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Evaluating Benefits from a Summer Legume to a Sunflower–Camelina Rotaton

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In the absence of soil fumigation, developing crop rotations to mitigate the impact of soilborne pests, improve soil quality, and generate additional revenue is critical for the continued existence of the Florida vegetable industry. Rotating tomato with oilseed crops has demonstrated potential, but its economic feasibility is limited by high input costs, particularly nitrogen fertilizer. A three-crop rotation consisting of jointvetch (*Aeschynomene americana*) grown as a green manure crop, sunflower (*Helianthus annuus* L.), and camelina (*Camelina sativa* L.) was evaluated for its impact on soil C and N and yield of camelina. Main treatments were a summer green manure consisting of a 67- or 88-day-old jointvetch crop and a bare ground fallow. Sunflower was planted on 22 Oct. 2010 and camelina on 24 Jan. 2011. The sunflower crop received P at 11.2 kg·ha^{-1} (10 lb/acre) and K at 43.7 kg·ha^{-1} (39 lb/acre). Split plots of N at 79.5 or 157.9 kg·ha^{-1} (71 or 141 lb/acre) were added during the sunflower crop. No additional fertilizer was applied to the camelina crop. A 67-day-old jointvetch crop returned N and C at 204 and 2,816 kg·ha^{-1} (182 and 2,514 lb/acre), respectively. An 88-day-old crop returned N and C at 254 and 3,689 kg·ha^{-1} (227 and 3,294 lb/acre), respectively. Camelina yield in plots where jointvetch was previously grown was 655 to 706 kg·ha^{-1} (585 to 630 lb/acre), which was significantly higher than yield in plots that received a summer tillage fallow [451 kg·ha^{-1} (403 lb/acre)]. The results demonstrate the potential to improve soil C and N and reduce subsequent fertility inputs by combining a tropical legume grown as a summer manure crop with sequential plantings of oilseed crops.

Crop rotations can benefit future vegetable crops by increasing soil organic matter, improving soil tilth, and reducing soil loss from wind and water erosion. Environmentally, they can protect surface and ground water quality by recycling nutrients remaining from previous crops and help to alleviate the impact of anthropogenic carbon dioxide emissions into the earth's atmosphere. Of particular interest to Florida vegetable growers dependent upon chemical fumigants for control of soilborne pests is the capability of crop rotations to mitigate the build-up pest populations in soil, thus reducing their economic impact (Cook and Baker, 1983; Glynne, 1965). Traditional applications of beneficial crop rotation involve their establishment and maintenance in fields for periods sufficient to reduce or eliminate soilborne pests. However, this approach is not economically sustainable unless additional revenue streams are created from their cultivation.

Oilseed crops are potential candidates for beneficial rotation crops because the revenue generated from their oil and meal can offset planting and cultivation costs and may provide supplemental income for Florida vegetable growers. Known mainly as a source of edible oil and seeds, sunflower is also an excellent feedstock for biodiesel production. In Florida, an active oilseed research program involving sunflower was initiated following the 1973 OPEC oil embargo and has continued into the early 1980s (Gallaher, 1982; Green et al., 1979). Field research trials were conducted in north Florida and the Florida panhandle during the summer months using traditional high linoleic acid sunflower varieties. A study of planting date effects on yield and oil composition included a November planting in southeast Florida (Robertson and Green, 1981). Regionally, the yield potential of mid-oleic hybrids has been examined over multiple locations in Mississippi (Zheljazkov et al., 2008). A more recent study demonstrated the agronomic potential of sunflower oil seed crops when integrated into Florida vegetable production systems (Chellemi et al., 2009). However, in that study, the breakeven cost per weight of seed volume of oil was not sufficient to generate the additional income needed to entice farmers to plant them (Chellemi, personal observation). Sunflower budget projections indicated that fertilizer accounted for 63% of the pre-harvest production costs.

Reducing fertility inputs, particularly N, would increase net returns to growers, thus increasing the economic incentive to plant rotation crops. Incorporating additional crops into the rotation sequence that can either add N and C to the soil as a green manure crop, thus reducing N inputs for the sunflower crop, or scavenge residual soil nutrients left over from the sunflower crop, thus stretching the fertility inputs over two oilseed crops, could potentially reduce the variable production costs and increase profit margins for growers. Jointvetch (*Aeschynomene americana*) is a tropical legume native to Florida (Kretschmer and Bullock, 1979). It is used primarily as grazing forage in mixtures with permanent pasture grasses. The objective of this study was to determine the impact of a three-crop rotation sequence consisting of jointvetch grown as a green manure crop, sunflower (*Helianthus annuus* L.), and camelina (*Camelina sativa* L.) on soil C and N and yield when camelina was grown without additional fertility inputs.

Materials and Methods

Field plot. A field trial was conducted on a commercial vegetable farm in St. Lucie County, FL, that had been cropped annu-

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ally to tomato and pepper since 2000. The soil type was a Pineda fine sand (loamy, siliceous, hyperthermic, Arenic, Glossaqualfs) (Watts and Stankey, 1980). The experimental design consisted of three main treatments replicated six times in a randomized complete-block design. Plots were 10 ft × 140 ft (0.032/acre). Main treatments were jointvetch grown for 87 d (A-87), 67 d (A-67), and a control plot (C) maintained as a bare-ground (disk) fallow. The A-87 and A-67 treatments were seeded on 2 and 22 July 2010, respectively. Hulled seed was broadcast at 37.7 lb/acre and then lightly incorporated using a field cultivator with rolling baskets. Prior to planting, seed was inoculated with *Rhizobium* inoculant to facilitate N fixation. Control plots were maintained vegetation free by periodic disking. The A-87 and A-67 plots were mowed with a flaw mower and on 28 Sept.

Plots were fertilized and planted to sunflower on 22 Oct. Plots received 71–1–39 lb/acre of N–P–K, spread and lightly incorporated using a field cultivator with rolling baskets. Planting beds were prepared using a John Deere 886 no-till bedder equipped with a bed shaping drag, creating 12-inch-wide × 4-inch-tall beds with a row spacing of 30 inches. Seed of a mid-oleic, dwarf hybrid sunflower cultivar ('S672'; Triumph Seed Co., Ralls, TX) was drilled into the center of each bed at a 9-inch spacing using a John Deere 1700 vacuum seeder. Total seeding rate was 22,000/acre. Herbicide (*S*-metolachlor, Syngenta Crop Protection, Inc., Greensboro, NC) was applied after seeding at 16 oz/acre in 40 gal/acre of water using a 36-ft boom sprayer equipped with flat fan nozzles. Subsurface (seep) irrigation was provided. Each plot contained four rows. A liquid side-dress application of N was made to two rows in each plot on 23 Nov. at 70 lb/acre, creating split plots with two rows receiving a total of 71–1–39 lb/acre of N–P–K and two rows receiving 141–1–39 lb/acre of N–P–K. Severe freezes occurred on 7, 8, and 15 Dec., damaging the sunflower crop and preventing harvest of seed. Plots were mowed and disked on 8 Jan. 2011.

Camelina (cv. Suneson, Montana State University) was planted on 24 Jan. using a precision seeder with dual cultipackers (Brillion Farm Equipment, Brillion, WI). The seed rate was 5 lb/acre. No fertilizer was supplied for the camelina crop.

Data collection. The quantity of C and N returned to the soil by the 67- and 87-day-old jointvetch crop was determined by harvesting all plants in a 4 ft × 11 ft grid placed in the center of each main plot. Roots and shoots were separated, dried at 75 °C (167 °F), and weighed to determine biomass/acre. The C and N contents of dried roots and shoots were determined using a total carbon–nitrogen analyzer, (Flash 2000 NC Analyzer, Thermoscientific, Pittsburgh, PA). Plant weights were multiplied by their C and N content (%) to provide an estimate of total C and N/acre produced by the joinvetch crop. Soil samples were collected from each plot on 20 Oct., 22 Dec., 8 Feb., and 18 Apr. Ten soil cores (2.5 cm × 6 cm) were collected from each split plot along a diagonal transect and bulked together. Total soil C and N was determined from each composite sample using the total carbon–nitrogen analyzer. Soil K was determined using Melich III extraction and Inductively Coupled Plasma-Atomic Emission Spectroscopy. Camelina yield was determined on15 Apr. by collecting seed pods from all plants in a 4 ft × 11 ft grid in the center of each split plot. The camelina crop was hand harvested and pods were dried, threshed, cleaned, and weighed.

Data analysis. Analysis of variance (ANOVA) was performed to determine the effect of main treatments (A-67, A-88, and C) and split plots (N at 71 and 141 lb/acre) on soil C, N, and yield of camelina. A general linear models procedure and Duncan's multiple range test and critical ranges were used to compare treatment means (STATISTICA, StatSoft, Inc., Tulsa, OK). Data were analyzed as a randomized block split-plot design with six replications.

Results and Discussion

On average, jointvetch roots contribute only 13% to16% of the C returned to soil and 9% to 11% of the N returned to soil (Table 1). This is because the majority of the biomass produced by jointvetch is in the foliage, which coincidently contains the higher concentration of photosynthates. It is important to note the quantity of C and N returned to the soil can be as high as 3689.3 kg·ha^{-1} (3,294 lb/acre) and 253.9 kg·ha^{-1} (226.7 lb/acre), respectively. Although previous studies examining the quantity of C and N returned to soil when jointvetch is grown as a green manure are not available, it has been estimated that jointvetch can provide up to 112 kg·ha^{-1}, (100 lb/acre) annually (Hodges et al., 1982). For comparison, 120-d crops of sunn hemp (*Crotolaria juncea*), velvetbean (*Mucuna pruriens*), and iron clay pea (*Vigna unguiculata* L. 'Iron Clay') grown in south Florida returned up to 356 kg·ha^{-1} (318 lb/acre), 255 kg·ha^{-1} (286 lb/acre), and 243 kg·ha^{-1} (217 lb/acre), respectively (Wang et al., 2005). In central Florida, sunn hemp returned up to 171 kg·ha^{-1} (318 lb/acre) to the soil (Cherr et al., 2006). Thus, the N accumulated and returned to the soil in this experiment was higher than iron clay pea and velvetbean and comparable to sunn hemp. In Florida, it is estimated that 50% of the total N produced from a cover crop is available to a subsequent vegetable crop (FLDACS, 2005). Thus, it is estimated that > 112 kg·ha^{-1} (100 lb/acre) was transformed to nitrate or ammonium N and available to the subsequent sunflower and camelina crops.

The jointvetch summer crop did not significantly impact soil C (Table 2). However, there was evidence of a trend of increased soil C where the jointvetch cover crop was grown in the Oct. and Dec. samples (Fig. 1). Sample date did significantly impact soil C. The jointvetch cover crop did increase total soil N ($P = 0.08$), particularly on the 22 Dec. sample date. The observed elevated soil N in the 22 Dec. sample coincided preceded the planting of the camelina (third) crop and most likely increased the content of available N. The summer jointvetch crop also had a pronounced effect ($P < 0.01$) on soil K. There was also a significant interaction between sample date and soil K ($P < 0.01$) with the largest difference between jointvetch cover crop vs. no cover crop occurring the 22 Dec. sample date.

Table 1. Quantity of C and N returned to soil by planting jointvetch (*Aeschynomene americana*) as a summer, green manure crop.

Age of crop	Roots	Shoots	Combined
		Carbon	
67 d	451.4 kg·ha^{-1} (403.0 lb/acre)	2364.4 kg·ha^{-1} (2,111.2 lb/acre)	2815.7 kg·ha^{-1} (2,514 lb/acre)
87 d	485.0 kg·ha^{-1} (433.1 lb/acre)	3204 kg·ha^{-1} (2,861 lb/acre)	3689.3 kg·ha^{-1} (3,294 lb/acre)
		Nitrogen	
67 d	23.0 kg·ha^{-1} (20.5 lb/acre)	180.2 kg·ha^{-1} (161.4 lb/acre)	203.7 kg·ha^{-1} (181.9 lb/acre)
87 d	23.40 kg·ha^{-1} (20.9 lb/acre)	230.50 kg·ha^{-1} (205.8 lb/acre)	253.9 kg·ha^{-1} (226.7 lb/acre)

Table 2. Results from repeated measures ANOVA for the effect of main treatment (jointvetch cover crop), split plot (sunflower N rates), and sample date (repeated measure) on soil carbon (C), nitrogen (N), and potassium (K).

Factor	F	*P*
Carbon		
Treatment	1.01	0.37
Split plot	2.00	0.16
Treatment × split plot	0.33	0.72
Date	3.92	0.01
Date × treatment	0.60	0.72
Date × split plot	1.42	0.24
Date × treatment × split plot	0.88	0.51
Nitrogen		
Treatment	2.59	0.08
Split plot	3.35	0.07
Treatment × split plot	0.14	0.87
Date	1.20	0.31
Date × treatment	0.98	0.44
Date × split plot	0.70	0.55
Date × treatment × split plot	0.50	0.80
Potassium		
Treatment	6.88	<0.01
Split plot	2.62	0.11
Treatment × split plot	0.03	0.97
Date	58.73	<0.01
Date × treatment	5.69	<0.01
Date × split plot	0.24	0.86
Date × treatment × split plot	0.41	0.87

Both the jointvetch cover crop and the split applications of N during the sunflower crop significantly affected the subsequent yield of the third crop (camelina). Yield of camelina was significantly higher in plots where jointvetch was previously cultivated and in plots received the high N rate during the sunflower (second) crop (Table 3). It is interesting to note the large discrepancy in camelina yield observed between the bare ground fallow plots receiving 79.5 and 157.9 $kg\cdot ha^{-1}$ (71 or 141 lb/acre) of N during the second (sunflower) crop (Fig. 2). Yield was almost double in plots that had received the higher rate of N during the previous sunflower crop. By contrast, applying additional N during the sunflower crop did not affect subsequent yields in the camelina plot. Camelina yields in the plots where jointvetch was cultivated the previous summer remained higher than yields in plots where no summer crop was grown, regardless of the quantity of N applied during the second (sunflower) crop.

Camelina yields ranged from 334 $kg\cdot ha^{-1}$ (298 lb/acre) to 752 $kg\cdot ha^{-1}$ (672 lb/acre). These yields are in the low range of yields reported from northern camelina production areas. In South Dakota, average yields of 321, 198, 370, and 675 $kg\cdot ha^{-1}$ (287, 177, 330 and 600 lb/acre) were reported in 2005, 2006, 2007, and 2008 respectively (Grady and Nleya, 2010). In Colorado, yields ranging from 1,784 to 2,548 $kg\cdot ha^{-1}$ (1,561 to 2,275 lb/acre) were reported depending upon cultivar, seeding rate, and N rate (Lafferty et al., 2009). In a 2-year field study in Minnesota, camelina yields ranged from 419 to 1,317 $kg\cdot ha^{-1}$ (247 to 1,172 lb/acre) (Gesch and Cermak, 2011). Thus, it appears that camelina grown in Florida in rotation with vegetables can produce yields

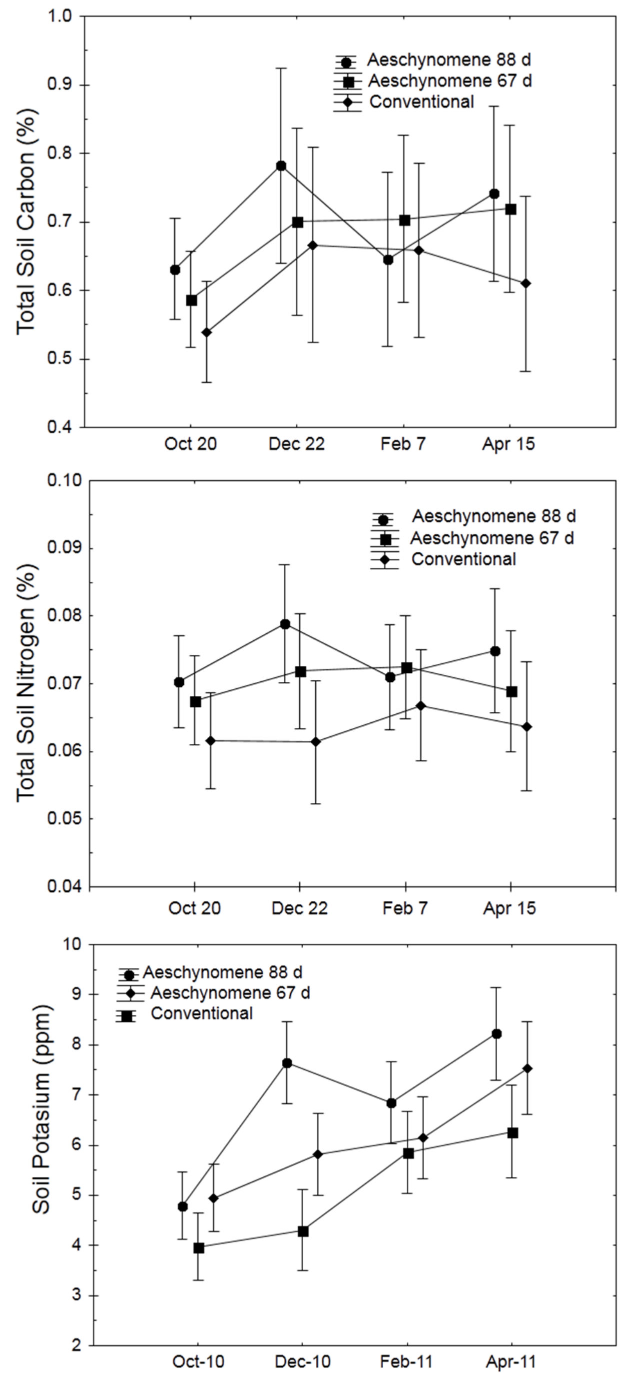

Fig. 1. Total soil (**top**) C, (**middle**) N, and (**bottom**) K from main plots. Vertical bars represent 95% confidence limits.

typical of camelina in more temperate regions were the crop is grown under low fertility inputs.

In summary, an oil-seed crop rotation for vegetable growers in the Florida Everglades Watershed that included jointvetch as a green manure was evaluated for its contribution to soil N, K, and C and for yield of camelina. Significant increases in soil N and K were observed although they were influenced by the time of year

Table 3. Effect of main treatment (jointvetch cover crop) and split plots (sunflower N rates) on yield of camelina seed.

Main plots ($P < 0.01$)	
Jointvetch 88-d crop	655.2 $kg \cdot ha^{-1}$ (585 lb/acre)
Jointvetch 67-d crop	705.6 $kg \cdot ha^{-1}$ (630 lb/acre)
Bare ground fallow	451.4 $kg \cdot ha^{-1}$ (403 lb/acre)
Split plots ($P = 0.04$)	
N applied at 156.8 $kg \cdot ha^{-1}$ (140 lb/acre)	667.5 $kg \cdot ha^{-1}$ (596 lb/acre)
N applied at 78.4 $kg \cdot ha^{-1}$ (70 lb/acre)	541.0 $kg \cdot ha^{-1}$ (483 lb/acre)

Main plot × split plot interaction was nonsignificant ($P = 0.43$).

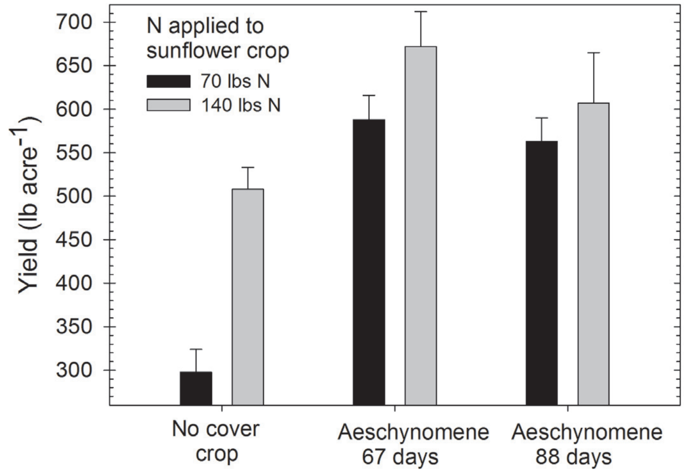

Fig. 2. Yield of dried and cleaned camelina seed. Error bars represent standard errors.

soil samples were collected. Yield of camelina seed, planted as the third crop in the rotation without additional fertility inputs, were significantly improved in plots where jointvetch was grown the previous summer as a green manure crop.

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