Reprinted from the
JOURNAL OF ECONOMIC ENTOMOLOGY, VOL. 76, NO. 5, OCTOBER 1983

Impact of the Red Imported Fire Ant, *Solenopsis invicta* (Hymenoptera: Formicidae), on the Growth and Yield of Soybeans[1]

C. T. ADAMS,[2] W. A. BANKS,[3] C. S. LOFGREN,[2] B. J. SMITTLE,[2] AND D. P. HARLAN[3]

J. Econ. Entomol. 76: 1129–1132 (1983)

ABSTRACT The yield of soybeans, *Glycine max* (L.) Merr., from experimental plots infested with the red imported fire ant, *Solenopsis invicta* Buren, was 400 to 575 kg less per ha than that from comparable noninfested plots. The loss was attributable primarily to destruction of germinating seeds and seedlings, as evidenced by significant reductions in plants per meter of row in the infested plots. Evidence obtained from ^{32}P radioisotope studies showed that the ants also fed on growing plants, probably on their roots. Growth, as measured by plant height, was reduced in the ant-infested plots, a factor that could be associated with root-feeding activity. It is suggested that the impact of red imported fire ants on germinating soybean seeds is associated with planting dates (May and June) which coincide with a period of food stress associated with intense brood-rearing activity by the ants.

Whitcomb et al. (1972) surveyed for ant species in Florida soybean fields and identified 50 species representing six subfamilies. In fields supporting heavy infestations of the red imported fire ant (RIFA), *Solenopsis invicta* Buren, however, the number of other ant species was reduced, with as few as five species in some fields. The authors made no assessment, however, of the possible impact of RIFA on soybean yield or growth.

In studies in Lowndes County, Ga., Adams et al. (1976) reported that small but significant losses of soybeans (ca. 0.22 hl/ha) were caused by the interference of RIFA mounds with harvest of the crop. Similar studies in Brunswick County, N.C., (Adams et al. 1977) indicated a loss of ca. 0.65 hl/ha. These losses occurred because either (1) the combine operators raised the header bar of the combine to avoid making contact with the tumulus of the RIFA mounds, or (2) the plants in the immediate area of a fire ant mound were pushed over by the combine and partially buried by the tumulus.

Subsequently, data on yield of soybeans in Georgia and North Carolina indicated that fields treated with mirex for RIFA control, or those fields found to be free of RIFA, yielded 1.7 to 7.2 hl more soybeans per ha than fields infested with RIFA. This represented an average reduction in yield of 5.7 hl/ha (14.5% less) in the infested fields (Lofgren and Adams 1981). More recently, Apperson and Powell (1983) found in tests in North Carolina that fire ant populations were negatively correlated with soybean yield.

In this report we present additional data relative to the reduction of yield of soybeans based on tests conducted with RIFA in Gainesville, Fla., and Gulfport, Miss.

Materials and Methods

Gainesville, Fla.

Two field plots located in Millhopper Sands Soil Associations were prepared. Each plot measured 20 by 26 m, and they were separated by 20 m. Fertilization, cultivation, irrigation, and pesticide application procedures were conducted in accordance with recommendations for soybean culture in Florida (Hinson 1969). Soil samples were taken in March 1981 to determine soil fertility and, on the basis of the analysis, fertilizer (0-20-10) was applied on 16 May at a rate of 168 kg/ha and lime at a rate of 2,270 kg/ha. Irrigation (via sprinklers) was initiated after fertilization and continued until a 2.5-cm equivalent of rain was obtained. The soybeans ('Bragg' variety) were planted on 18 May at the rate of 100 kg/ha. Because of subsequent drought conditions, irrigation was restarted on 22 May and continued as needed throughout the growing season to maintain a 2.5-cm equivalent of rain per week.

The control plot was periodically surveyed for RIFA by placing nontoxic baits (ground meat) at various sites in the plot. If RIFA were collected, a small amount of Amdro fire ant bait was exposed for a short time in a container at the site of RIFA collection. This procedure limited feeding on the bait to RIFA so that effects on the other ant species were negligible.

The test plot was infested with eight active queenright RIFA colonies before planting of the soybeans. Three of these colonies migrated outside the plot, possibly as a result of cultivation activity, but re-established themselves within foraging range of the ant-infested soybean plot. The plot was reinfested with three additional colonies of RIFA; however, continued migration of ants resulted in stablization of the infestation at five colonies (ca. 108 mounds per ha).

Monitoring of both plots for other soybean pests during the growing season revealed a spotty infestation of the lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller), on 1 June. The infestation was controlled through continued irrigation, because high soil moisture reduces the rate of oviposition of this species. Mole cricket infestations, noted on 15 June, were controlled by a single application of Baygon mole cricket bait. Shake cloth collections were taken when visual inspection of the fields suggested lepidopterous larvae might reach damaging levels. As a result of these observations, both plots were treated with Dipel (1.0 lb of AI/acre) on 21 July

[1]Mention of a pesticide or commercial or proprietary product does not constitute an endorsement or recommendation by the USDA. Received for publication 6 December 1982; accepted 23 May 1983.

[2]Insects Affecting Man and Animals Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, P.O. Box 14565, Gainesville, FL 32604

[3]Imported Fire Ant Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, P.O. Box 3269, Gulfport, MS 39503.

immediately after early pod set for control of the corn earworm, *Heliothis zea* (Boddie), and on 1 September for control of the velvetbean caterpillar, *Anticarsia gemmatalis* Hübner. All insecticide applications were in accordance with Florida Agricultural Extension Service recommendations.

Plant density counts (plants per row-m) were initiated 28 May and conducted twice weekly through 22 July at 20 stations in each plot. A final preharvest plant density count was made on 7 October. Locations where the plants were counted were randomized through the use of a computer with a random-number generator.

A comparison was made of the number of seed pods per plant and meter of row in the RIFA-infested and RIFA-free plots on 15 September. Twelve randomized sample areas (30.5 by 30.5 cm) were established in each plot. Plants were cut at ground level, bundled, and returned to the laboratory, where the total plants and pods per bundle were counted.

Mean plant height was determined on 14 October as an additional indicator of possible adverse effects due to RIFA. Mean heights of six plants from each of 12 subplots in the RIFA-infested and RIFA-free plots were recorded.

Evidence of feeding by RIFA on growing plants was determined by injecting plants with ^{32}P (ca. 50 μCi per plant) on 30 June. The plants were widely spaced throughout the plot to prevent possible bias because of ant colony proximity. Injections of ^{32}P in water were made with a 27-gauge needle on a gas-tight syringe before flower set; however, some blooms developed later in the test period. Collections of workers foraging on or at the base of plants were made three times per week for 2 weeks. Radioactivity was determined with a liquid scintillation counter. Only samples with counts twice or greater than background were considered radioactive.

Yield was determined on 23 October from 12 randomized subplots within each test plot. Each subplot consisted of a single row of soybeans measuring ca. 7.4 m. The plants in each subplot were hand cut, threshed, cleaned, bagged, and weighed in kg/ha equivalents.

Gulfport, Miss.

Radioactive tracer studies were conducted in a greenhouse, using three laboratory trays (54.6 by 109.2 by 25.4 cm) filled to a depth of 10 cm with steam-sterilized soil. Thirty soybean seeds were placed in two rows of 15 seeds each. On day 15 after planting, seedlings were thinned to 26 plants per tray and each plant was injected with 5 μl of ^{32}P (ca. 50 μCi). A laboratory colony of RIFA consisting of the queen, 5 to 10 ml of immatures, and 20,000 to 30,000 worker ants was introduced into each tray 24 h after the soybean plants were inoculated. The ants were fed laboratory diet (Banks et al 1981) as needed. Samples of worker ants were taken from trays 1, 4, 6, and 8 days after introduction into the soybeans. Five hundred ants from each sample were placed in lots of five ants each in Soluene-350 tissue stabilizer in glass scintillation vials for 24 h. Packard Dimilume-30 scintillation cocktail was added then, and each vial was counted for 5 min in a Nuclear Chicago Mark II liquid scintillation counter. Only samples with counts twice or greater than background were considered radioactive.

Plants were removed from the trays on day 8, and a representative sample of plants was divided into leaves, stems, and roots which were further subdivided for determination of radioactivity as described above.

Tests were conducted also with ^{32}P to detect RIFA feeding on growing soybean plants in the field. Three RIFA colonies were located, and the area around them was thoroughly disked to remove vegetation. Twenty-five soybean seeds were planted in a row 1 m from each colony. Nine days after planting there were 21 viable plants in each row. Each of these plants was injected near the stem base with 5 μl of ^{32}P (ca. 50 μCi). A second injection was made 14 days later. Samples of RIFA workers were taken from each colony at 7, 14, 21, and 28 days after the first injection. Ants collected were treated as indicated above to determine radioactivity. On the last 2 days however, the colonies had moved or the number of workers ants had so declined that less than 500 ants were collected for analysis.

Field plot tests were conducted on an ARS-owned farm in Harrison County, Miss., with Poarch soil type. A 1.4-ha block of land infested with ca. 160 mature mounds per ha was selected in late February. The block was divided into two equal-sized plots. Ants were eliminated from one plot with a mirex bait in early March, and an additional application of bait was made in late June. Baited transects run monthly showed that the plot remained essentially RIFA-free throughout the test.

The plots were disked three times in late April and early May. Soybeans (var. 'Bragg') were planted in rows about 1 m apart on 29 May. Fertilizer (0-24-24) at the rate of 336 kg/ha and preemergence herbicides (alachlor and metribuzin) were placed in the row as the soybeans were planted. The soybeans were cultivated once, and a herbicide (linuron) was applied to the middle of the rows and the lower one-fourth of the plants when they were 30 to 40 cm high for additional weed control. The herbicides were applied as WP or EC formulations by label directions.

Plant density counts were taken 4 weeks after planting in 62 locations in each plot. The count areas consisted of randomly selected, 1-m sections of each row except for the two outside rows on either side of each plot.

Yields from infested and noninfested plots were compared by harvesting the soybeans from 30 subplots. Each subplot consisted of two adjacent rows 5 m in length. Soybeans were cut at ca. 2.5 cm above soil level, gathered immediately, and threshed with a small-plot thresher. Soybeans from each plot were bagged separately and returned to the laboratory, where all debris was removed before they were weighed.

The difference between the means of the yields at both test sites was compared for significance by analysis of variance (ANOVA) and Duncan's multiple range tests. Differences in other parameters were compared by Student's *t* test.

Table 1. Mean density of soybean plants per meter of row in plots infested or noninfested with RIFA (1981)

Location	Date	Mean ± SE for treatment indicated:		
		RIFA infested	Noninfested	Difference[a]
Gainesville, Fla.[b]	29 May	41.3 ± 2.6	41.3 ± 1.8	0
	2 June	35.4 ± 1.3	48.8 ± 1.9	−13.4a
	24 June	35.1 ± 1.3	48.4 ± 3.1	−13.3a
	22 July	31.2 ± 1.7	39.6 ± 1.9	−8.4a
	7 Oct.	26.0 ± 1.3	40.1 ± 1.8	−14.1a
Gulfport, Miss.[c]	25 June	13.7 ± 7.6	17.2 ± 0.7	−3.5b

[a]Numbers followed by letter a, $P < 0.01$; by letter b, $P < 0.05$.
[b]Planting rate, 100 kg/ha.
[c]Planting rate, 46 kg/ha.

Table 2. Comparison of plant height, density, and yield in plots infested or noninfested with RIFA in two different locations

Location	Soybean parameter	Mean ± SE for treatment indicated:		
		RIFA infested	RIFA free	Difference[a]
Gainesville, Fla.	Plant height (cm)	63.9 ± 1.6	68.8 ± 1.4	−4.9b
	Pod set			
	Pods/plant	35.4 ± 3.8	28.2 ± 2.2	+7.2a
	Pods/row-m	919.9 ± 104.5	1,135.2 ± 88.6	−215.3a
	Yield (kg/ha)	1,134.9 ± 94.2	1,709.5 ± 93.0	−574.6a
Gulfport, Miss.	Yield (kg/ha)[b]	1,544.7 ± 09.6	1,951.5 ± 73.0	−406.8b

[a]Numbers followed by letter "a", $P < 0.01$; by letter "b", $P < 0.05$.
[b]574.6 kg/ha = 8.54 bu/acre; 406.8 kg/ha = 6.05 bu/acre.

Results

Gainesville, Fla.

On the day after planting RIFA workers were observed foraging and actively tunneling along the rows of soybeans. Seedling beans were observed cracking the ground on 20 May. Ants were observed feeding on the endosperm of germinating seeds and on cotyledons of seedlings in the "crook" stage on 21 May. This feeding continued until the appearance of the first foliage and chlorophyll formation on 26 May.

The number of plants per meter of row was identical (41.3) for the RIFA-infested and RIFA-free plots at the first count period on 21 May. In all successive counts, however, a higher plant density occurred in the RIFA-free plot (Table 1). For the first four counts the densities averaged 34.4 and 45.5/m of row for the infested and noninfested plots, respectively, a difference of 11.1 or 24.4%. In the final count on 7 October, there were 35% fewer plants in the RIFA-infested plot (26.0 and 40.3 plants per row-m). Statistical evaluation of the data showed that the difference between means was highly significant ($P < 0.01$).

The mean number of pods per plant (Table 2) was 20% greater in the RIFA-infested subplots (35.4 vs. 28.2), but the mean number of pods per meter of row was 19% lower in the RIFA-infested plot (919.9 vs. 1135.2). This apparent contradiction reflects the ability of less crowded plants to develop more pods. Student's t test indicated that the latter difference was highly significant.

Mean plant height for the RIFA-free plot was 68.8 cm as compared with 63.9 cm for the RIFA-infested plot, indicating a significant ($P < 0.02$) difference of 5.38 cm between the means.

Positive evidence of feeding on soybeans by RIFA was obtained in the ^{32}P tracer studies. Seven plants were injected with ^{32}P on 30 June, and a total of 376 ants were collected on or around these plants during the following 2 weeks. Thirty-eight percent of the ants contained a high level of radioactivity (mean = 601.4 counts per min). Ants were observed excavating soil from around the base of the plants, but there was no evidence of predation by RIFA on foliage-feeding arthropods. No honeydew-producing insects were observed at any time on the plants.

Soybeans harvested from the RIFA-infested subplots (108 mounds per ha) averaged 1,134.9 kg/ha, as compared with an average of 1,709.6 kg/ha for the RIFA-free subplots (Table 2). The difference in yield was ca. 574.6 kg/ha, which represents a highly significant reduction in yield (33%) in the RIFA-infested subplots ($P < 0.001$).

Gulfport, Miss.

Evidence of feeding on the soybean seedlings by RIFA was obtained from ^{32}P greenhouse studies. The percentage of collections of radioactive ants averaged 35% on day 1 after their introduction into the trays, 22% on day 4, 55% on day 6, and 66% on day 8. Analysis of plant parts after 8 days showed that essentially all radioactivity was in roots and stems. In radioisotope studies in the field, radioactive ants were collected from all colonies. Two colonies contained radioactive worker ants on all four collection dates, with 67 and 202 samples radioactive for one colony, but only 7 of 262 for the second colony. No radioactivity was detected in the first two collections from the third colony, but 22 of 200 collections made on days 21 and 28 after the second injection of ^{32}P were radioactive. Soil samples from around the roots of the soybeans were negative for radioactivity. We did not detect any evidence of feeding by honey dew or plant-feeding insects on the soybeans.

Plant density in the field plots was reduced by 20% or 3.5 plants per meter of row (Table 1). Soybean yields were reduced also by about 20% and averaged 1,544.7 kg/ha and 1,951.5 kg/ha for the RIFA-infested and RIFA-free plots, respectively. The difference in means, 406.8 kg/ha, was statistically significant ($P < 0.05$).

Discussion

The data clearly reveal a marked difference in yield of soybeans in the RIFA-infested plots in both locations. The lower yield in the RIFA-infested plots can be attributed primarily to a lesser number of plants per meter of row, although the Gainesville studies show that part of this difference was compensated for by a greater number of pods per plant in the infested plot. These data lead us to the conclusion that direct feeding by RIFA on germinating seeds and seedlings is the main causative for yield reduction. However, data from the ^{32}P radiotracer studies in the laboratory and field show that feeding occurs on growing plants as well. The site(s) of feeding were not identified, but almost certainly the root system is involved.

Reductions in yield observed (574 and 407 kg/ha) compare favorably with maximum reductions reported by Lofgren and Adams (1981) for soybean loss in fields in Sumter County, Ga. (501 and 555 kg/ha).

An analysis of agricultural practices related to soybean culture suggests that this crop may be uniquely vulnerable to RIFA damage, especially during early stages of plant growth. For example, recommended planting time for soybeans in Florida is from 15 May to 15 June (Hinson 1969). RIFA colonies in fields prepared for planting at this time of year are subjected to a food stress situation at a time in their developmental cycle when they are producing a maximum number of workers and sexual brood. Since RIFA are opportunistic omnivorous feeders, the presence of succulent germinating soybean seeds and plants would provide a ready source of food for colony sustenance. In addition, one could expect feeding on plants to continue until other food sources, primarily other arthropods, become available.

Very few data are available on infestation rates of RIFA in soybean fields in the southern states; however, Lofgren and Adams (1981) reported densities ranging from 49 to 176 colonies per ha in fields in Georgia and North Carolina. Obviously, such information needs to be obtained before the total impact of RIFA on soybean yield can be determined. It is also obvious that losses of soybeans, such as occurred in these tests and in those reported by Lofgren and Adams (1981) (131 to 578 kg/ha), represent a potentially severe yield reduction as well as monetary loss to farmers in RIFA-infested states.

Acknowledgment

We express our sincere appreciation to K. Hinson and F. McGraw, Research Agronomist and Research Technician, respectively, USDA, Plant Science Research, for their timely and constructive comments on soybean culture at the Gainesville, Fla., location. We also express appreciation to R. Davis, Agronomist, for his assistance in crop production and management at the Gainesville test site, and to P. M. Bishop, J. Mitchell, and L. Miles of the Gulfport, Miss., Imported Fire Ant Laboratory for their assistance in managing and harvesting the soybeans at that site.

REFERENCES CITED

Adams, C. T., J. K. Plumley, C. S. Lofgren, and W. A. Banks. 1976. Economic impact of the red imported fire ant, *Solenopsis invicta* Buren. 1. Preliminary investigations of impact on soybean harvest. J. Ga. Entomol. Soc. 11: 165–169.

Adams, C. T., J. K. Plumley, W. A. Banks, and C. S. Lofgren. 1977. Impact of the red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera, Formicidae), on the harvest of soybeans in North Carolina. J. Elisha Mitchell Sci. Soc. 93: 150–152.

Apperson, C. S., and E. E. Powell. 1983. Correlation of the red imported fire ant, *Solenopsis invicta* Buren, with reduced soybean yields in North Carolina. J. Econ. Entomol. 76: 259–263.

Banks, W. A., C. S. Lofgren, D. P. Jouvenaz, C. E. Stringer, P. M. Bishop, D. F. Williams, D. P. Wojcik, and B. M. Glancey. 1981. Techniques for collecting, rearing, and handling imported fire ants. U.S. Dep. Agric. Adv. Agric. Tech. AAT-S-21. 9 pp.

Hinson, K. 1969. Soybeans in Florida. Bull. 716. IFAS, Univ. of Florida, Gainesville. 121 pp.

Lofgren, C. S., and C. T. Adams. 1981. Reduced yield of soybeans in fields infested with the red imported fire ant, *Solenopsis invicta* Buren. Fla. Entomol. 64: 199–202.

Whitcomb, W. H., H. A. Denmark, A. P. Bhatkar, and G. L. Greene. 1972. Preliminary studies on the ants of Florida soybean fields. Ibid. 55: 129–142.