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Cover Page Footnote

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Is There an Economic Advantage to Planting Diverse Summer Annual Forage Mixtures?

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Abstract. This study examined economic implications of planting summer annual mixtures of grasses, legumes, and forbs at varying nitrogen rates. No differences in yield occurred between the three mixtures, indicating that mixtures with lowest seed cost will be most economical. Applying N resulted in yield increases of 12.26 lb DM per lb N applied. Although yield responses to N were positive, sensitivity analyses showed that applying N resulted in positive net returns only when hay prices were high and N prices were low. When utilization rates are accounted for, enterprise budgets determined grazing to be 18% cheaper to implement than haying.

INTRODUCTION

Utilizing summer annual forages in a grazing system has been described as "a breakeven proposition at best" (Ball et al., 2007, p. 232). Although these forages can fill the gap of forage quantity and/or quality deficit in cool-season perennial pastures, high annual production costs often limit their incorporation into grazing systems. In contrast to perennial forages where establishment costs are depreciated over 5–10 years, all annual production costs must be accounted for in one season.

Several studies have investigated various economic aspects of summer annual systems. Comerford et al. (2005) found that including annual forages into perennial systems resulted in lower net returns than pasture systems based solely on perennial species. Tracy et al. (2010) determined that native warm season grass pastures were more economical than summer annual pastures when included in a cool-season pasture rotation. After three years, annual warm-season costs exceeded those of native pastures, even though initial establishment costs for the native pastures were quite high due to seed prices. However, some producers encounter more difficulty when establishing native warm-season grasses as compared to annual warm-season species. The authors suggested that summer annual systems could be more economical if costs were reduced, specifically field operations and nitrogen fertilizer (Tracy et al., 2010).

Summarizing 37 studies that evaluate the economics of warm- and cool-season annual and perennial pasture types in Alabama, Ball & Prevatt (2009) showed that summer annual pastures ranked second highest in production costs as compared to other pasture types. Comerford et al. (2005) also concluded that including annual species into a perennial pasture system was not economical since calf gains were no different than perennial systems, but extra costs were incurred, primarily due to tillage. Similarly, Basweti et al. (2009) saw little benefit to no-till interseeding summer annuals into perennial pastures because there was no resulting increase in total system productivity.

In order to make these systems more attractive to producers, costs must be reduced or returns must be increased. One way to increase returns would be to improve yield, which can often be accomplished by N fertilization, although applying N increases input costs. Viets (1950) reported a nearly doubling of sudangrass yields when fertilized with 120 lb N/ac as compared to no N. Parks et al. (1965) additionally showed 2.5x yield increases in pearl millet when fertilizing with 240 lb N/ac.

Another strategy to increase yields is by increasing species diversity. Polycultures often yield more than monocultures in grassland systems (Lüscher et al., 2008), especially when including legume species (Ashworth et al., 2018; Huston et al., 2000). In perennial systems, N can be transferred to associated grasses via root exudation but is primarily accomplished by indirect means (root/shoot decomposition and redistribution via animal excreta) (Heichel & Henjum, 1991; Ledgard & Giller, 1995; Trannin et al., 2000). However, there is debate as to what extent, if any, this occurs in annual systems (Fujita et al., 1992; Layek et al., 2018).

Species diversity and nitrogen application interactions and their economic implications to annual grass-legume mixtures are not well understood. Therefore, an economic analysis is presented for varying levels of N application on different summer annual forage mixtures. Seed and N costs were evaluated in relation to yield response, and sensitivity analyses were conducted to determine optimal N rates for these mixtures at various N costs and hay prices. Input costs for grazing versus haying scenarios are also presented.

FIELD STUDY METHODOLOGY

This economic analysis was conducted utilizing yield data from Mercier et al. (2021). An experiment was conducted in Lexington and Princeton, Kentucky, USA, in 2018 and 2019. The experimental design was a randomized complete block with four replications and a two-factor factorial treatment arrangement. Factors of interest were nitrogen application rate (0 to 200 lb N/ac) and forage mixture complexity. Forage mixtures were as follows: 1) summer annual grass monoculture (control), 2) simple mixture consisting of two summer annual grasses + one summer annual legume, and 3) complex mixture containing four summer annual grasses, four summer annual legumes, two brassicas, and one summer annual forb. Species, cultivars, and seeding rates used can be found in Table 1. Seeds were treated with a multi-species inoculant (Link Cover Crop Inoculant, La Crosse Seed, La Crosse, WI) suitable for all legumes in mixtures. Nitrogen as ammonium nitrate was hand applied in split applications for each treatment, which is depicted in Table 2. A summary of climatological data during the experiment is presented in Mercier et al. (2021).

PLOT MANAGEMENT

Prior to planting, plot areas were sprayed twice with 2 qt glyphosate/ac, with approximately two weeks between applications. Plot areas were fertilized according to soil test results to meet warm-season forage fertility requirements (Ritchey & McGrath, 2018). Plots were planted into conventionally prepared seedbeds approximately one month following last herbicide application (late June 2018 and early June 2019) using a small plot walk-behind cultipack-type seeder (Carter Manufacturing, Brookston, IN). Harvest occurred three times each year (Lexington: 15 Aug 2018, 20 Sep 2018, 25 Oct 2018, 11 Jul 2019, 7 Aug 2019, and 20 Sep 2019; Princeton: 2 Aug 2018, 7 Sep 2018, 9 Oct 2018, 19 Jul 2019, 19 Aug 2019, and 3 Oct 2019) when plants reached approximately 30–40 inches. A 5' strip was clipped through the center of the plot using a Hege 212 small-plot forage harvester (Wintersteiger Inc., Salt Lake City, UT) leaving 7" residual after the first and second harvests, and 3" residual after the final harvest. A forage subsample was collected from each plot, weighed, dried in a forced air oven for 7 days at 130 °F, and weighed again to determine dry matter composition.

DATA ANALYSIS

Yield data were analyzed using SAS 9.4 software (SAS Institute, Cary, NC). The general linear model procedure was used to generate ANOVA tables and means were separated using Fisher's protected least significant difference post hoc test. Interactions between study location (Lexington, KY, and Princeton, KY) and study year (2018 and 2019) occurred, therefore data are presented by 'site-year': Lexington 2018, Princeton 2018, Lexington 2019, and Princeton 2019. Regression analyses were performed using the REG procedure on the appropriate model (linear or quadratic) which was selected based on the best fit (significant p-value and highest R^2 value). A significance level of $\alpha = 0.05$ was used for all analyses.

ECONOMIC MODEL

Inputs

Retail seed costs at the time of the experiment were obtained from a local seed supplier (Ramer Seed, Sharon Grove, KY). Cost of seed for forage treatments were as follows: monoculture costed \$99/ac, simple mixture costed \$90/ac, and complex mixture costed \$105/ac. Seed cost for the simple mixture was less than that of the monoculture because the prices of pearl millet and soybean were less than that of sudangrass.

Local fertilizer prices at the time of the experiment were obtained from Thomas Cayce Farm Supply (Princeton, KY). Ammonium nitrate (33.5% N) averaged \$345/ton or \$0.5149/lb N. Therefore, costs of \$0.40, \$0.50, and \$0.60/lb N are evaluated. Additional N application costs were added for the 100, 150, and 200 lb N/ac treatments because of split-application of N (Table 2). Phosphorus and potassium prices were \$0.30 and \$0.25 per pound of P and K, respectively. Additional P and K costs were calculated from crop removal based on yield responses for each N treatment (Eberly & Groover, 2007).

Yield Response to Nitrogen Rate and Mixture

No mixture x N rate interaction occurred, therefore yield responses to N rate were averaged across mixtures (Mercier

Table 1. Forage Species, Cultivars, and Seeding Rates of Forage Mixtures

Treatment	Scientific Name	Cultivar	Rate[a] (lb/ac)
Monoculture			
Sudangrass	*Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan	AS9302	**50**
Simple Mixture			
Sudangrass	See above	AS9302	25
Pearl Millet	*Pennisetum glaucum* (L.) R. Br.	Wonderleaf	5
Soybean	*Glycine max* (L.) Merr.	Large Lad	25
Complex Mixture			
Sudangrass	See above	AS9302	14
Pearl Millet	See above	Wonderleaf	4
Crabgrass	*Digitaria ciliaris* (Retz.) Koeler and *Digitaria sanguinalis* (L.) Scop.	Red River and Quick-N-Big	1
Corn	*Zea mays* L.	AgriGold 115 day	10
Soybean	See above	Large Lad	10
Cowpeas	*Vigna unguiculate* (L.) Walp.	Red Ripper	10
Korean lespedeza	*Kummerowia stipulacea* (Maxim) Makino	VNS	4
Sunn Hemp	*Crotalaria juncea* L.	VNS	2
Forage Rape	*Brassica napus* L.	T-Raptor	1
Daikon Raddish	*Raphanus sativus* L.	SF Select	2
Sunflower	*Helianthus annuus* L.	Peredovik	2

[a] Pure Live Seed calculations not used as pure seed and germination were considered adequate.

Table 2. Nitrogen Application Schedule and Rates

	N applied (lb N/ac)		
N Rate Treatment (lb N/ac)	At Planting	After 1st Harvest	After 2nd Harvest
0	--	--	--
50	50	--	--
100	50	50	--
150	50	50	50
200	80	80	40

et al., 2021). Additionally, mixture complexity did not affect annual DM production in three out of four site-years (study location x year combination) (Mercier et al., 2021). Therefore, yield responses to N were averaged across site-years and mixture complexity, resulting in a yield response of $y = 12.26x + 3837$, with x = lb N applied ($R^2 = 0.29$, $p < 0.0001$). These yields in response to N treatments are depicted in Table 3. Although the correlation between N and yield was low, it still provides a useful relationship to determine the impact of N price on yield.

Outputs

Hay prices ranging from $60 to $140/T were based on reasonable ranges in normal years for large round bales in central Kentucky. Hay prices reported to the National Agricultural Statistics Service for Kentucky were not used as they include both large round and small square bale prices,

Table 3. Impact of N Rate on Annual Forage DM Production Averaged Across Site-Years and Forage Mixtures (No Mixture x N Rate Interaction)

N Rate (lb N/ac)	Yield (lb DM/ac)
0	3837
50	4450
100	5063
150	5676
200	6289

thus overestimating the average price for round bales. Results of analyses are reported on a hay basis (15% moisture) rather than a dry matter basis, as it is a more common metric used to market hay.

Economic Advantage

Economic advantage was calculated as (hay revenue at specific N rate – hay revenue at 0 lb N/ac) – (production costs at specific N rate – production costs at 0 lb N/ac). Production costs include 1) N, P, and K fertilizer needed to achieve yield at a specific N rate, 2) additional fertilizer application fees for 100, 150, and 200 lb N/ac rates because of split applications for N [additional $6.50/ac for 100 lb N/ac treatment and additional $13/ac for the 150 and 200 lb N/ac treatment; Halich (2020)], and 3) additional harvest costs because of greater yields when applying N.

RESULTS AND DISCUSSION

SENSITIVITY ANALYSIS

Table 4 shows the economic advantage of various hay and N price scenarios. Nitrogen rates applied range from 0 to 200 lb N/ac at costs of $0.40, $0.50, or $0.60/lb N. Revenue from hay sales ranges from $60–140/T.

Interestingly, very few scenarios result in an economic advantage of applying nitrogen to summer annual forages as compared to not applying any N. The only scenario where N application is more profitable than no N is when hay prices are high ($140/T) and N prices are low. When N is $0.40/lb N, applying 200 lb N/ac results in the greatest increase in revenue as compared to 0 lb N/ac. Applying 50 lb N/ac is advantageous over other N rates when N is $0.50/lb and hay is $140/T.

These results contrast with Beyaert and Roy (2005), who determined approximately 90 lb N/ac to be the most economical N rate to three-cut sorghum-sudangrass in Canada. When N cost was high and crop value was low, approximately 75 lb N/ac was the most economical, while when N cost was low and crop value was high, approximately 95 lb N/ac was the most economical. Yield response to N differed in both experiments, likely driving differences in economic efficiency. In the current experiment, yield showed a linear increase in response to increasing N, while the response was quadratic in Beyaert and Roy (2005) with a peak near 110 lb N/ac. Beyaert and Roy (2005) also achieved higher annual yield which would improve economic efficiency of N application as compared to the results presented here.

Unfortunately, results from this analysis imply that the current agronomic N recommendations for summer annual forage crops are generally not economical at these yield responses to N and at the current N costs. In Kentucky, it is recommended to apply up to 220 lb N/ac in split applications to achieve highest yields. The results of this study suggest that applying recommended N rates greatly increases yield over no N, but the cost of extra fertilizer, application fees, and harvest costs are not economical unless hay prices are high. Results would likely have differed with earlier planting dates or different soil types and/or previous cropping history. More work may be needed to validate or change existing N recommendations to summer annual forage crops.

ENTERPRISE PROFITABILITY

Plot management in the current study mimicked a haying situation, however, grazing is perhaps a more common use of these forages; thus, both scenarios were evaluated. These scenarios included input costs for sudangrass pastures prior to feeding or grazing (Table 5). Assumptions used in calculations are listed in the footnotes below the table.

Grazing summer annual pastures results in pasture costs of $292/ac, which is 58% of the costs associated with haying ($502/ac). When utilization rates are considered, haying costs $200/DM T utilized, while pasture costs $155/DM T utilized. Thirty-two percent of haying costs come from harvest activities, followed by 20% for N fertilizer, while the largest costs of grazing are seed and N fertilizer (approximately 30% each).

It has been said that cattle are the most economical form of forage harvesting, and this holds true in this sudangrass system. In this scenario, producing sudangrass hay costs 1.7 times as much per DM ton as producing forage in a grazing system. However, when utilization rates of pasture and storage/feeding loss of bales is considered, the difference in cost is reduced, and grazing sudangrass costs approximately 78% of the cost of making hay.

Others have also evaluated hay vs. grazing systems with similar findings. At the whole farm level, Groover (2007) determined grazing to cost approximately 74% of making hay. Nyren et al., (2002) additionally determined grazing to provide 1.77 times greater return to land, labor, and management as compared to haying marginal, highly erodible

Table 4. Economic Advantage of Applying N to Summer Annual Forages at Varying Hay and N Prices, as Compared to No N Applied

N Price	Hay Price	N Application (lb/ac)				
$/lb N	$/T	0	50	100	150	200
0.40	60	-	-$20.26	-$47.32	-$74.08	-$94.64
	80	-	-$13.05	-$32.90	-$52.44	-$65.79
	100	-	-$5.84	-$18.47	-$30.81	-$36.94
	120	-	**$1.38**	-$4.05	-$9.17	-$8.10
	140	-	**$8.59**	**$10.38**	**$12.46**	**$20.75**
0.50	60	-	-$25.26	-$57.32	-$89.08	-$114.64
	80	-	-$18.05	-$42.90	-$67.44	-$85.79
	100	-	-$10.84	-$28.47	-$45.81	-$56.94
	120	-	-$3.62	-$14.05	-$24.17	-$28.10
	140	-	**$3.59**	**$0.38**	-$2.54	**$0.75**
0.60	60	-	-$30.26	-$67.32	-$104.08	-$134.64
	80	-	-$23.05	-$52.90	-$82.44	-$105.79
	100	-	-$15.84	-$38.47	-$60.81	-$76.94
	120	-	-$8.62	-$24.05	-$39.17	-$48.10
	140	-	-$1.41	-$9.62	-$17.54	-$19.25

Note. Economic advantage calculated as (hay revenue at specific N rate – hay revenue at 0 lb N/ac) – (production costs at specific N rate – production costs at 0 lb N/ac). Production costs include 1) N, P, and K fertilizer needed to achieve yield at a specific N rate, 2) additional N application fees for 100, 150, and 200 lb N/ac rates because they utilized split applications for N, and 3) additional harvest costs in relation to greater yields when applying N. Hay yield was obtained from the regression equation in Figure 1. Scenarios resulting in a positive marginal return as compared to applying no N are bolded.

land in North Dakota. Additional benefits from grazing may occur when high quality feed is required in the summer for grazing dairies or for grass fed beef. Alternatively, summer annuals preserved as stored forages may be utilized during the winter when most livestock operations have a feed deficit, therefore adding additional flexibility to use of mechanically harvested sudangrass.

Nitrogen cost also makes up a large proportion of inputs in both systems, however, summer annual grasses do not produce much biomass without N fertilization. With 200 lb N/ac, these plots averaged 3.14 T DM/ac, while with no N they only produced 1.9 T DM/ac. Additionally, N is a major determinant of crude protein content of forages, and the forages in this study not fertilized with N only had 7% crude protein (unpublished data), which does not meet the nutritional demands of growing or lactating cattle (National Academies of Sciences Engineering and Medicine, 2016). Treatments fertilized with 200 lb N/ac had approximately 10% crude protein, which is in the range of adequacy for lactating beef cattle (unpublished data).

Without N fertilization (and subsequent reductions in P and K fertilizer based on less yield removal), the hay costs were $75/DM T and $94/DM T utilized. Pasture costs without N fertilization was $43/DM T, while pasture per DM ton utilized was $72 (data not shown). This price for hay is in the expected range for poor quality hay in the region. If no N is applied, protein supplementation would likely be needed (and accrue additional costs), as crude protein content of unfertilized summer annuals would likely be inadequate for desired animal performance.

Price of seed is also a significant cost and was approximately 20 and 30% of total costs of production for haying and grazing, respectively. While it may be tempting to plant the cheapest seed possible, variety trials from the University of Kentucky have shown significant differences in yields of varieties (Olson et al., 2019). However, this study used high seeding rates that could likely be reduced with limited impact on forage yield.

Making sudangrass hay may not be economical, particularly if hay market prices are low, as this scenario

Table 5. Costs of Sudangrass Haying and Grazing Scenarios

HAYING		GRAZING	
Inputs	$/ac	*Inputs*	$/ac
Site Preparation		**Site Preparation**	
Disk-tandem	$15.50	Self-propelled sprayer (x2)	$15.00
Field cultivator	$14.50	Herbicide x2	$14.00
Fertility		**Fertility**	
N	$100.00	N	$100.00
P	$14.10	P	
K	$45.50	K	
Application	$19.50	Application	$19.50
Planting		**Planting**	
Drill	$18.00	No-till Drill	$19.50
Seed cost	$90.00	Seed cost	$90.00
Harvest		**Harvest**	
Cut, rake, bale (net wrap)	$158.84		
Moving Bales	$25.86	Bush hog (x2)	$34.00
Total	*$501.80*	*Total*	*$292.00*
Per DM Ton	*$159.81*	*Per DM Ton*	*$92.99*
Per Hay Ton	*$135.84*	*Per Hay Ton Equivalent*	*$79.04*
Per DM Ton Utilized	***$199.767***	***Per DM Ton Utilized***	***$154.99***

[1] Machinery and harvest costs derived from Halich (2020).

[2] Current fertilizer prices of $0.50/lb N, $0.30/lb P, and $0.25/lb K were obtained from a local agricultural cooperative. 200 lb N/ac was used as it is in the range of recommended N rates (Ritchey & McGrath, 2018) and results in the greatest economic return when hay prices are high and N is low. Phosphorus and K rates were calculated based on removal rate of forages in the hay scenario (Eberly & Groover, 2007). Soil pH was assumed to be adequate (no lime applied).

[3] Split application of N was used: one application before planting and once each after first and second harvests. Prior to planting P and K would have been blended with N.

[4] Seed cost of $90 for the simple mixture was used, as additional seed costs of other treatments did not result in increased yields.

[5] Hay harvest costs were computed for the entire season on a 'per bale' basis and converted to total costs per acre based on yield.6 85% DM was used to convert hay on a DM basis to a 'hay ton' basis.

[7] 20% storage and feeding loss was used for hay production.

[8] Soil P and K were assumed to be adequate and not applied as most nutrients are returned to the soil through manure and urine deposition.

[9] Grazing infrastructure was not included as an expense as it was assumed fencing and water systems are already established.

[10] Additional cost of clipping pastures was included, to more closely reflect management of experimental plots and would have occurred following first and second grazing events in a rotational grazing system.

[11] Includes labor for pasture rotation. It is assumed that fence and water infrastructure are already established.

[12] 60% utilization rate was used for forage consumption.

resulted in a breakeven hay price of $137/T, which is above the regional average of $100/T. Making hay offers additional challenges as compared to grazing, such as forage quality decreases if cutting is delayed due to weather constraints. Making hay in a timely manner may also be difficult, as sudangrass stalks are thicker than perennial counterparts resulting in longer drying times, so producing quality hay from summer annual species can be challenging in humid environments.

SUMMARY AND RECOMMENDATIONS

Sensitivity analyses indicated that with most hay and N price scenarios, it is not economical to fertilize with N in the scenarios presented here, but results could vary by altering several parameters. As N fertilization has been shown to improve forage quality, N application will likely be warranted in cases where improved forage quality is desired to avoid costs of supplemental feeding. The authors recommend that extension agents encourage producers that are interested in planting summer annuals to evaluate the costs of N application as compared to supplying supplemental feed to achieve similar rates of desired animal performance. Additionally, grazing sudangrass pastures is more economical than haying. Potential ways to improve the economics of grazing may be to graze at a younger stage to capture greater forage quality benefits or increasing utilization rates via more intensive grazing management.

Results of these analyses indicate that extension agents should use caution when recommending use of summer annual forages. Agents should encourage producers to conduct a simple economic analysis to ensure an understanding of input costs in relation to potential yields, particularly regarding N fertilization. For example, rather than using inorganic N sources, applying manure may result in more favorable whole-farm economics.

Alternatives that may result in more desirable economic outcomes would include planting crabgrass or a warm-season perennial grass. Crabgrass easily self-reseeds each year, reducing labor and input costs in subsequent years. Establishment costs for warm-season perennials will also be depreciated over 5–10 years, likely resulting in greater farm profitability as compared to establishing annuals every year. However, annual systems may fit well as a smother crop in a pasture renovation sequence, as a source of emergency forage, or in dairy or grass-finishing operations where high quality feedstuffs may not be achievable with cool- or warm-season perennial forages during the summer months.

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