Research in Applied Economics
ISSN 1948-5433
2019, Vol. 11, No. 2

An Economic Assessment of Nutrient Removal from Switchgrass Production

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Received: March 28, 2019 Accepted: May 5, 2019 Published: June 24, 2019

doi: 10.5296/rae.v11i2.14998 URL: https://doi.org/10.5296/rae.v11i2.14998

Abstract

The on-site loss of nutrients due to biomass removal creates additional costs for ethanol production however this aspect has not been properly incorporated in economic analyses of biomass production and processing. This study investigates costs of on-site nutrient losses in switchgrass fields in Tennessee. The replacement cost methodology was applied to measure on-site cost of nutrient losses due to biomass removal and was based on the costs of replacing nutrients removed from the production site. The estimated costs for total on-site nutrient loss due to biomass removal show a substantial loss of nutrients in switchgrass fields. The loss of major nutrients from biomass removal represents the major part of on-site economic costs. A declining trend of nutrient costs per Mg of harvested biomass was observed with increasing in harvesting time. The internalization of on-site costs of nutrient losses is possible by adopting an appropriate harvest schedule for switchgrass.

Keywords: Julian day, nutrients, replacement costs, simulation, switchgrass

1. Introduction

Perennial grasses are important cellulosic feedstocks being considered for biofuel production "because of their potential to reduce greenhouse gas emissions and to improve soil conservation" (Khanna et al., 2008; McLaughlin et al., 1998). Among various types of perennial grasses; switchgrass (*Panicumvirgatum L.*) and miscanthus (*Miscanthus x giganteus*) are considered to be the most common choices for biofuel production due to their high biomass production and comparatively low input requirement (Khanna et al. 2008). Switchgrass has been identified as a model bioenergy species by the Department of Energy (DOE) mainly because of "its high yield, high nutrient use efficiency and wide geographic distribution" (McLaughlin et al., 1998). Switchgrass is a perennial C_4type grass species, hence it is better suited for warmer climates (Mann et al., 2009) and adapt to a wide variety of soil and climatic conditions.

According to a study conducted by Thomson et al. (2009), the US has good potential for switchgrass production. This study used EPIC (Environmental Policy Integrated Climate); a process-level agro-ecosystem model to simulate possible production of switchgrass across the US for its use as a biofuel crop. Fig1 shows the growth potential of switchgrass across the US. Accordingly, there is a wide variation of yield which could range from >1 to> 11 Mg/ha. However, a more recent study (Wullschleger et al., 2010) reported higher biomass yields from switchgrass production.

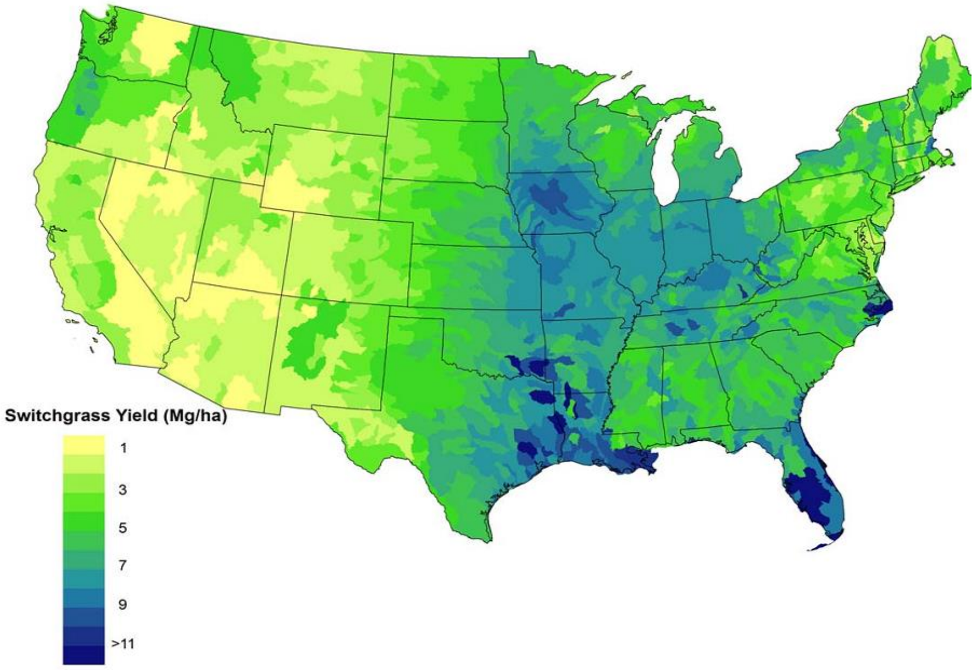

Figure 1. Simulated Potential 30 Year Average Switchgrass Yields for Lowland and Upland (north of 41° N) Ecotype with One Harvest per Year

Source: Jensen et al. (2005)

Perennial grasses, such as switchgrass, have greater efficiency for ethanol production as compared to grain crops such as corn. Also, perennial grasses need lesser amounts of nitrogen fertilizer and other inputs for production in comparison to grain crops. According to an estimate, 4.86 million ha of cropland would be enough to produce 133 x 10^9 liters of ethanol from cellulosic feedstock while the same land would result in only 49 x 10^9 liters of corn ethanol (Heaton et al., 2008). A study conducted to determine farmers' views about switchgrass cultivation across Tennessee (Jensen et al., 2005) reported the total acreage farmers were willing to convert to switchgrass cultivation was 18643ha. Statewide maps (Fig 2) of Tennessee were created that identified the locations of the acreage that could potentially be converted to switchgrass cultivation by county and by zip code (Jensen et al., 2005).

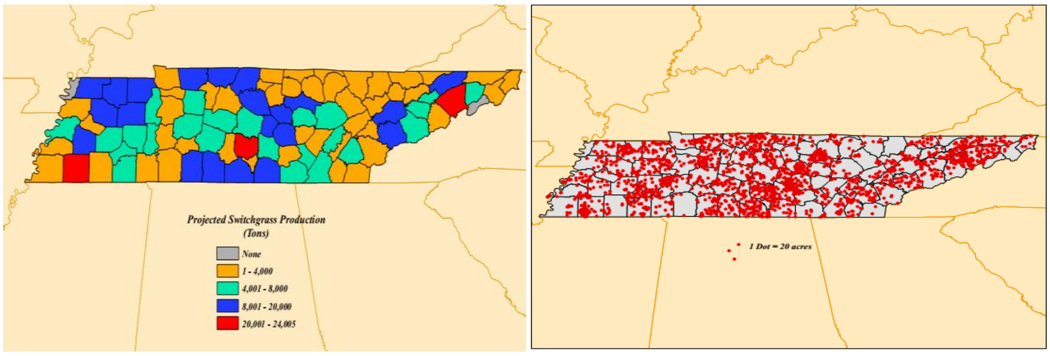

Figure 2. Acreage to Be Converted to Switchgrass Cultivation by County and Zip Code

Source: Jensen et al., (2005).

Tennessee is poised to become a national leader in the growth of switchgrass and production of cellulosic ethanol. The State has favorable climatic conditions for wide range of bioenergy crop production and a substantial amount of land is available for energy crop production. Field experiments in various locations have been carried out to evaluate switchgrass cultivars suitable for bioenergy production (George et al., 2008, Brummer et al., 2001, Khanna et al., 2007, Broekema, 2009, Jensen et al., 2005, Garland et al., 2008, Larson et al., 2010; Fulton et al., 2010). Major nutrients (NPK) are vital for plant growth and also support productivity of soil. If these nutrients are not properly utilized by plants they can be lost from farmer fields crating an economic cost for farm producers. There are three major impacts of nutrient losses namely; on-site effects, off-site consequences and inter-generational impacts. On-site effects of nutrient removal are measured in terms of impact on crop productivity; because the nutrient losses affect the future crop yield and economic costs for producers. In order to compensate these losses farmers may add additional levels of chemical fertilizers and organic matter. Some of the on-site damages due to soil nutrient losses can be mitigated if the expected paybacks exceed the cost of the lost nutrients. In switchgrass, nutrient removal depends on fertilizer application rates and the harvest system (Guretzky et al., 2011; Haque et al., 2009). Kering et al. (2009 & 2013) found that two-cut harvest systems remove more nitrogen as compared to a one-cut system. Accordingly, single harvest technique can result reduced total biomass but it also minimize the amount of nutrients removed in the harvested biomass. Cahill et al. (2014)

suggested that nutrient removal with the biomass is a factor to be considered in decision making in biomass harvesting. In order to motivate farmers, to enhance the likelihood of farmers producing switchgrass, they must be provided with information on the nutrient losses due to harvesting and the cost and benefits of different harvest timing. Considering the above issues, we designed this study to assess on-site costs of nutrient removal in switchgrass cultivation.

2. Data Sources and Methodology

The replacement cost approach which includes the cost of physical removal of nutrients from biomass was used for the study (Maynard et al., 1986). The replacement costs method is widely used to measure the cost of replacing nutrients with purchased inputs. The replacement cost was calculated by considering details about how much it costs to replace the removed nutrients with chemical fertilizer, and maintain a given level of productivity in switchgrass fields.

The primary data source includes biomass samples collected and tested from switchgrass fields (see de Koff and Allison, 2015) in Nashville, Tennessee. The samples were collected for the period of June 06 - November 02 in 2011 and 2012 (Julian day 157 to 306, 158 to 307, respectively). The samples were measured for concentration (g/kg) of macro(N, P, K) and secondary(Ca, Mg and S) nutrients. Estimated yield was calculated by taking the yield identified by Boyer et al. (2010) (12.72 Mg/ha) for a similar situation in Milan, TN and relating it to the dry weight samples collected by de Koff and Allison (2015). Therefore, the sample harvested on Nov. 2 was estimated to have the same yield as that of Boyer et al. (2010) and all other estimated yields shown were related to it by the dry weight measurements identified in de Koff and Allison (2015). Nutrients on a kg/ha basis were then calculated using the concentration data and estimated yields.

In this study, the nutrient removal from the switchgrass was calculated and the replacement cost of nutrients was determined based on nutrient prices. The nutrient prices were estimated based on market prices of fertilizer based on Farmer’s Cooperative Association Inc. Price of N, P and K was calculated based on fertilizer mixtures of 46-0-0, 18-46-0 and 0-0-60, respectively. Prices of micronutrients were based on various fertilizer mixtures (ammonium sulfate, potassium magnesium sulfate, magnesium sulfate, magnesium oxide, dolomite, calcium nitrate, calcium carbonate, gypsum, single superphosphate and triple superphosphate) and their chemical properties. We used the percentage of each nutrient in fertilizer mixtures to estimate the value of specific nutrient. Based on the data, we used pert distribution to crate probability distribution curves for quantity of macro and secondary nutrient removal from a hectare of switchgrass land and also for distribution of unit costs of nutrients. The Monte Carlo simulation was performed using Risk analysis Software (@Risk) to analyze the distribution of nutrient losses and economic value of nutrient loss from switchgrass fields.

3. Results and Discussion

We discuss the results under two separate time periods.Figures3 and 4 show distribution of macro and secondary nutrient removal from switchgrass in year 1. Among N, P, K, nitrogen is the major nutrient lost from the field (mean value of 114.4 kg/ha with st dev of 15.5). The loss value of both P and K are similar (20.9 kg/ha with s.d. of 1.07). Among the secondary nutrients, calcium was the greatest (24.9 kg/ha with s.d. 1.45) followed by Mg (15.76 kg/ha with s.d. of 1.48)) and sulphur (8.5 kg/ha with s.d. of 0.31)

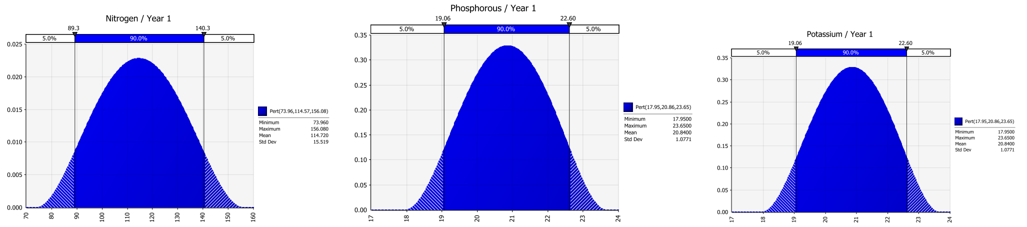

Figure 3. Distribution of Macro Nutrient Removal from Biomass in Year 1

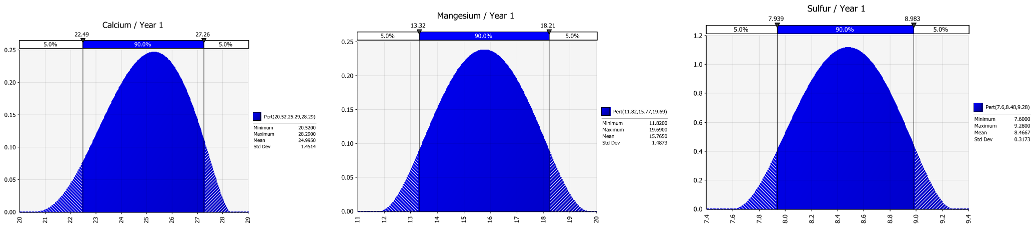

Figure 4. Distribution of Secondary Nutrient Removal from Biomass in Year 1

Accordingly, the mean yearly costs of total nutrient removal from switchgrass biomass is \$117.41/ha with 90% probability range of distribution from \$100.4 - \$136.4/ha (Fig 5). The total distribution range of nutrition removal costs was \$82.9 - \$176.7/ha. Other than the quantity of nitrogen, the price of N, P, Ca and K have the greatest effect on nutritional removal costs from switchgrass biomass (Fig 6).

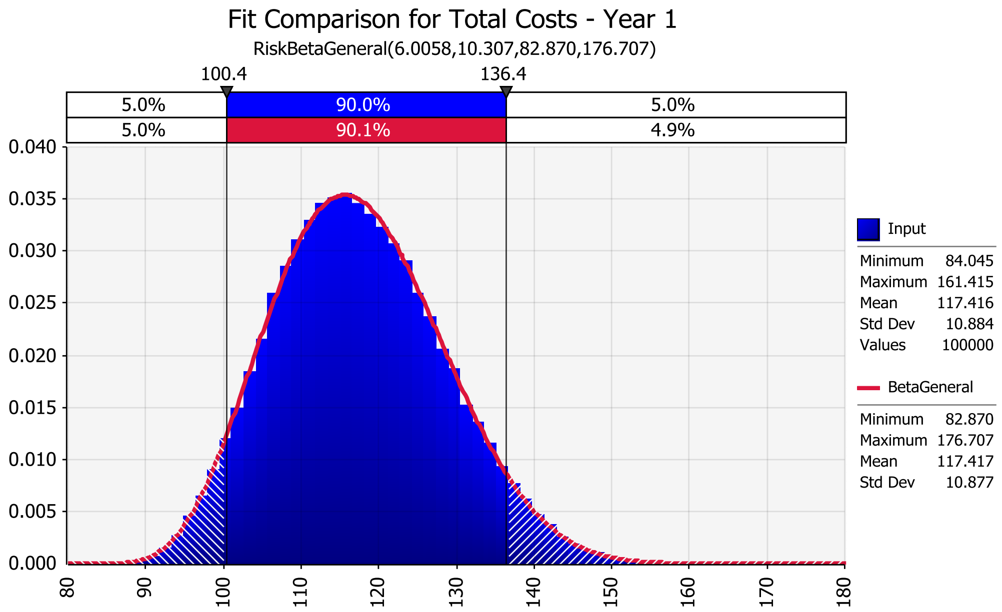

Figure 5. Distribution of Total Costs of Nutrition from Switchgrass Biomass in Year 1

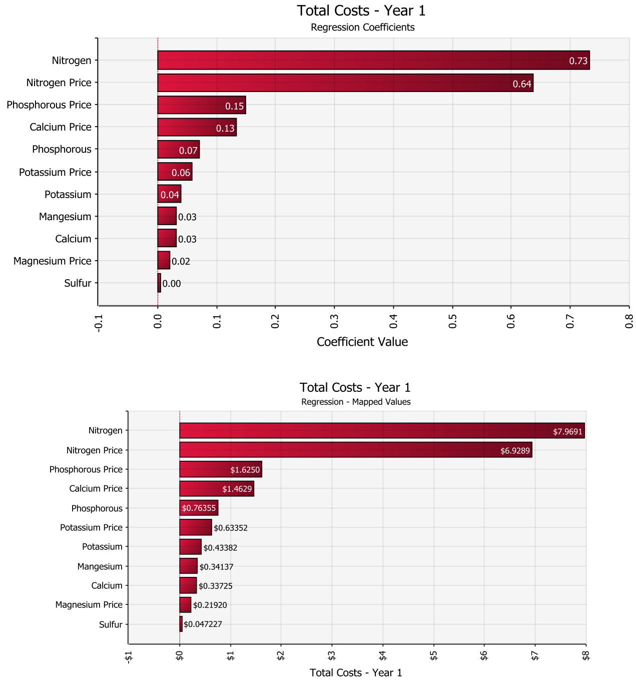

Figure 6. Regression Coefficients and Mapped Values

Figure 7 and 8 shows the distribution of macro and secondary nutrient removal from switchgrass in the following year. Among N, P, and K, the mean loss of potassium from switchgrass biomass was highest (65.8 kg/ha with s.d.7.12) while for nitrogen, the value was 47.26. The loss phosphorous was 13.25 kg/ha. Among the secondary nutrients, the calcium was greatest (15.07 kg/ha with s.d. 2.25) followed by Mg (9.26 kg/ha with s.d. of 1.3) and sulphur (5.3 kg/ha with s.d. of 0.57).

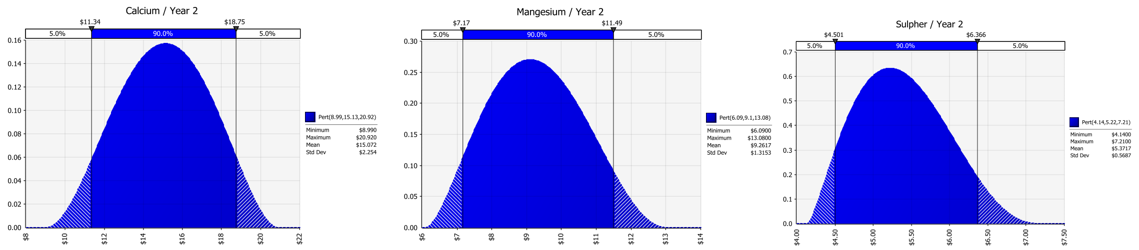

Figure 7. Distribution of Secondary Nutrient Removal from Biomass in Year 2

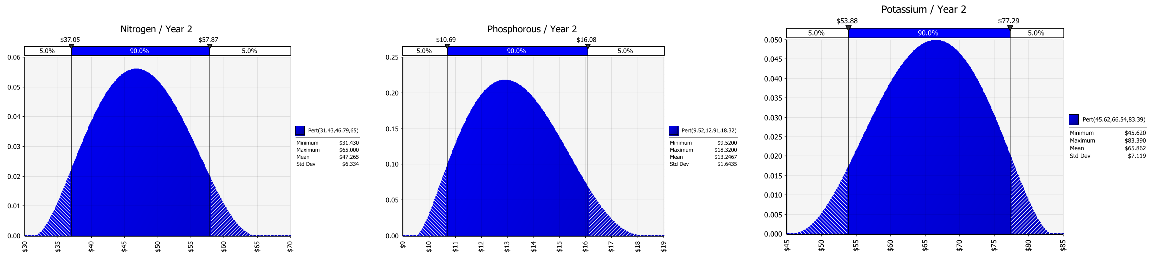

Figure 8. Distribution of Macro Nutrient Removal from Harvested Biomass in Year 2

Accordingly, the mean yearly costs of total nutrient removal from the switchgrass biomass is $91.2/ha with 90% probability range of distribution from $81.70 - $101.10/ha (Fig 9). The total distribution range of nutrition removal costs was $59 - $145.60/ha. Other than the quantity of nitrogen, the price of N, P, K have large effects on nutritional removal costs from switchgrass biomass (Fig12).

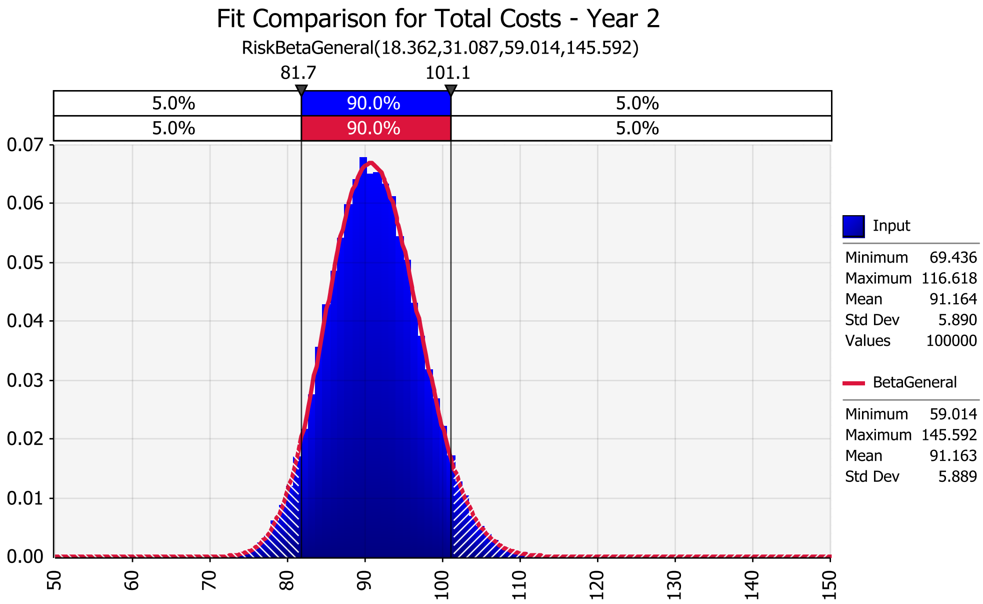

Figure 9. Distribution of Total Costs of Nutrition Replacement from Harvested Switchgrass Biomass in Year 2

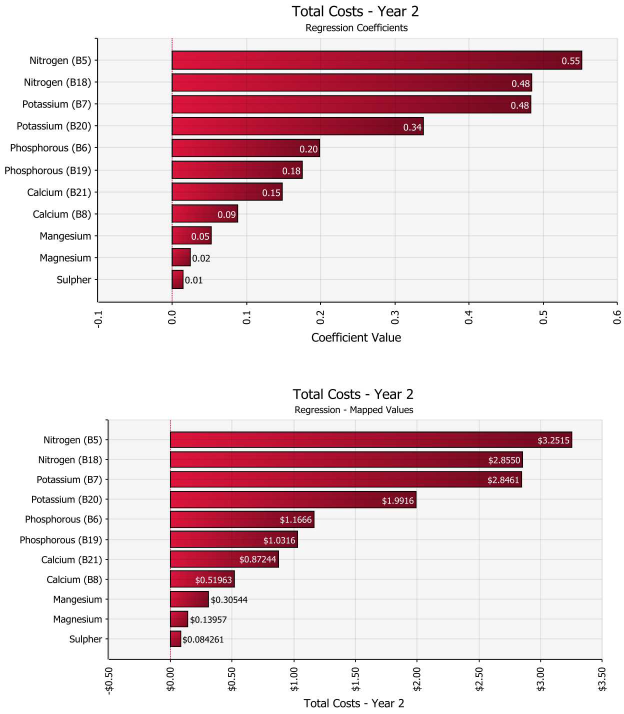

Figure 10. Regression Coefficients and Mapped Values

4. Economic Costs Associated with Biomass Harvesting Schedule

In order to determine the association between economic loss of nutrients with harvest schedule, nutrient loss from harvesting on various Julian days (see de Koffand Allison, 2015) were converted into monetary values. Figure 11 shows the nutrient replacement costs in the 2011 season. Total nutrient replacement costs declined for biomass harvested between Julian day 150 to 200 and 250 to 300. The harvested biomass yield in various harvesting schedules is in the range between 7.58 -14.36 Mg/ha (std 2.04). The lowest nutrient costs ($195/ha yr^{-1}) was associated with a biomass yield of 12.99 Mg/ha on Nov. 2nd (Julian day 306). The highest yield of 14.36 Mg/ha was associated with nutrient costs of $346/ ha yr^{-1} on August 22nd (Julian day 234).

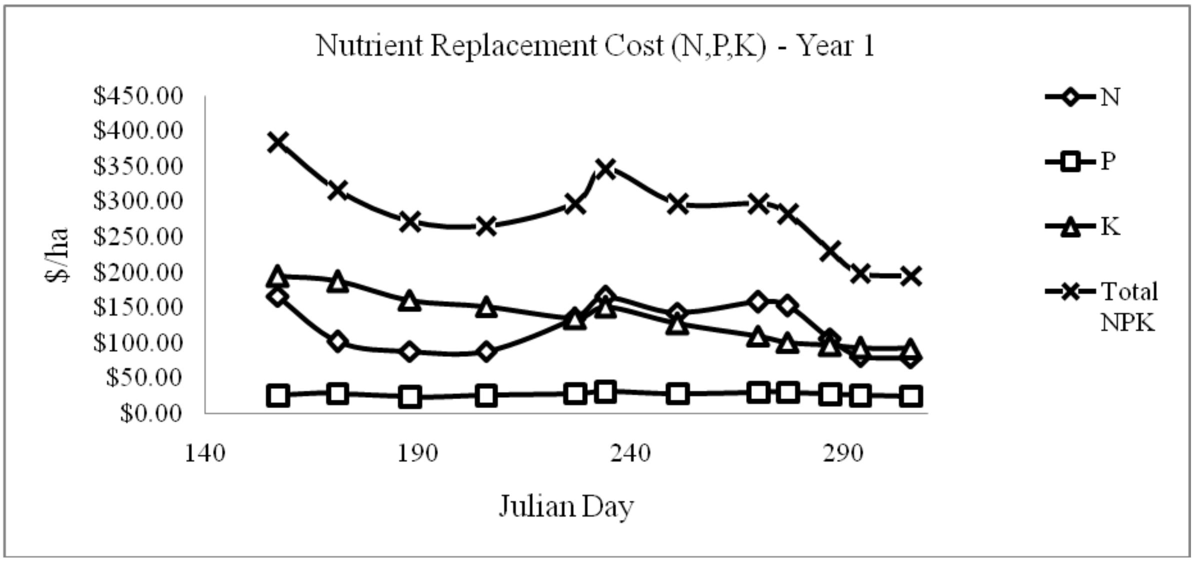

Figure 11. Major Nutrient Replacement Costs in Year 1

Comparison of biomass yield and replacement costs shows additional costs of nutrients of $151/ha yr^{-1} for 1.37 Mg ($110/Mg) of yield. There is a sharp drop of nutrient costs of harvested biomass between 157-206th Julian day $51 to $23/Mg) and becomes constant between 227- 277 Julian day ($24 to $22). The late harvesting of Julian days 227 to 306 shows lowest cost per Mg of biomass (Fig. 12).

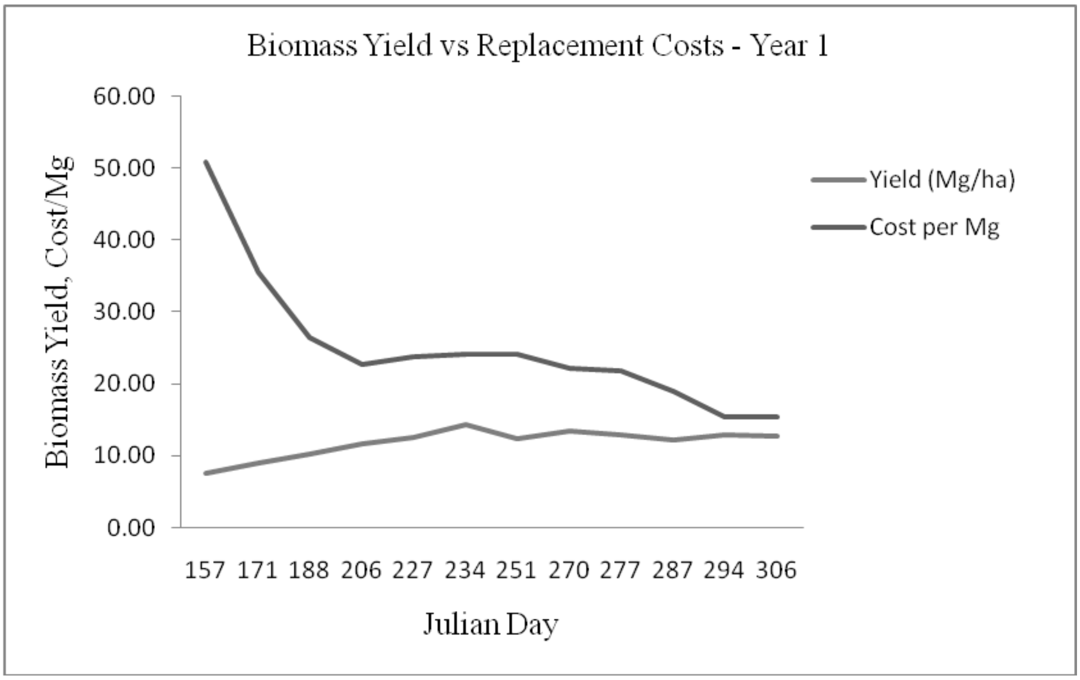

Figure 12. Nutrient Replacement Costs per Mg of Biomass Yield in Different Harvesting Schedules in 2011

The major nutrient replacement costs in the 2012 drought season show a declining trend after the 250thJulian day (Fig 13). The harvested biomass yield ranged between 4.44 and 7.53 (std 1.56) Mg/ha which is nearly a half of the yield compared to previous year. The lowest nutrient costs (\$105/ha yr^{-1}) were associated with a biomass yield of 6.27 Mg/ha on the 307th Julian day.

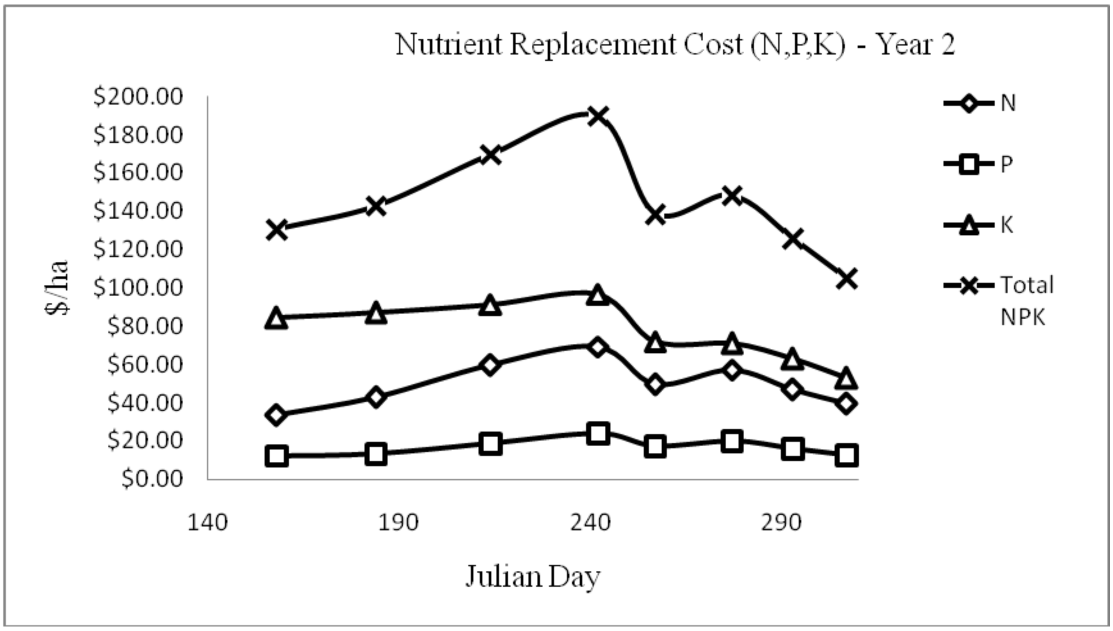

Figure 13. Major Nutrient Replacement Costs in Year 2 (drought season)

The highest yield of 9.06 Mg/ha was associated with nutrient costs of \$190/ha yr^{-1}. Comparison of biomass yield and replacement costs shows additional costs of nutrients of \$85/ha yr^{-1} for 2.79 Mg (\$30.50/Mg) of yield. The nutrient costs show a declining trend between 158 and 242 Julian days (\$29 to \$21/Mg). The later harvests between Julian days 277 and 307 show the lowest cost per Mg of biomass (Fig 14).

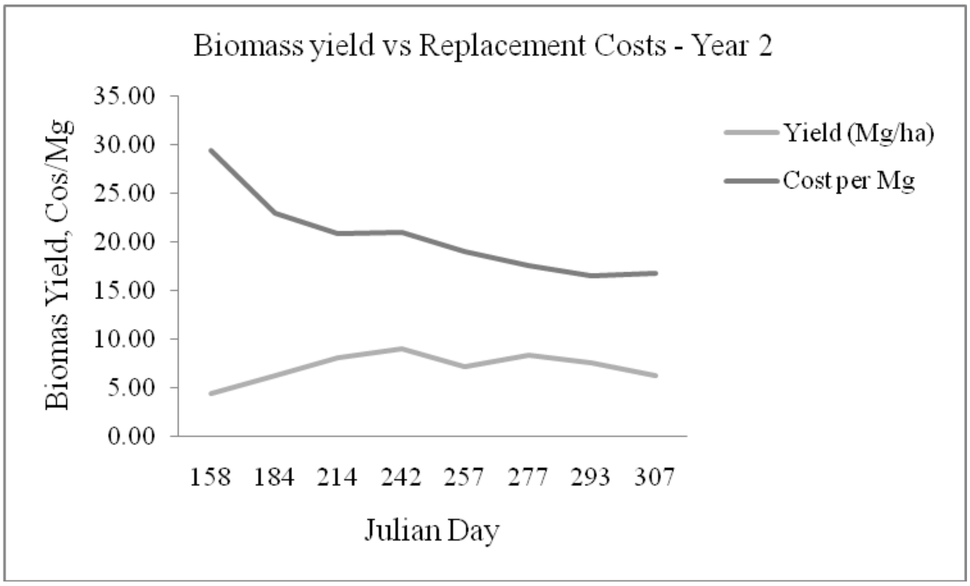

Figure 14. Nutrient Replacement Costs per Mg of Biomass Yield in Different Harvesting Schedules in Drought Season in Year 2

5. Conclusions

Measuring on-site effects of nutrient removal is important since nutrient losses affect future crop yields thereby creating economic costs for producers. In order to compensate these losses, an economically motivated farmer may add additional chemical fertilizers up to the level of on-site removal of nutrients. Therefore, in order to motivate farmers to manage nutrients, they must be provided with information on economic costs of nutrient removal hence the objective of the study is to perform an economic assessment of on-site costs of nutrients losses in switchgrass cultivation. We generated distributions for macro and secondary nutrient removal based on data from switchgrass production and market prices for the nutrients and performed Monte Carlo simulation to generate a range of economic losses of nutrients due to switchgrass harvest. The economic costs of nutrient removal could vary from year to year, however, on average the mean yearly costs of total nutrient removal from the switchgrass biomass is in the range of \$103.08 to \$129.33/ha. The macronutrients have contributed the greatest to these economic costs. The assessment of costs of nutrient removal with different harvesting schedules shows declining nutrient costs per Mg of biomass removal in late harvests as compared to early harvests of switchgrass. Also, drought years may lead to lower overall nutrient replacement costs per Mg of biomass produced for early harvests and greater overall costs of nutrient replacement in later harvests as compared to years with no drought. There is also a smaller overall change in nutrient replacement costs in the drought year. These factors may lead to its greater potential dual-use options as a forage under drought conditions when other grasses may be difficult to grow or it may allow for more staggered harvests for bioenergy as identified by de Koff and Allison (2015).

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