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Economic effects and Energy Use Efficiency of Incorporating Alfalfa and Fertilizer into Grass-Based Pasture Systems

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***Abstract*—**A ten-year grazing study was conducted at the Agriculture and Agri-Food Canada Brandon Research Centre in Manitoba to study the effect of alfalfa inclusion and fertilizer (N, P, K, and S) addition on economics and efficiency of non-renewable energy use in meadow brome grass-based pasture systems for beef production. Fertilizing grass-only or alfalfa-grass pastures to full soil test recommendations improved pasture productivity, but did not improve profitability compared to unfertilized pastures. Fertilizing grass-only pastures resulted in the highest net loss of any pasture management strategy in this study. Adding alfalfa at the time of seeding, with no added fertilizer, was economically the best pasture improvement strategy in this study. Because of moisture limitations, adding commercial fertilizer to full soil test recommendations is probably not economically justifiable in most years, especially with the rising cost of fertilizer. Improving grass-only pastures by adding fertilizer and/or alfalfa required additional non-renewable energy inputs; however, the additional energy required for unfertilized alfalfa-grass pastures was minimal compared to the fertilized pastures. Of the four pasture management strategies, adding alfalfa to grass pastures without adding fertilizer had the highest efficiency of energy use. Based on energy use and economic performance, the unfertilized alfalfa-grass pasture was the most efficient and sustainable pasture system.

***Keywords*—**Alfalfa, grass, fertilizer, pasture systems, economics, energy.

I. Introduction

BEEF producers are considering better utilization of pasture land to reduce feed costs and improve economics of their beef production system. Fertilization of grass or alfalfa pastures was considered an option to improve yield and productivity. However, the stability of income may improve only marginally, if at all, if the limiting agronomic and climatic variables such as moisture are not cooperative. In a review of alfalfa production in pasture systems [10] found that when pasture utilization is less than 70%, individual animal gains are maximized in a range from 107 kg ha^{-1} on dry land to 1946 kg ha^{-1} on irrigated pastures. Improved management techniques are required to attain the higher level of weight gains. Management of renewable resources such as grazing systems can use a threshold policy as a means to maximize production. Reference [1] have shown that threshold forage stand densities combined with the proper stocking intensity can lead to a sustainable grazing system. Reference [9] found that grazing was similar in net return to intensive feedlot systems. In the grazing system, productivity was enhanced by fertilizer and barley supplements to produce acceptable weight gains. These management practices tended to increase profitability and reduce risk. Variability of net return, or risk, is a function of management decisions in response to environmental effects on pasture production, and selling price, see [9]. This variability in net return is due to the fall selling price of steers-pastured in the summer is not known at the time of purchase unless a contract with a feedlot or meat packer is obtained.

The optimal use of inputs (fuel, pesticides and fertilizer) through improved management practices can help increase the profitability of agricultural production while helping to address some of environmental concerns. Fossil fuels provide energy to manufacture fertilizer, fuel, pesticides and other inputs used to produce agricultural products, but they also produce greenhouse gases responsible for climate change. In the past few decades, there has been significant growth in the use of non-renewable energy inputs for agricultural production. Reference [13] reported a 61% rise in energy inputs used on Saskatchewan farms between 1961 and 1976, and [2] reported a further 11% rise between 1990 and 1996. The energy use efficiency of traditional cropping systems has decreased in recent years due to energy inputs increasing faster than energy output as a result of the growing dependency on inorganic N fertilizers and fossil fuels [4], [14]. Agriculture is increasingly dependent on inorganic nitrogen fertilizers and fossil fuels. For example, on-farm fertilizer and fuel use represents more than 80% of the total energy inputs used in conventional grain production systems [15]. Reducing energy inputs reduces cost of production and improves sustainable use of energy. Limited information is

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available about the merits of pasture management system with added alfalfa and fertilizer utilization, on profitability and efficiency of non-renewable energy use at field or farm level.

Adding alfalfa and/or fertilizer to grass-based pastures can increase the profitability of agricultural production while promoting sustainable energy use. Therefore, the objective of this project was to evaluate the effect of alfalfa inclusion and fertilizer (N, P, K, and S) addition on economics and efficiency of non-renewable energy use in meadow brome grass-based pasture systems for beef production.

II. Materials and Methods

A ten-year grazing study was conducted at the Agriculture and Agri-Food Canada Brandon Research Centre in Manitoba from 1994-2004. In the spring of 1994, pastures were established on a Souris fine sandy loam. The study used rotational grazing on four combinations of pasture type and fertilizer management. There were two different pasture types (100% grass or mixed alfalfa-grass) and two different fertilizer treatments (no fertilizer, or spring fertilization to full soil test recommendation levels). This resulted in a total of four treatments, shown in Table I.

TABLE I
Pasture Types and Fertilizer Treatments used in the Study

	Pasture type	Fertilizer added
1	Meadow bromegrass	No
2	Meadow bromegrass	Yes
3	Meadow bromegrass + Alfalfa	No
4	Meadow bromegrass + Alfalfa	Yes

The grass-only pastures were seeded with 11.2 kg ha^{-1} ‘Paddock’ meadow bromegrass. The mixed alfalfa-grass pastures were seeded with 7.8 kg ha^{-1} ‘Paddock’ meadow bromegrass and 3.4 kg ha^{-1} ‘Spredor II’ alfalfa. Starting in 1995, fertilizer was surface-applied as a dry blend prior to grazing each spring. The concentration of each nutrient in the blend was based on soil samples collected the previous fall.

Each pasture was 3.7-ha in size and was divided into five paddocks for rotational grazing. Animals were rotated through the system on the basis of residual forage at exit. Clipped quadrat samples were collected from each paddock in all eight pastures as animals entered into that paddock and at exit when they were rotated out. Samples were hand-separated to measure botanical composition in the mixed pastures and dried and weighed to measure total forage production. Samples were later combined and analyzed for forage quality. Cumulative forage production was calculated by measuring herbage mass production at the start and end of grazing in each paddock, adding together the forage yields measured as animals enter a paddock, and subtracting residual forage from previous grazing in a given growing season. Due to obvious differences in pasture production under the various treatments, stocking rates in each pasture were adjusted to target uniform defoliation across treatments and uniform residual forage at exit.

At the beginning of each season, the grazing group assigned to each system was sorted for uniformity. Four tester animals were assigned to each pasture and these animals remained in their designated pasture for the entire grazing season. The gains of these tester animals were used to determine individual animal performance on the different pastures. Additional animals were used to adjust stocking rates twice-weekly so that the amount of forage remaining after the grazing period was equal in each pasture. The presence and gains of these additional animals were used to determine the carrying capacities of the different pastures. All the animals in all the treatments were rotated at the same time. All animals were weighed after an 18-hour shrink at the beginning and the end of the season to determine individual animal performance. The gains of the tester animals was used to determine individual performance data by treatment and the weights of the put-and-take animals were factored into the calculation of the carrying capacities of the different treatments in Animal Unit Days ha^{-1} (AUD ha^{-1}). Over the 10 years of recorded data we have grazed 3 classes of cattle: cow/calf pairs, bred heifers, and grasser steers. In all cases, their weights have been factored back to the Animal Unit standard (454 kg BW) for reporting purposes.

A. Economic Analysis

The economic performance of the four different pastures was compared based on annual net revenue. Net revenue was calculated by subtracting all production and input expenses from gross revenue. Gross revenue was assumed to be \$0.95 kg^{-1} of animal gain, which was the typical revenue for custom grazing during the last few years of the study. Production and input expenses included: labour, variable costs (i.e., seed, fertilizer, chemical, fuel and oil, repairs, land taxes, interest cost on variable inputs, and miscellaneous), and fixed costs for machinery and livestock handling systems (depreciation, interest on investment, insurance and housing). Annual input expenses included the cost of pre-planting activities, fertilization, planting, harvesting, and transportation. Farm-level machinery and equipment were used to estimate costs. The labour cost and lifespan of machinery for farm operations was calculated according to the machinery work rate per acre [11]-[12]. The lifespan of infrastructure, determined from published values and other sources, was used to calculate infrastructure depreciation and interest on investment. No allowance was made for interest costs associated with land equity. The economic results were expressed in Canadian dollars on a per hectare basis for each pasture system.

B. Energy Analysis

In order to evaluate the efficiency of non-renewable energy use of beef production in these four different pasture systems, both energy inputs and energy outputs were calculated. Energy inputs were determined from the non-renewable energy inputs into the grazing systems. All direct and indirect non-renewable energy inputs used in the manufacturing, formulation, packaging, transportation, maintenance and application of all purchased inputs were included.

Direct energy inputs are those that can be easily converted into energy units; for example, the diesel fuel used to seed a pasture. Amounts of fuel and lubricants used by machinery were determined from [11]-[12].

Indirect energy inputs are not as easily measured. For example, the energy required to manufacture the metal frame and rubber tires of the tractor used to seed the pasture is an indirect energy input. The amounts of both the direct and indirect energy inputs used were calculated in Megajoules per ha (MJ ha^{-1}). As a comparison, burning one litre of gasoline produces approximately 40 MJ of energy. Table II shows the energy inputs that were included in the study as well as those that were not.

Energy outputs were determined from the energy retained in the beef produced by the cattle grazing for the different pasture types. The energy retained was calculated from equations, see [8].

The use of non-renewable energy was measured in two different ways:

1. Total energy inputs per acre (MJ ha^{-1})
2. Efficiency of non-renewable energy use. This is the energy output per MJ of non-renewable energy input used.

Data were analysed as a completely randomised 2 × 2 factorial with repeated measures (year) using Proc Mixed of SAS, see [5]. Differences were considered significant at $P \leq 0.05$ and discussed as a tendency if $0.05 < P < 0.10$. Economic cost, gross revenue, net revenue, and energy data were calculated with E-Views software (E-Views Version 4.1, 2006) and compared between individual pasture systems.

C. Things that were not Considered

Alfalfa has the ability to fix its own nitrogen and its deep root system help in increasing the fertility and tilth of the soil as N is available to subsequent crops and rooting depth increases. Also, forage crops play an increasingly important role in providing critical habitat for many species, including migrating waterfowl [3]. These benefits and other environmental benefits that are not mentioned here were not taken into consideration and therefore were not economically quantified.

III. Results and Discussion

A. Forage Yield and Animal Gain

Adding fertilizer and/or alfalfa to grass-based pastures improved pasture productivity. Table III shows that the highest forage yield and animal gain were achieved in the fertilized alfalfa-grass pastures. Percentage of alfalfa in mixed grass-alfalfa pasture declined over the course of study regardless of fertilizer application and total precipitation (Fig. 1).

TABLE II
ENERGY INPUTS INCLUDED AND NOT INCLUDED IN THE STUDY

Energy inputs included	Energy inputs not included
• Fuel & lubricants • Machinery • Fertilizer • Pesticides • Infrastructure (fencing, corrals, water, etc.)	• Human labour (it accounts for less than 0.2% of the energy input in most cropping systems) • Plant nutrients removed from soil • Increases or decreases in soil organic matter • Energy captured directly from the sun by growing plants • Transportation and processing of crops beyond the farm • Heating and electricity for home/farm buildings • Seed (it was subtracted from harvested forage yield)

TABLE III
EFFECT OF PASTURE TYPE (P=0.05) AND FERTILIZER (P=0.004) ON CUMULATIVE FORAGE YIELD AND ANIMAL GAIN, AVERAGE 1994-2004

Pasture management strategy	Forage yield (tonnes ha^{-1})	Animal gain (kg ha^{-1})
Fertilized alfalfa-grass	5.4	251.1
Fertilized grass-only	5.0	243.2
Unfertilized alfalfa-grass	3.8	174.9
Unfertilized grass-only	2.5	111.0

TABLE IV
FERTILIZER COST FOR THE DIFFERENT PASTURES, BASED ON 2007 FERTILIZER PRICES ($ HA^{-1})

Pasture management	Fertilizer cost (10-year average)
Unfertilized grass only	$0
Fertilized grass only	$160
Unfertilized alfalfa grass	$0
Fertilized alfalfa grass	$77

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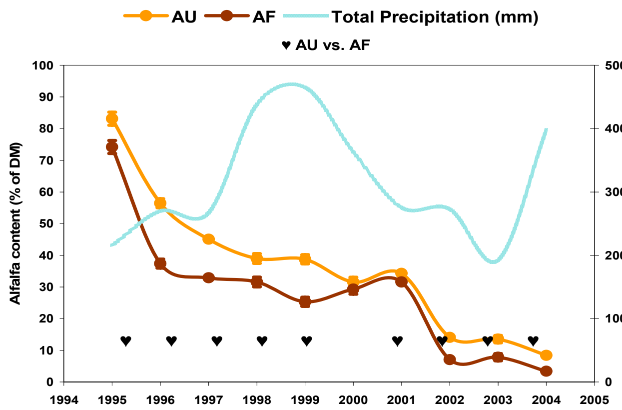


Fig. 1 Annual precipitation and Fertilizer × Year interaction ($P \leq 0.01$) on alfalfa content of pastures, AU – Alfalfa Unfertilized, AF – Alfalfa Fertilized

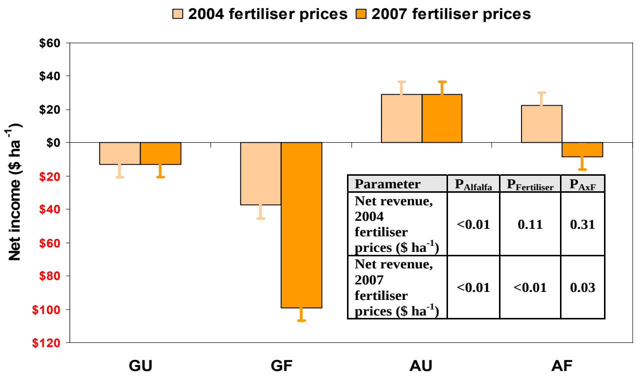
B. Economic Analysis Based on 2007 Fertilizer Prices

Table IV shows the annual fertilizer cost for the four pastures, based on spring 2007 fertilizer prices (\$1.10 kg^{-1} N, \$0.84 kg^{-1} P, \$0.49 kg^{-1} K, \$0.75 kg^{-1} S). Fertilizing either grass-only or alfalfa-grass pastures at least doubled the forage yield compared to unfertilized grass-only pastures. However, the yield increase in alfalfa-grass pastures was achieved with less than half the cost required to fertilize grass-only pastures. Despite these yield increases, both fertilized pastures resulted in a net loss when 2007 fertilizer prices were used to calculate net revenue.

Fig. 2 shows the net revenue for the four pastures based on spring 2007 fertilizer and input prices. The bars above the horizontal line show a net profit, while the bars below the line show a net loss. Averaged over the 10 years of the study, the only pasture improvement strategy with a net profit was the unfertilized alfalfa-grass pastures, which had a profit of \$29.03 ha^{-1}. The other three pasture improvement strategies resulted in a net loss. It should be noted that all the pastures had fairly similar fixed costs. While the unfertilized grass-only pasture was the lowest-cost grazing system, it was not the most profitable because the fixed costs were high, relative to the low level of productivity.

The highest net loss (\$99 ha^{-1}) was for the fertilized grass-only pastures, even though adding fertilizer doubled the forage yield compared to unfertilized grass-only pastures. Therefore, fertilizing grass-only pastures to full soil test recommendations is not advised. Fertilizing alfalfa-grass pastures to full soil test recommendations resulted in a yield increase of 0.785 tonnes ha^{-1} each year compared to unfertilized alfalfa-grass pastures. Despite this yield increase, fertilizing alfalfa-grass pastures to full soil test recommendations resulted in a net loss of \$8.30 ha^{-1}.

Based on 2007 fertilizer prices, every pasture management strategy resulted in a net loss for at least two years of the ten-year study. Even the most profitable strategy, the unfertilized alfalfa-grass pastures, had a net loss in two out of ten years. In comparison, a net loss was seen in fertilized alfalfa-grass pastures for five out of ten years, in unfertilized grass-only pastures for six out of ten years, and in fertilized grass-only pastures for nine out of ten years.



Parameter	$P_{Alfalfa}$	$P_{Fertiliser}$	P_{AxF}
Net revenue, 2004 fertiliser prices (\$ ha^{-1})	<0.01	0.11	0.31
Net revenue, 2007 fertiliser prices (\$ ha^{-1})	<0.01	<0.01	0.03

Fig. 2 Net Income of four pasture systems calculated using 2004 and 2007 fertilizer prices, 10-year average ±SEM, GU – Grass Unfertilized, GF – Grass Fertilized, AU – Alfalfa Unfertilized, AF – Alfalfa Fertilized

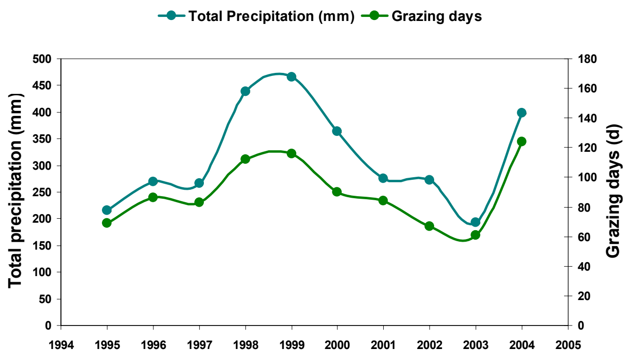


Fig. 3 Seasonal precipitation and grazing days

C. Economic Analysis Based on 2004 Fertilizer Prices

The results of the economic analysis depend heavily on fertilizer price. As a comparison to 2007 costs, calculations were done using 2004 fertilizer prices (\$0.73 kg^{-1} N, \$0.26 kg^{-1} P, \$0.26 kg^{-1} K, \$0.57 kg^{-1} S), which were lower than in 2007. The year 2004 was chosen because it was the last year of the study. Fig. 2 shows that with 2004 fertilizer and input prices, both of the alfalfa-containing pastures generated a net profit. The unfertilized alfalfa-grass pasture was still economically the best choice (\$29.03 ha^{-1} profit). However, under this scenario, the fertilized alfalfa-grass pasture also produced a net profit (\$22.45 ha^{-1}).

Precipitation strongly affected net revenue. Between 1998 and 2000, most of the pastures showed a net profit. Fig. 3 shows that during these years, higher precipitation tended to result in higher grazing days.

Both of the grass-only pasture pastures resulted in a net loss. Fertilizing grass-only pastures was still economically the worst option, followed by unfertilized grass-only pastures. With the assumed 2004 fertilizer prices, the relative profitability among the four pasture systems remained the same, with the unfertilized alfalfa-grass pasture being the most economical system.

D. Fertilizer Inputs

The average amount of fertilizer applied each spring to each pasture type is shown in Table V. The amount of nitrogen (N) applied on fertilized grass-only pastures were three times higher than that applied on fertilized mixed alfalfa-grass pastures.

TABLE V
FERTILIZER APPLIED ANNUALLY TO EACH PASTURE TYPE, 10-YEAR AVERAGE

Pasture management	N	P	K	S
	(kg ha^{-1})			
Unfertilized grass-only	0	0	0	0
Unfertilized alfalfa-grass	0	0	0	0
Fertilized grass-only	111	29.1	25.8	7.84
Fertilized alfalfa-grass	35.8	33.6	22.4	12.3

E. Total Non-Renewable Energy Input and Output

Fertilizer, especially N fertilizer, accounts for a large amount of the total non-renewable energy input. Fertilizer was responsible for 93% of the total energy input for fertilized grass only pastures and 75% for fertilized alfalfa-grass pastures.

Fig. 4 shows that the energy input per ha was highest for fertilized grass-only pastures, requiring more than 9143 MJ ha^{-1}. This is approximately equivalent to burning 236 litres of gasoline per ha (see Table VI). In comparison, the total energy input for both unfertilized pastures was very low, requiring about 494 MJ ha^{-1}, approximately equivalent to burning 12.2 litres of gasoline per ha. Fig. 5 shows the energy output per ha for all pastures. Alfalfa-grass fertilized and grass-only fertilized pastures produced the highest energy output as expected since the yield of these two pastures were higher that the other two unfertilized pasture systems.

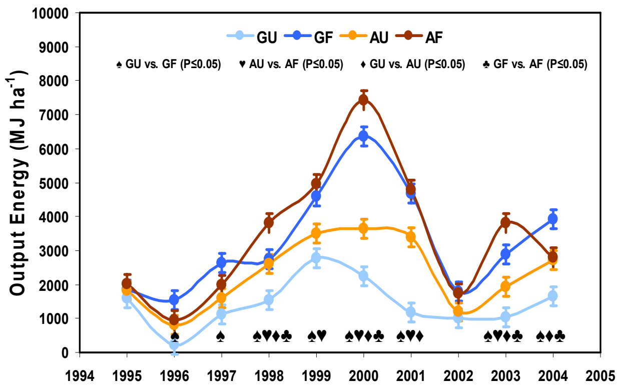


Fig. 4 Input energy (MJ ha^{-1}) to pastures, GU – Grass Unfertilized, GF – Grass Fertilized, AU – Alfalfa Unfertilized, AF – Alfalfa Fertilized

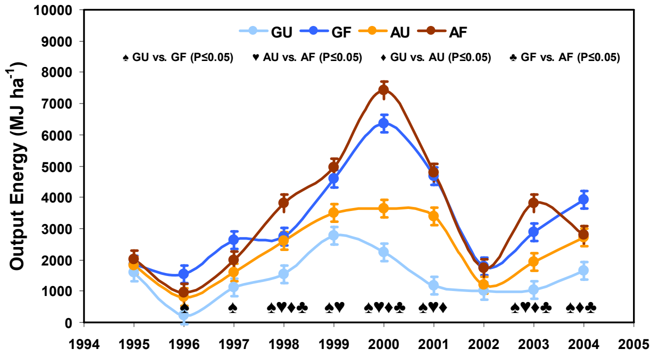


Fig. 5 Output energy (MJ ha^{-1}) from pastures, GU – Grass Unfertilized, GF – Grass Fertilized, AU – Alfalfa Unfertilized, AF – Alfalfa Fertilized

TABLE VI
ENERGY INPUT AND OUTPUT IN EQUIVALENT LITRES OF GASOLINE ha^{-1} (10-YEAR AVERAGE)

Pasture management	*Energy input*	**Energy output – beef production**
	(Litres of gasoline ha^{-1}*)	
Unfertilized grass-only	11.6	36.3
Unfertilized alfalfa-grass	12.8	58.6
Fertilized grass-only	236.2	83.3
Fertilized alfalfa-grass	91.4	86.5

*Gasoline contains approximately 39.6 MJ per litre.

Although fertilizing grass-only pastures doubled the forage yield compared with unfertilized grass-only pastures (see Table III), it also required more than 20 times the energy input. Similar yield increases were also achieved in fertilized alfalfa-grass pastures; however, this required less than half the energy input required in fertilized grass-only pastures. Adding alfalfa without applying fertilizer also increased forage yield (by 55%), although the yield increase was less than that achieved by adding fertilizer to either grass-only or alfalfa-grass pastures. However, the unfertilized alfalfa-grass pastures required only a small increase in energy input (11%) compared to unfertilized grass-only pasture.

F. Efficiency of Non-Renewable Energy Use

Another way of measuring non-renewable energy use is to calculate the ratio of energy output to energy input. This ratio shows how much energy is produced for every MJ of energy input. Higher ratios mean more energy is produced per MJ of energy input, resulting in a more efficient use of non-renewable energy. Fig. 6 shows the efficiency of energy use for the four pasture systems. The highest efficiency of energy use was calculated for unfertilized alfalfa-grass pastures, with

4.6 MJ of energy produced for every MJ of non-renewable energy input. The fertilized pastures had the lowest efficiency of energy use. Again, this is due to the high energy cost associated with the manufacturing of chemical fertilizers.

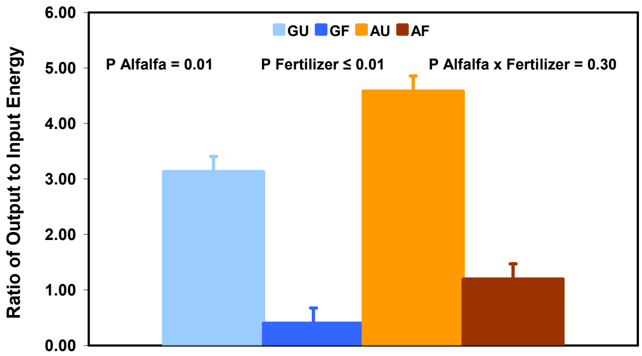


Fig. 6 Efficiency of energy use in pastures, GU – Grass Unfertilized, GF – Grass Fertilized, AU – Alfalfa Unfertilized, AF – Alfalfa Fertilized

IV. Conclusion

While converting poorer soils from cropland to perennial forage grasses may improve soil health and reduce erosion, it is not always profitable unless pasture improvements are made. These improvements include adding nutrients as either commercial fertilizer or supplemental feed, or simply by adding alfalfa or other nitrogen-fixing legumes at the time of seeding. Pasture improvements can increase forage yield, but superior yields do not necessarily translate into increased profits. Fertilizing grass-only or alfalfa-grass pastures to full soil test recommendations improved pasture productivity, but did not improve profitability compared to unfertilized pastures. Fertilizing grass-only pastures resulted in the highest net loss of any pasture management strategy in this study. Adding alfalfa at the time of seeding, with no added fertilizer, was economically the best pasture improvement strategy in this study. Because of moisture limitations, adding commercial fertilizer to full soil test recommendations is probably not economically justifiable in most years, especially with the rising cost of fertilizer. However, improved productivity could probably be achieved with much lower rates of fertilizer. Further research is needed to determine what level of fertilization would be optimal.

Including alfalfa as a legume component in pasture stands has demonstrated other significant improvements to a number of factors used to measure environment and economic gain. However, these benefits were not taken into consideration in our study and therefore were not economically quantified.

The unfertilized grass-only pasture used the least amount of non-renewable energy. Improving grass-only pastures by adding fertilizer and/or alfalfa required additional non-renewable energy inputs; however, the additional energy required for unfertilized alfalfa-grass pastures was minimal compared to the fertilized pastures. In the fertilized pastures, N fertilizer accounted for most of the total energy input. Since there was no fertilizer applied to the unfertilized pastures, they required much less energy.

Of the four pasture management strategies, adding alfalfa to grass pastures without adding fertilizer had the highest efficiency of energy use. The unfertilized alfalfa-grass pasture was also the best choice in terms of net revenue. Based on energy use and economic performance, the unfertilized alfalfa-grass pasture was the most efficient pasture system.

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