014/01/BaleStorage5-7-04.xls).

III. Stakeholder Interest

1. Landowners

The GIS mapping exercise reported in section I.A. makes it clear that many thousands of acres of grass and idle land are potentially available for grass biomass production in the towns of

Caribou, Easton, Fort Fairfield, and Presque Isle. With effective market incentives, extension support, a ready supply of seed, and availability of custom haying operations, there is potential for grass biomass to be produced at a significant scale without impinging on current food crop or grain production. However, the large stock of current grass and idle land does not tell us whether and under what conditions the land's owners would be prepared to commit their fields to grass biomass cultivation.

To help answer that question we inventoried Fort Fairfield (FF) landowners' resources, knowledge, attitudes, and expectations through a survey made available to all owners of at least ten acres. Over the summer and fall of 2012, one third of FF landowners (59 of 182) submitted usable survey responses.

The survey findings are on the whole quite promising regarding the prospects for grass biomass. In a nutshell:

- Over half of FF landowners already have some land in hay fields; for most, hay is grown on well below 50 acres, but a few owners have over 500 acres in hay fields.
- Most landowners are somewhat or very optimistic about the prospects for grass biomass in Aroostook County, and one-in-three is moderately or very interested to participate in a grass biomass field trial.
- It is likely that many more would commit some land to biomass grass production if there were reliable buyers, adequate prices, and custom harvesting services.
- Several equipment owners currently perform custom haying operations and would be interested in custom harvesting grass biomass. (This finding was confirmed by focus group discussions with equipment owners.)

The following discussion expands on these core findings which are fully reported in *Fort Fairfield Landowner Survey: Perspectives on Grass Biomass* (Vail and Johnston 2012).

The majority of respondents can be described as older, well educated men with relatively small land holdings and no current engagement in commercial farming: the median sample age is 58 years, 88% are men, 43% hold at least a bachelor's degree (compared to 27% of Maine's adult population), six in ten own less than 100 acres (see Figure 7), and nearly two-thirds are not active commercial farmers. However, the non-farmers are an important source of productive and potentially productive land: three-fourths of non-farmers rented-out or leased land to active farmers in 2011; one-third of them had hay custom harvested on their land; and over half had scrub land bush hogged to suppress woody growth.

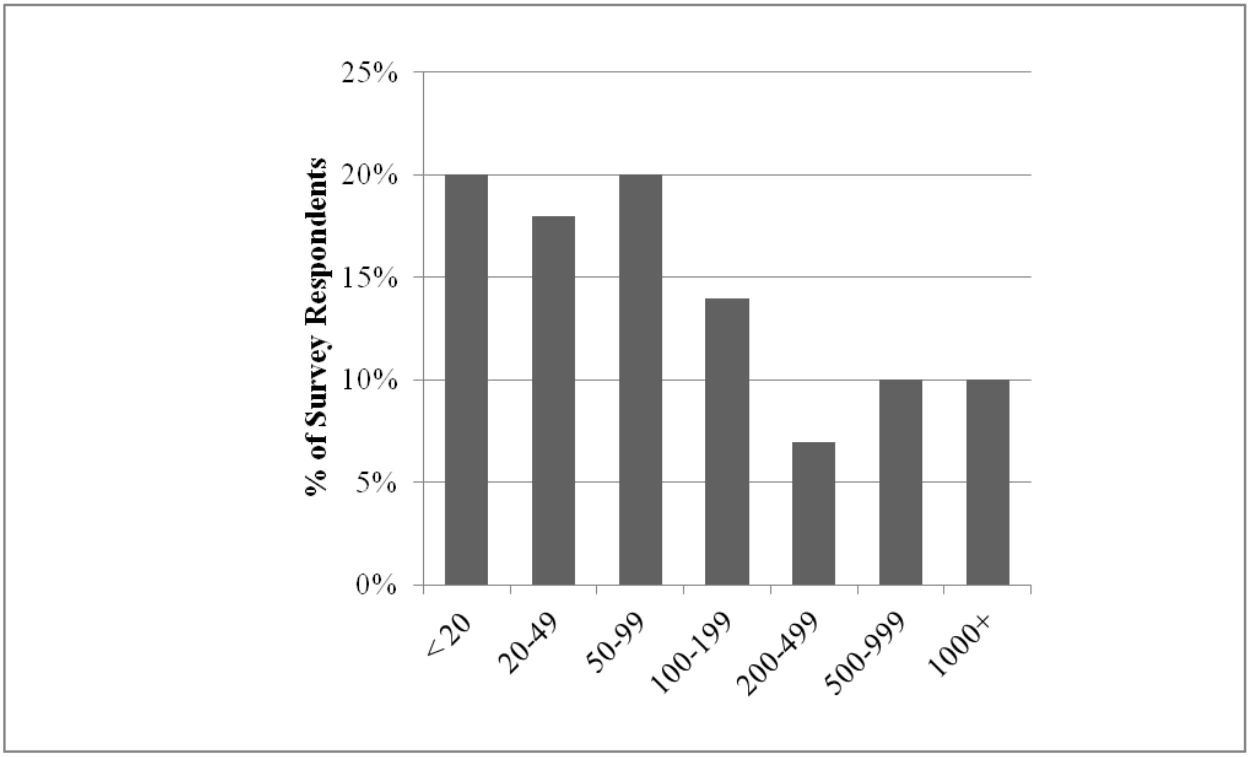

Figure 7: Distribution of farm size of 59 Fort Fairfield survey respondents by total acres owned.

Most survey respondents consider their current knowledge about grass biomass to be poor. Even so, a majority are somewhat or very optimistic about the prospects for grass biomass production in Aroostook County. (On the whole, the optimistic group is somewhat younger than the full sample and more of them own at least 20 acres of land.) The most serious obstacles they foresee are market-related: an unprofitably low price, insecure contracts, and unreliable buyers. Costs associated with harvesting and transportation are considered "minor" to "moderate" obstacles; while land conversion, labor shortages, and production risks (e.g. drought, pests) are viewed as minor.

Nearly one-third of respondents express moderate or strong interest in participating in a perennial grass field trial. Although most in this group grew hay on less than 50 acres in 2011, the total hay acreage of interested landowners approaches 1500 acres. The interested owners are not easily categorized: although they are somewhat younger than the full sample, they range widely across land holding sizes, involvement in commercial farming, and educational attainment. We speculate that, following successful field trials and creation of reliable markets and an adequate price, many more would probably be prepared to commit some land to grass biomass.

The survey confirms the GIS analysis presented in section I.A.: Fort Fairfield has abundant fallow and scrub land, most of which was once used for agricultural purposes and, with effective incentives, could be converted to perennial grass production. Ninety percent of the survey respondents own such land, most in small parcels; however, 8% own 50-99 acres and 22% own more than 100 acres of idle land. Most respondents (61%) had some land bush hogged in 2011 to suppress woody growth. Nearly one-in-five had at least 50 acres bush hogged. Conceivably, a fuel market might even develop for bush hogging residues -- a mix of woody, grassy and herbaceous species. Nearly half of survey respondents express moderate or strong interest in supplementing their incomes by selling such residues from their land.

The machinery used for harvesting and handling hay is basically the same as for grass biomass. In 2011, three comparatively young FF farmers did custom haying for other local landowners; two additional survey respondents expressed interest in doing custom harvesting if grass biomass production were to take off.

A complicating factor that warrants mention is the substantial in-migration of Amish families to Fort Fairfield and Easton in recent years. The five Amish farmers who completed our survey grow hay and silage to feed their livestock and use some of their fields for seasonal pasture. With continued expansion of Amish land ownership, these growing uses could compete for the limited supply of land well suited to grass biomass. (That said, one Amish farmer expressed great interest and another moderate interest in participating in a grass biomass field trial. Four have some interest in selling bush hog residues from scrub fields if a market develops for mixed biomass.) We can get a sense of the possible agricultural implications of continued Amish in-migration by noting that 80% of the Amish men we surveyed (four of five) are 45 years of age or younger, compared with just 17% of the full sample; and all are full-time farmers, compared with just 27% of the full sample.

2. Prospective Custom Haying Operators

There might be some individual grass biomass producers with sufficient acreage to justify a full suite of harvesting and transportation equipment dedicated to the grass production enterprise. However, given the size and ownership of the idle land available it is more likely that multiple landowners would aggregate smaller acreage, and individual landowners are not likely to own the requisite suite of equipment. That need not be a constraint, since custom hay harvesters operate throughout Aroostook County, e.g. in Fort Fairfield our survey identified up to 5 custom operators. Additionally, since grass biomass is typically harvested later than haying operations (e.g. October), grass biomass would comprise an additional harvest season and source of revenue for these operators.

3. Municipal, Agency, and Other Stakeholders

A variety of municipal and institutional stakeholders have expressed interest in or given feedback to this feasibility study. These include the municipalities of Caribou, Easton, Fort Fairfield, and Presque Isle, the Aroostook Partnership for Progress, Northern Maine Development Commission, Maine Farmland Trust, the Maine Farm Bureau, Farm Services Agency, and the Natural Resources Conservation Service. Landowners and businesses interested in pursuing opportunities to develop grass biomass or alternate land uses are encouraged to contact these organizations, as well as the authors of this study.

IV. Ecosystem Impacts

1. Life Cycle Analysis

A major compelling reason to burn grass as biomass, from an emissions standpoint, is that emissions from combustion of solid biomass are estimated at 5-10% of petroleum-based emissions (Duxbury, 2006). In the early stages of this study, there was interest in conversion of crop and forest biomass into liquid fuels, however, the potential of utilizing solid biofuels emerged as a competing interest. Large-scale systems for processing biomass into liquid fuels such as ethanol have several disadvantages, namely: they require transport to bring in raw materials from a distance, processing consumes substantial energy, and cellulosic feedstocks rely on technologies that are not as yet economical. The energy output-to-input ratio of combusting solid biomass can be as much as much as 16 times higher than for some petroleum-based fuels. Comparing solid biomass combustion with conversion to liquid biofuels (biodiesel or ethanol), this output-to-input ratio is still from 2.2 to 6.3 times higher, depending on the feedstock. Also, in terms of greenhouse gas emissions (grams CO_2 equivalents), liquid biofuel emissions are estimated to be 40-50% of those for petroleum based fuels.

Two of this project's motivating questions are:

- What is the potential of grass biomass to increase northern Maine's energy self-reliance by reducing dependence on "imported" liquid fossil fuels?
- Could production of grass biomass for thermal energy reduce northern Maine's emissions of carbon dioxide and other greenhouse gases?

The underlying scientific idea is tapping perennial grasses' photosynthetic capacity, converting solar energy into useful thermal energy.

Answering these two questions requires accurate estimates of all the energy inputs and outputs, as well as greenhouse gas sequestration and emissions, at each stage of the production and utilization process. This method is commonly called *Life Cycle Analysis*, or LCA. There is a growing body of life cycle studies for biofuel crops, ranging from the "first generation" of feedstocks -- corn and soybeans -- to "second generation" woody species and perennial grasses, like those we are investigating in Aroostook County.

Existing LCA research has not yet converged on either a unified estimation method or consistent conclusions about life cycle energy and emissions for grass-based feedstocks. Researchers have employed a range of assumptions and estimation techniques and both field trials and simulation exercises also reflect varied soil and climate conditions. Nonetheless, we take heart from several LCAs for two species of interest, reed canary grass and switchgrass. With optimal farming practices, they show the desired positive "Net Energy Values": usable energy output is greater than the sum of all energy inputs. And they show negative "Greenhouse Gas Fluxes": life cycle emissions are lower than for fossil fuel equivalents. Moreover, grass biomass has the greatest energy and emissions benefits when it is used for heat energy, its presumed use in Aroostook County, rather than liquid fuel (ethanol) or electricity generation (Cherubini, 2009).

We have not been able to collect all the data needed for life cycle energy and emissions analysis specific to reed canary grass and Aroostook County's soil and climate conditions. As an alternative, we summarize two kinds of relevant information here.

First we "inventory" the energy inputs and the emission sources throughout the *production chain* for thermal energy from grass biomass. In a fully developed life cycle analysis, the sum of energy inputs and the usable energy "output" would be compared with the displaced fossil fuel energy over the grass crop's ten to fifteen year life cycle. A similar exercise would be done for greenhouse gas emissions, including the indirect benefit of increased organic carbon "stored" in the grass's root system.

Second, we summarize recent scientific studies of net energy values and greenhouse gas fluxes, to get a sense of the *potential* energy conservation and global warming benefits from grass biomass and to highlight potential weak points in the grass biomass life cycle.

The following discussion employs two core concepts: the "Life Cycle Inventory" of distinct activities involved in producing and utilizing grass biomass; and the "System Boundary," specifying the scale and geographic scope of the analysis.

Overview of the Life Cycle Inventory for Grass Biomass in Aroostook County

1. **Upstream from the farm**
   - Energy and emissions *embodied* in the production of farm equipment, soil amendments, seed and other farm inputs. On a per acre basis, these are sufficiently small that some LCA studies do not include them within the "system boundary" (Davis et al., 2008).
   - Energy and emissions in transporting inputs to the farm. These are also small on a per acre basis and excluded from some LCA's.
2. **On farm**
   - Fuel for farm equipment
   - Land conversion: seedbed preparation, planting, application of soil amendments, herbicide, etc.
   - Recurring operations: application of soil amendments
   - Harvesting
   - On farm storage (drying, air circulation)
   - Greenhouse gas fluxes in the cropping cycle
   - Negative example: nitrous oxide (N_2O), a very potent greenhouse gas, is released with nitrogen fertilizer applications. One study indicates that this is the largest on-farm source of GHG emissions in producing fertilized grass biomass (Adler et al., 2007)
   - Positive example: perennial grasses sequester (store) carbon in their root systems (Yuan et al., 2008)
3. **Downstream from the farm**
   - Transport to processing facility
   - Storage
   - Processing (e.g. pellet or briquette manufacture)
   - Fuel transport to end user

- Embodied energy and emissions in production of equipment for transport, storage, processing and combustion.

4. Yield of useful energy and emissions avoided by displacing fossil fuels. (Plus the additional soil organic carbon, mentioned above.) In estimating life cycle impacts, these beneficial effects are weighed against the total of all the preceding energy uses and emissions.

Insights from the Scientific Literature on Life Cycle Analysis

The Federal mandate to expand production of liquid fuels from renewable feedstocks has prompted considerable research into the life cycle energy and greenhouse gas properties of several plant species. Given the United States' troubled experience with "first generation" energy crops – corn and soybeans – a growing interest in "second generation" feedstocks – grass and woody species -- has prompted considerable scientific research. Before summarizing findings from several investigations of perennial grass life cycles, five of their limitations should be mentioned.

First, few published field trials include reed canary grass as a biomass feedstock. Research has focused on switchgrass and "Giant" *Miscanthus*, a sterile hybrid.

Second, most life cycle studies focus on ethanol or electricity as end products, not combustion of solid biomass for thermal energy. (Davis et al. 2012 underscore that an economically competitive technology for converting grass to ethanol does not even exist at present.) Importantly, there are few experimental data on the energy and emissions entailed in transporting, storing and processing grass for burning.

Third, the most rigorous studies are based on field trials in regions, such as the Midwest cornbelt and Pennsylvania, which have longer growing seasons and possibly better soils than Aroostook County. Thus, the direct transferability of farm-level findings is limited. An example conveys how these three factors limit our ability to draw inferences for Aroostook County: in a Pennsylvania trial, reed canary grass is fertilized and harvested twice yearly -- the first harvest is as an early summer green crop. Grass is then fermented to produce ethanol. In Aroostook, reed canary grass is fertilized and harvested just once a year and it is intended for combustion, not liquid fuel (Adler 2007).

Fourth, published studies have not dealt consistently with scale and organizational factors that could have a major impact on life cycle energy and emissions under Aroostook conditions. We anticipate, for example, that small, widely scattered perennial grass plots in Aroostook would increase energy inputs and emissions in harvesting and transport operations. (See Davis et al. 2012 and our analysis, above.)

Fifth, the studies vary in their choices of what to include in life cycle inventories and where to set system boundaries. This contributes to the wide variations in estimates. As Davis et al. (2009) stress, "Many life-cycle inventories are incomplete, neglecting components of the production chain that are important for assessing biofuel sustainability….The uncertainty associated with each item in a life-cycle inventory [also] contributes to variation in the final LCA estimates."

Reed Canary Grass Findings

There are few published studies of reed canary grass (RCG). Davis et al. (2009) summarize a modeling exercise based on Pennsylvania field trials. It indicates that RCG does in fact produce a positive life cycle Net Energy Value. (It is difficult to give an intuitive meaning to their specific estimate, 4.88 mega joules per square meter.) Reed canary also has the desired negative life cycle Greenhouse Gas Flux, a reduction of 850 kilograms of CO_2 -equivalent per hectare per year. In more common sense terms, reed canary produced efficiently and converted to ethanol would displace ~84% of the emissions from using gasoline. If the grass was burned for its heat energy, the comparative benefit would be still greater. As Cherubini et al. (2009) note, "Uses of biomass for heating generally gives greater GHG reductions per hectare than [for either] transportation biofuels or electricity."

Comparative Findings on Switchgrass and *Miscanthus*

Davis et al. (2009) report the results of several switchgrass LCA studies. The general conclusion is that switchgrass, at its best, is superior to reed canary grass in terms of both net energy value and greenhouse gas flux. This seems to be in large measure because switchgrass produces comparable or higher dry matter yields with smaller applications of fertilizer and limestone – especially of nitrogen fertilizer. (Note, however, that *some* nitrogen fertilizer is needed to achieve optimum switchgrass yields. Davis et al., 2012). Nitrogen fertilizer uses energy and causes GHG emissions in three main ways: energy and emissions embodied in the fertilizer, fuel used to spread it, and N_20 emissions. To make the comparison more concrete, recall the conclusion that ethanol from reed canary grass could displace 84% of carbon emissions from burning gasoline. Switchgrass displaced 114% of gasoline emissions, by eliminating fossil fuel emissions and sequestering more organic carbon in the plants' root system. (Comparative data for reed canary come primarily from Adler et al., 2007)

The positive conclusions about growing switchgrass for thermal energy on marginal farmland in the Northeast are confirmed in a recent study prepared for the Vermont Sustainable Jobs Fund (Wilson Engineering, 2014).

It is worth mentioning briefly another perennial grass species, "Giant" *Miscanthus*, that may have promise for Aroostook County. Miscanthus is already grown as a biofuel feedstock in Europe (primarily for thermal energy) and research in the USA indicates several beneficial characteristics: cold tolerance, higher yield and greater root system carbon sequestration than switchgrass, and no need for nitrogen fertilizer (Davis, 2012; Yuan, 2008).

Putting it all together, Cherubini et al. (2009) offer the following recipe for producing renewable energy on farmland: "Grow biomass crops that have minimal processing requirements on sites with high growth rates, while minimizing external inputs such as fertilizers and pesticides."
It is not clear whether growing reed canary grass on Aroostook County's marginal farmland can meet all these criteria. Specifically, a combination of low yields on low fertility land, yearly

fertilizer applications, and long transportation distances could tip the balance in a negative direction. However, the available land base may be suitable to grass production since only 4.9% of grassland or idle land in the 4 townships studied (Table 1) comprise parcels with poor or very poorly drained soils.

2. Wildlife Habitat

A potential benefit of converting row crop to grasslands is improved wildlife habitat, especially for grassland birds and deer. Deer are at the northern edge of their range in Northern Maine, and management of the population depends mainly on managing winter deer yards and browse. While increased grasslands may not have a major population impact, this may create more opportunity for hunting. Both hunting (IAFWA, 2002) and bird-watching (Maine Audubon Society, 2000) represent significant economic activity. As of 2011, total wildlife-related expenditures in Maine were $1.4 billion, with $618 coming from hunting and fishing and the remaining $799 million generated from wildlife-watching expenses (USFWS and U.S. Census Bureau, 2011). There may also be opportunity to contribute to a growing agritourism sector in Maine (Department Of Agriculture, Food & Rural Resources, 2008). Of course, the relative economic impact of converting a few to several thousand acres to grassland in Aroostook County may be small or difficult to measure; but, given the rarity of grasslands statewide both the economic and ecological impact could be important.

Grassland habitats are relatively uncommon in Maine, and the creation of hundreds or thousands of acres of perennial grassland, when combined with current hayfields may result in enough habitat across Aroostook to augment both relatively common bird species, as well as species of concern. Relatively common grassland bird species include Savannah sparrow, bobolink, killdeer, red-winged blackbird, Wilson's snipe, American kestrel, and northern harrier. Less common species include vesper sparrow, horned lark, upland sandpiper (a state threatened species), and perhaps grasshopper sparrow (state-endangered). Grassland birds were historically more common in the northeastern U.S., but, have lost habitat to reforestation and suburban development. In Aroostook County, there has been a loss of farmland since a peak in the 1940's (Johnston and Cardenas, 2012), and likely a more substantial proportional loss in hayfields and pastureland that likely supported a richer and more abundant grassland bird community. One potential benefit of biomass grasses like RCG is that they get harvested much later than a typical first cutting of hay, and thus provide time for nesting and production of one or two broods of offspring. Conversely, RCG may not provide suitable habitat for birds due to its height or the insect community (or lack thereof) that it supports.

To evaluate the potential benefit of increased acreage of grasslands we surveyed bird species abundance, measured food availability, and measured physiological condition of breeding birds in a variety of agricultural habitats. We compared row crop habitats (including grains) to grassland habitats (including hayfields and idle lands bush hogged annually). Fields managed for grassland birds (upland sandpipers) at the Aroostook National Wildlife Refuge (ArNWR) were used as a relative control. As expected there were more grassland birds in both agricultural land covered in grass (e.g. hay) and ArNWR than in current row crop land (Figures 8, 9). Grassy habitats had more Savannah sparrows, bobolinks, upland sandpipers, killdeer, and snipe. However, there were differences in bird abundance between the agricultural grasslands and the

ArNWR; there were no bobolinks at ArNWR – this species is a relatively common breeder in hayfields. There were fewer song sparrows at ArNWR than either the row crop or agricultural grasslands – this species likes shrubby or edge habitat suggesting that ArNWR is a better habitat for true grassland bird species.

Along with the difference in species abundance, we also found differences in arthropod (insects and spiders) food availability between habitat types. ArNWR plots had generally higher arthropod abundance than all the agricultural habitats – in some cases 3 times the number of a given arthropod group. There were few differences between agricultural habitat types (e.g. reed canary grass, hayfields, and fallow/bushogged plots did not differ).
Despite the differences in abundance of birds and food availability, we did not find differences for body mass and hormone levels of breeding male Savannah sparrows.

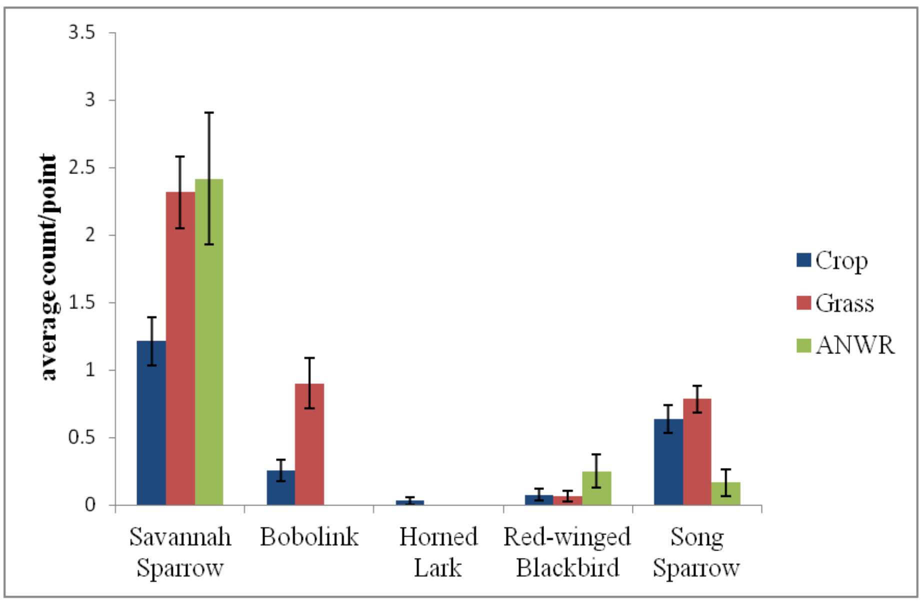

Figure 8: Average number of individuals observed in 5-minute point counts in crop (potato or grain, n=66), grass (idle or hayfield, n=60), or ANWR (Aroostook National Wildlife Refuge, n=24) plots.

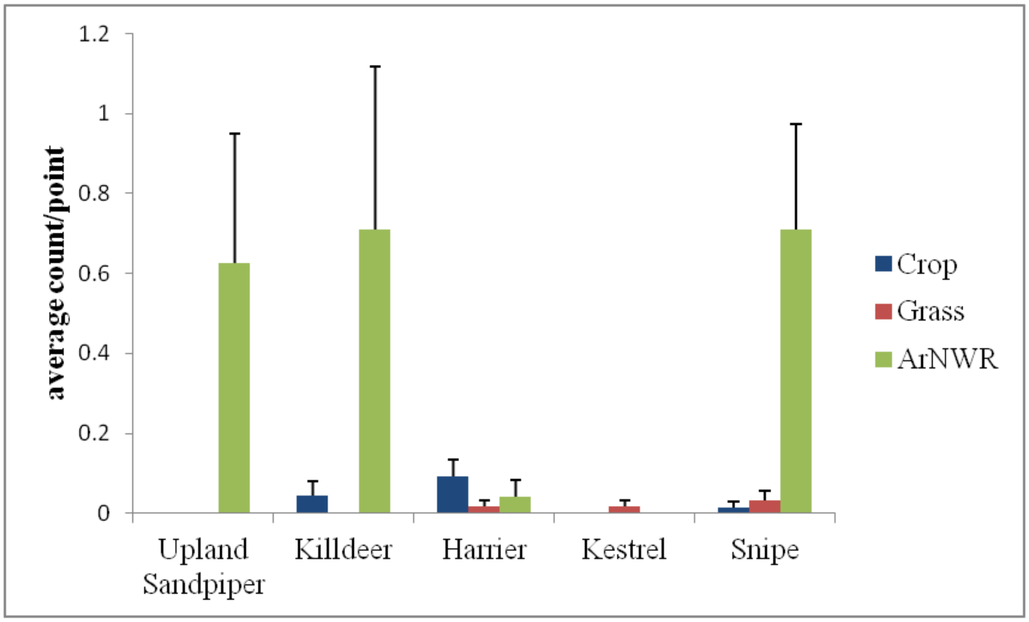

Figure 9: Average number of individuals observed in 10-minute point counts in crop (potato or grain, n=66), grass (idle or hayfield, n=60), or ANWR (Aroostook National Wildlife Refuge, n=24) plots.

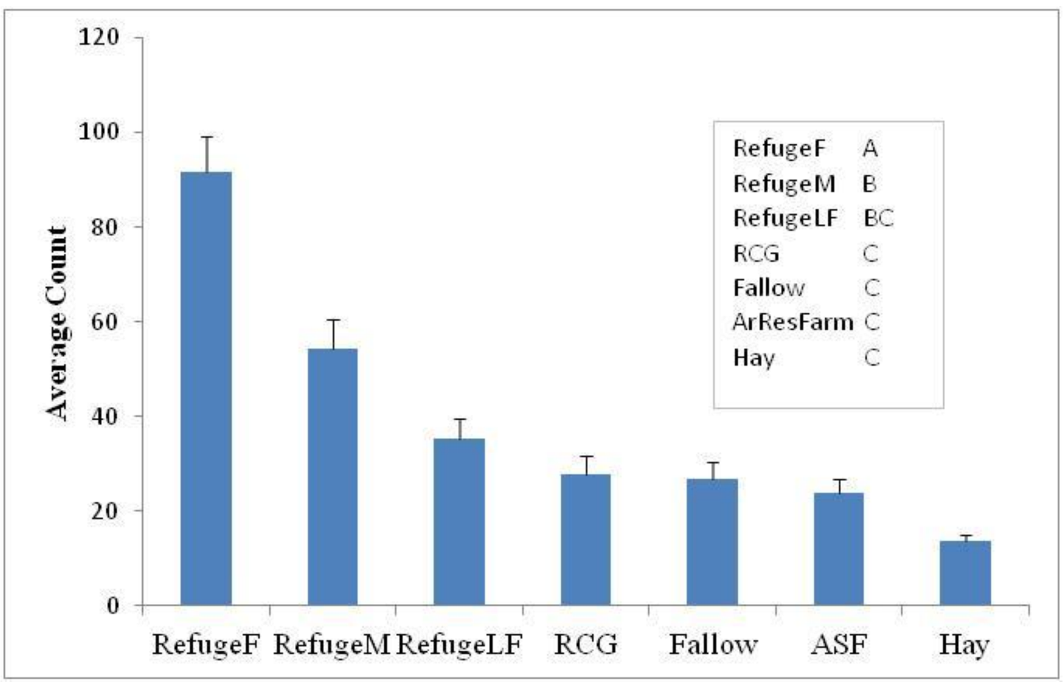

Figure 10: Average total arthropods from sweepnet samples (20 sweeps X 10 samples per site) in 3 ArNWR plots (Refuge F, M, LF), reed canary grass (RCG), fallow land, rotational cover at Aroostook Research Farm, and hayfield.

Overall, our data support four conclusions about effects of potential grass biomass development on grassland birds: 1) reed canary grass plantations may support a similar number of grassland birds as other perennial agricultural uses, e.g. timothy, 2) refuge grasslands maintained for grassland birds are superior habitats for some species e.g. threatened Upland Sandpipers, but, this may be due in part to soil characteristics that result in sparser and shorter vegetation than agricultural grasslands, 3) rare species often sought out by birdwatchers were, in fact, rarely or not at all observed in our surveys, and 4) one common grassland species (bobolink) was more prevalent in agricultural grasslands than ArNWR.

3. Potential Invasiveness of Reed Canary Grass

Reed canary grass has been identified as an invasive species (Lavergne, 2004) that is particularly effective at spreading to and dominating wetlands. A statewide survey of Wisconsin's five million acres of wetlands found that roughly half a million acres were dominated (> 50% coverage) by this species, with 26% of open canopy wetland was dominated by RCG (Hatch and Bernthal, 2008). RCG has become established initially through its use as forage or cover crop, or as erosion control along roadsides or other erodible land. While it is nominally a native species in Maine and other regions where it has been identified as invasive, it is likely that the invasive populations originate from planted cultivars rather than native populations.
Given these concerns, we sought to collect local data on potential invasiveness of RCG. We identified a field in Washburn, ME where RCG had been planted in the mid-1970's to facilitate nutrient control of sludge spread from a potato processing facility. Despite extensive searching, DEP could not locate the file on this project, and thus we have little detailed information on the location or extent of the planting. To measure the spread of RCG from the established field, we identified six sites ranging from 8 to 1,181 meters from the edge of the established field. Sites were fields or wetland edges suitable for RCG. Percent coverage (0, 25, 50, 75, or 100% dominance) in a 1 m^2 quadrat at ten points along a transect were measured for a total of 730 points along 73 transects. There was no relationship between distance from the established RCG field and % coverage of RCG at sample sites ranging from a few meters from the established field to over 1 kilometer away. However, the percent coverage of RCG ranged from 31% to 57% across the six sites. These results suggest that wetlands within one kilometer of RCG fields could become dominated by RCG within 40 years.

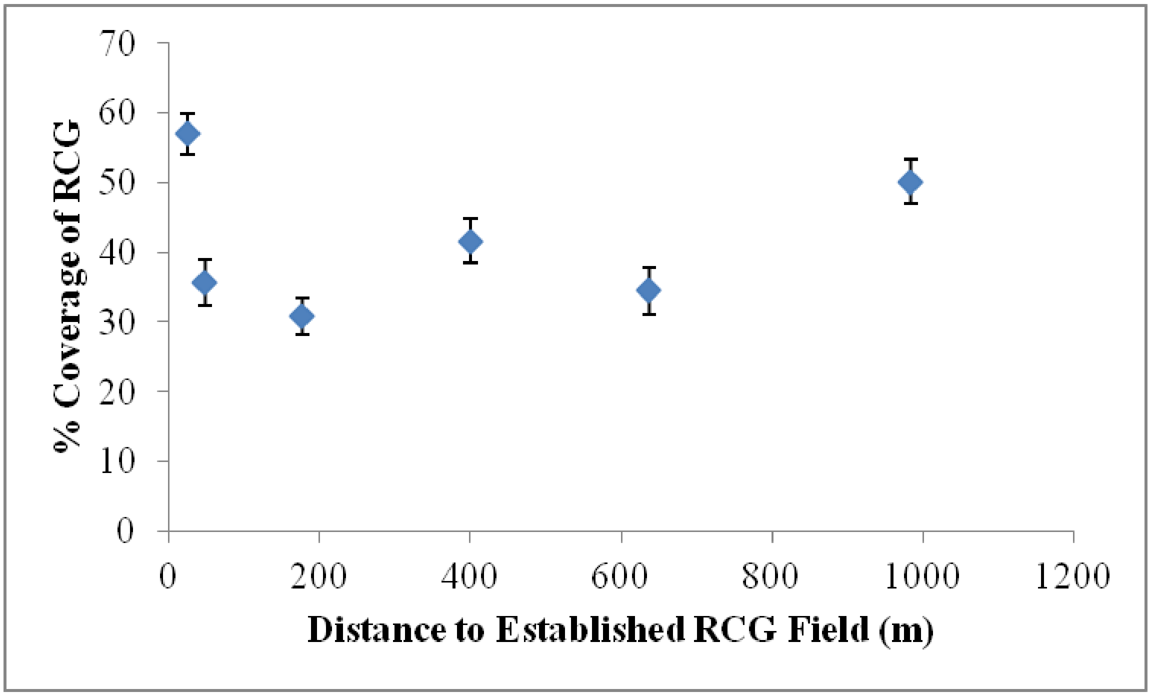

Figure 11: Average percent coverage by RCG in points within a transect at varying distances from a RCG field planted in the mid-1970's.

V. Farm-Level Economic Feasibility

An important precondition for successful introduction of a sustainable grass biomass system is its economic feasibility at the farm level. Farm-level viability of the grass biomass system was analyzed utilizing assumptions based upon field trials, the scholarly literature, and farmer interviews. The following analysis estimates costs and returns at scales ranging from 250 acres to 2000 acres. Given the much smaller plots that many Aroostook landowners might make available for grass biomass, our calculations rest on the assumption that farm operations would be rationally organized and harvesting carried out by custom haying operators.

Enterprise Budget Estimates

Hypothetical grass biomass enterprise budgets were constructed from research findings, interviews, and templates available from several land grant universities. Table 3 illustrates a budget estimate for grass biomass grown at a scale of 500 acres, with a yield of 3.5 dry matter tons (DMT)/acre yield and a farm gate price of $80 per DMT. (Full cost details are presented in the appendix.) Additional budgets were estimated for scales ranging from 250 to 2000 acres, with prices from $70 to $85 per DMT and average yields from 2.0 to 4.0 DMT per acre over the grass crop's expected ten year life-cycle.

From field studies conducted locally and throughout the northeast, the following analysis is based upon the assumption that farmers will ideally manage the soils and grass crops to include herbicide treatment, liming (maintaining or increasing soil pH to > 6.0), and fertilization (nitrogen). With proper management and variety selection, the expected 10-year yield ranges, based upon our local studies, should be between 3.2 DMT/Ac. and 4.0 DMT/Ac. (Yr 1: 1.0-2.0 DMT/Ac., Yr 2: 2.5-3.5 DMT/Ac., Yr 3-10: 3.0-4.5 DMT/Ac..

Table 3: Illustrative Enterprise Budget for Biomass Grass: 500 acres

	Total	Per Acre	Per DMT
Number of Acres	500	-	-
Biomass Yield (DMT[a])	1,750	3.5	-
Price ($/DMT[a])	-	-	$80
Annual Revenue	**$140,000**	**$280.00**	**$80.00**
Annual Operating Expenses			
Total Operating Expenses	**$99,215**	**$198.43**	**$56.69**
Annual Ownership Expenses			
Total Ownership Expenses	**$40,720**	**$81.44**	**$23.27**
Total Annual Cost	**$139,935**	**$279.87**	**$79.96**
Net Farm Income (NFI)	**$65.00**	**$0.13**	**$0.04**

a. DMT= Dry Matter Ton, $/DMT= Dollars per Dry Matter Ton

In the preceding calculations, the initial establishment costs for grass seed, fertilizer, planting, etc. are annualized over the crop's assumed ten year life cycle. Annual operating costs include such items as fertilizer, labor, equipment depreciation, transportation, storage and short term interest. Annual ownership costs include long term interest, taxes and insurance and, importantly, a $50/acre "land rent" to the owner. The estimated net farm income is thus over and above any rent or lease fee to the landowner. (For details and data sources, see the appendix.)

The takeaway message from this illustrative budget is that grass biomass is barely a break-even operation at a scale of 500 acres, combined with a yield of 3.5 tons/acre, and a price of $80/ton. As we show below, the economics look better with increases in scale, yield, or price. Conversely, growing grass for biomass is a losing proposition at a smaller scale, lower yield, or lower price.

Moreover, as we illustrate in the appendix, even under the most optimistic scale, yield, and price conditions, the "up front" costs of converting land to perennial grass are not recouped until roughly five years after the grass crop is planted. (see details in appendix B.)

Breakeven Prices for Different Combinations of Scale and Yield

Expanding on the previous conclusions, we constructed budgets with different combinations of scale and yield, to see what price per dry ton of biomass would be required for the farm operator to cover all operating and ownership costs and thus break even. (Recall that an annual $50/acre landowner rent is included as a cost.) Table 4 shows the breakeven price per DMT at the indicated production scale and yield combinations.

Recent price patterns for hay in Aroostook County suggest that a price above $85/ton is highly unlikely. Assuming this to be the probable maximum price, we have highlighted the scale and yield combinations that could at least minimally qualify as economically feasible: 4 tons/acre at a 250 acre scale, 3.5t/a at 500 acres, and 3t/a at 1,000 and 2,000 acres. Based on yield data reported earlier, economic feasibility might occur at a scale of 500 acres. The big differences in breakeven price shown in Table 4 reflect the fact that production costs per acre and per ton of biomass are significantly lower with larger scale operations: in highly mechanized grass production, there are important "economies of large scale." (Note, however, that the breakeven price changes little beyond a scale of 1000 acres, due to the added labor and equipment required for a timely harvest of 2000 acres in the late autumn.)

Table 4: Breakeven Price per Dry Matter Ton (DMT). Per ton costs[a] of production at different average yields and scales of production.

Yield / Acre (DMT)	250	500	1000	2000
2	$142.61	$123.57	$115.77	$114.09
2.5	$119.11	$103.22	$96.96	$95.71
3	$103.45	$89.65	$84.42	$83.46
3.5	$92.26	$79.96	$75.47	$74.71
4	$83.86	$72.69	$68.75	$68.15

Both the budget simulations and the breakeven analysis strongly suggest that economic feasibility would require a combination of at least 500 acres of grass production, average yield of at least 3 tons/acre, and a price of at least $80. In the 'real world', if any of the three parameters fell below those levels, grass biomass would probably be a losing – and in any case a risky – proposition. That conclusion is illustrated by the graphs in Figure 12.

Based on our simulations, the "sweet spot" for economic profitability appears to be a production system with at least 1000 acres of biomass grass -- within a reasonable radius of the custom haying operator -- plus a yield of at least 3.5 tons dry matter per acre. Those system features would pretty well insulate the farm operator from fluctuating hay prices.

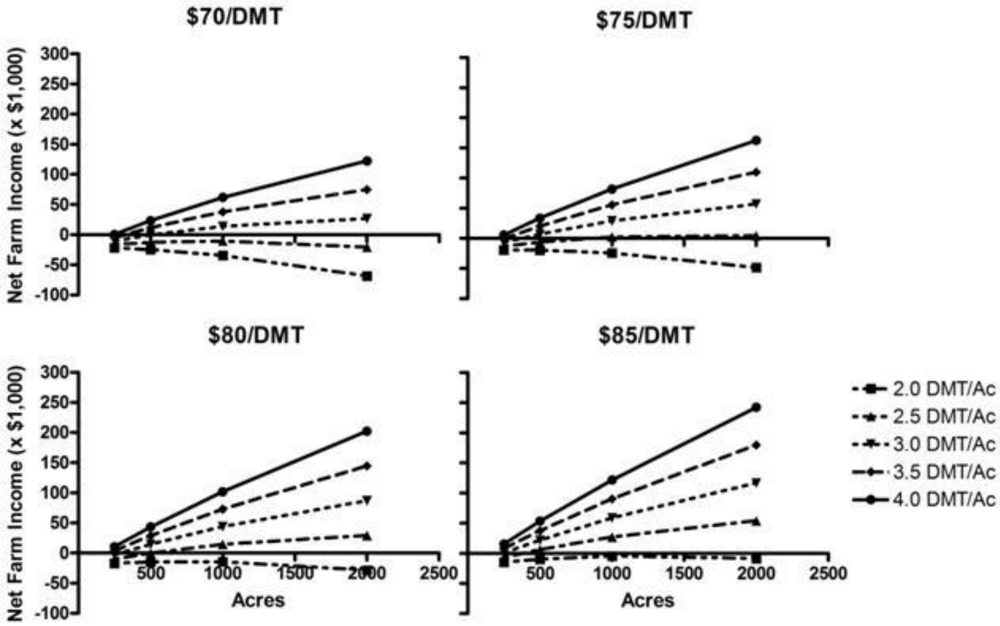

Figure 12: Estimated Annual Net Farm Income[a]. Net farm income levels are dependent upon production scale, yield, and price. Income estimates displayed are for production scales of 250-2000 acres (on the horizontal axis), ten-year average yields of 2.0-4.0 dry matter tons/acre, and farm-gate prices of $70-$85/ton.[b]

a. Net Farm Income = Revenues – Total operational expenses – Total ownership expenses. Model assumes farmer receives the entirety of a $50 per acre assessment on Land and Management charge, and is able to conduct 100% of Field Labor (250-1000 acres), or 50% of Field Labor (2000 acres).
b. DMT= Dry Matter Ton, DMT/Ac.= Dry Matter Tons per Acre

VI. Processing and End Uses

A basic question about the feasibility of growing grass for biomass in Aroostook County is what type of fuel is most likely to be technologically viable and economically cost-effective. There are several possibilities for processing grass biomass into a thermal energy feedstock, after it leaves the farm. The choice of a cost-effective processing system hinges on many factors, including most critically:

- The existence of end users for different grass-based fuels and the volume of demand.
- The cost of producing and storing different fuel products.
- The current and expected market price for different fuels.
- Transportation distances and costs, from farm-to-processor and from processor-to-end user.

A feasibility analysis should also take into account the *opportunity cost* posed by existing markets for non-fuel uses of the harvested grass.

Processing

1. Minimal or No-Processing Systems

A minimal or no-processing system would utilize whole grass bales, with either automated or manually-fed combustion technology. These systems are best suited for on-farm, institutional (e.g. schools/hospitals), or district (municipal) heating applications. All whole bale systems require some operator labor to unload feedstock, and most require loading of bales onto a conveyor system or directly into the combustion chamber. Lin-ka (linka.dk) and Skanden (skanden.com) are manufacturers that advertise highly automated whole-bale systems. These systems employ combustion chambers that are fed indirectly, whereby the operator loads bales onto a conveyor (typically large square bales) and the conveyor feeds them into a mill where the straw is reduced to a uniform length, metered, and fed into the combustion chamber.

The principal benefit of whole-bale systems is minimal processing, saving much of the fossil fuel and equipment cost of more elaborate fuel densification systems. The primary drawbacks are higher capital costs for the combustion system and larger and more expensive storage facilities.

2. Centralized Processing

A centralized processing system would employ the same industrial model as the current Maine wood pellet industry. A pellet-making facility would be constructed in a central location and farmers would deliver raw feedstock to be processed into densified fuels. Size and geographic reach of the pellet facility would depend upon the current and projected volume of market demand, based on the scale of investment in pellet-burning facilities in the region. The benefit of a centralized processing facility is production of a uniform, energy-rich fuel with greater BTU output per unit volume. Densifed fuels would permit a greater geographical market range than grass bales, given their lower transport cost per energy unit and the existence of many pellet burning facilities in the region. Grass *could* be blended with wood to produce pellets lower in ash and corrosive combustion byproducts than purely grass pellets. Primary drawbacks of centralized processing are the higher processing cost, energy input, and emissions (compared to whole bales) and the typically longer transportation distances for both raw feedstock and finished product. On a cost per energy unit basis, densified products are more expensive than whole-bale systems. For example, baled grass may have a higher moisture content than pellets and thus have fewer useable BTUs. However, at a price of $100 per ton baled versus $200 per ton pelletized, having 10% fewer usable BTUs still leaves whole grass combustion cost-effective, at approximately $8.40/mbtu for bales versus $15.03/mbtu for pellets.

One recently developed potential is a business in Waterville, Bragdon Farms, LLC, that just began (March, 2015) using waste hay to produce 4” diameter by 12” long densified hay logs for use in stoves. They plan to produce up to 1 million logs per year in Waterville; at 5 pounds per log, this could utilize over six thousand round bales (at 750 pounds). Mr. Bragdon said he may be shipping hay in from Quebec, and thus there may be feasibility to ship from northern Maine.

A similar facility could also be developed for Aroostook County. Interested producers should contact Peter Bragdon at p.bragdon@myfairpoint.net.

3. Decentralized or Mobile On-Farm Processing

On-farm processing technology became popular in the mid-2000's with the advent of bio-diesel fuels. It was often considered an inexpensive alternative to buying commercial diesel. Too often though, the cost-and-return calculations of farmer-created fuel have not taken into consideration the labor involved in creating the on-farm fuel.

Small-scale densification systems are readily available and marketed to do-it-yourselfers as the cheaper route for creating pellet fuels. Buskirk Engineering (buskirkeng.com) has several lines of small-scale adaptable mills that are mobile and can be electrically powered or tractor-driven. Several start-ups in the northeast are currently conducting trials with mobile densification units. Mobile, on-farm units provide benefits of decreased transportation and associated energy and emissions costs, as well as physically uniform fuel. The drawbacks however, are significant labor inputs and high unit costs at small scale. In addition, the ash, clinker and corrosive by-products characteristic of all-grass pellets would remain (see below). In principle, the scale limitation could be somewhat offset if a farmer cooperative or a custom pellet maker used a mobile unit on several farms.

4. Densified Fuel Types and Combustion Appliances

Though whole bales may be used as fuel, densified grasses provide greater uniformity, energy density, and market access. Biomass can be made into pellets, briquettes, or cubes. The quality of the feedstock and the resultant combustion characteristics may be more important for market acceptance than any other factor.

Grass generates more ash residue than wood pellets, so combustion appliances need some way of handling large amounts of ash. A number of appliances currently sold or under design have either automatic ash removal systems or expanded ash holding capacities. Another problem identified with burning grass is its high potassium content compared to wood pellets. This typically results in clinkers: large aggregates of ash that bind and form hard deposits in combustion chambers. This limitation can be overcome either by adding a liming agent in the pellet making process or by installing a combustion chamber with a moving-grate system or stir bars; the latter has already been added by some appliance manufacturers. The most difficult problem is increased corrosion due to the high chlorine content of most grasses (Glarborg, 2007). Corrosion is significantly higher than with a woody counterpart. Although there has been little study into the seriousness of this problem, it is expected that hydrochloric acid corrosion would severely shorten the useful life of most appliances. Possible solutions might be to line exposed combustion areas with expensive stainless steel or to use ceramic linings. In sum, it is likely that these technical problems can be overcome, but at an as yet undetermined expense.

5. Pellets

The production of grass pellets is similar to that of wood pellets. It employs the same equipment and has a roughly comparable final product appearance. The processing includes size reduction of the raw feedstock with a hammer mill or grinder, moisture conditioning (drying or wetting), addition of binders or blending with woody feedstock, densification, cutting, and then cooling and storage.

Pelletizing grass would give access to the largest current market. Pellets can be used at any scale, from home heating systems to large industrial facilities. However, pure grass pellets would be unsuitable for most existing small-scale appliances and would void their warranties. Warranty is based on standards created by the Pellet Fuel Institute (PFI, pelletheat.org). Three categories of pellet quality are recognized ranging from Premium to Standard and Utility grade. Because of their high ash content, grass-only pellets will likely only achieve utility grade unless significant treatments are designed in the future to lower the chlorine and potassium effluents. There are currently few biomass facilities capable of using utility grade pellets and they are priced well below premium pellets, making it doubtful whether farmers and pellet manufacturers could cover their costs and make a profit.

Provided that farmers could supply grass for $80-$85 per ton of dry matter, the estimated total costs of producing a ton of grass pellets in using a centralized processing facility would range from $185 to $225 per ton of pellets, depending on the scale of the facility and transport distances. This estimated production cost range is above the current $145-175 per ton wholesale price for premium grade wood pellets, and it is highly unlikely that the market would accept a lower grade fuel unless users were offered a substantial discount from the current wood pellet price.

Promising pellet-making experiments have been conducted with various grass-wood blends. Blends in the range of 5-10% grass and 90-95% wood have shown the most promise for reaching standard or even premium grade, suitable for most combustion systems. Given Aroostook County's large volume of woody biomass feedstock, this approach would seem to have considerable promise. However, the problem that has arisen in trials is getting blended feedstocks to extrude and bind into a pellet. A potential solution is to run separate dedicated production lines and blend appropriate proportions of grass and wood pellets after densification.

Grasses mixtures with other feedstocks should provide better results for ash and energy content compared to grass-only fuels. In a Vermont Grass Energy Partnership study (Wilson, 2014), 12 different grass/wood blends were compared against standard wood pellets. Grass types included switchgrass, reed canary grass, and mulch hay, and fuel ratios consisted of 100%, 25%, 12%, and 6% blends of these grasses with wood. Energy content, ash content, chlorine content, emissions, and combustion behavior were analyzed for each blend. Results indicate that 10%-20% grass material in a grass/wood blend can achieve sufficient fuel quality to be marketable as standard grade. As mentioned, the challenge is getting different feedstocks to bind into one pellet.

6. Briquettes and Cubes

Briquettes and cubes are densified fuels that require less energy to produce than pellets. Much of the pre-densification treatment, such as material size reduction, drying, and mixing, is similar to pellet production. Briquettes and cubes are also made through an extrusion process, but they are larger than pellets. Cubes and small briquettes measure approximately 1.5 inches in width and up to 3 inches in length. Briquettes can be made into different lengths ranging from 0.75 inches to over 12 inches.

Briquettes and cubes would compete in markets for larger scale users such as institutions and industries. Ash and clinkers would presumably be easier to handle with larger-scale equipment. For instance, combustion systems at this scale are available with moving grates and automated ash removal. That said, corrosion remains a problem for these systems to contend with.

Total estimated production cost for briquettes ranges from $155 to $185 per ton, while cubes are estimated at a range of $150-$180 per ton. In the market where wood chips currently sell for $45-$75 per ton, these fuels would not be competitive.

Alternative Markets for Grass Biomass

Finally, as previously mentioned, there are a number of alternative uses for grass biomass. The feasibility of growing perennial grass for biomass in Aroostook County will depend in part upon the prices and reliability of markets for uses such as fodder, mulch, and – in prospect – liquid fuel (ethanol) or biogas (methane).

1. Animal Forage

This is currently the primary market for most grass produced in Aroostook County. Research is being conducted at some universities to evaluate the suitability of some high-yielding biomass grass species as feed. Locally, Lucerne Farms utilizes a small amount of RCG in its feed and bedding products.

2. Energy

Within the realm of energy, grass biomass may be better qualified as a feedstock for ethanol production or anaerobic digestion. Neither is commercially viable at scale at present, but both have potential for the future. Cellulosic ethanol would be blended with gasoline. Anaerobic digestion, in which vegetation and/or manures are broken down to provide biogas (methane), has gained traction in recent European research. Biogas could be utilized for energy in several ways. Primarily it is used for heat or combined heat and power (CHP) where it produces electricity and usable heat. Biogas could also go through a cleaning process to provide pure methane (natural gas) and be put into pipelines or compressed to provide a mobile fuel powering automobiles or tractors. From a farm perspective, the crop would be handled like silage, cut and harvested at high moisture and stored in silos or silage bags.

3. Fiber

Grass can be alternative to woody-based fiber in some uses, such as compressed fiber board and paper. Several reports (Nagarajan et al., 2013, Pahkala et al., 1997; Samson et. al, 2014) indicate that in some regions this market has been more lucrative to farmers than the energy market.

4. Bedding/Absorbent Material

A number of farm byproducts have found secondary markets as animal bedding. Some have proven to be more lucrative than their primary market as forage. Wood pellets have been marketed in recent years as both a bedding material and absorbent. Absorbent markets are wide-ranging from retail consumer to industrial-scale.

5. Phytoremediation

Some biomass grasses are being utilized to clean up contaminated soils such as brown field sites and waste-water discharge areas.

Overall Conclusion – Can Perennial Grasses be Grown Locally and Marketed?

Several challenges presented in utilizing grass as an energy resource are not yet fully understood, much less resolved. It is best currently thought of as a potential alternative feedstock to call upon if the need arises in the future. At current prices for competing fuels, grass is too expensive to produce, handle, and process, especially given its sub-standard quality relative to wood-based pellets or chips. The most cost-effective current scenario is to use grass in large-scale, whole-bale systems for industrial, institutional, or district heating applications. As a locally or regionally sustainable fuel, it makes greater financial sense to avoid the densification process, since whole bales can be shipped well beyond the borders of Aroostook County for the estimated per ton cost of processing. Foregoing processing is also more sustainable from an energy and emissions perspective.

The current state of densification and combustion technology alleviates some but not all technical problems. Improvements are needed for managing nutrient and salt content. This could be achieved through either agronomic means, such as varietal development, or technological means, such as extraction systems that reduce concentrations of problematic constituents to levels acceptable for use in a wider range of combustion systems. Another research area is combustion system technology. From small-scale appliances such as stoves to large-scale, multi-million BTU systems, steps are being made to develop multi-fuel capable systems. For example, some currently marketed combustion systems have moving grates or stirring mechanisms to prevent clinker formation; some have automatic ash removal systems and high-capacity ash storage; and some have both features. The most lacking area of current research is into the long term effects of corrosion: its effects on combustion systems and how to reduce them in a cost-effective manner.

In sum, given the combination of currently available technologies and transportation costs, the greatest near-term promise appears to be for whole bale combustion systems located within a short radius of the producing farms. A mix of technological obstacles, high densification costs, and grass' inherent limitations as a feedstock make it very unlikely that markets will develop any time soon for densified fuels made entirely or partially of grass.

Alternatives to Growing Grass Biomass on Idle Agricultural Lands

We have concluded that technological or market factors make widespread perennial grass production unlikely until several hurdles are eliminated. However, many other opportunities for using these lands would benefit from private-public discussion and partnerships. Indeed, given the recent release of thousands of acres from the Federal Conservation Reserve Program, there may be considerable interest in re-evaluating land use for these and other agricultural land not used for higher value row crop production. The initiatives described here would require pro-action, stakeholder engagement, and, in some cases, government incentives to be realized. One land use change, which may continue with little pro-action, stems from the in-migration of Mennonite and Amish families to the towns of Smyrna, Bridgewater, Easton, and Fort Fairfield. These communities have added value to the local economies by purchasing and renovating underutilized agricultural and forest land, converting it to pasture, forage crops, and other uses. Commercial hay production is also poised for growth, given both the regional demand for hay and continued growth and success of value-added livestock feed production at Lucerne Farms of Easton. Although the number of farms producing hay has decreased since the 1980's, yields have risen and the total dry tonnage and yield per acre is higher than in earlier years for which data are available (Table 5).

Table 5: Total hay production in Aroostook County, ME for select years.

	2012	2007	2002	1987
farms	241	269	261	329
acreage	27362	21175	33073	17561
dry tons	54079	49712	47237	28902
dry tons/acre	2.0	2.3	1.4	1.6

Within the energy sector, alternatives to grass for biomass would also require new equipment, processing facilities, or markets. One option is cultivating shrub willow (*Salix salix),* harvested every three years, as a woody feedstock for pellet manufacture or for the biomass electricity generators in Ashland and Fort Fairfield (owned by ReEnergy corporation). According to ReEnergy, the gate price would be the same as for wood chips; and they are interested in purchasing willow biomass (personal communication, 2015). Advances in harvesting technology, cultivar selection, and agronomic practices have lead to viable production of willow in New York and in many parts of Europe. To insure a steady harvest each fall, plots should be established in three consecutive years. Current incentives to defray establishment costs, available through USDA's Biomass Crop Assistance Program (BCAP), help make willow production economically viable. A specialized New Holland harvester is being marketed; and hay wagon and other transportation and handling equipment are required. However, given the lack of processing and the existing local market, willow may be a profitable alternative for some underutilized land.

Another energy sector alternative is production of sugar beets for ethanol. The agronomic feasibility of this option is excellent: pH management (i.e. liming) and early season weed management are the most important requirements. However, ethanol production requires a processing facility which would likely need greater than 10,000 acres in beet production (plus additional rotation land) to be economically feasible. The most compelling reason to explore ethanol production from sugar beets is the Federal renewable fuel standard, which requires gasoline producers to blend up to 10% ethanol in gasoline. While sugar beets have a stigmatized history in Aroostook County going back to the 1970's, these new options may be worth pursuing. A related alternative is to grow organic fodder beets for feed in the organic dairy and beef markets. Organic Valley is expanding milk and crop production in Maine, and has begun trials of beet production for dairy cows, including in Aroostook County during 2014.

The final alternative worth consideration has a long and storied history in Aroostook County: food production. As potato acreage has declined over several decades, few other crops - apart from broccoli and small grains in rotation - have received widespread adoption. The recent growth of the "eat local" movement, increasing worldwide food demand, and the growth of small farms operated by younger farmers throughout Maine may position northern Maine to increase crop and livestock production on smaller farms, for statewide, niche, and organic markets. The Northern Maine Development Commission/Aroostook Partnership for Progress, the Maine Sustainable Agriculture Society, Maine Farmland Trust, and the Maine Farm Bureau are working to identify new markets and to reduce transportation and other logistical barriers.

In conclusion, conversion of Aroostook County's extensive sub-prime farmland to grass biomass production is not feasible under present technological and market conditions. However, our investigation suggests that "its time may come" in the future; and, in the meantime, there are brighter prospects for several other, more productive, land uses.

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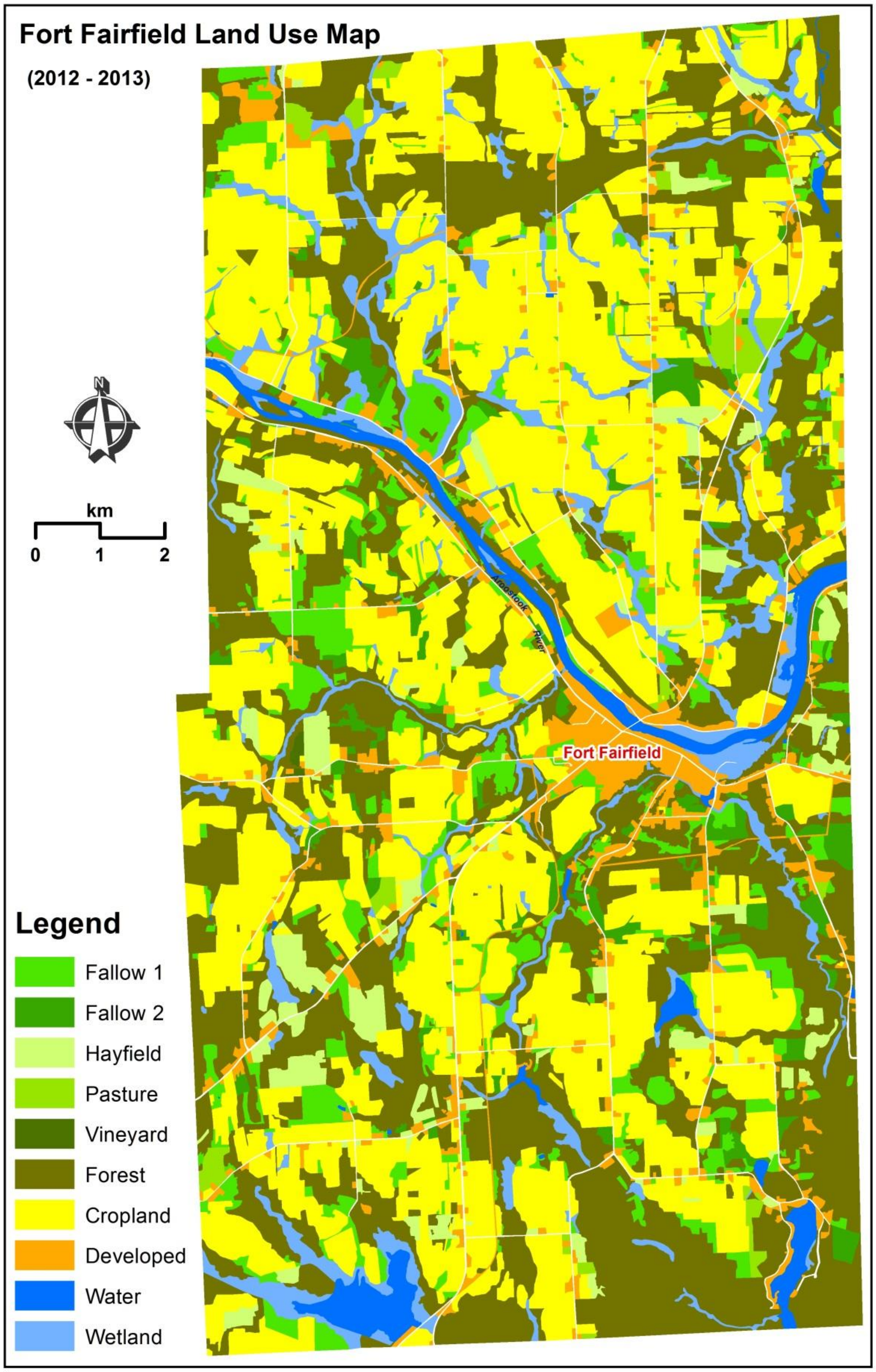
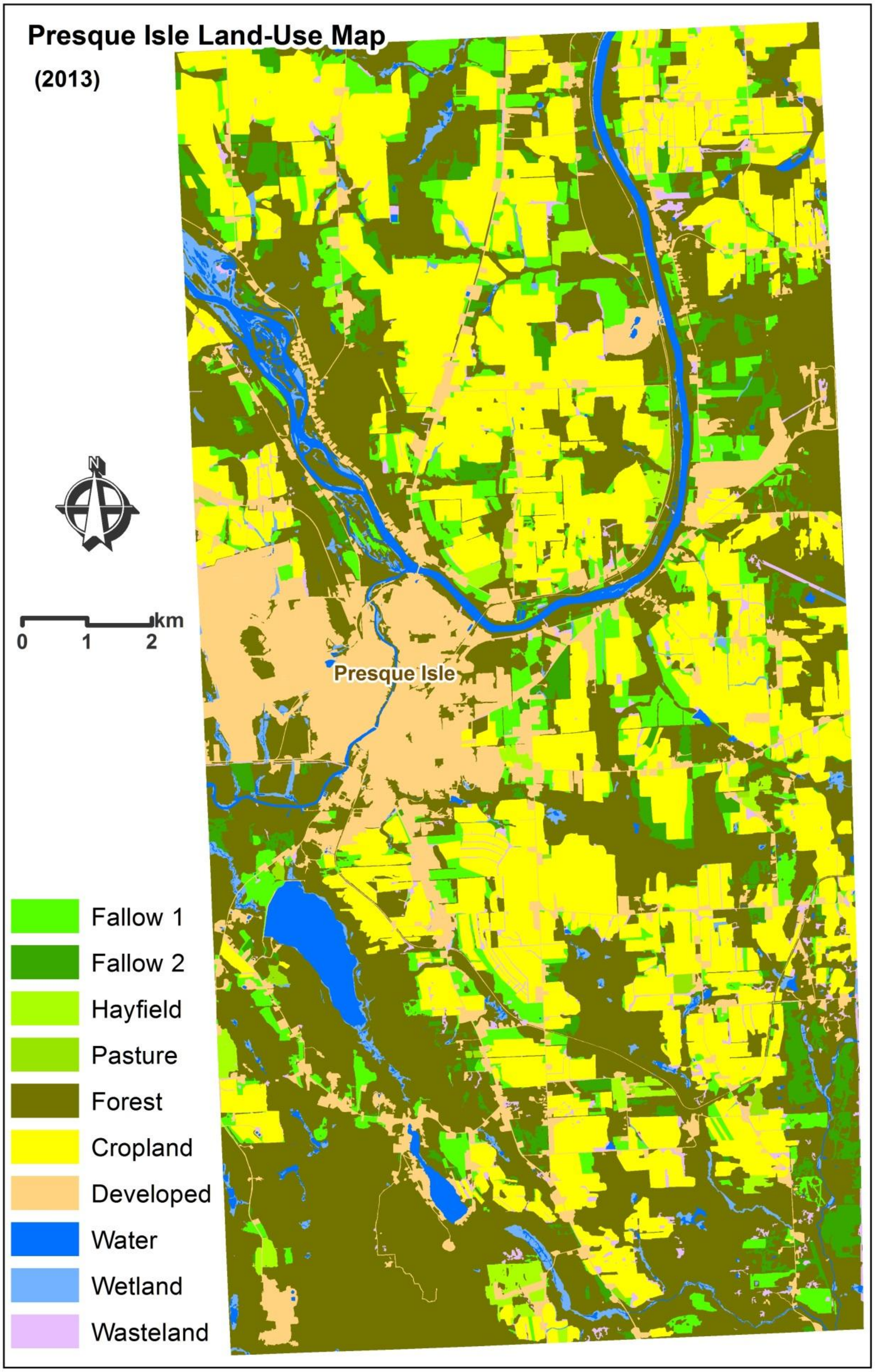
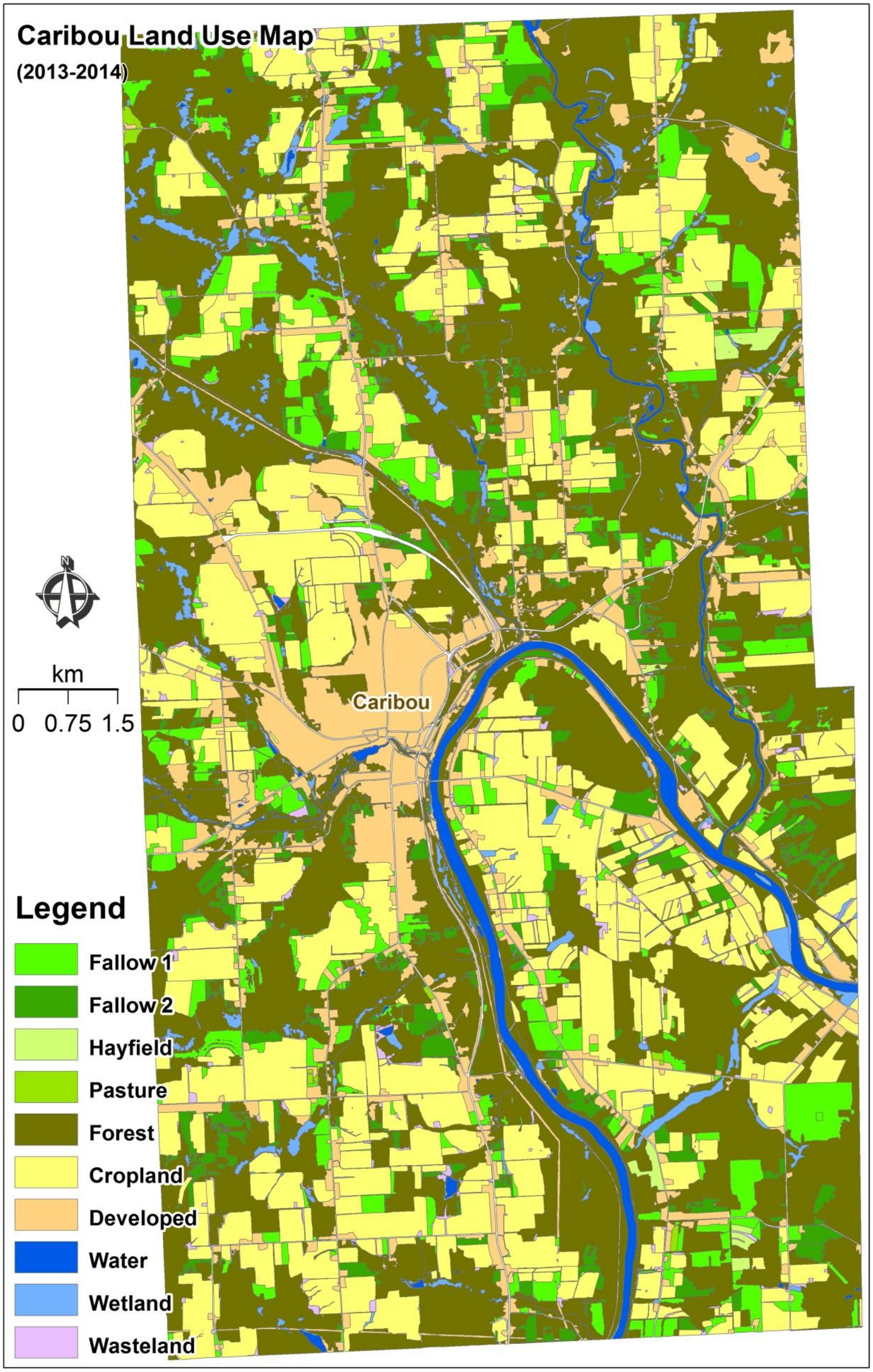
Appendices

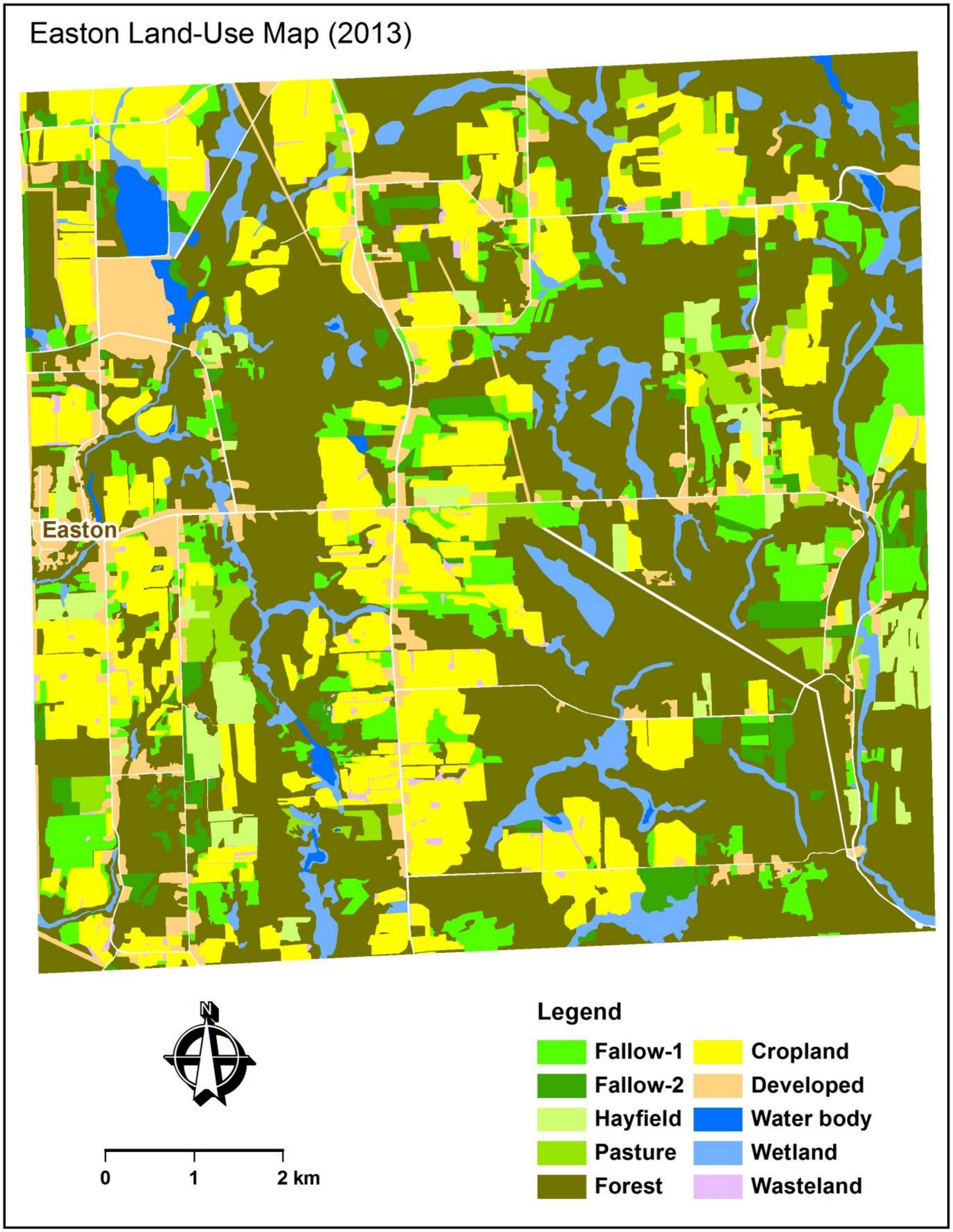
Appendix A1: Land-use maps of Fort Fairfield, Presque Isle, Caribou, and Easton



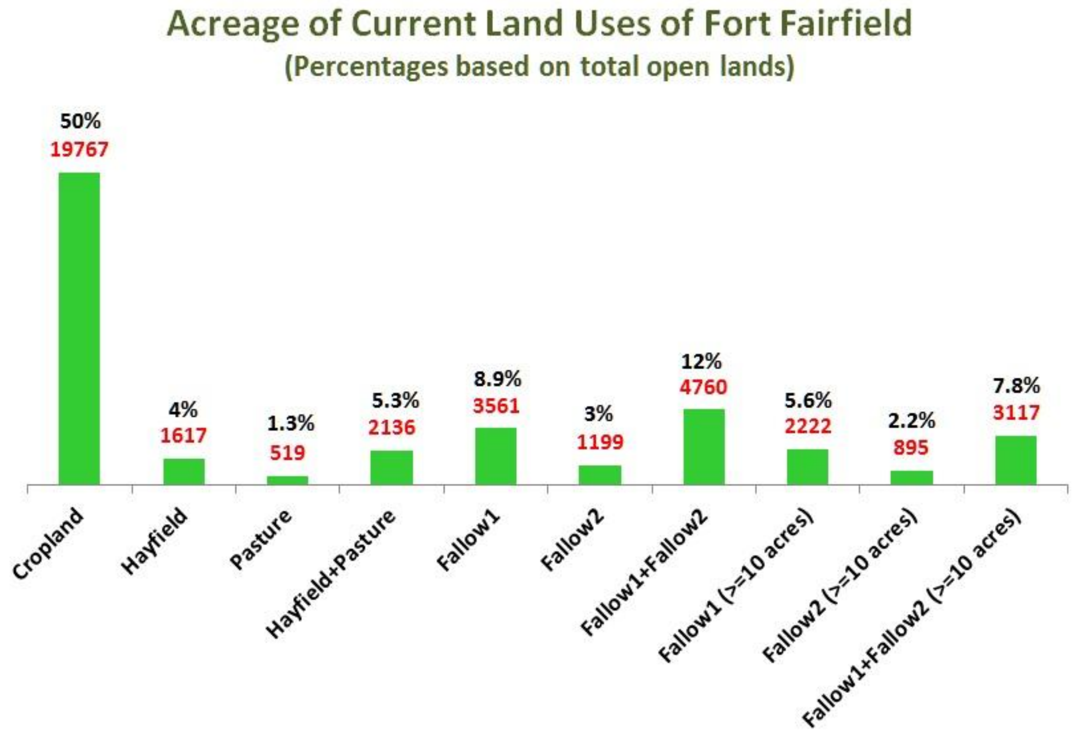

Presque Isle Land-Use Map
(2013)
N
0
1
2
km
Presque Isle
Fallow 1
Fallow 2
Hayfield
Pasture
Forest
Cropland
Developed
Water
Wetland
Wasteland

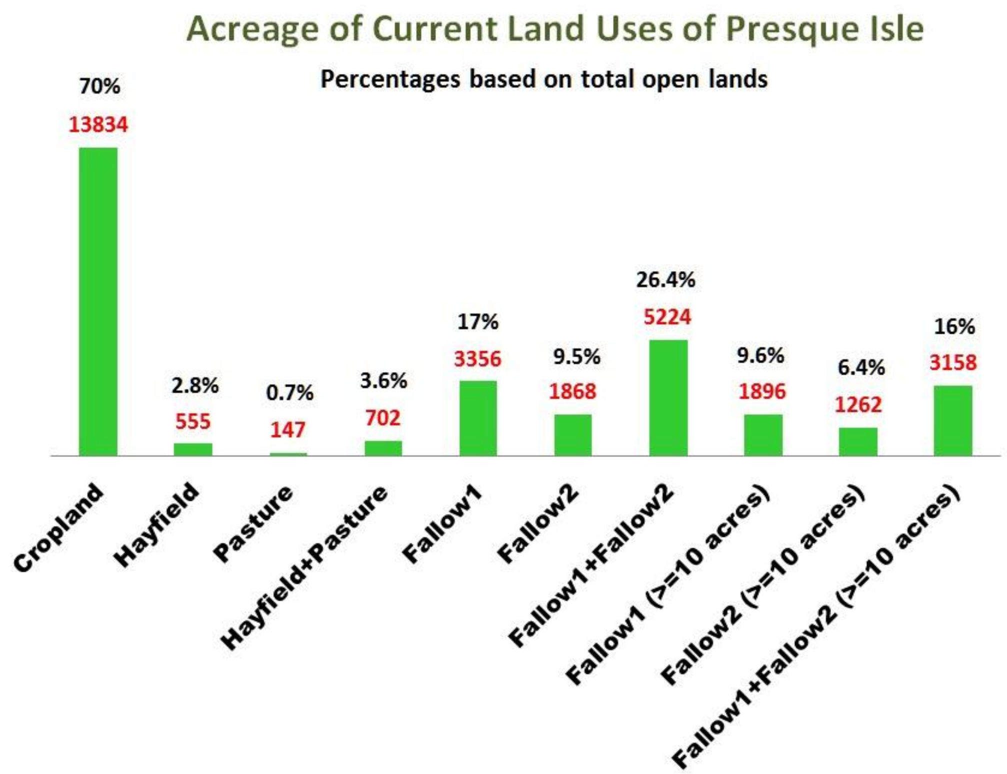


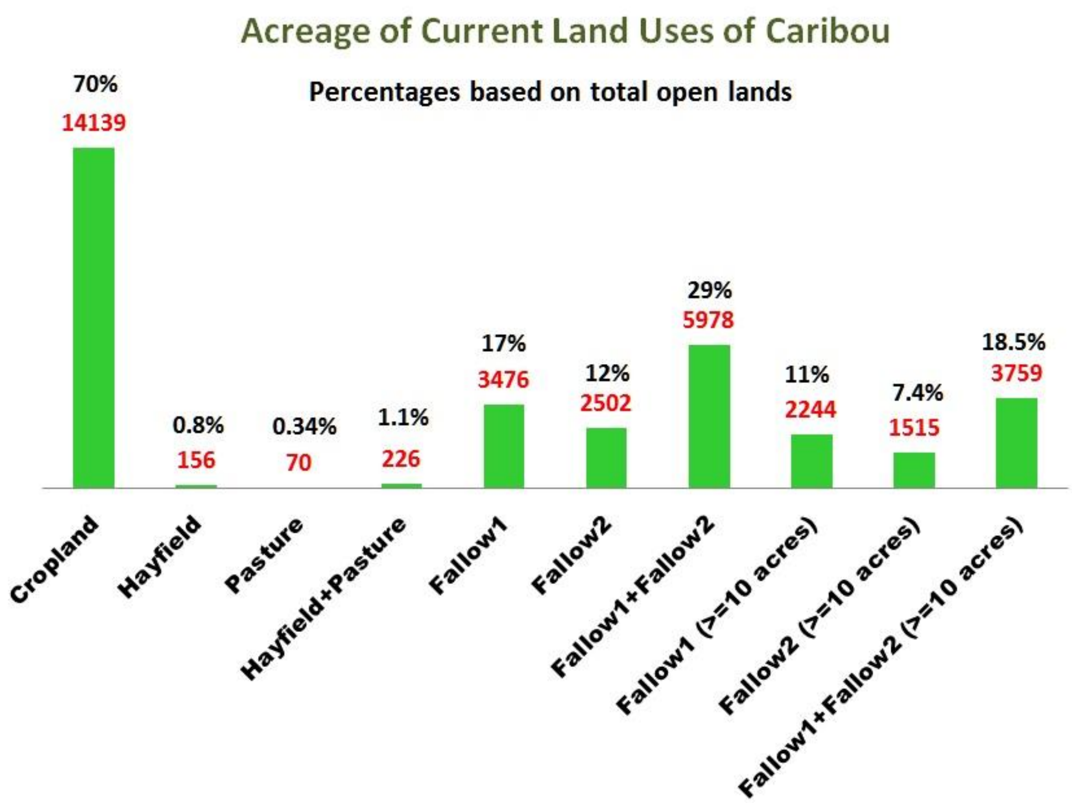
Caribou Land Use Map
(2013-2014)
km
0 0.75 1.5
Caribou
Legend
Fallow 1
Fallow 2
Hayfield
Pasture
Forest
Cropland
Developed
Water
Wetland
Wasteland

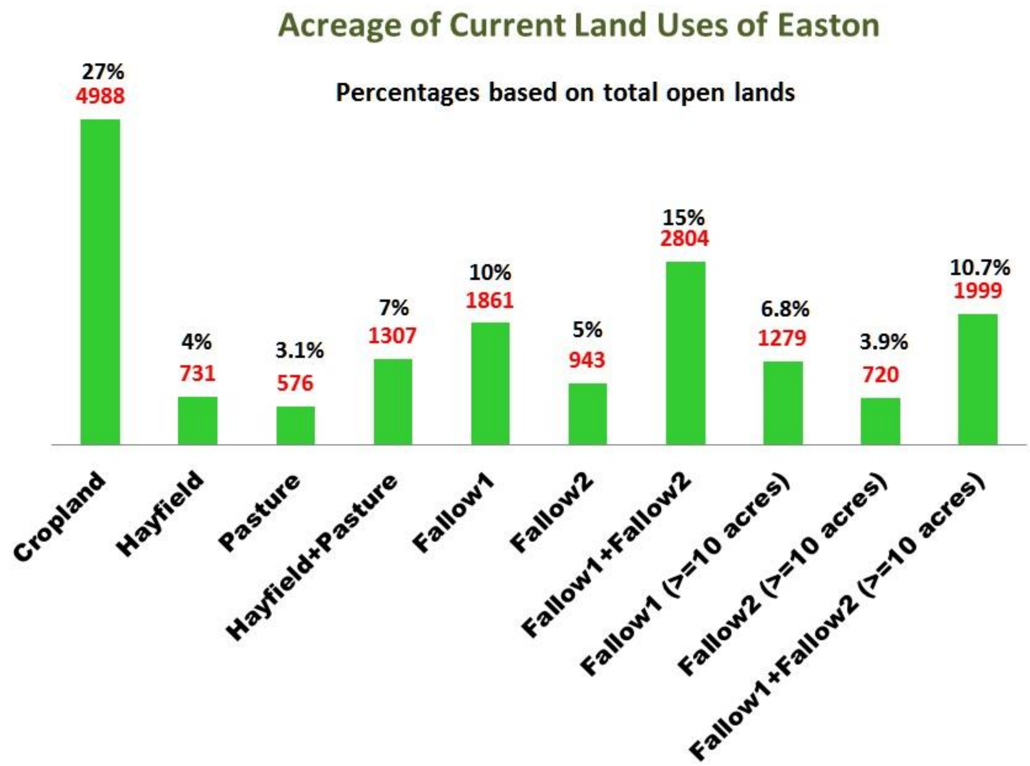

Easton Land-Use Map (2013)
Easton
Legend
Fallow-1
Fallow-2
Hayfield
Pasture
Forest
Cropland
Developed
Water body
Wetland
Wasteland
N
0
1
2 km

Appendix A2: Acreage of current land uses in the four townships of Fort Fairfield, Presque Isle, Caribou, and Easton




Acreage of Current Land Uses of Presque Isle
Percentages based on total open lands
70%
13834
2.8%
555
0.7%
147
3.6%
702
17%
3356
9.5%
1868
26.4%
5224
9.6%
1896
6.4%
1262
16%
3158
Cropland
Hayfield
Pasture
Hayfield+Pasture
Fallow1
Fallow2
Fallow1+Fallow2
Fallow1 (>=10 acres)
Fallow2 (>=10 acres)
Fallow1+Fallow2 (>=10 acres)


Acreage of Current Land Uses of Caribou
Percentages based on total open lands
70%
14139
0.8%
156
0.34%
70
1.1%
226
17%
3476
12%
2502
29%
5978
11%
2244
7.4%
1515
18.5%
3759
Cropland
Hayfield
Pasture
Hayfield+Pasture
Fallow1
Fallow2
Fallow1+Fallow2
Fallow1 (>=10 acres)
Fallow2 (>=10 acres)
Fallow1+Fallow2 (>=10 acres)



Appendix B: Perrenial Grass Yield Trials, 2010-2012

Table B1: Yield in dry matter tons per acre (DMT/Ac.), British thermals units (BTU), and ash as a percentage of dry matter content, of reed canary grass (RCG) and switchgrass (SWG) from plots in Caribou, Maine. Plots were fertilized (75 lbs N/Ac., Ammonium Nitrate 30-0-6) with one spring application.

Variety	Yield (DMT/Ac)		BTU/lb (Dry)	Ash (%, DM)
Palaton (RCG)	0.94	ab	8,317	1.46
Venture (RCG)	0.74	b	7,820	1.63
Marathon (RCG)	0.86	ab	8,197	1.57
Cave-in-rock (SWG)	0.69	b	8,024	1.97
Shawnee (SWG)	1.07	ab	7,496	1.64
Carthage (SWG)	1.01	ab	7,996	1.91
Blackwell (SWG)	1.39	a	8,324	1.37
Dacotah (SWG)	0.98	ab	8,016	1.97

*Yield means followed by the same letter are not significantly different (Tukey's HSD, p=0.05) from each other.

Table B2: Yield in dry matter tons per acre (DMT/Ac.), British thermals units (BTU), and ash as a percentage of dry matter content, of reed canary grass (RCG) and switchgrass (SWG) from plots in Houlton, St. Agatha, and Caribou, Maine during 2011. For each variety collected, split-plots of spring fertilization versus no fertilization were compared (75 lbs N/Ac., Ammonium Nitrate 30-0-6).

Houlton, ME		
Variety	**Fertilization**	**Yield (DMT/Ac.)**
Palaton(RCG)	Y*	2.37 ab**
	N	1.40 b
Venture(RCG)	Y	3.17 a
	N	1.47 b
Marathon(RCG)	Y	3.35 a
	N	1.67 b
Caribou, ME		
Variety	**Fertilization**	**Yield (DMT/Ac.)**
Palaton(RCG)	Y	0.74 b
	N	0.54 b
Venture(RCG)	Y	0.61 b
	N	0.62 b
Marathon(RCG)	Y	1.15 a
	N	0.45 b
Blackwell(SWG)	Y	1.81 a
	N	1.09 ab
St. Agatha, ME		
Variety	**Fertilization**	**Yield (DMT/Ac.)**
Palaton(RCG)	Y	1.55 ab
	N	0.65 b
Venture(RCG)	Y	1.61 ab
	N	1.45 ab
Marathon(RCG)	Y	2.26 a
	N	1.28 ab

* Fertilization: Y = 75lb/ac nitrogen (30-0-6), N= 0lb/ac nitrogen
**Yield means followed by the same letter are not significantly different (Tukey's HSD, p=0.05).

2012
Tables B3: Yield in dry matter tons per acre (DMT/Ac.) of reed canary grass (RCG) and switchgrass (SWG) varieties grown in Caribou and St. Agatha, ME during 2012. For each

variety collected, split-plots of spring fertilization versus no fertilization were compared (75 lbs N/Ac., Ammonium Nitrate 30-0-6).

Caribou, ME		
Variety	**Fertilization**	**DMT/Ac.**
Palaton (RCG)	Y*	1.46 abc**
	N	0.38 bc
Venture (RCG)	Y	0.84 bc
	N	0.42 bc
Marathon (RCG)	Y	1.74 abc
	N	0.00 c
Blackwell (SWG)	Y	3.74 a
	N	2.24 abc
Shawnee (SWG)	Y	2.61 abc
	N	0.41 bc
Dacotah (SWG)	Y	2.53 abc
	N	1.53 abc
Cave-in-Rock (SWG)	Y	3.01 ab
	N	0.87 bc

St. Agatha, ME		
Variety	**Fertilization**	**DMT/Ac.**
Palaton (RCG)	Y	4.09 a
	N	1.70 b
Venture (RCG)	Y	3.26 ab
	N	1.72 b
Marathon (RCG)	Y	4.03 a
	N	1.63 b

* Fertilization: Y = 75lb/ac nitrogen (30-0-6), N= 0lb/ac nitrogen
**Yield means followed by the same letter are not significantly different (Tukey's HSD, p=0.05).

Illustrative Enterprise Budget for Biomass Grass: 500 acres

	Total	Per Acre	Per DMT

Number of Acres	500	-	-
Biomass Yield (DMT[a])	1,750	3.5	-
Price ($/DMT[a])	-	-	$80
Annual Revenue	**$140,000**	**$280.00**	**$80.00**
Annual Operating Expenses			
Seed (RCG/SWG[b])[c]	$3,600	$7.20	$2.06
Fertilizer (30-0-6) 250lbs/Ac.	$34,200	$68.40	$19.54
Lime (1 Ton/ 3yr)	$4,950	$9.90	$2.83
Chemicals (Herbicides)[c]	$1,175	$2.35	$0.67
Field Labor	$3,850	$7.70	$2.20
Diesel Fuel, Oil, Grease	$2,495	$4.99	$1.43
Maintenance and Upkeep	$1,940	$3.88	$1.11
Supplies	$1,815	$3.63	$1.04
Custom Hire (Establishment tillage & seeding)[c]	$7,350	$14.70	$4.20
Freight and Trucking (Fuel and Labor)	$16,480	$32.96	$9.42
Storage and Warehousing (6mo, Crushed Rock Pad & Tarp)	$20,355	$40.71	$11.63
Operating Interest (6mo, 4%)	$1,005	$2.01	$0.57
Total Operating Expenses	**$99,215**	**$198.43**	**$56.69**
Annual Ownership Expenses			
Depreciation and Ownership Interest	$14,305	$28.61	$8.17
Tax and Insurance	$470	$0.94	$0.27
Equipment Housing	$945	$1.89	$0.54
Land and Management Charge[d]	$25,000	$50.00	$14.29

Total Ownership Expenses	**$40,720**	**$81.44**	**$23.27**
Total Annual Cost	**$139,935**	**$279.87**	**$79.96**
Net Farm Income (NFI)	**$65.00**	**$0.13**	**$0.04**
Return over Variable Cost (ROVC)	**$40,720**	**$81.44**	**$23.27**

a. DMT= Dry Matter Ton, $/DMT= Dollars per Dry Matter Ton
b. RCG= Reed Canarygrass, SWG= Switchgrass
c. Budgeted costs in these categories are annualized over a ten year period (expected productive life of grass stand).
d. Land and Management Charge is a nominal fee to guarantee a return to land and ownership of land and operations. A $50/acre payment to landowners was assigned as being at the low end of the scale for net returns on annual row-crop production (potential competing market for future land-use, i.e. food crop production).

Budget Line Item Definitions and Explanations

Number of Acres- Grass acres farmed by individual or cooperative. Financial analyses ranged from 250 to 2000 acres.

Biomass Yield- Average yield in dry matter tons (DMT) expected per year over a ten year period. Range for analyses was 2.0-4.0 DMT/Acre, based upon field experiments conducted from 2009-2012.

Price- $/DMT paid to the grower. For all analyses this was assumed to be at the farmgate or Freight On Board (FOB) pricing. Range for analyses was $70-$85/DMT.

Annual Revenue- The gross expected income based upon the preceding data inputs.

Annual Operating Expenses- Listed below are variable costs that a farmer would account for and likely change on a yearly basis.

Seed- Reed Canary grass is typically planted at a recommended rate of 10-12lbs/acre depending on purity of seed and germination rates. Switch grass is typically planted at a rate of 8-9 lbs/acre, again depending on the purity and germination. Costs of Reed Canary grass and Switch grass respectively range from $6-$8/lb and $8-$10/lb. For this annual budgeted line-item, the cost has been annualized over a ten year period.

Fertilizer- Annual applications of fertilizer will be of benefit to the crops to replace harvested nutrients. Cost is based upon the purchase of Ammonium Nitrate (30-0-6), and applied at a rate of 250 lbs/acre.

Lime- Grass will grow best when maintaining soil pH levels between 6.0-7.0. Post-establishment maintenance of pH assumes an application of 1 ton of lime or liming equivalent (wood-ash) every 3-4 years.

Chemicals- The only currently assumed required chemical inputs for this system would be broadleaf herbicides. For this budget estimate it is assumed to include a pre-plant burndown of existing vegetation using glyphosate, followed by an application of a broadleaf herbicide such as 2,4-D the year after grass establishment. For this annual budgeted line-item, the cost has been annualized over a ten year period.

Field Labor- This estimate only includes the labor associated with conducting field work prior to stacking, hauling, and storage of harvested bales. Hourly rate used is $14.00 per hour.

Diesel Fuel, Oil, Grease- This is an estimate of cost per acre in running a tractor and selected implements. Assumed cost per gallon is $3.75.

Maintenance and Upkeep- Estimate of repair and upkeep for equipment and tractor.

Supplies- Budgeted items such as twine and tools for equipment repair.

Custom Hire- Implements used for establishment would rarely be used (1 in 10 years). It is therefore economically beneficial to contract with a third party or rent implements to complete establishment. This estimate includes primary and secondary tillage (2x disc and harrow), 2-ton application of liming agent, the use of a seed drill, and the fuel and labor associated with the practices. For this annual budgeted line-item, the total establishment cost has been annualized over a ten year period.

Freight and Trucking- This is an estimate of cost for taking harvested bales from field to storage. The estimate includes labor costs of stacking, trucking, and unloading, as well as the fuel costs for the transportation of materials. It is assumed that average loaded trip length for 250 and 500 acre scale is 5 miles; 10 miles for 1000 acre scale, and 15 miles for 2000 acre scale. (http://www.farmfoundation.org/news/articlefiles/364-Popp%20Switchgrass%20Modules%20SS%20no%20numbers.pdf)

Storage and Warehousing- It is assumed that whether on-farm processing or processing at a centralized facility is employed, that farmers will need to store the harvested crop. This estimate is based upon the cost to build and maintain a crushed-rock pad with a tarp to go over a pyramid-stacked pile. It also includes an estimate of dry matter loss due to spoilage of the stored crop over a 6-month period. (http://fyi.uwex.edu/forage/files/2014/01/BaleStorage5-7-04.xls)

Interest- Estimate of interest paid over the time period of six months for a production loan that covers the costs of operating expenses. Estimated interest rate of 4%.
Total Operating Expenses- The sum total of Annual Operating Expenses.

Annual Ownership Expenses- Listed below are portions of the estimated budget that include costs associated with owning equipment, vehicles, housing, and land.

Depreciation and Interest- Estimate of cost for decreasing value and loan interest for ownership of equipment. Equipment included a 75 HP Tractor, half-ton pickup, 9-foot mower conditioner, 9-foot hydraulic hay rake, 2 hay wagons, fertilizer spreader, and a 1,000lb round bale hay baler.

(Values for equipment were obtained from University of Minnesota Extension's Machinery Cost Estimates; Lazarus, 2012).

Tax and Insurance- Estimated costs of taxes and insurance on capital equipment.

Equipment Housing- Estimated cost of providing storage areas for equipment.

Land and Management Charge- A nominal fee to guarantee a return to land and ownership of land and operations. A $50 value was assigned as being at the low end of the scale for net returns on annual row-crop production (potential competing market for land-use).

Total Ownership Expenses- Sum total of Annual Ownership Expenses.
Total Annual Cost- Sum total of Annual Operating and Ownership Expenses.

Net Farm Income- Sum of Annual Revenues minus Total Annual Cost. Note: for farmers who own and farm their own land, and conduct a majority of the field labor, they will have a greater portion (or total) of the Land Management Charge and Field Labor values, and should adjust their net income levels according to their own situation.

Return over Variable Costs- Sum of annual revenues minus total operating expenses.

Payback of Biomass Grass Investment
In view of the significant "up front" cost of converting idle acreage to high yielding grass species intended for high-volume, low-value markets, we analyze the "payback period" on initial investment. The analysis takes account of establishment costs described in the sample budget (Table x), including seed, custom hire, and herbicide applications. Payback periods, dependent on production scale, yield, and price, are shown in Figure y. The year of establishment, when a crop should not be harvested, is folded into the analysis.

Estimates of productive stand-life are fairly subjective, with most research providing a range of 10-20 years depending upon grass species, geographic location, associated climate, nutrient management, and harvest frequency. For budgeting purposes, the more conservative value of 10 years productive stand-life was utilized when annualizing costs in the budget.

As expected, years to payback decrease with increasing prices and average yields. The magnitude of the decrease in years to payback, however, becomes successively less with each increment to yields and prices. This is likely a reflection on yields and prices having greater influence on years to payback than scale of production. The effect of production scale is similar to the net farm income response, where the greatest effects are observed between 250 and 500 acres, with little change from 500-1000 acres and essentially none beyond 1,000 acres.

Most noteworthy is that, regardless of scale, price or yield, the shortest payback period is roughly 5 years. This could be concerning to farmers deciding whether to invest in biomass grass crops. The time needed to pay back the initial investment could be as much as half of the expected useful life of the crop. This calculation, combined with the inherent risk of poor weather and longer term climate effects may discourage many farmers from making such an investment.

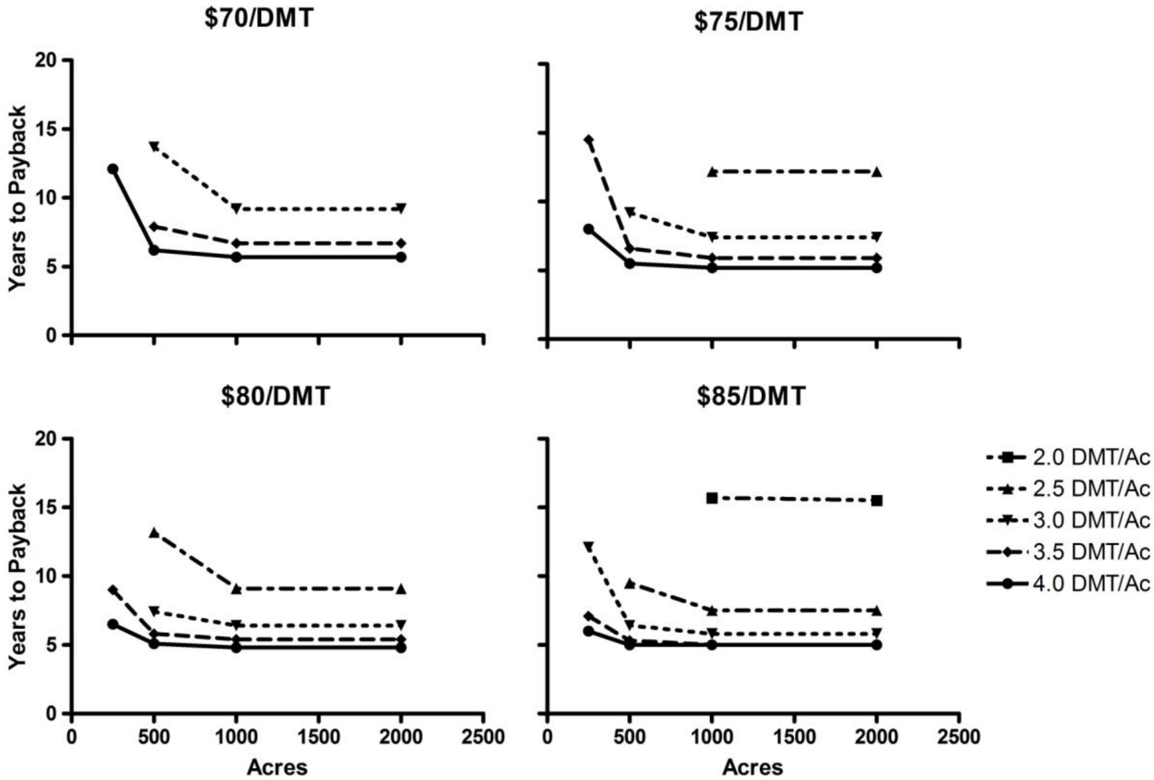


Figure B1: Estimated years[a] to payback initial investment (reseeding with new grass variety). The amount of time it takes to recoup the investment of renovating existing grass stands with new, high-yield grass species is dependent upon production-scale, average potential yields, and farm-gate price per DMT. Values displayed are for expected independent variable ranges of production-scales (250-2000 Acres), ten-year average yields (2.0-4.0 DMT/Ac.), and farm-gate prices per DMT ($70-85).[b]

a. The number of years in the analysis is restricted to 20 years as that is the generally accepted upper limit of expected stand life expectancy. Conservatively, stands should be budgeted to last approximately 10 years before needing to be renovated.
b. DMT= Dry Matter Ton, DMT/Ac.= Dry Matter Tons per Acre

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