Insect Pests and Yield Potential of Vegetable Soybean (Edamame) Produced in Georgia[1]

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Abstract A series of replicated field experiments was conducted with vegetable soybean (edamame), *Glycine max* (L.) Merrill, to assess the impacts of cultivars, planting dates, and insecticidal controls on insect pest abundance, crop damage and yield potential. The velvetbean caterpillar, *Anticarsia gemmatalis* Hübner, was the most common lepidopteran defoliator in this study, causing heavy defoliation in some years when left untreated. Other lepidopterans observed included the soybean looper, *Pseudoplusia includens* (Walker), and the green cloverworm, *Hypena scabra* (F.). Stink bugs, primarily the southern green stink bug, *Nezara viridula* (L.), also caused seed damage in some cultivars when left untreated. Stink bug damage exceeded expectations on edamame seeds when exposed to moderate stink bug densities ($\leq$3 bugs per 25 sweeps). Other arthropods that were commonly observed included threecornered alfalfa hoppers, *Spissistilus festinus* (Say), grasshoppers, *Melanoplus* spp., and the potato leafhopper, *Empoasca fabae* (Harris). Arthropod infestations on edamame were similar to reported pest problems on conventional soybeans being produced for oil and meal. Midseason applications of the insecticides diflubenzuron plus l-cyhalothrin reduced insect pest populations, percentage of arthropod-induced defoliation and percentage of seeds damaged by stink bugs, but had little effect on edamame yields. Most defoliation and seed damage occurred during R5 development when seeds were approaching full size, thus only minimal yield reductions were noted. However, seed quality of the untreated vegetable soybeans would be unacceptable for the consumer. Total fresh green yields ranged from 2343-11,895 kg ha^{-1}, depending on year, cultivar and planting date, whereas fresh green seed yields ranged from 1208-6,119 kg ha^{-1}. Early-maturing edamame cultivars planted in April had fewer insect pests and less damage than the cultivars planted later. Avoidance of insect pests is an important production consideration for insect management, especially critical in an organic production system. The fresh green seed yields produced during this study demonstrate that this emerging alternative crop has the potential for economic success in the southern region, assuming that the arthropod pests are effectively managed to maintain acceptable edamame quality and yield.

Key Words *Anticarsia gemmatalis*, *Nezara viridula*, insect pest management, alternative agriculture

Soybean, *Glycine max* (L.) Merrill, production has steadily increased throughout the United States during the past decade. Over 198 billion kg were produced on 30.2 million ha in 2004, making it one of the largest crops ever planted (American Soybean

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Association 2004). In Georgia, hectares planted in soybean have generally been declining over the same period; however, in 2004 there were 109,000 ha harvested, which was up slightly from 2003 plantings (Georgia Agricultural Statistics Service 2005). The overall reduction in soybean production during recent years in Georgia, and throughout most of the southern states, is due to several factors including an increase in cotton hectares planted, reduced loan rates under the 2002 farm bill and lack of production efficiency due to lower prices, lower yields due to drought and pest problems, and rising production costs (Shumaker 2003).

An endeavor to develop a niche for fresh-market green vegetable soybeans (referred to as edamame) has been initiated in Kentucky, South Carolina, North Carolina and other areas in the southern U.S. (Ernst and Woods 2001, Hamilton 2007). This new crop faces many challenges, including developing market strategies, breeding new cultivars, implementing pest management options, and improving harvesting techniques (Johnson 1999, Johnson et al. 1999, 2001, Bernard 2001). Edamame is an important high protein crop in Asia (Nguyen 2001) and is growing in popularity in America, especially among those who are more health conscious (Rao et al. 2002, Hamilton 2007). Soy foods can help reduce the risks of certain cancers, coronary disease, osteoporosis, weight gain, and relieve menopausal symptoms (Physicians Laboratories 2006). Fresh vegetable soybean seeds are high in protein (35-38%) and low in lipids (5-7%), and most of the lipids are monounsaturated fatty acids, which makes vegetable soybeans a highly nutritious food (Mentreddy et al. 2002). Soybeans are also one of the few natural sources of isoflavones and tocopherols (vitamin E) plus have high levels of Ca, P, K, Na, carotene, iron, vitamins B_1, and B_2, and ascorbic acid (Mentreddy et al. 2002).

Research is needed under Georgia growing conditions to confirm profit margins being reported for vegetable soybean production in Kentucky (Ernst and Woods 2001). Also, research is needed to investigate the impact of insect pests on edamame quality, yield, and production efficiency. Insect pests, especially stink bugs (primarily *Nezara viridula* (L.)), velvetbean caterpillars, *Anticarsia gemmatalis* Hübner, and soybean loopers, *Pseudoplusia includens* (Walker), are a major threat to the soybean crop every year in the southern states (Funderburk et al. 1999). The date of planting and the maturity grouping of the soybean cultivar (Fehr et al. 1971) reportedly impact the seasonal incidence of insect pests (All 1999, McPherson 1996, McPherson et al. 1996), especially when planted earlier than the conventional planting dates (McPherson et al. 2001). Insect pests cause over $2 million USD in soybean losses due to control costs and crop damage in most years in Georgia (Guillebeau et al. 2004). It is unknown whether insect pest problems are this damaging to edamame that have been developed for flavor and nutritional value for human consumption. Pest management information is essential for protecting edible soybeans from insect-induced crop losses due to quality and yield reductions. Thus, a series of field experiments was conducted to assess the seasonal incidence of insect pests on different vegetable soybean cultivars planted on different dates, to examine the injury that insect pests can cause when not managed on this alternative crop, and to evaluate the production potential of the crop grown under Georgia conditions.

Materials and Methods

2002 planting date and insecticide study. Three vegetable soybean cultivars, 'Midori Giant', 'Green Lion', and 'Bellesoy' were planted on 2 dates, 19 April and 17

May, at the Coastal Plain Experiment Station Rigdon Farm in Tift Co., GA, in 2002. In addition, Midori Giant was planted a third time on 9 July 2002, in the same plots where Midori Giant had been planted on 19 April and harvested on 29 June. Main plots were 24 rows (0.91 m spacing) by 15 m long and were split, with 12 rows left untreated and 12 rows sprayed on 28 June, 23 July, and 22 August, with foliar applications of diflubenzuron (Dimilin™ 2L, 0.05 kg ha^{-1}, Chemtura, Middlebury, CT) plus l-cyhalothrin (Karate™ 2.08Z, 0.035 kg ha^{-1}, Syngenta Crop Protection, Greensboro, NC). The insecticides were applied using a CO_2-powered backpack sprayer delivering 187 L per ha at 414 kPa through two TX-12 nozzles per row. The 19 April planting of Midori Giant was not treated with insecticides because it was harvested in late June. Also, the 9 July planting of Midori Giant was treated only on 25 July and 22 August. The cultivars were arranged in a randomized complete block design with a split-plot arrangement of treatments with 3 replications, with variety as the main plot and insecticide treatment as the spilt-plot. The experimental site was plowed, bedded and treated with a preplant incorporation of pendimethalin (Prowl™ 3.3, 0.84 kg ha^{-1}, BASF Corp., Research Triangle Park, NC) herbicide following current soybean production guidelines (Jost 2006). Prior to plowing, 500 kg ha^{-1} of fertilizer (3% N, 9% P_2O, 18% K_2O, Fletcher Limestone, Tifton, GA) was broadcast over the test site.

All plots were sampled weekly for insect pests using a 38-cm diam sweep net. A 25-sweep sample was taken from a single row within each subplot (Kogan and Pitre 1980), making sure that no row was sampled more than once per month. Each sample was placed into a clear plastic bag, labeled, returned to the laboratory, and frozen until it could be sorted and the insects counted at a later date. All commonly observed arthropods were identified to species and recorded. Sampling began when the plants were large enough for sweeping, around 4-5 wks after planting and the plants were in the V_4 growth stage (3 uncurled trifoliolates) (Fehr et al. 1971) and continued until plots were harvested. When the plants reached the R_4 growth stage, pods filling with seeds (Fehr et al. 1971), plant heights were measured from the ground to the uppermost point from 3 random sites within each subplot. The percentage defoliation was estimated for each subplot every 2 wk during mid-July through mid-Sep. Once all defoliation estimates were obtained, in increments of 5%, each subplot was examined a second time, and the defoliation estimates were compared with the estimates of adjacent plots to ensure that they were relative to the other plots. This method of visual defoliation has proven to be a reliable estimate of relative defoliation among treatments when compared with leaf area removed that is measured with an area meter (McPherson et al. 1996) or compared with photographs of similar leaves with known percentage defoliation (All et al. 1989). At R_6 growth stage, pods containing full-size green beans (Fehr et al. 1971), all plants in 3.1 m from the center row were cut, and all fresh green pods were removed and weighed. From this harvest sample, 100 pods were randomly selected and all fresh green seeds were shelled and weighed to determine the percentage of seed weight to total weight (pods containing seeds). The seeds from each fresh green sample were individually examined for stink bug damage. Each seed was rated for either no damage or stink bug damage (stink bug puncture observed) and the percentage of damaged seeds was calculated. For each planting date, all insect count, plant height, defoliation, yield and stink bug damage data were subjected to the GLM analysis of variance procedure of SAS, $P = 0.05$ (SAS Institute 2003) for a randomized complete block design with a split-plot arrangement of treatments. The percentage defoliation and percentage of damaged seeds were transformed to the square root of the arcsine, and both the transformed and nontransformed data were analyzed. Cultivar means were separated using a Waller-Duncan K-ratio *t*-test (SAS Institute 2003).

2003 insecticide study. Two vegetable cultivars, Midori Giant and MoJo Green, were planted on 29 April 2003 at the Rigdon Farm. In addition, Midori Giant was planted a second time on 22 May. The test site was prepared, fertilized, and treated with herbicides as described previously. However, a post emergence application of bentazon (Basagran™ 4, 1.1 kg ha^{-1}, BASF Corp., Research Triangle Park, NC) also was applied on 10 June over all plots using a tractor-mounted sprayer delivering 162 L per ha. Individual plots were 24 rows (0.91 m spacing) by 15 m long arranged in a randomized complete block design with 4 replications. On 11 July, the MoJo Green and later-planted Midori Giant were split and 12 rows treated with diflubenzuron plus l-cyhalothrin, using a CO_2-powered backpack sprayer, as described previously. The Midori Giant planted on 29 April was harvested on 7 July, before the insecticide application was made.

All plots were sampled weekly using a sweep net as previously described, taking one 25-sweep sample per plot, bagging each sample in a plastic bag, freezing, and counting at a later date. Sampling began in mid-June and continued until the plots were harvested at the R_6 growth stage. At R_4 growth stage each variety was measured for plant height, taking 3 random measurements within each plot. Percentage defoliation estimates were obtained from each plot in late June, mid-July, and mid-August, using identical procedures as those reported for the 2002 trial. At R_6 growth stage, all plants in 3.1 m from the center row were cut and all fresh green pods were removed and weighed. From this harvest sample, 100 pods were randomly selected, and all fresh green seeds were shelled and weighed to determine the percentage of seed weight to total weight (pods and seeds). The seeds from the fresh green sample were examined for stink bug damage, as reported previously. All insect count, plant height, defoliation (both transformed and nontransformed data), yield and stink bug damage (transformed and nontransformed) data from the untreated plots from each variety were subjected to the GLM analysis of variance procedure of SAS, $P = 0.05$ (SAS Institute 2003). Cultivar means were separated using a Waller-Duncan K-ratio *t*-test. An ANOVA also was used to compare the treated versus untreated data for each cultivar (SAS Institute 2003).

2004 planting date study. Three vegetable soybean cultivars, Dawn, Midori Giant, and MoJo Green were planted on 21 April and 14 May 2004 at the Rigdon Farm. The experimental design was a randomized complete block with the treatments arranged in a split-plot. Cultivar was the main plot and planting date was the split-plot with 4 replications. Individual plots were 6 rows (0.91 m row spacing) by 15 m long. The experimental site was fertilized, turned, bedded, and treated with herbicides as previously described for the 2002 trial. All plots were sampled weekly, beginning at the V_4 growth stage and continuing until harvest at early R_6 stage, by taking a 25-sweep sample from each plot on each date. Each sample was bagged, frozen, and counted at a later date. No foliar insecticides were applied at this test site. Plant height was determined at the R_4 growth stage by measuring 10 consecutive plants on row 2, beginning with plant number 10 on the row. Yields were obtained at the early R_6 growth stage by harvesting all fresh green pods from a random 3.1 m sample in each plot. After the total fresh green weight was determined, all green seeds were removed from the pods and a fresh green seed weight was determined. Plant height and yield data were subjected to an ANOVA (SAS Institute 2003). The seasonal mean insect count data were analyzed with a Proc GLM procedure of SAS (SAS Institute 2003), and cultivar means were separated using the Waller-Duncan K-ratio *t*-test (SAS Institute 2003).

2004 edamame cultivar study. Seven vegetable soybean cultivars were planted on 1 July 2004 at the Coastal Plain Experiment Station Horticulture Hill Farm in Tifton, GA. The experimental design was a randomized complete block with 4 replications. Plots were four rows (0.91 m spacing) by 23 m. The land was prepared and herbicides applied as previously reported. No fertilizer was applied because the P_2O and K_2O levels were already high. All plots were sampled every 7-10 d during August and September by taking a 1-m ground cloth sample per plot (Kogan and Pitre 1980), and all arthropods were counted in the field. On 30 August, plant height was measured in all plots by measuring 10 plants from rows 2 and 3. On 2 Sep and 27 Sep, all plots were rated visually for percentage defoliation. No foliar insecticides were applied at this test site. At R_6 growth stage, total fresh green weights and fresh green seed weights were obtained from a 3.1 m sample from row three. Plant height, yield, percent defoliation (transformed and nontransformed data) and insect count data were analyzed using a GLM analysis of variance procedure of SAS (SAS Institute 2003). Cultivar means were separated using the Waller-Duncan K-ratio *t*-test (SAS Institute 2003).

Results

2002 planting date and insecticide study. Insect pests were low in all vegetable soybean plots until early August in 2002, except for potato leafhoppers, *Empoasca fabae* (Harris), which were abundant in the early-planted (19 April) experiment. Bellesoy had a mean ± SE of 45.0 ± 6.8 and 61.8 ± 10.3 leafhoppers per 25 sweeps on 29 May and 4 June, respectively, compared with 12.0 ± 2.3 and 15.3 ± 4.5 per 25 sweeps on Midori Giant, and 6.5 ± 1.3 and 8.3 ± 2.5 per 25 sweeps on Green Lion, respectively. The 17 May planting had a total of 4 potato leafhoppers collected from all the sweep samples taken on the 4 June sampling date. On all other sampling dates for the remainder of the season, potato leafhoppers were low in all 3 planting dates, and when they were collected, they were on the Bellesoy cultivar only. Stink bugs, primarily *N. viridula*, but also including some *Euschistus servus* (Say), *Acrosternun hilare* (Say) and *Piezodorus guildinii* (Westwood), began to increase in mid-August and peaked on the last sampling date on 25 Sep with means ± SE of 12.0 ± 5.8 and 22.3 ± 6.1 per 25 sweeps in the untreated Bellesoy, early and late plantings, 9.7 ± 1.5 and 8.3 ± 1.4 in the Green Lion early and late plantings, and 10.3 ± 5.0 in the July planted Midori Giant cultivar, respectively. The Midori Giant cultivar never had over 1 stink bug per 25 sweeps in the 19 April planting and 3 per 25 sweeps in the 17 May planting on any sampling date up to harvesting on 28 June and 31 July, respectively. This very early maturing variety (R_6 growth stage in around 70 d after planting) was ready to harvest before the high stink bug populations were reached in September. The later-planted Midori Giant (9 July planting) sustained high stink bug populations in August and Sep, similar to those in Green Lion.

The Midori Giant cultivar planted in both April and May never had more than a mean ± SE of 1.2 ± 0.4 velvetbean caterpillar larvae per 25 sweeps, escaping the larval population peak that occurred on 6 Sep, when the untreated Green Lion early and late plantings, Bellesoy early and late plantings, and Midori Giant July planting had means (±SE) of 20.7 ± 3.8, 41.0 ± 20.4, 21.5 ± 4.5, 37.3 ± 4.5 and 33.5 ± 10.6 larvae per 25 sweeps, respectively. The early plantings of Midori Giant (April and

May) also had very low populations of threecornered alfalfa hoppers, *Spissistilus festinus* (Say), and grasshoppers, *Melanoplus* spp., compared with Green Lion, Bellesoy and late-planted Midori Giant. The alfalfa hoppers were never higher than 0.3 ± 0.3 per 25 sweeps (on 4 June) in the earlier-planted Midori Giant, whereas they peaked between 7.5 ± 3.3-9.2 ± 4.8 per 25 sweeps on 25 Sep in the other entries. Grasshoppers reached 1.4 ± 0.4 per 25 sweeps in the earlier-planted Midori Giant (on 21 June) whereas they peaked between 8.7 ± 4.8-10.3 ± 3.5 on 25 Sep in the other entries.

The 19 April 2002 planting of Midori Giant soybean was significantly shorter (F = 7.86; df = 2,8; P = 0.015) than the other 2 varieties planted on this date, but there was no insecticide treatment effect on plant height (Table 1). The 17 May planting had no variety or treatment effect on plant height, nor was a difference in plant height observed between the treated and untreated Midori Giant planted on 9 July (Table 1). The percentage defoliation was not different between cultivars planted on 19 April; however, for the 17 May planting, the Midori Giant had significantly less defoliation (F = 6.54; df = 2,8; P = 0.028) on 5 August than the other varieties. The insecticides treatments applied in June, July and August significantly reduced the amount of defoliation on both the 19 April planting (5 Aug; F = 12.23; df = 1,4; P = 0.025; 19 Sep: F = 26.01; df = 1,4; P < 0.01) and the 17 May planting (5 Aug: F = 7.11; df = 1,8; P = 0.033; 19 Sep: F = 10.98; df = 1,4; P = 0.029). There were no cultivar x treatment interactions for defoliation for either the 19 April planting or the 17 May planting. The July and August insecticide applications also significantly reduced the amount of defoliation on both 5 August (F = 18.79; df = 1,2; P = 0.049) and 19 Sep (F = 48.5; df = 1,2; P = 0.02) in the Midori Giant planted on 9 July (Table 1).

Fresh green total yields (pods with seeds) from the 19 April planting were significantly lower in Midori Giant (F = 7.17; df = 2,4; P = 0.043) than the other cultivars, and fresh green seed yields were approaching significance as well (F = 5.02; df = 2,4; P = 0.081). There were no treatment effects or cultivar x treatment interactions in the 19 April planting, nor any cultivar or treatment effects for total or seed yields in the 17 May planting or the 9 July planting of Midori Giant (Table 1). It is interesting to note that defoliation levels were higher in the untreated plots; however, yields were not different between the treated and untreated plots. Previous studies have reported that soybean yield reductions will be minimal when lepidopteran defoliation occurs after midseed filling (Board et al. 1994, McPherson and Buss 2007). It appears that the vegetable soybean cultivars examined in this study also have minimal yield reductions when defoliation occurs late in the season. Both the Green Lion and Bellsoy cultivars planted on 19 April were in R_6 development on 19 Sep when defoliation was 16.7% in the treated plots and 44.2% in the untreated plots (Table 1). Likewise, these cultivars, when planted on 17 May, were both in the late R_5 to early R_6 growth stage on 19 Sep when defoliation was 35.9% in the treated plots compared with 60.0% in the untreated plots. Similar defoliation differences on 19 Sep were noted in the Midori Giant variety (in the R_6 growth stage) planted on 9 July; yet, no yield differences were noted between the treated and untreated plots (Table 1).

Stink bug damage was significantly lower in the Midori Giant cultivar (7.8%) planted on 19 April than the other 2 cultivars planted on this date (33.2% in Bellesoy and 47.8% in Green Lion) (F = 5.21; df = 2,8; P = 0.03) (Table 1). Planting this early-maturing cultivar in April is an important production practice for managing stink bug damage, especially if edamame is being produced in an organic production system. Applying an insecticide treatment also reduced the percentage of damage in the 19 April planting ($F = 16.13$; df = 1,4; $P = 0.018$), with 28.1% damaged seeds in the treated plots compared with 53.0% in the untreated plots. Treatment differences also were noted for stink bug damaged seeds for the 17 May planting ($F = 6.87$; df = 1,8; $P = 0.028$) and for the Midori Giant 9 July planting ($F = 20.20$; df. = 1,2; $P = 0.042$) (Table 1). There were no cultivar x treatment interactions for stink bug damage for either planting date. It is interesting to note that the Midori Giant 17 May planting had nearly 40% damaged seeds even though stink bug densities never exceeded 3 per 25 sweeps on any sampling date. This is much more damage than would normally be expected from a peak population of 3 stink bugs per 25 sweeps in conventional soybeans (McPherson 1996). Most of this damage was minimal (a puncture on the seed but no shriveling or discoloration, McPherson and McPherson 2000) and would probably not be detected by a seed grader and most consumers.

2003 insecticide study. Both the 29 April and 22 May plantings of Midori Giant had lower seasonal populations of all the common insect pests when compared with MoJo Green. On 9 July, stink bug densities, primarily *N. viridula*, peaked at 2.6 ± 0.5 per 25 sweeps in the Midori Giant that was planted on 29 April compared with peak stink bug densities of 5.5 ± 2.8 per 25 sweeps on 30 July in Midori Giant planted on 22 May and 13.3 ± 5.5 per 25 sweeps on 20 August in MoJo Green. Lepidopteran larvae were low in all vegetable soybean plantings in 2003, with only around 0.5-2.0 larvae per 25 sweeps in most samples. The highest population of lepidopteran larvae occurred on 19 June, with 3.3 ± 1.2, 0.3 ± 0.4, and 2.8 ± 0.8 larvae per 25 sweeps in Midori Giant (29 April planting), Midori Giant (22 May planting), and MoJo Green plantings, respectively. All of the lepidopteran larvae on 19 June were green cloverworms, *Hypena scabra* (F.). Grasshoppers were commonly observed in all plots sampled between 5 June and 4 Sep, peaking between 9 July and 26 July at 1.5 ± 1.1, 1.8 ± 1.4, and 4.3 ± 0.4 per 25 sweeps in the Midori Giant (29 April planting), Midori Giant (22 May planting) and MoJo Green, respectively. Threecornered alfalfa hoppers also were commonly observed in all plots from 19 June to 26 August, peaking on 9 July at 0.3 ± 0.4 per 25 sweeps in Midori Giant (29 April planting), 0.8 ± 0.4 on 25 July in Midori Giant (22 May planting), and 2.0 ± 1.0 on 6 August in MoJo Green.

Plant height was significantly lower in both Midori Giant plantings than in MoJo Green in 2003 ($F = 8.77$; df = 2,6; $P = 0.015$), but there were no differences between the treated and untreated comparisons for either MoJo Green or Midori Giant (22 May planting) (Table 2)

The percentage defoliation was low at this test site in all varieties, whether treated with insecticides or untreated, even on 10 August when the highest defoliation levels were recorded (Table 2). Most of the defoliation was caused by grasshoppers and green cloverworms at this test site in 2003. No cultivar or treatment effects were noted for defoliation levels. Total fresh green yields ($F = 117.1$; df = 2,6; $P < 0.01$) and fresh green seed yields ($F = 56.58$; df = 2,6; $P < 0.01$) were lower in both Midori Giant plantings compared with MoJo Green, but no insecticide treatment effects were observed for either MoJo Green or Midori Giant. The Midori Giant 29 April planting had significantly less stink bug feeding damage than the other two entries ($F = 6.13$; df = 2,6; $P = 0.04$) (Table 2). Both MoJo Green treated ($F = 15.43$; df = 1,3; $P = 0.03$) and 22 May planted Midori Giant treated ($F = 10.08$; df. = 1,3; $P = 0.05$) had significantly less stink bug damage than their corresponding untreated plots (Table 2).

2004 planting date study. The seasonal mean numbers of insect pests across all 15 sampling dates reveal that threecornered alfalfa hoppers ($F = 8.26$; df = 2,228; $P < 0.01$), stink bugs ($F = 18.97$; df = 2,228; $P < 0.01$), velvetbean caterpillars

Table 1. Mean (± SEM) plant height, percentage defoliation, percentage of seeds with stink bug damage, and total fresh green yield (pods with seeds) plus green seed yield of three vegetable soybean cultivars planted on three different dates and either treated with insecticides (T) or left untreated (UT), Tift Co. GA, 2002

Soybean cultivars	Plant ht (cm)	% defoliation		% damaged seeds	Yield kg ha^{-1}	
		5 August	19 Sept.		Total	Seed
			19 April planting Varietal effect			
Midori Giant	36.8 ± 2.1b	—	—	7.8 ± 2.1c	2343 ± 615b	1208 ± 347a
Green Lion	75.1 ± 6.9a	11.7 ± 6.7a	29.2 ± 1 6.0a	47.8 ± 2.3a	5400 ± 410a	2656 ± 237a
Bellesoy	70.9 ± 4.4a	15.0 ± 6.7a	31.7 ± 11.8a	33.2 ± 2.9b	4720 ± 437a	2232 ± 220a
			Treatment effect*			
Treated	73.6 ± 6.6a	6.7 ± 1.7b	16.7 ± 3.4b	28.1 ± 1.8b	5060 ± 811a	2481 ± 311a
Untreated	72.4 ± 5.1a	20.0 ± 1.7a	44.2 ± 0.9a	53.0 ± 3.4a	4856 ± 606a	2455 ± 421a

Table 1. Continued.

Soybean cultivars	Plant ht (cm)	% defoliation		% damaged seeds	Yield kg ha^{-1}	
		5 August	19 Sept.		Total	Seed
			17 May planting			
			Varietal effect			
Midori Giant	41.3 ± 3.3a	7.4 ± 3.7b	—	39.6 ± 9.8a	3006 ± 714a	1542 ± 367a
Green Lion	47.0 ± 5.2a	21.7 ± 11.7a	50.9 ± 14.2a	52.4 ± 2.9a	3226 ± 1443a	1336 ± 723a
Bellesoy	43.9 ± 3.5a	19.2 ± 7.5a	45.0 ± 10.1a	40.0 ± 3.9a	3905 ± 1008a	1858 ± 1408a
			Treatment effect			
Treated	43.9 ± 4.7a	8.5 ± 3.4b	35.9 ± 0.9b	33.6 ± 4.3b	3645 ± 1392a	1714 ± 714a
Untreated	44.3 ± 3.9a	23.7 ± 9.3a	60.0 ± 5.1a	57.7 ± 6.7a	3113 ± 1045a	1444 ± 580a
			9 July Planting*			
Midori Giant (T)	26.2 ± 2.1a	6.7 ± 2.4b	26.7 ± 2.4b	47.1 ± 2.9b	1698 ± 321a	869 ± 201a
Midori Giant (UT)	26.7 ± 2.6a	16.7 ± 6.8a	53.3 ± 2.4a	59.3 ± 3.6a	1664 ± 230a	848 ± 153a

* Only Green Lion and Bellesoy were treated with diflubenzuron plus 1-cyhalothrin insecticides on 28 June, 25 July and 22 August in the 19 April planting because Midori Giant was harvested in late June. The Midori Giant planted on 9 July was treated with insecticides on 25 July and 22 August only.

Column means for cultivar within the same planting date with the same letter are not significantly different, Waller-Duncan k-ratio *t*-test, $P = 0.05$.

Table 2. Mean (± SEM) plant height, percentage defoliation and total fresh green yield (pods with seeds) and seed yield of two vegetable soybean cultivars either treated with insecticide (T) or left untreated (UT), Tift Co. GA, 2003*

Soybean cultivar and (planting date)	Plant ht. (cm)	% defol. 10 Aug.	% damaged Seeds	Yield kg ha^{-1} Total	Yield kg ha^{-1} Seeds
Untreated cultivar comparisons					
Midori Giant UT (4/29)	41.4 ± 3.3b	—	8.5 ± 2.9b	6,487 ± 460b	3,302 ± 465c
Mo Jo Green UT (4/29)	76.7 ± 6.0a	11.8 ± 2.1a	27.0 ± 2.3a	11,895 ± 508a	5,930 ± 225a
Midori Giant UT (5/22)	41.9 ± 5.3b	15.0 ± 1.1a	31.5 ± 3.3a	7,361 ± 392b	4,085 ± 388b
Treatment comparisons for each cultivar					
Mo Jo Green T (4/29)	73.1 ± 4.7A	11.3 ± 2.1A	6.7 ± 1.5B	11,691 ± 336A	6,119 ± 310A
Mo Jo Green UT (4/29)	76.7 ± 6.0A	11.8 ± 2.1A	27.0 ± 2.3A	11,895 ± 508A	5,930 ± 225A
Midori Giant T (5/22)	40.1 ± 2.1A	10.5 ± 0.9A	22.4 ± 4.5B	7,514 ± 473A	4,204 ± 347A
Midori Giant UT (5/22)	41.9 ± 5.3A	15.0 ± 1.1A	31.5 ± 3.3A	7,361 ± 392A	4,085 ± 388A

* Treated on 11 July with diflubenzuron plus l-cyhalothrin. Midori Giant planted on 29 April was harvested on 7 July before the insecticides were applied. No defoliation ratings were taken on 10 Aug in the early-planted Midori Giant because they were already harvested.

Column means for cultivar comparisons followed by the same lower case letter are not significantly different, Waller-Duncan K-ratio *t*-test ($P = 0.05$). Column means for treatment comparisons for each variety followed by the same capital letter are not significantly different (ANOVA).

(F = 13.58; df = 2,228; P < 0.01) and soybean loopers (F = 14.72; df = 2,228; P < 0.01) were higher in MoJo Green than in Dawn and Midori Giant cultivars at the 2004 test site (Table 3). These differences were primarily due to the fact that Mojo Green was sampled an additional 7 wks, from 9 July to 20 August, until reaching the R_6 stage for harvest compared with the Dawn and Midori Giant varieties that were much earlier maturing. There was no varietal difference in grasshopper populations, plus there were no planting date differences among the 5 insect pests sampled; however, there was a trend toward more grasshoppers in the early planting date (F = 2.73; df = 1,228; P = 0.1) (Table 3). No cultivar x planting date interactions were observed for the seasonal mean populations of any of the insect pest species reported. Potato leafhoppers were commonly observed only on 17 June, and then, only on the late-planted soybeans. There were 2.3 ± 1.3, 3.0 ± 1.2, and 2.0 ± 1.2 leafhoppers per 25 sweeps on the late-planted Mojo Green, Dawn, and Midori Giant, respectively, and no leafhoppers on any of these 3 cultivars planted earlier. There was no cultivar effect for potato leaf hoppers on 17 June, but there was a planting date effect (F = 6.65; df = 1,12; P = 0.024) on this sampling date. Green cloverworm larvae were observed at low population densities (from 0-4 per 25 sweeps) in June and July in all three cultivars planted on both 21 April and 14 May, but there were no cultivar, planting date, or cultivar x planting effects for this insect pest. The MoJo Green cultivar was significantly taller than Dawn and Midori Giant (F = 8.66; df = 2,12; P < 0.01) at the R_4 growth stage, due primarily to its longer growing season due to later maturity (Table 4). Although there was no planting date effect for plant height (Table 4), there was a significant planting date x cultivar interaction (F = 57.45; df = 2,12; P < 0.01). Both the Dawn and Midori Giant cultivars were 5-10 cm taller when planted later; whereas, the Mojo Green was 28 cm shorter when planted later. Total fresh green yields (F = 10.70; df = 2,12; P < 0.01) were lower in the Midori Giant and MoJo Green

Table 3. Seasonal mean (± SEM) incidence of insect pests in three vegetable soybean cultivars planted on 21 April and 14 May, Tift Co. GA, 2004

Soybean cultivar	Mean insects per 25 sweeps*				
	TCAH	SB	GH	VBC	SBL
			Cultivar effect		
Dawn	0.3 ± 0.5b	0.2 ± 0.6b	0.6 ± 3.0a	0.0 ± 0.0b	0.0 ± 0.2b
Midori Giant	0.1 ± 0.4b	0.2 ± 0.4b	0.2 ± 0.4a	0.0 ± 0.2b	0.1 ± 0.2b
Mojo Green	0.6 ± 0.8a	2.6 ± 4.2a	0.5 ± 0.8a	4.1 ± 8.4a	0.6 ± 1.2a
			Planting date effect		
21 April	0.4 ± 0.7a	1.3 ± 3.0a	0.6 ± 2.3a	2.0 ± 7.0a	0.3 ± 0.9a
14 May	0.4 ± 0.6a	1.3 ± 3.2a	0.3 ± 0.5a	1.8 ± 5.2a	0.3 ± 0.7a

* Mean from 4 reps × 8 weeks (n = 32) for Dawn and Midori Giant (early maturing cultivars) and 4 reps × 15 weeks (n = 60) for Mojo Green (a late maturing cultivar). Insect pests included threecornered alfalfa hoppers (TCAH), stink bugs (SB), grasshoppers (GH), velvetbean caterpillars (VBC), and soybean loopers (SBL).
Column means for cultivar effect followed by the same letter are not significantly different (Waller-Duncan K-ratio t-test, P = 0.05).

Table 4. Mean (± SEM) plant height at R4 growth stage (pods forming) and fresh green total (pods with seeds) and seed yield of three vegetable soybean cultivars planted on 21 April and 14 May, Tift Co. GA, 2004

Soybean cultivar	Plant ht. (cm @ R4)	Yield kg ha^{-1} Total	Seed
	Cultivar effect		
Dawn	53.8 ± 8.2b	10,475 ± 510a	4956 ± 348a
Midori Giant	46.2 ± 4.5b	8,245 ± 907b	5398 ± 454a
Mojo Green	71.3 ± 16.5a	8956 ± 885b	3737 ± 577b
	Planting date effect		
21 April	60.7 ± 20.3a	9742 ± 734a	5122 ± 517a
14 May	54.7 ± 7.3a	8822 ± 807a	4272 ± 385b

Column means for overall effect followed by the same letter are not significantly different (Waller-Duncan K-ratio *t*-test, $P = 0.05$).

cultivars than in the Dawn cultivar (Table 4), and fresh green seed yields were lower ($F = 25.70$; df = 2,12; $P < 0.01$) in MoJo Green than in either Dawn or Midori Giant. Midori Giant had lower total fresh green yields than the Dawn cultivar; however, green seed yields were similar between the 2 cultivars (Table 4), due to the large seed size of Midori Giant compared with Dawn. Over 65% of the total yield (pods and seeds) of Midori Giant was seed weight compared with 47% seed weight for Dawn. Planting date did not affect total fresh green yield ($F = 4.04$; df = 1,12; $P = 0.068$); however, the later planting date had a lower fresh green seed yield ($F = 18.78$; df = 1,12; $P < 0.01$) than the earlier planting date (Table 4). There was a significant planting date x cultivar effect for total yield ($F = 5.14$; df = 2,12; $P = 0.024$). The total yield for the Dawn cultivar was 741 kg ha^{-1} higher when planted later, whereas Midori Giant and Mojo Green were 2245 and 561 kg ha^{-1} lower, respectively, when planted on 14 May compared with 21 April. There was also a significant planting date x cultivar interaction ($F = 6.23$; df = 2,12; $P = 0.014$) for fresh green seed yield. The Dawn cultivar was 410 kg ha^{-1} lower in the 14 May planting whereas Midori Giant and Mojo Green were 1831 and 313 kg ha^{-1} higher, respectively, in the 14 May planting.

2004 edamame cultivar study. Insect pest populations were low throughout the season in all 7 cultivars. However, there were higher numbers of velvetbean caterpillars on the Asmara cultivar than on some of the other cultivars on 30 August ($F = 2.83$; df = 6,18; $P = 0.037$) and 27 Sep ($F = 5.01$; df = 6,18; $P = 0.01$) (Table 5). Stink bug and soybean looper populations were low in all cultivars throughout the season, and no cultivar differences were noted, not even at the population peak on 30 August (Table 5). The Moon Cake variety was taller in late August than all other varieties ($F = 8.50$; df = 6,18; $P = <0.01$) (Table 6). Total fresh green yields ($F = 3.72$; df = 6,18; $P = 0.013$) and seed yields ($F = 2.76$; df = 6,18; $P = 0.047$) were higher in Dawn, Asmara, and Owens. The percent defoliation was higher in the Asmara cultivar than in several of the other cultivars on 2 Sep ($F = 6.40$; df = 6,18; $P = 0.01$) and higher in

Table 5. Abundance of stink bugs (SB), velvetbean caterpillars (VBC), and soybean loopers (SL) during population peaks on seven vegetable soybean cultivars, Tifton, GA, 2004

	Insects per 3 row-m			
	30 August			27 Sept.
Soybean cultivar	SB	VBC	SBL	VBC
Midori Giant	0.5 ± 0.1a	2.8 ± 1.1ab	2.0 ± 0.3a	1.5 ± 0.5c
Dawn	1.3 ± 0.3a	1.0 ± 0.3bc	0.5 ± 0.1a	2.5 ± 0.8bc
Mojo Green	0.3 ± 0.1a	2.0 ± 0.8abc	0.5 ± 0.2a	3.3 ± 0.8bc
Owens	0.3 ± 0.1a	1.5 ± 0.8bc	1.8 ± 0.3a	6.5 ± 2.3abc
Randolph	0.0 ± 0.0a	2.0 ± 0.5abc	2.0 ± 0.5a	2.8 ± 1.1bc
Asmara	0.3 ± 0.2a	3.8 ± 1.3a	2.3 ± 0.8a	10.0 ± 4.3a
Moon Cake	0.0 ± 0.0a	0.3 ± 0.1c	1.0 ± 0.3a	8.0 ± ab

Soybeans planted on 1 July. Stink bugs included all pest species combined but were primarily southern green stink bugs. Column means followed by the same letter are not significantly different (Walker-Duncan k-ratio *t*-test, $P = 0.05$).

Table 6. Mean (± SEM) plant height (on 30 August), fresh green total yield (pods with seeds), seed yield, and percent defoliation on 7 vegetable soybean cultivars, Tifton, GA, 2004

Soybean cultivar	Plant ht. (cm)	Yield kg ha^{-1}		% defoliation	
		Total	Seed	2 Sept.	27 Sept.
Midori Giant	52.0 ± 8.3d	2764 ± 743d	1821 ± 567bcd	5.8 ± 1.3c	—
Dawn	62.2 ± 1.3cd	8131 ± 355a	4115 ± 249a	11.7 ± 6.2bc	—
Mojo Green	52.0 ± 18.0d	3415 ± 322d	1399 ± 189d	7.0 ± 1.3c	21.3 ± 5.4b
Owens	57.9 ± 16.5cd	6667 ± 279ab	2911 ± 238ab	18.8 ± 4.1ab	32.5 ± 5.6a
Randolph	74.4 ± 2.8c	4879 ± 926c	1691 ± 553cd	17.5 ± 5.5ab	21.3 ± 4.1b
Asmara	92.2 ± 5.1b	7156 ± 415ab	2976 ± 369ab	21.3 ± 1.3a	30.0 ± 6.1ab
Moon Cake	116.3 ± 13.9a	5854 ± 229bc	2863 ± 174abc	11.8 ± 2.0bc	26.3 ± 2.0ab

Soybeans planted on 1 July. Yields obtained at early R6 growth stage (pods filled with full-sized seeds). No defoliation ratings were obtained for Midori Giant and Dawn on 27 Sep because they had already been harvested. Column means followed by the same letter are not significantly different (Walker-Duncan k-ratio *t*-test, $P = 0.05$).

Owens than in MoJo Green and Randolph on 27 Sep ($F = 3.44$; df = 4,12; $P = 0.045$) (Table 6). However, defoliation levels were light to moderate (20-30%) in all cultivars in late Sep, due to low overall populations of defoliating insect pests throughout the season. Stink bug damage to seeds was very low (3-7% damage) in all 7 cultivars being examined at this test site.

Discussion

The results from this series of studies on cultivar selection, planting date and insecticidal controls within the vegetable soybean production system in Georgia, suggest that vegetable soybeans provide an economical alternative crop for the southern U.S. The insect pest complex appears to be similar to insect pests on traditional soybeans being produced for oil and meal. Stink bugs, lepidopteran larvae, grasshoppers, threecornered alfalfa hoppers and potato leafhoppers were the most abundant pests observed. Vegetable soybeans planted in April had lower insect pest densities and seed damage than soybeans planted later. The early maturing Midori Giant cultivar also had low insect populations when planted in April or May due to its very short growing season. The early planting and early maturity of edamame to escape insect pests are important production considerations for insect management, especially in organic production systems. However, Midori Giant had higher stink bug damage than expected based on stink bug population densities. This is cause for concern because edamame is produced for human consumption, and seed injury due to stink bug feeding would affect the overall cosmetic appearance of the product due to discoloration and distortion of seed. This would most likely cause unacceptable marketable quality specifications for the consumer. Thus, effective stink bug sampling and management practices would be essential in vegetable soybean production to maintain or improve cosmetic appearance, extrinsic quality, aggregate sales and buyer's satisfaction.

The insecticidal controls (diflubenzuron plus l-cyhalothrin) applied when insect pests were present effectively reduced the amount of arthropod-induced defoliation and stink bug damaged seeds. However, yields were not improved with insecticide applications compared with the untreated plots, although seed quality was improved as previously mentioned. Most insect pest defoliation and seed damage occurred during the R5 plant growth stage as the seeds were approaching full size, and thus only minimal or no yield reductions would have been expected from defoliation or stink bug damage (Boethel et al. 2000, Board et al. 1994, McPherson and McPherson 2000). Insect damage, both percentage defoliation and damaged seeds, was higher on the edamame cultivars planted later in the season (mid-May to early July) than when planted in mid-April (Table 1). This is similar to the reports of more total insect damage being reported in North Carolina, when edamame was planted on 2 June (63.6% damage) compared with 15 May (23.8% damage) (Hamilton 2007), although specific insect pest species and pest-induced injury were not separated.

It appears that several vegetable soybean cultivars can be grown under Georgia conditions, planted from mid-April to early July, and produce fresh green seed yields that could be profitable to the grower. The Moon Cake cultivar, that was included in the study, has been developed for its tall growth characteristic (up to 1.5-2.0 m) and later maturity (Devine 2003), and should be especially valuable for organic production because of weed suppression due to shading (Devine 2003). Two other entries evaluated in this study, Mojo Green (late maturing) and Midori Giant (very early maturing) have been reported as edamame cultivars with good agronomic qualities under an organic production system in the south, although seed germination was not good for Midori Giant (Hamilton 2007). Other edamame cultivars and germplasm continue to be examined for production efficiency in the South (Rao et al. 2002).

In conclusion, edamame is a specialty crop for Georgia producers that offers an alternative to conventional row cropping systems. Edamame can be produced under an organic or conventional crop protection system. Under Georgia growing conditions, a number of insect pest problems can be expected to occur during the season. Stink bugs, velvetbean caterpillars, soybean loopers and grasshoppers appear to the most common insect pests on edamame, similar to insect pest problems on conventional soybeans. When early-maturing edamame cultivars are planted in mid-April, very little insect damage occurs prior to harvesting of the fresh green pods and seeds. Additional evaluations on insect pest population dynamics and crop injury are needed on edamame to assist with the development and implementation of economic thresholds and insect pest management programs for this alternative cropping system.

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