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Effects of Soil Compaction on Bollworm (Lepidoptera: Noctuidae) Moth Emergence[1]

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ABSTRACT Bollworm, *Heliothis zea* Boddie, moth emergence was measured from a sandy loam soil after increasing levels of soil compaction. Soil strength as measured by indentation probe resistance in kg/cm^2 was measured at successive depths under each level of compaction and related to the moth emergence pattern. Possible physical damage to pupae and the condition of the pupal chamber by the compaction process was determined by placing individual insects in cylindrical containers of soil, compacting the soil in the containers, and then excavating the pupae. Moth emergence decreased significantly with increasing soil compaction and also showed a definite relationship to the pattern of soil compaction vs. depth. Excavation of pupae from compacted soil indicated that soil compaction, rather than physical damage to the pupae, was the primary cause of reduced moth emergence.

In 1905, Quaintance and Brues published the first comprehensive study of the biology of the cotton bollworm, *Heliothis zea* (Boddie), in the United States. They observed a remarkable number of different aspects of the life cycle of the insect, including observations on the effects of loose vs. packed, and wet vs. dry soils as they affected the ability of the moths to emerge from pupation. Breaking up the pupation cell, adding rainfall, and packing the soil all inhibited moth emergence. Several later studies (Barber and Dicke 1937, Fife and Graham 1966, Hopkins et al. 1972, and Roach 1981) showed that various forms of soil cultivation reduced or eliminated moth emergence. Most of these studies did not consider the soil type or compaction level in any detail. Roach and Hopkins (1979) made a more extensive study of soil types and soil strength as related to *Heliothis* spp. moth emergence and found soil moisture and strength to be more important in limiting moth emergence than soil type.

The present experiments were conducted to give actual measurements of soil strength under different compaction levels and to relate these measurements to the ability of bollworm moths to emerge from the soil.

Materials and Methods

These experiments were conducted during the period from January to April 1981 and 1982 in a heated, 1/190-ha greenhouse constructed over a Dothan fine sandy loam Plinthic Paleudult soil. To test the effects of compacting this soil on the ability of bollworm moths to emerge, the soil was thoroughly wet, then tilled to a depth of 30 cm by a roto-tiller when the soil moisture level was between 9 and 11% (weight of water/weight of soil × 100). The soil was smoothed with a rake and partitioned off in 0.5-m^2 plots, each covered with a wood-framed, 10-cm-high, screen-covered emergence cage. The following day, last-instar bollworm larvae (ready to pupate) were removed from rearing containers and released, 25 per plot, into each of the test plots. Larvae which died or pupated on the soil surface were eliminated from the test. Seven days later, the soil in each plot was compacted 0, 1, 2, 3, 6, or 9 times by repeatedly dropping a 800-cm^2, 7.3-kg flat weight from a height of ca. 30 cm. Compaction treatments above one were performed by alternating the direction the weight was dropped each time the plot was compacted so that no edge areas were left uncompacted in the plots. Each treatment was replicated four or six times. Soil temperatures at the 10- to 12-cm depth were continuously recorded with a remote sensor (2-cm radius) thermograph. A series of soil strength tests were also conducted on the soil under the same test compaction conditions, using a 5-mm-diameter indentation penetrometer (Campbell et al. 1974). Observations were made on the level of soil compaction at depths of 1.2, 3.7, 6.2, 8.7, and 11.2 cm from the surface. Bulk density at the various compaction levels were also measured by a soil core technique at depths from 2 to 12 cm.

In 1982, four additional treatments were performed in which last-instar larvae were released (25 per plot) in plots prepared as previously described and the soil was: (1) left dry and uncompacted, (2) left dry and compacted two times, (3) compacted two times and wet with 3.8 liters of water slowly sprinkled from a height of 30 cm, or (4) compacted two times and wet every 3 days thereafter with 3.8 liters of water sprinkled from a height of 30 cm. Moth emergence from the plots was recorded every 2 days for a period of 30 days after the moths began emerging. The experiment was replicated four times.

The depth distribution of the pupae in uncompacted soil was determined by carefully exhuming a total of 71 pupae from plots treated the same way as the compaction plots.

A further test was conducted to determine if the pupae were physically damaged by the compaction process. Soil taken from the greenhouse was moistened to a water content of 6% (wt/wt) and placed in aluminum cylinders, 7.5 cm in diameter by 15 cm high. Each core was firmed by bouncing the soil-filled cylinders on a table top to give a uniform bulk density of 1.58 g/cm^3 to a

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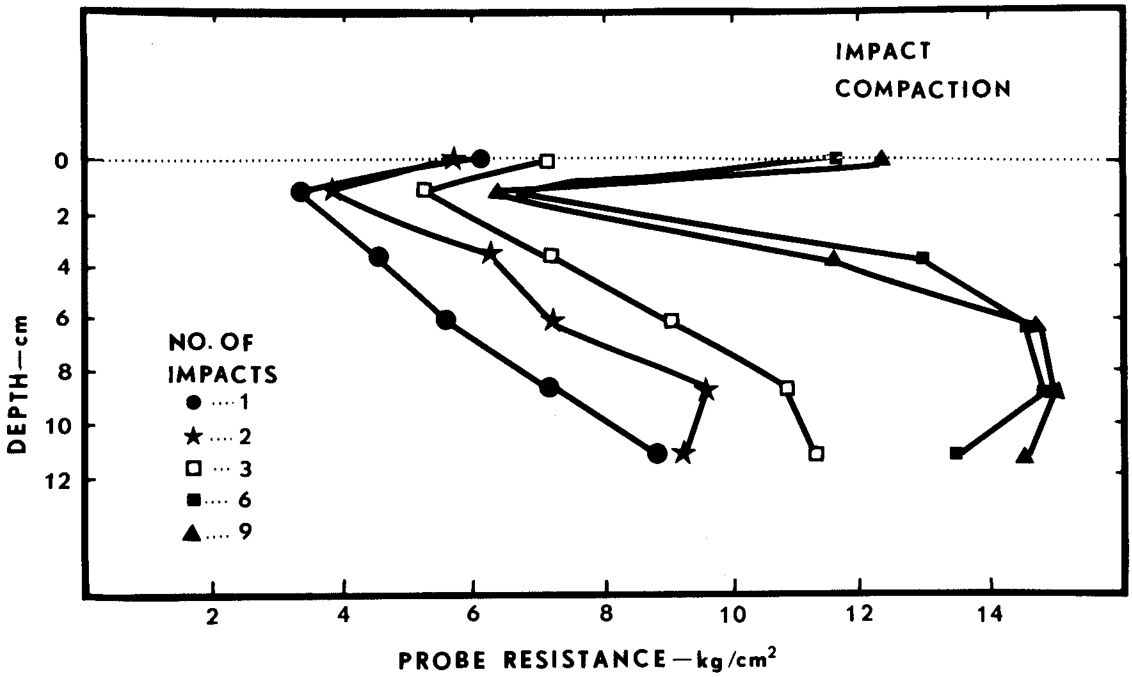

FIG. 1. Soil penetrometric resistance of Dothan fine sandy loam soil at various depths and varying levels of compaction.

depth of 7 cm. Last-instar larvae were transferred to the soil surface in inverted, 30-ml plastic cups containing 10 ml of rearing medium. These containers (3.8-cm-diameter opening) were inverted in the center of the soil cylinders to provide control over the point at which larvae entered the soil. After 7 days, the soil in the cylinders containing the pupae were compacted in three groups with cylindrical hammer blows of one, three, or six blows each having kinetic energy at the instant of impact of 360 g-cm per cm^2 of area on the core surface. This was the same compaction energy used in the greenhouse phase of the study. After compaction, the cylinders were held at 25°C for 3 days, and then excavated individually to determine the physical condition of the pupae and the appearance of the pupal burrow and chamber.

One final treatment was conducted in the field to compare the degree of compaction by a loaded and unloaded four-wheel-drive tractor with (tires 51 by 86 cm) with that observed with the impact compaction technique. The tractor itself weighed 7,425 kg, and ca. 11,960 kg when loaded. This tractor was driven two and six times (wheel passes) loaded and unloaded over a field of sandy loam soil freshly disked to a depth of ca. 25 cm. Penetrometer measurements were made at the same depth increments in cross section as the greenhouse test in 10 locations under each compaction treatment.

Results

Average (maximum-minimum) daily soil temperatures at the 10- to 12-cm depth during the experimental period were 23.1°C in 1981 and 26°C in 1982. Butler

Table 1. ***H. zea*** **moth emergence from fine sandy loam soil after successive compactions with a 7.3-kg flat weight**

Series	No. of times soil compacted	Mean % moth emergence[a]
I (1981)[b]	0	74a
	1	45b
	2	42b
	3	24c
II (1982)[c]	0	50a
	3	15b
	6	3c
	9	2c

[a]Means separated by Duncan's multiple range test at 0.5 level.
[b]Four replications of 25 prepupae each per treatment.
[c]Six replications of 25 prepupae each per treatment.

Table 2. ***H. zea*** **moth emergence from fine sandy loam soil under different compaction and simulated rainfall conditions**

No. of times soil compacted[a]	No. of times soil watered[b]	Mean % moth emergence[c]
0	0	42a
2	0	36a
2	1	13b
2	7	7b

[a]Soil compacted by dropping a 7.3-kg flat weight from a height of 30 cm 7 days after prepupae entered soil.
[b]Soil watered each time with 3.8 liters of water sprinkled on the plot from a height of 30 cm. Water applied 7 days after prepupae entered soil.
[c]Five replications of 25 prepupae each per treatment. Means separated by Duncan's multiple range test at 0.5 level.

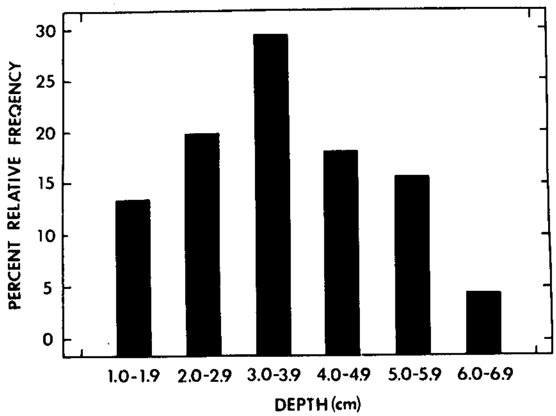

FIG. 2. Frequency distribution of *H. zea* pupal depth in soft soil when allowed to enter the soil naturally.

and Henneberry (1976) indicated the pupal period required 16.9 days at 23.1°C and 13.2 days at 26.1°C. Thus, soil temperatures were warm enough to allow the pupae to develop and emerge normally.

Bulk density of the soil after compaction remained relatively constant during the test period but varied with depth, and increased with the number of impacts. The penetrometer measurements, which showed a similar soil compaction pattern, varied with bulk density and soil water content; therefore, penetrometer data were used as the primary index of soil compaction in these tests. Figure 1 shows the probe resistance or degree of compaction in kg/cm^2 of the soil after the compaction treatments with the pupae in the soil. Moth emergence from the various compaction levels is shown in Table 1. Emergence was mildly depressed even with limited compaction, but was drastically depressed after three or more weight drops. However, after six and nine compactions, a few moths still emerged from the plots. Figure 2 shows the depth distribution of the pupae in the soil and indicates that pupae ranged from 1 to 7 cm deep, with the highest number located at 3 to 4 cm. A substantial number, 34%, were located between 1 and 3 cm. The compaction pattern (Fig. 1) may help explain the moth emergence pattern. It is apparent that the degree of compaction of the soil varied with depth and number of the compacting blows. The surface layer is reasonably compact, followed by a marked reduction in compaction at the 2-cm depth, and then increasing thereafter to the 10-cm depth. Moths in the 1- to 2-cm depth, unless physically damaged by the compaction process, would be located in a relatively mildly compacted zone, whereas moths below 2 to 3 cm would be held in increasingly firm soil. Interestingly, six and nine compactions gave almost the same probe resistance curves, reaching a maximum compaction level of approximately 15 kg/cm^2 at the 8- to 9-cm depth. This degree of compaction is considerably below the level of 20 kg/cm which severely restricts plant root growth (Campbell et al. 1974).

The moth emergence from the treatments when the soil was lightly compacted with and without water added is shown in Table 2. Moth emergence after two compactions without water was not significantly different from that with no compaction. The addition of water after two compactions significantly reduced moth emergence. Soils compact to varying degrees under the same load at different water contents, and this decreased moth emergence may be related to the increased soil strength resulting from the combination of added water and compaction.

Excavation of the insects in the cylinders compacted one, three, or six times indicated an average depth of 18.8 mm with a range of 6 to 70 mm (75 observations) or considerably shallower than the 35-mm depth observed in the greenhouse experiments. This was probably due to the more compact soil in the cylinders caused by the "settling" technique of bouncing the soil-filled cylinders on a table top to ensure uniform soil volume. The condition of the pupae when excavated and the appearance of the burrow and pupal chamber indicated that soil compaction, not physical damage to the pupae, was the primary cause of reduced emergence. At one compaction, no pupae were crushed or ruptured (19 observations), and the pupal cavity was usually fully intact, regardless of the depth of the pupae in the soil. After three compactions, one pupa (at a depth of 1 cm) was damaged (24 observations), whereas in most cases the pupal cavity was intact or partially filled with loose soil. With six compactions, three pupae were damaged (25 observations), and the pupal cavity ranged from fully open to loosely filled with soil. All three of the injured pupae were located 6 to 10 mm deep, or very close to the soil surface. Thus, the primary cause of reduced moth emergence noted in this series of experiments seems more related to the degree of soil compaction than to depth in the soil or physical damage to the pupae by the compaction process.

Results of the observations on soil compaction by the loaded and unloaded tractor are shown in Fig. 3. The tractor compaction patterns are very similar to those produced by the impact-compaction technique used in the greenhouse studies. After six passes with the loaded tractor, compaction at a depth of ca. 2 cm was only 6.5 kg/cm^2, or very similar to the values obtained with six and nine impact compactions at the same depth in the greenhouse.

Bollworm moth emergence from pupae in the soil in field situations may occur after brief 2- to 3-week periods during the summer months, or after 6 months or more when overwintering. Exit tubes in field soils would be much more likely to retain their integrity if not tilled during most of the year, since the soil compacts naturally due to rainfall and other physical forces. However, once the soil is tilled, bollworm pupae and the emerging moths face a bleak prospect without the presence of the exit tubes. Our studies give quantitative evidence that moth emergence is related to different levels of soil strength and the integrity of the pupation burrow.

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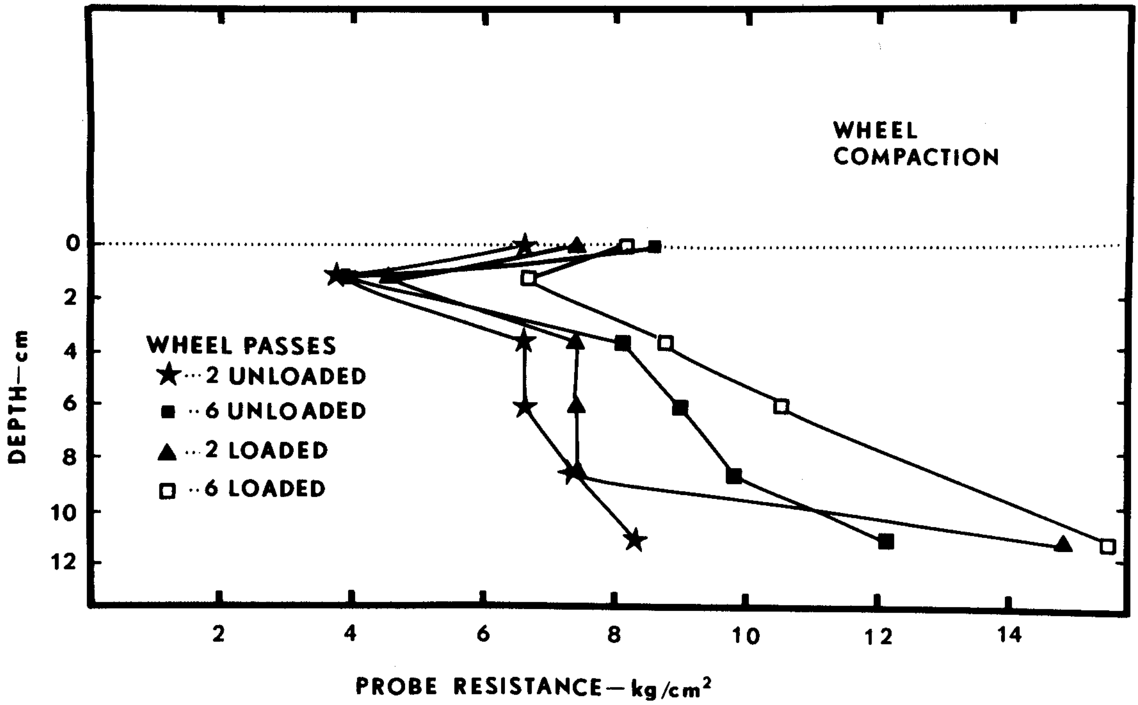

FIG. 3. Soil penetrometric resistance of fine sandy loam soil at various depths after two or six tire passes with a loaded and an unloaded four-wheel-drive tractor.

cian, who performed many of the tedious soil measurements presented in this study.

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