SWITCHGRASS: N, P AND K REMOVAL RATES VS. DRY MATTER YIELD FOR OPTIMAL HARVEST TIME

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Abstract

Switchgrass (*panicum virgatum* L.), a viable option for second-generation renewable fuels, has an extended harvest window with optimal harvest affected by yield, storage losses and nutrient uptake. This research shows that optimal harvest occurs later than maximum yield for Haskell, OK and Fayetteville, AR with different fertilizer and switchgrass prices.

Switchgrass: N, P and K Removal Rates vs. Dry Matter Yield for Optimal Harvest Time

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Introduction

- Second-generation fuels for transportation are an important topic in policy debate and legislative action due to a decrease in low-cost oil reserves and concerns over global warming. As such, renewable fuels derived from dedicated energy crops are posed as a solution.
- The Energy Independence and Security Act of 2007 mandated 21 billion gallons of advanced biofuels per year by 2022. The U.S. needs substantial amounts of cellulosic biomass per year from various areas of agriculture to meet these biofuel targets. The use of switchgrass (*Panicum virgatum* L.) to help meet these requirements is considered a viable option.
- Switchgrass, a warm-season, perennial grass, indigenous to the North American prairie, is a high biomass producer that is drought tolerant, establishes by seed, requires few nutrients and can be harvested over an extended period.
- Guretzky et al. (2011) noted that a two-cut system resulted in greater nutrient removal than a late harvest, one-cut system because greater translocation of nutrients to the roots occurs as the plant goes dormant in the fall.
- Production data on switchgrass from 5 different trials in Fayetteville, AR and one trial in Haskell, OK were collected to compare removal of nitrogen (N), phosphorus (P) and potassium (K) in the harvested biomass as well as dry matter yield by harvest date under varying fertilizer application rates.

Objectives

- The objective of this study was to determine the optimal time of harvest by analyzing temporal tradeoffs between:
  - N, P, and K removal rates and
  - Yields
- Conduct sensitivity analyses by varying:
  - N fertilizer prices
  - switchgrass price

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Data

- Plots were located at Fayetteville, AR (36 5' 42" N, 94 10' 25" W) and Haskell, OK (35 49' 12" N, 95 40' 37" W) experiment research station with the following variables tracked.
  - Date of stand establishment
  - Dry matter yield
  - Amount of N, P, and K applied (in the form of fertilizer and poultry litter)
  - Amount of N, P, and K removed in biomass harvested
  - Yield data collection started May 1, 2009 and ended December 15, 2011
- Plots were arranged as a randomized complete block design with N application as the main effect.
- Fertilizer application occurred in mid-to-late April with various N application rates from urea fertilizer (0,50, 60, 67, 100 and 150 lbs per acre) and poultry litter (0, 100 and 200 lbs per acre).

Methods

- Yield (Y) in dry tons/acre was regressed against location (Fayetteville, AR = base with 0/1 dummy variables for Haskell, *OK*), year of harvest (2009 = base with 0/1 dummy variables for *2010* and *2011*), day harvested past end of winter dormancy or March 1 (D), commercial nitrogen (N) and poultry litter (L) application rates in lbs/acre. A non-linear functional form provided the best fit (Table 1).

  $(1)\ Y = f(D, D^2, OK, 2010, 2011, N, N^2, L, L^2)$
- Harvest dates (D) analyzed ranged from 150 days past March 1 to 354 days past the beginning of new growth
- Each of N, P and K removal rates in lbs/ac were regressed against location, year, day of harvest and yield as defined above using multiple linear regression techniques (Table 2)

  $(2)\ NR = g(day, Haskell, 2010, 2011, Y)$

  $(3)\ PR = f(day, Haskell, 2010, 2011, Y)$

  $(4)\ KR = g(day, Haskell, 2010, 2011, Y)$
- This was done to determine the cost of nutrient replacement (Table 3) for partial profit (π) calculations as follows:

  $(5)\ \pi = \hat{Y} \cdot s - [\, D^* - (\alpha/-2\beta)] \cdot (i\text{-}sl)\cdot s - N^* \cdot n - L^* \cdot l$

  with optimal nutrient application costs $N^* \cdot n - L^* \cdot l$ replaced by nutrient removal on the basis of estimated yield $(\hat{Y})$ at optimal D^*, N^* and L^* or

  $NR(\hat{Y}, D^*)\cdot n - PR(\hat{Y}, D^*)\cdot p - KR(\hat{Y}, D^*)\cdot k$

  using Eqs. 2 – 4 pending statistical significance.

Methods (cont.)

- Optimal harvest *day* accounted for the opportunity cost of delayed harvest as well as storage losses. Daily interest foregone (i) was based on 4% p.a. and daily storage loss savings (sl) were based on 10% per 6 month baled storage loss. Profit-maximizing day, D^*, is:

  $(6)\ D^* = (1/2\beta)\cdot\{[(i - sl)\cdot P + (-.07)p+(-.39)k + (-.3)n]/P-\alpha\}$

  where α/β are the D/D^2 coefficients in Eq. 1 and the numerical values are D coefficients for NR, PR and KR from Eqs. 2 – 4.
- Optimal N fertilizer and poultry litter (L) application rates are determined by:

  $(7)\ N^* = (n - \delta\cdot s) / 2\mu\cdot s$
  $(8)\ L^* = (l - \rho\cdot s) / 2\Theta\cdot s$

  where n is the price of N, l is the price of L, s is the price of switchgrass, δ/ρ are the N/L and μ/Θ are the N^2/L^2 coefficients in Eq. 1, respectively.

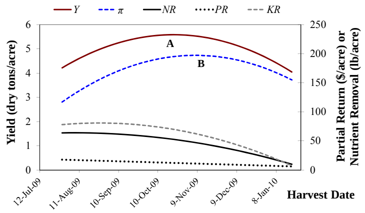
Results

- Statistical results of the yield response function (Eq. 1) shown in Table 1 revealed significant effects for location, production year, harvest date and nitrogen fertilizer rate (N) but a numerically and statistically insignificant contribution for poultry litter (L). Harvest date results are similar to Ashworth (2010).
- Table 2 shows that all nutrient removal rates are affected by harvest date and yield for N and K only.
- These results supported two-factor profit maximization for N and D with estimated, profit-maximizing switchgrass yields and harvest date used for estimating P and K removal and profitability.
- Table 4 showcases how partial profitability (switchgrass revenue – fertilizer, storage and opportunity cost associated with delayed harvest) varies by s and n.
  - Optimal harvest date (D^*) is delayed from the maximum yield allowed by N^* as n increases and s decreases
  - N^* increases with s and decreases with n and ranges from 33to 90 lbs per acre
  - $\hat{Y}$ changes from 4.79 to 5.76
  - P removal is relatively unchanged across n and s
  - K removal is larger than P, is impacted by switchgrass prices indirectly via yield changes driven by N^*
  - As expected profitability increases with switchgrass price (s) and decreases when fertilizer cost (n) increases
- Maximum yield (A), as shown in Figure 1, occurs earlier than at profit-maximizing harvest date (B) as nutrient savings with delayed harvest are possible after senescence and depends on s and n.

Conclusions

- Results suggest that applying more initial N fertilizer increases yields at a decreasing rate and also increases nutrient removal in the forage harvested.
- Optimal harvest date occurs after yield maximum as primarily nutrient cost savings play a role in delaying harvest. The greater the cost of these nutrients the lesser the quantity harvested.
- Future research with greater location differences is expected to show differences regarding litter efficacy as a nutrient source and changes in D^*.

Figure 1. Relationship between Estimated Yield, Nutrient Removal and Resultant Partial Returns for Fayetteville, 2009.



NOTES: s = \$50/ton, n = \$0.63/lb, N^* = 66 lb/ac, p = \$0.71/lb, k = \$0.49/lb, i = 4% p.a. and sl = 10% over 6 months (i and sl effects on π are +/-\$2).

Table 4. Impact of N fertilizer prices (n) and switch-grass prices (s) on Profit Maximizing Yield, Harvest Date, N, P and K removal for Fayetteville, 2009

s ($/dry ton)	*Variable*	*n (adjusted to $/ton)*			
		$300	**$500**	**$700**	**$800**
$40	D^*	258	262	267	269
	N^*	80	61	42	33
	$\hat{Y}$	5.64	5.38	5.01	4.79
	π	$166	$151	$142	$139
	NR	46	42	37	34
	PR	11	10	10	10
	KR	62	56	47	43
$50	D^*	254	257	261	262
	N^*	86	70	55	48
	$\hat{Y}$	5.71	5.55	5.31	5.17
	π	$223	$206	$194	$189
	NR	48	46	42	40
	PR	11	11	11	10
	KR	65	61	55	52
$60	D^*	251	254	257	258
	N^*	90	77	64	58
	$\hat{Y}$	5.76	5.64	5.48	5.38
	π	$282	$263	$249	$242
	NR	50	48	45	44
	PR	11	11	11	11
	KR	69	64	60	57

n = \$0.64/lb, p = \$0.69/lb, k = \$0.49/lb, i = 4% p.a. and sl = 10% over 6 months.

Tables

Table 1. Yield Response to Location, Year, Harvest Date, Commercial Fertilizer and Poultry Litter, 2009 to 2011 for Fayetteville, AR and Haskell, OK.

Effect	Coefficient	Standard Error
Constant	-6.36***	1.09
OK	1.30***	0.34
2010	1.51***	0.27
2011	0.72**	0.29
D	0.09***	0.01
D^2	-1.9 E-04***	2.4 E-05
N	0.032***	0.009
N^2	-1.5 E-04*	6.8 E-05
L	0.006	0.006
L^2	-1.0 E-06	2.71E-05

*, ** and *** indicate significance at P = 0.05, 0.01 and <0.01, respectively, using 71 observations and an adj. R^2 of 0.732.

Table 2. N, P and K Removal Rates, 2009 to 2011 for Fayetteville, AR and Haskell, OK.

Effect	*NR*	*PR*	*KR*
Constant	65.02*** (11.95)	27.77*** (4.61)	60.37** (22.92)
OK	-14.07*** (4.94)	5.59*** (1.90)	-36.54*** (9.47)
2010	8.68* (3.81)	-0.01 (1.47)	-2.04 (7.29)
2011	12.95*** (4.07)	0.53 (1.57)	25.14* (7.80)
D	-0.30*** (0.04)	-0.07*** (0.02)	-0.39*** (0.08)
Y	10.33*** (1.54)	0.02 (0.59)	17.96*** (2.95)
Adj. R^2	0.77	0.41	0.65

*, ** and *** indicate significance at P = 0.05, 0.01 and <0.01, respectively. Values in parentheses are standard errors using 38 observations.

Table 3. Fayetteville 2012 fertilizer prices.

Fertilizer Type	N, P, and K makeup	Cost/ ton	Cost/ lb	
Urea	46-0-0	$575.00	$0.63	n
Triple S Phosphate	0-45-0	$635.00	$0.71	p
Potash	0-0-60	$590.00	$0.49	k

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