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Evaluation of mechanized row cover establishment for cantaloupe and summer squash

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Abstract.
Excluding insects by covering rows of cantaloupe or summer squash with spunbond polypropylene material offers an alternative to insecticide application. Labor for manually establishing row covers may be reduced if a satisfactory system to mechanize row cover establishment can be developed. Field tests of a commercial semi-mechanized implement were conducted in medium and coarse soils at two different moisture contents to examine the machine's ability to successfully insert supporting hoops and lay fabric row cover in these soil conditions. This study also helped identify specific facets which require modification to improve machine performance.

Soil bin tests indicated adequate soil force to resist hoops springing out of the ground with minimal insertion. Subsequent implement operations in the field indicated that other machine adjustment features were affecting success of wire insertion after depth wheels were set to at least 13 cm insertion. Success of wire insertion generally increased with experience operating the implement. Hoops inserted deeper into coarse soil, but were more likely to lean in the direction of the row. Covering hoops with spunbond polypropylene material was successful if hoop placement was successful.

Keywords. *Cucurbit, disease, horticulture, insects, supports, tunnels.*

Introduction

About 41,000 growers in the eastern half of the U.S. produce $1.02 billion in value from cucurbit crops such as cantaloupe and summer squash on 374,000 acres (USDA-NASS, 2008). A major challenge for growers is feeding on the plants by cucumber beetle (*Acalymma vittatum* and *Diabrotica undecimpunctata howardi*) and squash bug (*Anasa tristis*). In addition to direct feeding these insects also transmit bacterial wilt (*Erwinia tracheiphila)*. Bacterial wilt can reduce cantaloupe and cucumber production by 80% and also impact pumpkin, winter squash, and zucchini (Latin, 1993; McGrath 2001). The disease costs eastern U.S. growers $18.9 million annually (Adams and Riley, 1997). Pesticide strategies require frequent re-application, can be costly, and are not an option for organic growers.

As an alternative to pesticides, some growers have used a spunbond polypropylene material, (Agribon®, Growers Supply Company, Dexter, MI) to cover the crop and exclude insect pests during the period from transplanting until flowers bloom. Using a cover may also extend the growing season in cooler areas. Avoiding insecticide use limits potential damage to pollinators such as bees. To maintain plant productivity the material is supported by wire hoops approximately 1.2 m wide, keeping material from resting directly on the plants.

Support hoops and spunbond covers are typically installed manually, requiring several additional workers at an already labor intensive time during transplanting. Normal within-row spacing of hoops is about 1.4 m, requiring a large number of hoops to be placed even in small land areas. A potential semi-mechanized solution to installing cover material is to use an existing implement marketed to install clear polyethylene plastic cover over individual rows to extend an earlier growing season in colder climates. A tractor-mounted implement (model 95 Tunnel Layer; Mechanical Transplanter, Holland, MI; figure 1), is marketed for this application. Spunbond polypropylene is more fragile however than polyethylene plastic. Also successful insertion of support wires with the implement has been observed as a problem by horticultural staff at the University of Kentucky and Iowa State University. Identifying requirements for successful wire insertion and study of implement operation in the field to increase success rate of wire insertion and cover establishment may allow the row cover process to be successfully mechanized for grower production.

Therefore, the objective of this research was to measure and improve the ability of a row cover implement to establish a cover with spunbond polypropylene.

Methods and Materials

Initial tests were done to evaluate how deep wire should be inserted to resist springing out of the ground. Subsequent field tests evaluated suitable depth of insertion by implement operation along with wire insertion measurements in different soil conditions when the implement was judged to be optimally adjusted.

Wire and soil resisting forces

A preliminary series of four tests were done to identify soil resisting forces to wire hoops springing out of the ground. Tests were done in smaller soil containers (20 L) with a silty clay loam typical of central Iowa glacial till soils at 2.5, 10.0, and 12.9% (low, medium, and high) moisture content. Measurements were replicated four times in medium and high moisture content soils and three times in low moisture content soils. A 2.6-mm diameter wire 2.13 m long similar to that used for the tunnel layer was used. Tensile force to move the wire was measured by a tensile scale used to weigh luggage. In each test wire was inserted to depths of 5, 7.5, 10, 12.5, 15, 17.5, and 20 cm.

Figure 1. Tunnel layer inserting wire hoops and establishing row cover over hoops.

Test #1 measured the horizontal force applied at the soil surface to move the wire after one end was inserted vertically into the soil. Test #2 was similar except the wire was bent into a hoop shape typical of field insertion with the other end inserted into a soil container with the same moisture content. Force required to initiate horizontal displacement of wire on one side of the hoop was measured. Test #3 was similar to test #2 except the maximum force during a 5-cm horizontal displacement of the wire was recorded. Test #4 measured the amount of tensile pulling force applied at the buried end of the wire, at a 45° angle upward from horizontal, to initiate wire displacement.

In each of the tests (#1 - #4) and at all three soil moistures, a statistical correlation between force required to move wire and insertion depth was done to estimate how much soil resisting force is present to prevent inserted wire from popping out of the soil due to latent spring force of the bent wire.

To measure latent spring force present in the wire, one end of the wire was fixed while the amount of force was measured to bend the wire into a hoop shape similar to field use (slightly narrower with 1.1 m across wire ends at the base). Measurements of spring force were replicated six times with different wires.

Field tests

An initial field test was done in May 2013 to gain experience with operation and adjustment of the tunnel layer. Shallow (10 to 12.5 cm) and deep (15 cm) wire insertion with the tunnel layer was done with 50 wire hoops. Each treatment depth was replicated three times in medium-textured soil.

Following experience from this initial trial, the tunnel layer was operated in July and August in dry and moist soil conditions in medium- (silty clay loam) and coarse- (fine sandy loam) soil conditions. In each combination of soil type and moisture, approximately 30 to 45 minutes was allotted for operator adjustment and practice operation of the tunnel layer in raised-bed plot areas before field measurements were recorded. After the adjustment period, three replications of 75 to 85 hoops each were inserted along the plot row. Following this, the tunnel layer laid 15 m of Agribon® while inserting support hoops, in two replications. Cover material establishment was evaluated by inspecting for tears or rips in Agribon® material and presence of any gaps more than 0.5 m long in the soil covering thrown over the edges of the material by covering discs to anchor material and exclude insects.

Several measurements assessed wire insertion. Measurement on each hoop included: 1) successful (or not) insertion of both wire ends into the soil, 2) insertion depth of both left- and right-sides of the hoop (as viewed in the direction of travel), 3) vertical angle of the hoop in the direction of travel, and 4) maximum height of the hoop's peak above the soil surface. Hoop angles that differed substantially from a 90° vertical angle to the soil surface indicated how hoops were being inserted into the ground or being dislodged by machine operation. Hoop width at the base on the soil surface and distance between hoops were generally fixed by implement configuration, but were randomly measured during field tests.

Results and Discussion

Wire and soil resisting forces

Soil resisting force to wire movement was well correlated with depth of insertion. Correlation coefficients across tests #1 - #4, and all three soil moisture contents ranged from 0.80 to 0.97, averaging 0.88. Average amount of force per insertion depth is shown for soil tests #1 - #4, at each soil moisture in table 1.

Table 1. Soil resisting force to wire movement per wire insertion depth into soil (N/cm)

Soil moisture	Test #1	Test #2	Test #3	Test #4
Low	2.56	1.38	2.45	N/A[a]
Medium	1.33	1.16	3.5	1.93
High	2.36	2.35	2.89	2.19

[a]Test information not available.

Average latent spring force measured between the ends of the wire when bent into a hoop shape similar to field use was 2.24 N. The lowest soil resisting force in table 1 (1.16 N/cm) suggested that half of wire hoops inserted to a depth of at least 2 cm would resist spring wire force dislodging one end of the wire from the ground (assuming both wire ends are initially inserted below the soil surface).

Field tests

During initial field tests in May, travel speed was limited to about 1.4 km/h so that an operator on the implement could keep pace with inserting individual wires into a receiving cradle for wire insertion (figure 1). A problem was noted in the first replicated trial for shallow insertion when depth-gauge wheels on the implement were set for a nominal 10 cm insertion depth. Over 70% of wire hoops failed to successfully insert. Depth setting for the additional two shallow replications was set to 12.5 cm. Average wire insertion measurement parameters are shown in table 2 for each depth test. Soil moisture content was 19.3%.

Table 2. Wire measurements for shallow and deep insertion treatments in initial field test

	Depth					
Measurement	Deep #1	Shallow #1	Deep #2	Shallow #2	Deep #3	Shallow #3
Hoop height, cm	36.3	39.9	34.3	35.1	34.6	36.5
Left depth, cm	19.4	12.6	16.3	15.3	18.2	14.6
Right depth, cm	10.0	10.4	13.4	12.4	11.5	11.3
Angle toward tractor, °	92.8	88.9	89.4	90.0	90.6	92.0
Insertion success, %	80	24	96	78	70	78

Perhaps due in part to just three replicated measurement trials at shallow and deep depths, no statistical differences were able to be detected between setting the implement for shallow or deep insertion for hoop height, left- and right-insertion depths, insertion angle, or success rate. Although success rate was greatly reduced in the first shallow trial, success rate for later shallow trials (after depth-gauge wheels were raised for nominal 12.5 cm insertion) was similar to success rate for deep trials. Although experimental design limited the number of field replications that could be done in a single day's time to detect statistical differences, hoop height seemed to be slightly greater with shallower insertion and hoop angle was unaffected.

Left-side insertion was statistically deeper than right-side insertion when means from each of the six test runs were compared. Because of this difference between sides, in later tests extra care was taken with other factors on the implement such as placement of wire in the receiving cradle by the operator on the implement, and timing and placement geometry of operating fingers grasping the wire for insertion on the implement. Since wire insertion success seemed independent of depth wheel adjustment but perhaps related to other implement adjustments, depth wheel setting for further field tests was a nominal 13 cm. More attention was given to adjustments involving release of the wire at the insertion point, and settings for trenching and covering discs. It was observed that discs on the implement used to create a trench and then cover edges of the cover material could affect wire insertion by supporting the implement further above the soil surface or affecting surface topography near the wire insertion point.

Prior to each mid-summer test in a soil texture/moisture combination, sixteen different implement adjustments were evaluated. Measurements included depth wheel height, height and angle of trenching and covering discs for Agribon® insertion, for the grasping finger mechanism cam plate operating angle and distance away from grasping finger (all both left- and right-sides of implement), angular position of grasping finger arms at the point of opening, and front toolbar height. Recorded information helped to develop a better understanding of the implement and hopefully enhanced success of wire insertion and reduced adjustment time required in subsequent field conditions.

Field tests during a relatively dry mid-summer period were done on July 11 in the medium-textured soil and July 12 in the coarse-textured soil at moisture contents of 12.6 and 9.9%, respectively. Following rainfall, field tests were repeated in these soils on August 15 (medium-textured soil) and August 16 (coarse-textured soil) at soil moisture contents of 16.9 and 11.0%, respectively. Average wire insertion measurement parameters are shown in table 3 for each summer field test.

Table 3. Wire measurements in different soil texture and moisture conditions, without and with covering the wire hoops with cover material

	Relative soil moisture condition and soil texture							
	Dry				Wet			
Measurement	Medium[a]	Medium A[b]	Coarse[a]	Coarse A[b]	Medium[a]	Medium A[b]	Coarse[a]	Coarse A[b]
Hoop height, cm	40.2	31.0	44.3	31.2	43.5	29.5	40.9	31.7
Left depth, cm	10.2	12.3	15.3	14.1	9.0	10.1	15.4	16.9
Right depth, cm	10.4	8.5	11.3	10.3	9.5	9.6	18.0	15.7
Angle toward tractor, °	91.1	77.7	91.0	72.8	93.5	74.1	86.0	75.1
Insertion success, %	74	70	84	71	95	90	88	100

[a]Wire insertion only
[b]Wire insertion and covering with Agribon®

A statistical paired t-test was done for wire insertion measurements of hoop height, left- and right-side insertion depth and hoop angle. Each t-test compared measurements in the medium soil with those in the coarse soil or measurements in the dry soil with measurements in the wet soil. Probability of numerically larger t values are shown in table 4.

Table 4. Probability of numerically larger t value for paired tests of soil insertion measurements between soil texture and soil moisture

	Soil insertion measurements			
Soil parameter	Hoop height	Left depth	Right depth	Hoop angle
Texture	0.24	>0.01	>0.01	>0.01
Moisture	0.20	0.05	>0.01	0.33

Depths of wire insertion was greater in the coarse-textured soil. Wire insertion also was affected by soil moisture, however effects were mixed. Insertion was shallower in dry soil on the right side, as might be expected if penetration resistance increased as soil dried. Insertion on the left side was not affected as much and somewhat unexpectedly was slightly deeper in dry soil. Hoops leaned more in coarse textured soil. Sandy soil may have provided less resistance if a cross-piece on the implement brushed against the top of a hoop that had been inserted or as cover material was laid and stretched over the hoops.

Successfully inserted hoops were consistently 1.20 m wide at the soil surface and spaced 1.37 along the row length.

Inspection of the two Agribon® segments installed in each soil texture/moisture combination showed no tearing of the cover material. There were no gaps in soil coverage along material edges greater than 0.5 m, except for an occasional time when a cross-wind gust lifted material away from the reach of a covering press wheel between trenching and covering discs that pushed material down into a trench created by the first disc on each side of the implement.

Conclusions

Within the range of conditions tested for the tunnel layer implement and wire:

- Wire inserted at various depths into soil in soil bins suggested that a minimal insertion depth of 2 cm would supply adequate force to resist wire hoops from springing out of the ground after placement.
- During initial field tests, wire insertion success was less than 50% until depth gauging wheels were set to at least a nominal 12.5 cm insertion depth. Other implement adjustments including timing and placement of the finger mechanism used during wire insertion, and disc placement for cover insertion and establishment were noted and recorded after field adjustment in other tests.
- Successful wire insertion continued to be challenging in dry mid-summer soil conditions (70 to 84%), but improved later with wetter soil and more experience with implement settings (88 to 100%).
- Ends of wire hoops tended to be inserted more deeply into coarser soil, but hoops were also more likely to deviate from a vertical plane if bumped by the implement or when covering material was stretched over them.

Overall success rate with the implement suggests further work with adjustment or modification if greater than 95% successful wire insertion rate is desired for this type of application.

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