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RESEARCH

Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, and Zinc in Southeastern USA Harvested Flax

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Abstract

Flax (*Linum usitatissimum* L.) is a winter crop in the southeastern United States that has potential in double cropping systems. This research was conducted to provide estimates of N, P, K, Ca, Mg, and Zn removal in the harvested portions of the crop (straw and grain). Four fiber-type cultivars and one seed-type cultivar were grown with and without irrigation for 2 years. The four fiber-types were grown without irrigation in the third year. Nutrient concentrations were determined on the straw and grain in the first 2 years when the crop was harvested at seed maturity. In the third year, only nutrient concentrations in the straw were measured. Irrigation had a very limited impact on straw and grain nutrient concentrations. Differences among years were greatest for K concentration in the straw as K concentration in 2011 to 2012 was >1.00% and almost five times greater than in the other two years. Higher K concentration in that year is likely due to differences in the amount of K leached from the straw before it was harvested. Differences occurred between the fiber-type cultivars and the seed-type cultivars for both straw and seed nutrient concentration, but these were generally small. Nutrient removal in the flax straw and grain were primarily dependent on biomass. Our results indicate a flax straw crop of 5000 lb per acre will remove 48 lb N, 8 lb P, 13 to 56 lb K, 17 lb Ca, 9 lb Mg, and 0.28 lb Zn per acre.

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Flax is a dual-purpose crop. The grain is harvested for feed, food, oil, and industrial products. The straw contains fibers that can be used as a feedstock for the paper, composite, and textile industries. Flax production in the Southeast, when both the seed and straw are harvested, consists of combine-harvesting the seed and then cutting the straw and allowing it to dew ret on the soil surface before baling (Foulk et al., 2004a,b; Parks et al., 1991). Dew retting is necessary for mechanical separation of the fibers from the rest of the straw. The time needed for adequate dew retting is dependent on temperature and dew amounts (Akin, 2013).

Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
1.12	pound per acre, lb/acre	kilogram per hectare, kg/ha

Plant Nutrient Conversion

Oxide		Elemental	
0.437	P_2O_5	P	2.29
0.830	K_2O	K	1.20

Flax growth and productivity is optimum at relatively cool temperatures (Dybing and Zimmerman, 1965). Because of high summer temperatures, flax is grown in the southeastern United States only as a winter crop (Parks et al., 1991). Winter crops are often immediately followed by summer crops; the most common double crop rotation is soft red winter wheat (*Triticum aestivum* L.) followed by soybean [*Glycine max* (L.) Merr.]. Ideally for most environmentally sound nutrient management, growers collect soil samples for fertilizer recommendations before planting of both winter and summer crops and fertilize before both crops based on the results of the soil tests. In practice, however, fields are generally only sampled before planting of winter crops and nonmobile nutrients applied for both crops in the fall of the year.

Information from the region is lacking on nutrient removal by a winter flax crop grown for seed, fiber, or both. Information is readily available for other winter crops (for example Mitchell, 2011; Osmond and Kang, 2008). For winter wheat, removal of nutrients by a 40 bushel/acre grain crop has been estimated at 50 lb N, 8.7 lb P, 12.5 lb K, 1 lb Ca, 6 lb Mg, and 0.14 lb Zn (Osmond and Khang, 2008). If the straw is also harvested, removal of nutrients in 3000 lb of straw has been estimated at 20 lb N, 2 lb P, 29 lb K, 6 lb Ca, 3 lb Mg, and 0.05 lb Zn (Osmond and Kang, 2008).

Fiber-type and seed-type cultivars can be grown in the region. Recent research in the southeastern United States has focused on using European fiber-type flax cultivars for fiber production (Foulk et al., 2004b; Parks et al., 1991), though growing flax for fiber industries using high-straw-yielding seed-type cultivars and harvesting both straw and seed is a potential production scenario. In this research, we compared four fiber-type cultivars with a seed-type cultivar for nutrient removal in the harvested portions of the crop (seed and straw) to provide estimates of the amount of N, P, K, Ca, Mg, and Zn removed in harvested flax crops.

FIELD EXPERIMENTAL PROCEDURES

Nutrient analysis was conducted on samples of flax straw and seed that were collected from field experiments near Florence, SC, during the 2010–2011, 2011–2012, and 2012–2013 winter growing seasons (hereafter referred to as the 2011, 2012, and 2013 seasons) on a Norfolk loamy sand soil (Typic Kandiudult). Bermudagrass (*Cynodon* spp.) hay was the previous crop in 2011. In 2012, plots were rerandomized on the same area used in 2011. In 2013, the experiment was moved to an area that had not been used for crop production the previous 2 years. Treatments each year were irrigation (irrigated and rainfed) and cultivar. During 2011 and 2012, four fiber-type cultivars (Agatha, Caesar Augustus, Electra, and Melina) and one seed-type cultivar (Flanders) were evaluated. In 2013, only the four fiber-type cultivars were grown. Straw, fiber, and grain yield comparisons among the treatments are summarized in Bauer et al. (2014). Experimental design was randomized complete block with a split-plot treatment arrangement. Irrigation levels were the main plots and cultivars were the subplots. There were four replicates. Subplot size was 10 ft wide (16 rows spaced 7.5 inches apart) by approximately 300 ft long.

Soil samples were collected before the growing seasons and lime, P, and K were broadcast applied to the entire experimental area based on those results and Clemson University's recommendations for winter wheat. No lime, P, or K was applied before establishing the plots in 2011. In 2012, 2000 lb of lime and 50 lb of P_2O_5 were applied approximately 1 month before planting. In 2013, 2000 lb of lime, 50 lb of P_2O_5, and 50 lb of K_2O were applied 2 weeks before planting.

In 2011, the experiment was planted on 9 Nov. 2010 but had to be replanted on 15 Feb. 2011 because of severe stand reductions caused by an ice storm in early January. Planting date was 3 Nov. 2011 for the 2012 season. For the 2013 season, planting began on 14 Nov. 2012 but was interrupted by heavy rain. Planting was resumed and finished on 19 Nov. 2012. Planting was done each year with a John Deere model 750 grain drill (Deere and Co., Moline, IL). Seeds were planted approximately 0.75 inches deep at a rate of 120 lb seed per acre. Soil samples were collected before planting each season and lime, P, and K were broadcast applied based on soil test results. Twenty pounds of N per acre was applied in a preplant fertilizer application. Additional N fertilizer (as urea-ammonium nitrate) was applied via the irrigation system during the spring each year. During the first two seasons, 80 lb N acre^{-1} was applied in April 2011 and in February 2012. During the 2013 season, an 80 lb N acre^{-1} application was made in February. Significant amounts of precipitation occurred following the N application and much of the N appeared to have been lost as plants appeared N deficient in late March. An additional 40 lb N acre^{-1} was applied at that time.

Weeds were managed with preplant and postemergent herbicides. Rashid (1998) reported first observing powdery mildew (*Oidium lini* Škorič) on flax in Canada in 1997. We had not previously observed this disease, but powdery mildew was found on some of the plants in both 2011 and 2012. In 2013, two fungicide (pyraclostrobin) applications were made (early March and early April) to control this disease.

A site-specific center pivot irrigation machine (Camp et al., 1998) was used to apply water to the irrigated plots. Irrigations were triggered when soil water tension at the 12-inch depth was −0.3 bars. In 2011, 0.5 inches of irrigation was applied on 20 and 29 April and on 4, 9, 12, 13, 23, and 25 May. In addition, 1.0 inches of irrigation was applied on 28 April and 6 May. In 2012, 0.5 inches of irrigation was applied on 12, 13, 18, and 20 May and 1.0 inch of irrigation was applied on 16 May. Tensiometers did not reach −0.3 bars in 2013 so no irrigation applications were made.

Both straw and grain yield and nutrient content were determined in 2011 and 2012. Grain yield was determined when almost all seeds were mature by collecting all plants in six 3.3-ft-long sections of row within each subplot, manually threshing seeds from the plants, and then drying and weighing. Harvest dates were 14 June 2011 and 29 May 2012. After collecting the grain samples, plots were cut as described below. In 2013, severe lodging occurred during May due to thunderstorms. Therefore, only straw yield and nutrient analysis were determined in that year. Cutting date in 2013 was 29 May. In all 3 years, an area of approximately 600 ft^2 of each subplot (10 ft by 60 ft) was cut with a 5-ft-wide disc mower. In 2011, the flax straw was left on the soil surface to dew ret. When the straw was well retted, it was raked into windrows and baled. The bales were weighed and a 1.0-lb sample of the straw was collected for determining water and nutrient content. In the last 2 years of the study, flax was cut and allowed to dry on the soil surface for several days. Yield was determined by hand-raking all of the straw in a 100-ft^2 area (5 ft by 20 ft) onto a tarp and weighing. Samples (approximately 1 lb) were collected for determining water content and nutrient content. Water content was determined by drying the samples at 140°F for 3 days in a forced-air oven.

NUTRIENT CONTENT DETERMINATIONS

Dried flax straw and seed samples were finely ground before analysis for nutrient concentration. Total N concentration in the straw was determined by combustion using a Leco TruSpec CN analyzer (Leco Corp., St. Joseph, MI). Total N concentration in the seed was determined at the Clemson Agricultural Service Laboratory using a LECO FP528 Nitrogen Combustion analyzer. Total P, K, Ca, Mg, and Zn in both the seed and the straw were determined using an inductively coupled plasma–atomic emission spectrometer at the Clemson University Agricultural Service Laboratory. Total nutrient content was determined by multiplying the nutrient concentration of the plant part by harvest weight of that plant part.

Table 1. Effect of cultivar type on nutrient concentration in flax straw and flax seed.

		Straw			Seed		
Year	Nutrient	Fiber-type	Seed-type	Mean	Fiber-type	Seed-type	Mean
2011	N (%)	0.86	0.91	0.87	4.46**	3.56	4.28
	P (%)	0.10	0.11	0.10*	0.84**	0.72	0.81**
	K (%)	0.26	0.25	0.26**	1.00	1.00	1.00**
	Ca (%)	0.33	0.36	0.33	0.20**	0.24	0.21
	Mg (%)	0.12	0.12	0.12**	0.41*	0.40	0.41
	Zn (ppm)	63.3**	74.5	66.0*	76.4**	58.0	72.7
2012	N (%)	0.97	1.09	0.99	4.43**	3.63	4.26
	P (%)	0.15**	0.21	0.17	0.74**	0.62	0.72
	K (%)	1.31**	0.90	1.23	0.79*	0.74	0.78
	Ca (%)	0.35**	0.45	0.37	0.23	0.23	0.23
	Mg (%)	0.20	0.22	0.20	0.41**	0.38	0.40
	Zn (ppm)	49.8**	75.9	54.9	72.8**	57.6	69.9

* In the fiber-type columns, * indicates mean of fiber-type cultivars differed from the seed-type cultivar at $P < 0.05$ by use of single degree-of-freedom contrast. In the mean columns, * indicates differences between the years for that nutrient averaged across all cultivars at $P < 0.05$ from the analysis of variance.

** In the fiber-type columns, ** indicate mean of fiber-type cultivars differed from the seed-type cultivar at $P < 0.01$ by use of single degree-of-freedom contrast. In the mean columns, ** indicate differences between the years for that nutrient averaged across all cultivars at $P < 0.01$ from the analysis of variance.

Statistical Analysis

All data were subjected to analysis of variance using the GLM procedure in SAS 9.2 (SAS Institute, 2009). Data for straw and grain were analyzed over 2011 and 2012. Single degree-of-freedom contrasts were conducted to compare the four fiber-type cultivars to the seed-type cultivar in the 2011 and 2012 seasons. Analysis of the data from the straw in the 2013 experiment was conducted separately because the seed-type cultivar was not grown in that year. Regression was used to examine the relationship between nutrient content and biomass across years and irrigation levels. For this analysis, cultivar means in each irrigation level and year were used.

NUTRIENT CONCENTRATIONS IN STRAW AND GRAIN

Differences occurred between 2011 and 2012 for concentrations of P, K, Mg, and Zn in the flax straw. Though statistically significant, differences in concentration between these two years for P, Mg, and Zn (Table 1) were small. A much larger difference between these two years occurred for K concentration: K concentration in 2012 was >1.00% and almost five times greater than in 2011. Nutrient concentrations in the straw of the four fiber-type cultivars in 2013 were numerically similar to the 2011 concentrations. In that year, the straw contained 1.00% N, 0.13% P, 0.16% K, 0.39% Ca, 0.12% Mg, and 24.9 ppm Zn. Small differences among years for

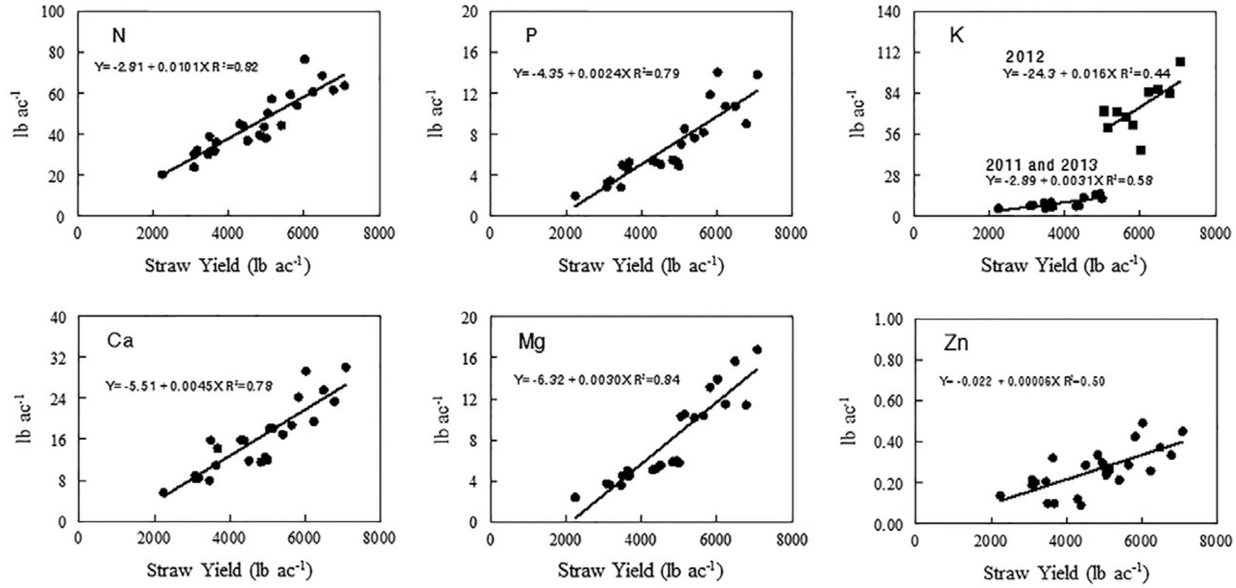

Figure 1. Nutrient removal as a function of flax straw yield. Data are the means of the five cultivars with and without irrigation in 2011 and 2012 and the four fiber-type cultivars in 2013. Straw in 2012 had a much higher K concentration, so the years of the study that the data were collected are indicated. ac = acre.

nutrient concentrations are not unexpected. The late planting in 2011 delayed the onset of flowering by about 1 month compared to the other two years, so average daily temperatures were considerably higher during the reproductive period. Data from 2013 were collected from plants that were lodged and on the soil surface for a few weeks before they were cut. On the other hand, the large difference in K concentration among the years is likely due to differences in the amount of K leached from the straw. The flax straw was on the soil surface for a much longer period of time in 2011 (due to waiting for dew retting) and 2013 (due to lodging) than in 2012. Potassium is soluble in the plant cells and not bound to any plant compound, so it is readily leached from plant materials.

Grain P and K were slightly higher in 2011 than in 2012 (Table 1). The two years did not differ for concentrations of any of the other nutrients.

Irrigation had almost no effect on straw and seed nutrient concentrations. In both 2011 and 2012, irrigation was applied only after reproductive growth had begun. In 2011, irrigation applications began shortly after the onset of flowering. In 2012, all of the irrigation applications were made between 20 days after the onset of flowering and seed maturity. Water applications affected the concentrations of only straw N and seed Ca in the harvested flax. Averaged over these two years, the straw from the irrigated flax had 0.86% N and the straw from the rainfed flax had 1.00% N. In the seed, Ca concentration was 0.02% greater in irrigated than in rainfed flax ($P \leq 0.01$). No irrigation × cultivar interactions occurred for concentrations of any nutrient in either the straw or the seed.

In the first two years of the study, the cultivar source of variation in the analysis of variance was highly significant for all of the nutrients in both the straw and the seed. Year × cultivar interactions occurred for P, K, Mg, and Zn concentrations in the straw and for Ca and Zn concentrations in the seed. Not surprisingly, the differences among cultivars for straw and seed nutrient concentration were primarily because the four fiber-type cultivars had different nutrient concentrations than the seed-type cultivar. No differences occurred among the four fiber-type cultivars for straw nutrient concentration in 2013. The influence of cultivar type on straw and seed nutrient concentrations in 2011 and 2012 is shown in Table 1. For the straw in 2011, the cultivar types differed only for Zn concentration. Phosphorus, K, Ca, and Zn concentrations differed in 2012. Potassium concentration was higher for the fiber-type cultivars than for the seed-type cultivar in 2012; otherwise, nutrient concentrations (when different) were lower in the fiber-type cultivars than in the seed-type cultivars. In the seed, nutrient concentrations tended to be higher in the fiber-type cultivars than in the seed-type cultivar. Both years, N, P, Mg, and Zn concentrations were higher in the fiber-type cultivars than in the seed-type. The influence of cultivar type on seed K and Ca concentrations were not consistent across the two years (Table 1).

NUTRIENT REMOVAL IN HARVESTED STRAW AND SEED

The 3 years of study, with and without irrigation in 2011 and 2012, together with five cultivars provided a wide range of straw and grain yields. The relationship between nutrient removal in the straw and straw yield for each nutrient is shown in Fig. 1. With the exception of K, nutrient removal was closely related to biomass. This close relationship was expected because differences in nutrient concentrations were generally small, even when significant. For K, the large difference between 2012 and the other two years for K concentration had a larger impact on nutrient

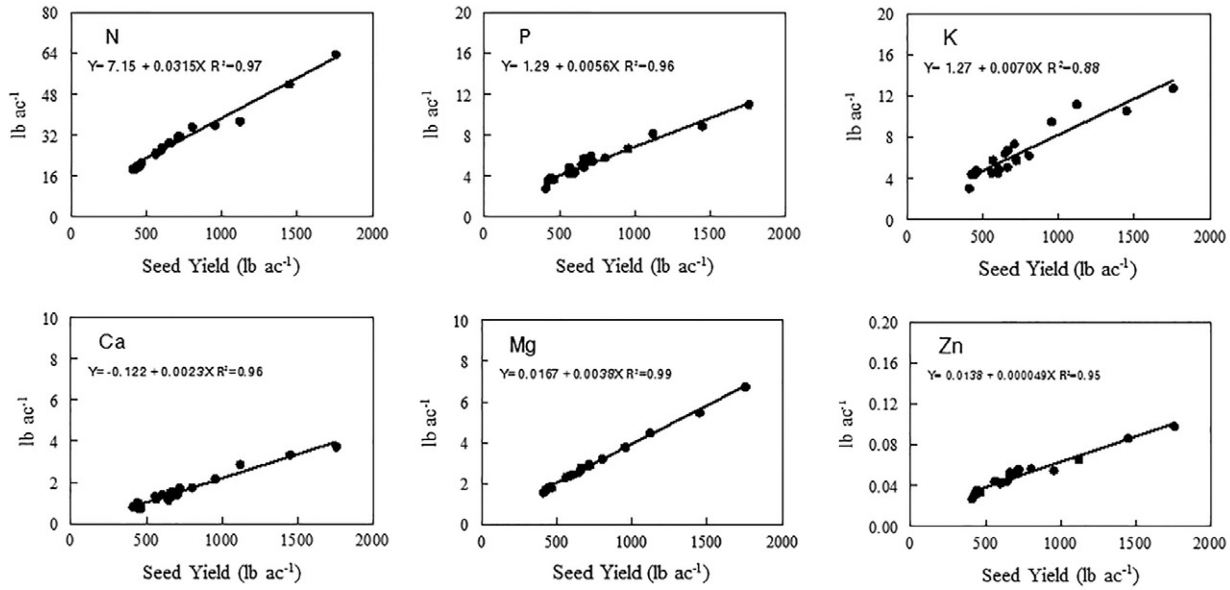

Figure 2. Nutrient removal in flax grain as a function of grain yield. Data are the means of the five cultivars with and without irrigation in 2011 and 2012. ac = acre.

Table 2. Estimated nutrient removal by flax. Estimates based on 5000 lb per acre of straw and 10 bushels per acre of seed for the fiber-type cultivars and 25 bushels of seed per acre for seed-type cultivars. Estimates based on regression equations in Fig. 1 and 2.

		Seed	
Nutrient	Straw	Fiber-type	Seed-type
		lb per acre	
N	47.7	26.1	54.4
P	7.7	4.7	9.7
K	12.6; 55.7†	5.5	11.8
Ca	17.0	1.3	3.3
Mg	8.7	2.3	5.7
Zn	0.28	0.04	0.09

† K low number based on 2011 and 2013 results, and high number based on 2012 results.

removal than biomass. In the seeds, removal of all fertilizer nutrients was closely related to grain yield (Fig. 2).

Using the regression equations generated in Fig. 1 and Fig. 2, nutrient removal estimates were calculated for a crop yield of 5000 lb of straw and either a 10- (fiber-type cultivars) or 25- (seed-type cultivar) bushel per acre seed yield (estimates based on dry weight of straw and grain). Estimates are shown in Table 2. Because grain yields of seed-type cultivars are generally much higher than fiber-type cultivars, nutrient removal when both the straw and seed are harvested will be considerably more for the seed-type cultivars than the fiber-type.

Mengel (2006) reported a K removal value in flax straw that is the equivalent of 53.4 lb K in a 5000-lb straw yield. Our findings for 2012 (55.7 lb) agree with this estimate, but it is much higher than the estimate for the other two years (10.9 lb). We are unaware of any value that K in adds to the processing of fibers into paper, composites, or textiles. It appears rain that leaches K from retting flax could potentially save growers K fertilizer costs in subsequent crops while not reducing straw value as a fiber feedstock. Over-retting of straw, though, causes weaker fibers (Akin, 2013). Delaying harvest past optimum retting to reduce K removal from the field could compromise fiber quality.

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