Switchgrass Yield and Stand Dynamics from Legume Intercropping Based on Seeding Rate and Harvest Management

Amanda J. Ashworth[1], Fred L. Allen[1], Pat D. Keyser[2], Don D. Tyler[3], Arnold M. Saxton[4], and Adam M.Taylor[2]

University of Tennessee Plant Sciences[1], Forestry, Wildlife and Fisheries[2], Biosystems Engineering & Soil Science[3], and Animal Science[4]

Introduction

Intercropping legumes may reduce inputs and enhance sustainability of forage and feedstock production, especially on marginal soils. This approach is largely untested for switchgrass production, yet producer acceptance should be high given the traditional use of legumes in agricultural systems. Our objectives were to evaluate three cool-season and two warm-season legumes, and their required densities to influence yield and supply nitrogen (N) compared to three inorganic-N levels in two experiments. Harvest treatments were annual single, post-dormancy biofuel (Experiment One) or integrated forage-biofuel (pre-anthesis and post-dormancy; Experiment Two).

Materials and Methods

This experiment tested two-factors arranged factorially under a randomized complete block design at three locations in Tennessee (Knoxville [Sequatchie Silt Loam], Crossville [Lilly Loam]; and, Milan [Loring B2 Series]). The first factor was harvest system, with regimes including i) a single, end-of-season harvest in November (one-cut system), and ii) an integrated forage and biofuel production paradigm June and November (two-cut system) with each harvest treatment analyzed separately; and, iii) the sum of the two-cut system under an integrated approach.

The second factor, N treatments, included five legume species drilled at low, medium, and high seeding rates, and inorganic-N applied at 0 (control), 33, and 67 kg N ha^{-1} into established 'Alamo' switchgrass. Inorganic-N was applied in a single application (approximately April, 15) in 2010 and 2011. Fall 2010 seeded, cool-season legumes (red clover, hairy vetch, ladino clover) and spring 2011 seeded, warm-season legumes (partridge pea, and arrowleaf clover) were interseeded into switchgrass at three (high, medium, and low) seeding rates each in two experiments.

Legumes and respective seeding rates were: red clover at 9, 13, and 18 kg PLS ha^{-1}; hairy vetch at 7, 10, and 13 kg PLS ha^{-1}; ladino clover at 3, 5, and 7 kg PLS ha^{-1}; partridge pea at 13, 20, and 27 kg PLS; and, arrowleaf clover at 11, 17, and 22 kg PLS ha^{-1}.

Forage quality was analyzed on the forage cut of the two-cut harvest system. The analysis included ADF, NDF, CP, hemicellulose, and ash content. Ground (2-mm) switchgrass tissue was analyzed with near-infrared spectroscopy using a LabSpec® Pro Spectrometer (Analytical Spectral Devices).

Three separate models were analyzed to elucidate the relationship between selected legume intercrops and switchgrass via the SAS macro 'pdmix800' (Saxton 1998) with Fisher's LSD with a Type-I error rate of 5%. Legume intercropping impacts on switchgrass yield and forage quality versus inorganic nitrogen model; ii) intercropped legume persistence in switchgrass sward model; and, iii) a switchgrass yield and legume density relationship model.

Results

Table 1. Switchgrass forage (early June) quality results (switchgrass tissue only) by legume and nitrogen treatments by location (East Tennessee Research and Education Center, Plateau Research and Education Center, and Milan Research and Education Center) and by year (2011 and 2012).

Year	Location	Treatments	Crude protein	ADF	NDF	Ash	Hemi-cellulose
			-----------------------------%				-----------------------------
2011	ETREC	AC*	10.55 a†	38.58 a	66.52 a	6.24 a	27.94 a
		RC	10.03 a	40.96 a	66.51 a	6.28 a	25.55 a
		LC	9.99 a	39.21 a	67.48 a	5.94 a	28.28 a
		PP	10.80 a	37.34 a	69.17 a	5.95 a	31.83 a
		HV	10.09 a	43.44 a	68.14 a	6.50 a	24.70 a
		IF	11.21 a	41.75 a	64.33 a	6.06 a	22.58 a
	PREC	AC	8.77 a	41.05 a	66.96 a	5.49 a	25.91 a
		RC	9.32 a	37.26 a	66.45 a	5.07 a	29.19 a
		LC	9.22 a	40.21 a	66.67 a	5.32 a	26.46 a
		PP	9.17 a	39.61 a	65.84 a	5.41 a	26.22 a
		HV	10.92 a	36.71 a	64.20 a	5.15 a	27.49 a
		IF	10.58 a	35.01 a	64.25 a	4.85 a	29.24 a
	RECM	AC	8.4 b	44.03 a	78.96 a	7.21 a	34.92 ab
		RC	9.62 ab	44.26 a	78.18 a	7.38 a	33.92 ab
		LC	7.50 b	46.68 a	78.33 a	6.73 a	31.65 b
		PP	8.89 b	45.51 a	79.26 a	7.25 a	35.75 a
		HV	11.91 a	46.17 a	70.57 b	6.82 a	24.40 c
		IF	8.63 b	43.58 a	79.30 a	7.02 a	35.72 a
2012	ETREC	AC	5.58 ab	46.19 c	83.05 ab	4.47 ab	36.86 a
		RC	5.21 ab	48.27 a	85.44 a	3.83 b	37.16 a
		LC	4.78 b	48.63 a	85.31 a	3.85 b	36.67 a
		PP	5.95 a	45.78 c	81.96 b	5.01 a	36.18 a
		HV	5.51 ab	46.40 bc	83.64 ab	4.58 ab	37.24 a
		IF	5.14 ab	48.08 ab	84.14 ab	3.81 b	36.06 a
	PREC	AC	7.66 a	40.17 a	79.62 a	2.82 a	39.45 a
		RC	7.86 a	40.03 a	79.73 a	2.90 a	39.69 a
		LC	7.88 a	39.76 a	79.13 a	3.22 a	39.36 a
		PP	7.68 a	39.63 a	78.72 a	3.13 a	39.08 a
		HV	7.75 a	39.63 a	78.96 a	3.03 a	39.27 a
		IF	7.83 a	39.90 a	79.00 a	2.95 a	39.08 a
	RECM	AC	1.33 a	52.51 a	91.12 a	6.73 a	38.60 a
		RC	1.77 a	52.69 a	89.88 a	7.38 a	37.21 a
		LC	0.36 a	58.90 a	87.50 a	7.25 a	28.59 a
		PP	1.59 a	52.97 a	90.01 a	7.02 a	37.04 a
		HV	1.43 a	52.90 a	90.74 a	6.82 a	37.83 a
		IF	1.23 a	53.67 a	91.77 a	7.21 a	38.10 a

†different letters indicate differences within a given location and year combination at the P<0.05 level.
* legume intercrop treatments: arrowleaf clover (AC), red clover (RC), ladino clover (LC), partridge pea (PP) hairy vetch (HV), and inorganic fertilizer [(IF), combined across inorganic-N rates: 67 & 33 kg ha^{-1}].

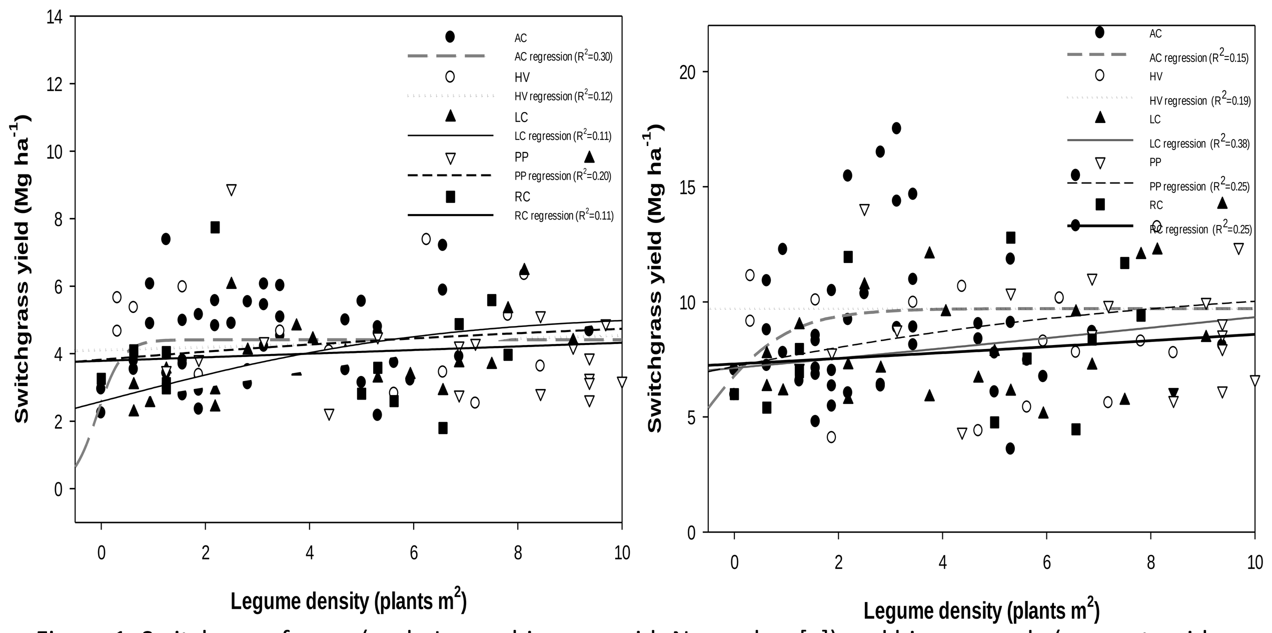

Figure 1. Switchgrass forage (early June + biomass mid- November [a]) and biomass-only (one-cut; mid-November [b]) yields regressed against legume density by species (arrowleaf clover [AC], hairy vetch [HV], ladino clover [LC], partridge pea [PP], red clover [RC]). Data were collected from the East Tennessee, Plateau, and Milan Research and Education Centers from 2011-2012, and regressed with non-linear regression (equation: Sigmoidal, Sigmoid 3 Parameter).

Table 2. Switchgrass forage (early June), biomass only (mid-November), biomass, and integrated (forage + biomass) yield by treatment at the East Tennessee Research and Education Center, Plateau Research and Education Center, and Milan Research and Education Center for 2011 and 2012.

		2011				2012			
Location	Treatment	Biomass only	Forage	Biomass	Integrated (Forage + Biomass)	Biomass only	Forage	Biomass	Integrated (Forage + Biomass)
		----------------	----------------	----------------	-------Mg ha^{-1}	----------------	----------------	----------------	----------------
ETREC	AC	11.15 a§	5.72 a	8.54 a	14.26 a	11.80 a	4.70 a	5.58 ab	10.29 a
	RC	11.06 a	5.47 a	9.14 a	14.61 a	11.16 a	5.30 a	5.88 a	11.19 a
	LC	9.912 a	5.26 a	7.85 a	13.11 a	11.15 a	4.20 a	5.92 a	10.12 a
	PP	10.93 a	6.08 a	7.82 a	13.90 a	10.88 a	4.22 a	5.58 ab	9.78 a
	HV	10.26 a	5.37 a	9.33 a	14.70 a	12.05 a	4.59 a	5.83 a	10.43 a
	N-0	9.27 a	6.07 a	8.74 a	14.81 a	12.00 a	4.59 a	5.05 ab	9.65 a
	N-33	9.44 a	6.04 a	10.41 a	16.45 a	12.10 a	4.20 a	4.15 b	8.36 a
	N-67	12.86 a	6.84 a	8.13 a	14.97 a	10.60 a	5.22 a	5.12 ab	10.34 a
PREC	AC	9.02 bc	3.51 bc	2.79 a	6.30 a	5.99 d	1.82 cd	3.32 a	5.14 a
	RC	8.68 bc	3.10 c	2.65 a	5.75 a	6.89 bcd	1.69 d	3.30 a	5.00 a
	LC	8.41 c	3.99 bc	2.81 a	6.64 a	6.09 cd	2.34 abc	3.42 a	5.75 a
	PP	9.73 b	3.33 bc	2.59 a	5.93 a	7.42 b	1.88 cd	3.34 a	5.23 a
	HV	8.78 c	3.18 bc	2.88 a	6.05 a	7.05 bc	1.96 bcd	3.50 a	5.46 a
	N-0	8.15 bc	3.44 bc	2.35 a	5.79 a	5.85 bcd	1.51 d	3.02 a	4.54 a
	N-33	9.95 ab	4.24 ab	3.12 a	7.36 a	8.84 a	2.69 ab	3.54 a	6.23 a
	N-67	11.61 a	5.10 a	3.23 a	8.33 a	9.48 a	2.78 a	2.88 a	5.67 a
RECM	AC	10.02 a	4.15 a	3.97 a	8.13 a	8.38 a	3.47 cd	3.76 c	7.23 d
	RC	9.97 a	5.34 a	4.54 a	9.89 a	8.06 a	4.33 bc	3.76 c	8.10 bcd
	LC	9.67 a	5.41 a	3.98 a	10.16 a	7.89 a	3.56 cd	4.40 abc	7.96 cd
	PP	8.68 a	5.4 a	3.95 a	9.36 a	7.57 a	4.95 ab	4.64 ab	9.60 ab
	HV	9.91 a	6.33 a	4.12 a	10.45 a	7.59 a	4.14 bcd	4.73 ab	8.88 bc
	N-0	8.15 a	5.54 a	2.66 a	8.11 a	6.97 a	2.71 d	4.03 bc	6.73 d
	N-33	9.92 a	5.7 a	4.28 a	10.0 a	7.13 a	6.13 a	5.25 a	11.39 a
	N-67	7.99 a	9.01 a	3.87 a	12.89 a	7.53 a	6.22 a	4.99 ab	11.22 a

§different letters indicate a significant difference within a given harvest, location, and experimental year at the P<0.05 level.

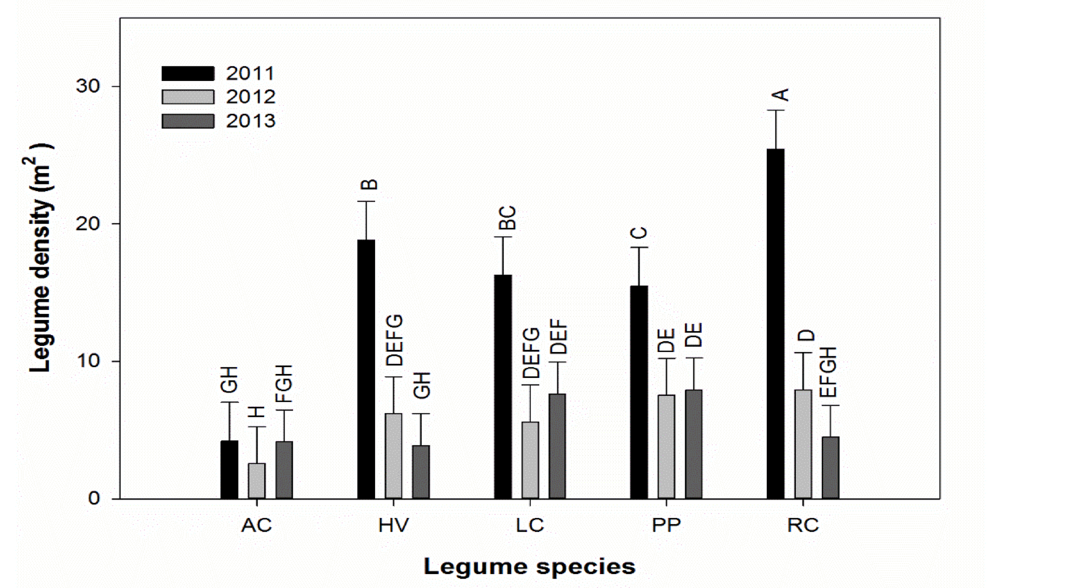

Figure 2. Legume density by seeding rate (low, medium, and high) and species (arrowleaf clover [AC], hairy vetch [HV], ladino clover [LC], partridge pea [PP], and red clover [RC]) combined across locations (East Tennessee, Plateau, and Milan Research and Education Centers) during 2011-2013, and analyzed within years. Vertical bars are +/- one standard error.

Results & Discussion

- During 2011 and 2012 forage harvests, switchgrass quality was impacted by legume species at RECM and ETREC, respectively [(hairy vetch, red clover, and partridge pea resulted in the highest CP (P=0.013) and lowest NDF (P<0.05); Table 1].
- During yr-2, legumes had more beneficial impacts on yield. For 2012, forage yield (P=0.028) and biomass-only (P<0.0001) at PREC were impacted by treatments. At RECM, forage (P=0.005), biomass (P=0.012), and integrated (P=0.003) yields were affected by legume intercrops. At PREC, the 67 and 33 kg N ha^{-1} rate produced equivalent forage yields to that of ladino clover and hairy vetch (Table 2).
- Harvest treatment did not impact legume persistence (P=0.99); neither seeding rate within legume species (P=0.38), nor seeding rate x year within legume species was affected (P=0.78). Among all legumes, red clover had the highest initial density, with partridge pea, ladino clover, and hairy vetch not differing, and arrowleaf clover being the lowest (P<0.05; Fig. 2).

Conclusions

There are a multitude of benefits from introducing legumes into pasture and monoculture biofuel systems in the humid east, including increased soil carbon additions from green manure, and reduced fertilizer inputs, weed pressure due to niche differentiation, and leaching of soil nitrate to groundwater.

- Switchgrass hay and biofuel swards can be interseeded successfully with cool-season legumes (ladino and red clovers) and partridge pea, without annual re-seeding (≥3 yrs; depending on soil texture, soil fertility, and rainfall).
- Legume intercropping may improve switchgrass forage quality results (reduced ADF, NDF, and increased CP levels). More beneficial legume intercropping results were observed during the second year, suggesting more cumulative beneficial forage quality impacts from legume integration.
- Hairy vetch, ladino clover, and partridge pea in some cases had the greatest efficacy for improving yields when compared to medium and low inorganic-N levels (67 and 33 kg N ha^{-1}), and in other instances did not differ from 0 kg N ha^{-1}.
- For integrated and forage yields, relationships with legume density were generally positive with increasing legume density until reaching approximately 10 plants m^{-2} (Fig. 1).

Consequently, red clover, partridge pea, and ladino clover intercrops may enhance forage quality and yield (equivalent to 33 kg N ha^{-1}) while reducing fertilizer costs and carbon-positive inputs in the Mid-South.

Contact

Amanda J. Ashworth
University of Tennessee
Email: aashwor2@utk.edu

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