Cost Benefit Analyses of Using Grafted Watermelon Transplants for Fusarium Wilt Disease Control

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Abstract
Research on grafted watermelon at the Lane Agricultural Research and Extension Center in Lane, Oklahoma provided data for the cost benefit analyses performed in this work. Grafting of watermelon onto resistant rootstock was found to provide effective resistance to Fusarium wilt but at an increased cost of $1,743 per hectare. The resistance of these plants to multiple soil-borne diseases provides the farmer a viable risk management strategy and an alternative to methyl bromide for disease control. Soil-borne diseases such as Fusarium wilt continue to plague watermelon growers in intensive production areas where land resources are scarce and rotation of various crops is limited. Fusarium wilt is generally observed in farmers’ fields during the latter stages of production when most of the costs have been incurred. Risk management alternatives available to the farmer have been reduced by the loss of soil fumigation chemicals such as methyl bromide. Currently, most seedless cultivars are susceptible to Fusarium wilt. It would appear that many of the present-day triploids have a similar genetic background. With triploids commanding almost 75\% of the watermelon market in 2006, Fusarium wilt resistance has become a major emphasis for seed companies. A farmer planning for yields of 40,000 kg/ha would have to receive a price of $0.19/kg to breakeven with grafted plants while non-grafted plants would breakeven at $0.13/kg with the same yield. In the case where a field is known to have a history of Fusarium wilt, the probability of losing most or all of the crop after the majority of production costs have been expended forces the farmer to evaluate best alternative decisions based on costs versus probable revenues.

INTRODUCTION
Grafting watermelon onto other Cucurbitaceous crops for soil-borne disease and nematode control has been practiced for many years in Europe and Asia (Oda, 1999). Because of limited ability for crop rotation, the practice of grafting has provided a useful method for growing watermelons on land which would otherwise require fumigation or be abandoned. Grafting has been routinely utilized in Japan and Korea since the late 1920s for the control of Fusarium wilt (Lee, 1994). Historically, Fusarium wilt has been the greatest yield-limiting disease of watermelon worldwide. Recently, Bruton et al. (2007) stated that 75\% of the United States watermelon production is at risk for Fusarium wilt.

Fusarium wilt symptoms include damping-off, seedling disease, or wilt during any stage of plant development. The specific symptom that may be exhibited is dependent on environmental conditions, age of plants when infected, and the density and virulence of the pathogen population. Symptoms on mature plants typically appear following fruit-set and may appear as a dull gray-green appearance of the leaves followed by yellowing of the crown foliage, wilting during the heat of the day, and eventual death. Fusarium wilt is considered to be a vine decline disease of watermelon where vine vigor gradually deteriorates (Bruton et al., 1998). Propagules of the fungus may be spread by soil, plant debris, and farm implements. Fulton and Winston (1915) first noted that the Fusarium wilt pathogen can be carried on seeds. Several additional reports (Martyn, 1985, 1987;
Porter, 1928; Taubenhaus, 1935) confirmed that the pathogen can be seed-transmitted. Consequently, infestation of new land may be through infested seed or infected transplants. Once the pathogen is established in a field, it may survive for 10 years or more in the absence of watermelon (Cirulli, 1972; Ioannou and Poullis, 1991).

Grafting watermelons in the United States has not been previously practiced because of sufficient land for rotation, availability of methyl bromide, and increased costs of grafted transplants. However, we have experienced in recent years constraints of new land for rotation, loss of methyl bromide, and increased soil-borne disease pressures. Historically, Cucurbita, Benincasa, Lagenaria spp., and some hybrid rootstocks have been utilized for grafting watermelon. However, these rootstocks are not resistant to all diseases. In Spain, Armengol et al. (2000) noted that Fusarium solani f. sp. cucurbitae race 1 could be particularly damaging to the rootstock of grafted watermelon. Bottle gourd (Lagenaria siceraria) is often used as rootstock for watermelon and is susceptible to the seed-borne (Kuniyasu, 1981) fungus F. oxysporum f. sp. lagenariae (Matsuoo and Yamamoto, 1967). Cucurbit yellow vine disease (CYVD), caused by Serratia marcescens, causes a vine decline of watermelon, squash, and pumpkin (Bruton et al., 2003). More recently, CYVD has been observed in watermelon grafted onto Lagenaria or Cucurbita sp. rootstocks (unpublished data).

More than 95% of the watermelon in Japan, Korea, and Taiwan are being grafted onto squash and gourd rootstocks (Lee et al., 1998). However, rootstock-scion selection has a profound effect on yield and fruit quality attributes (Huh et al., 2003; Pulgar et al., 2000; Yetisir and Sari, 2003). When squash (Cucurbita sp.) was used as the rootstock, the yield and/or quality of the fruit was often inferior to fruit of plants grafted on bottle gourd (Lagenaria siceraria) or non-grafted watermelon (Yetisir et al., 2003).

Despite some advantages, the use of methyl bromide has been associated with major problems, including the depletion of the ozone layer (Environmental Protection Agency, 2005). Because of this, its use was scheduled to be phased out on a world-wide scale, by the end of 2005 in the E.U. and other developed countries, including the United States and by 2015 in the developing countries (Rowlands, 1993). Therefore, there is an urgent need to define and implement alternative solutions for managing soil-borne pathogens. Grafting is one such alternative practice that has potential for cucurbits.

Ioannou et al. (2000) stated that, “Although growing grafted watermelon represents a novel horticultural practice for Cyprus, the technique has been quickly and widely adopted by growers. Presently, over 80% of watermelons grown in the open field and under low tunnels are grafted on various rootstocks. Grafted plants are produced by fully equipped commercial nurseries. Research efforts have been directed towards the utilization of wilt-resistant rootstocks for off-season watermelon production in heated greenhouses. Although there are still many technical aspects that need further investigation, results so far are quite promising since this method enables watermelon production as early as March, when prices are very high” (Ioannou et al., 2000). They also stated, “The yield of grafted ‘Crimson Sweet’ watermelon reached a record level of 150 tons/ha” (Ioannou et al., 2000). The use of grafted watermelon as a technique to prevent losses due to diseases is widespread throughout the world but other positive aspects may be equally important to the producer/decision maker regarding the potential to harvest watermelons during a market window where high prices exist that were previously unreachable (Ioannou et al., 2000).

The objectives of this study were to: 1) determine if there were differences in resistance to Fusarium wilt between non-grafted and grafted seedless watermelon scions and 2) compare the costs of production between non-grafted versus grafted seedless watermelons to determine if the risk of losing a crop to Fusarium wilt would justify the increased costs of using grafted plants.

MATERIALS AND METHODS

Researchers at Lane, Oklahoma completed two years of experiments that included tests of five (5) watermelon (Citrullus lanatus) scions on four (4) rootstocks of squash or

Controls consisted of non-grafted cultivars ‘Sangria’, ‘Royal Sweet’, ‘Jubilee’, and ‘Jamboree.’ Two fields were planted each year with three replications per field.

The grafting was performed by Speedling Inc. at Alamo, Texas. All plants were grafted by hand using the ‘tongue/approach’ type graft. They were grown in Speedling® trays containing 128 cells per tray using peat moss and vermiculite as a medium. Plants were approximately 15 cm tall at planting during the third week of May. Plants were grown on 1 m spacing between plants, with rows 3 m apart at the Lane Agricultural Research and Extension Center on a Bernow fine sandy loam soil with 0%-3% slope. All plants were evaluated at weekly intervals. Any plants exhibiting signs of vine decline were tested for Fusarium wilt disease. Plants were classified as either resistant to the disease or susceptible. Healthy plants were rated as resistant. All susceptible plants showed signs of severe vine decline and many subsequently died.

Costs of production were determined by actual costs of purchased resources and using custom rates for cultural practices (Doye et. al., 2006). The general form of the linear programming model used for the revenue maximization is written as:

\[
\max Z = \sum_{j=1}^{n} c_j X_j \\
\text{Subject to} \quad \sum_{j=1}^{n} a_{ij} X_j \leq b_i, \quad \text{all } i=1 \text{ to } m \\
\text{and} \quad X_j \geq 0, \quad \text{all } j=1 \text{ to } n
\]

where

- \( Z \) = the objective function
- \( C_j \) = forecasted per unit return of the \( j^{th} \) activity
- \( X_j \) = the possible alternative activity (enterprise)
- \( a_{ij} \) = the quantity of the \( i^{th} \) resource required to produce one unit of the \( j^{th} \) activity
- \( b_i \) = the amount of \( i^{th} \) resource available

The model assumes maximization of objective function. (Hazell and Norton, 1986, p.13).

RESULTS AND DISCUSSION

There were no grafted plants lost to Fusarium wilt. However, some of the other cultivars did exhibit varying degrees of wilt incidence, especially ‘Jubilee’ which exhibited a 43% incidence of Fusarium wilt. ‘Royal Sweet’ had a 16.7% loss while all other non-grafted plants had less than a 4% loss to Fusarium wilt. Yields of grafted plants were generally equal to or greater than the non-grafted plants.

We estimate that the cost to purchase a grafted seedling plant from a seedling supplier currently would be $ US 0.75, which would include the cost of the seed and the grafting operation. Non-grafted seedless plants cost approximately $ US 0.28 per plant. Assuming 3,706 plants per ha, grafted seedless transplants would cost approximately $ US 1,743 per ha more than the non-grafted plants (Table 1). Since methyl bromide usage is not an option in the United States, comparing the costs between planting grafted plants versus fumigating with methyl bromide and planting conventional transplants is a moot point for US growers but should be of interest to international growers. The following costs of production are estimated with the single variable being whether grafted or non-grafted seedless watermelons are planted. All other costs are held constant. Average costs of production for non-grafted seedless watermelons was determined to be $2,698 per hectare while grafted seedless watermelons cost approximately $4,441 per hectare or an
increased cost of $1,743 per hectare when planting grafted plants. Due to the early stage of development of grafting watermelon in the U.S., it must be understood that only a producer with consistently high yields should consider using a technology that increases the costs of production by $US 1743 per ha. However, the risk associated with the loss of part of the crop or loss of the entire crop due to Fusarium wilt compared to an assured harvest and a high yield with the use of grafted plants makes the increased investment an option that should be considered. Assuming variable prices and yields per ha, sensitivity analyses were developed (Tables 2 and 3) to evaluate the breakeven yield or price required for the farmer to consider planting grafted seedless watermelons versus non-grafted seedless watermelons. As the data indicate for non-grafted plants (Table 2), a farmer producing 50,000 kg per ha would be able to breakeven with a selling price of $US 0.12/kg. If the farmer consistently produced 50,000 kg per ha with non-grafted watermelon plants and the average selling price was $US 0.17/kg the farmer could expect a net profit of $US 2,302 per ha (Table 2). Assuming that Fusarium wilt is not a problem this farmer should not consider incurring the increased costs of using grafted transplants.

A more practical question facing a farmer is the potential of losing all or part of the crop after the entire costs of production have been expended. In most cases of an outbreak of Fusarium wilt, the plants begin to decline late in the production season after virtually all production costs have been spent. This is one of the situations frequently faced by a farmer when symptoms of Fusarium wilt have been observed in previous years in a particular field. Determining when a farmer should consider using the more expensive grafted watermelon plants is a dynamic question given that future yields and prices are unknown at planting time. Therefore, a farmer’s production history becomes a critical decision factor along with the history of the specific field. If a farmer has consistently had high yields over several years with certain fields there is a high probability that his experience will enable him to continue to produce at a high level in the next season. Prices are less predictable but historical price “ranges” at harvest time can generally be expected. If the expected breakeven price for the farmer falls within that range there is a fairly high probability of a profitable crop.

In the case of a farmer that has consistently produced 50,000 kg per ha (or higher) on a particular field that has begun to decline in yields due to Fusarium wilt the question is asked, “At what level of expected yield should using grafted transplants be considered?” As an example: If expected prices are $US 0.17/kg and yields have declined to 25,000 kg/ha in a field capable of producing 50,000 kg/ha, the farmer will lose approximately -$US 198 per ha using non-grafted transplants (Table 2). However, if the same field is planted with grafted transplants and 50,000 kg per ha are harvested the farmer would receive $US 560 per ha profit (Table 3). If a farmer is planning to adjust planting dates to try and harvest when prices are higher, Tables 2 and 3 can be used to determine the expected net return or breakeven price for a particular field at various levels of production with or without grafted transplants given different expected market prices at harvest.

A farmer planning for yields of 40,000 kg/ha would have to receive a price of $0.19/kg to breakeven with grafted plants while non-grafted plants would breakeven at $0.13/kg with the same yield. In the case where a field is known to have a high incidence of Fusarium wilt, the probability of losing most or all of the crop after the majority of production costs have been expended forces the farmer to evaluate best alternative decisions based on costs versus probable revenues. When different planting dates are used, additional factors not calculated in the original costs of production may need to be considered such as foliar diseases, insects or different numbers of irrigations, all of which would change the cost of production. Therefore, real yields and historical costs of production on a particular field increase the accuracy of profitability predictions.

ACKNOWLEDGEMENTS

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Literature Cited


Taubenhaus, J.J. 1935. Seeds of watermelons and okra as possible carriers of *Fusarium*
wilt. Phytopathology 25:969.

Tables

Table 1. Cost of seedless watermelon production per ha.

<table>
<thead>
<tr>
<th>Input</th>
<th>Non-grafted seedless</th>
<th>Grafted seedless</th>
<th>Cost difference</th>
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<td>Pre-plant</td>
<td>$ US 618</td>
<td>$ US 618</td>
<td>$ US 00</td>
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<tr>
<td>Growing season</td>
<td>$ US 2080</td>
<td>$ US 3823</td>
<td>$ US 1743</td>
</tr>
<tr>
<td>Total</td>
<td>$ US 2698</td>
<td>$ US 4441</td>
<td>$ US 1743</td>
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Table 2. Expected net return per hectare for non-grafted seedless watermelon at different yields and prices (based on $ US 2,698 per ha cost of production and $ US 0.07 per kg harvest, pack, and ship cost).

<table>
<thead>
<tr>
<th>Yield (kg/ha)</th>
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<th>$0.14</th>
<th>$0.15</th>
<th>$0.16</th>
<th>$0.17</th>
<th>$0.18</th>
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<td>($1,648)</td>
<td>($1,498)</td>
<td>($1,348)</td>
<td>($1,198)</td>
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<td>20,000</td>
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<td>($698)</td>
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<td>30,000</td>
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<td>$302</td>
<td>$602</td>
<td>$902</td>
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<tr>
<td>35,000</td>
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<td>($248)</td>
<td>$102</td>
<td>$452</td>
<td>$802</td>
<td>$1,152</td>
<td>$1,502</td>
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<td>40,000</td>
<td>($298)</td>
<td>$102</td>
<td>$502</td>
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<td>$1,702</td>
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<td>$3,352</td>
<td>$3,902</td>
</tr>
</tbody>
</table>

Breakeven Price at 50,000 kg/ha $0.12 per Kilogram

\(^a\) ( ) Parenthesis equal negative income.
Table 3. Expected net return per hectare for grafted seedless watermelon at different yields and prices (based on $ US $4,440 per ha cost of production and $ US 0.07 per kg harvest, pack, and ship cost).

<table>
<thead>
<tr>
<th>Yield kg/ha</th>
<th>$0.13</th>
<th>$0.14</th>
<th>$0.15</th>
<th>$0.16</th>
<th>$0.17</th>
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<td>40,000</td>
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<td>$1,060</td>
<td>$1,610</td>
<td>$2,160</td>
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</table>

Breakeven Price at 50,000 kg/ha $0.16 per Kilogram

\(^a\) Parenthesis equals negative income.