Comparison of Weed Suppression and Mandarin Fruit Yield and Quality Obtained with Organic Mulches, Synthetic Mulches, Cultivation, and Glyphosate

H.F. Abouziena
Botany Department, National Research Center, Dokki, Giza, Egypt

O.M. Hafez
Pomology Research Department, National Research Center, Dokki, Giza, Egypt

I.M. El-Metwally
Botany Department, National Research Center, Dokki, Giza, Egypt

S.D. Sharma and M. Singh
Horticultural Sciences Department, University of Florida, Institute of Food and Agricultural Sciences, Citrus Research and Education Center, 700 Experiment Road, Lake Alfred, FL 33850-2299

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Abstract. Organic crop production, whether for export or local consumption, is increasing to avoid the residual effects of synthetic herbicides in foods, soil, and water, toxicity to other nontarget organisms, and herbicide-resistant weed populations. Organic farmers consistently ranked weed management as one of their most important production problems. Therefore, a 2-year study was conducted under 15-year-old mandarin trees to compare the effects of rice straw mulch, cattail mulch, black plastic mulch, hand hoeing, cultivation, glyphosate, and unweeded control treatments on weed control, fruit yield, and fruit quality. The greatest control (94%–100%) of weeds occurred with the plastic mulch (200 or 150 µm) and three mulch layers of rice straw or cattail. Covering soil with cattail or rice straw mulch (two layers) gave 85% to 98% control of weeds. Uncontrolled weeds in the weedy control caused significant reduction in yield and fruit quality and decreased the yield/tree by 62% compared with hand hoe treatment. Plastic mulches of 200 and 150 µm, cattail (Cyprus articulatus L.) mulch (two or three layers) and two mulch layers of rice (Oryza sativa L.) straw treatments significantly increased the fruit yield/tree by 24%, 18%, 20%, 11%, and 12% more than cultivation treatment, respectively, without significant differences among these superior treatments. Soil mulching with three layers of rice straw, cultivation, glyphosate, and 80-µm plastic mulch treatments caused a significant reduction in weed density and weed biomass, but gave lower yield than superior treatments. Total soluble solids of fruits was unaffected by any of the weed management strategies, whereas values of total acidity and vitamin C were significantly lower in the unwedded control than most weeded treatments. These results demonstrate that two layers of cattail or rice straw mulch could be used effectively for controlling weeds in citrus groves. Their effectiveness in controlling weeds may increase their use in agriculture systems with a concomitant decrease in the need for synthetic herbicides. Further studies are needed to evaluate their side effects on beneficial organisms, diseases, and insects.

Egyptian citrus, especially organic fruits, is exported to many countries. Weeds compete with citrus for nutrients and water, they harbor pests and host pathogens, and they lower the efficiency of orchard operations (Tucker and Singh, 1984). Chemical control of weeds in citrus was reported to affect various physical and chemical properties and quality of fruits (Mohanty et al., 2002; Sabbah et al., 1994).

In sandy soil with surface irrigation, weed infestation is much higher than with other types of irrigation. Manual weed control is temporary and significantly drains the resources of the growers. Indeed, Bredell (1973) reported that hand cultivation was not effective in controlling weeds, as weed regrowth occurred rapidly after hand cultivation. Glyphosate has been the most widely used herbicide for postemergence weed control in citrus (Barbora et al., 2002; Martini et al., 2002; Sabbah et al., 1994; Singh and Singh, 2004). They also reported that over-reliance on a single herbicide could result in loss of effectiveness from selection pressure on weeds, and there was evidence for a shift in weed flora. Weed species that are not effectively controlled by glyphosate have increased in citrus groves (Singh and Singh, 2004).

Interest in nonchemical weed control methods has been increasingly popular in recent years with the spread of organic farming and environmental concerns over adverse effects of herbicides. Radosevich et al. (1997) and Li et al. (2003), reported that the potential problems associated with herbicides use are injury to nontarget vegetation, crop injury, residues in soil and water, i.e., reduction of soil and water quality, toxicity to other nontarget organisms, concerns for human health and safety, and herbicide-resistant weed populations. Economically and environmentally sustainable weed control alternatives, such as nonsynthetic or natural mulch, can provide many benefits, including weed suppression and delayed weed seedling emergence (Bond and Grundy, 2001; Hussein and Radwan, 2002; Teasdale and Mohler, 1993), soil moisture conservation, and improved water infiltration (Faber et al., 2001; Hoyt and Hargrove, 1986). Benefits also include enhanced soil stabilization, soil porosity, water-holding capacity, microbial population activity, cation exchange capacity (Abdul-Baki and Teasdale, 1993), and decreased plant disease (Gleason et al., 2001). Synthetic mulches, manufactured from petroleum-based materials, have been used extensively in agriculture, but problems with these materials include increased runoff compared with living mulches, disposal and landfill concerns, and their restriction in “certified organic” production as a long-term management strategy. Consumption of organic products is increasing, and there is very little research support for this expanding production system (Doug et al., 2002).

Waste materials such as rice straw, weeds, aquatic weeds, bark, and composted municipal green waste can provide effective weed control. Because of a higher depth of mulch required to suppress weed emergence, it is likely that transport costs will be high, which may prohibit their use unless the material is produced on the farm (Merwin, 1995; Radwan and Hussein, 2001). The fresh bark of conifers, oak (Quercus spp.), and rape (Brassica napus L.) straw gave good control of weeds when they were used as mulches under apple (Malus domestica Borkh.) trees (Weibel and Niggli, 1990). Following straw mulch, fruit size and potassium content in the apple leaves increased with increasing organic mulches (Pedersen, 1999). However, organic mulches, especially wood chips,
were ineffective in controlling perennial weeds, whereas the most effective was plastic mulch. However, Merwin (1995) reported that an alternative weed control strategy that provides potential benefits is mulching, although cost of mulching can be much higher than herbicides. Radwan and Hussein (2001) concluded that organic mulches, i.e., rice straw, sawdust, clover (Trifolium repens) weed, and cogon grass [Imperata cylindrica (L.) Palisot] significantly reduced the total dry weight of weeds in onion (Allium cepa L.) fields. The dry weights of lambsquarters (Chenopodium album) and Italian ryegrass [Lolium perenne L. ssp. multiflorum (Lam.) Husnot] weeds increased with the use of sawdust as mulch. Broadleaf weeds were more susceptible to mulching than grassy weeds. Mukhopadhyay (2006) reported that the crop residue mulch with an allelopathic effects may be the most promising weed management practice in the future.

In Egypt, rice straw is considered one of the most important plant waste problems, and cattail weed is a problem in all water canals. The use of these materials as mulch may serve to eliminate the waste problem while providing weed control.

The objective of this study was to investigate the effect of plant mulches with different depths as physical methods in comparison with synthetic mulch, hand hoeing, cultivation, and glyphosate on weed control efficacy, and quantity and quality of mandarin fruits.

Materials and Methods

The study was conducted during 2005–2006 and 2006–2007 in a uniform 15-year-old Balady mandarin (Citrus reticulata Blanco) orchard budded on Sour orange (Citrus aurantium L.) in a private orchard located at El-Salhia District, Sharkia Governorate, Egypt. Trees were spaced 5 x 5 m apart and were grown in a sandy soil using flood irrigation. Fertilization, irrigation, and other agricultural practices were applied as recommended. The soil texture of the experimental site was sandy with 1.41% organic matter, pH 7.9, E.C. 1.08 ds/m, and 1.78% CaCO3; 0.06 N, 0.017 P, 0.02% K, 0.62 Zn, 0.4 Mn, and 3.7 Fe ppm. The treatments presented in Table 1 were evaluated and compared for their effect on weed control, and quantity and quality of mandarin fruits.

Weeds at the base of the trees were controlled by hand. Treatments 4 through 13 were used as soil covers between the trees. Treatments were applied to six trees per plot and were replicated four times each year using randomized complete block design. Mulches were applied to plots during the first week of March each year, after winter cultivation, application of farmyard compost, and the first application of chemical fertilizer in the third week of February.

Weeds. The plots were visually rated for percentage of weed control 3, 5, 7, and 9 months after the mulch treatments application. We used a rating scale of 0 (no effect on weeds) to 100 (complete weed control) as approved by the Weed Science Society of America (Frans et al., 1986). Percentage control values were transformed to arcsine before analysis to improve the homogeneity of the error variance (Table 2). The original percentage scale is used in the tables. Weed counts were recorded per square meter randomly in each plot 3 and 6 months after treatment application in both years. Individual weeds were identified. Weeds were dried and their dry weights were determined.

Yield and yield components of mandarin trees. At harvest (mid-January) in both years, numbers of fruit per tree, fruit weight, and yield/tree were recorded.

Fruit quality characteristics. Samples of 20 fruit from each tree were randomly taken to determine the physical characters (fruit length, fruit diameter, and fruit length/diameter ratio). Chemical characteristics of fruit juice, i.e., total soluble solids, total acidity, ascorbic acid, and vitamin C were analyzed as described by the Association of Official Agriculture Chemists (1995).

Statistical analysis. The data from replicated experiments were combined, and after analysis showed nonsignificant year by treatment interactions. Analysis of variance was determined and the means were compared by Duncan’s multiple-range test at 5% level of significance (SAS, Cary, NC).

Results and Discussion

Effect of treatments on weeds. The major grass weeds present on the experimental site were bermudagrass [Cynodon dactylon (L.) Pers.], barnyardgrass [Echinochloa colorum (L.) Link], torpedo grass (Panicum repens L.), and sandbur (Cenchrus pensetiformis, Hochst. & Steud.) as a grass, and redroot pigweed (Amaranthus retroflexus L.), common purslane (Portulaca oleracea L.), and petty spurge (Euphorbia peplus L.) as broadleaf weeds. The dry weight of broadleaf weed species was less than the grass species as shown in unweded treatment (Table 3). Maximum biomass was recorded from bermudagrass.

As shown in Tables 2 and 3, all weed control treatments were effective in reducing the weed density and dry weight compared with weedy control plots. Covering the soil of mandarin orchards with one layer of rice straw, cattail, and wild oat mulch, as well as the thinnest black plastic layer, had less effect against grasses, where torpedo grass emerged through the mulch. Similar results were reported by Mohanty et al. (2002) and Shigure et al. (2003) in citrus orchards, and by Ghosh et al. (2006) in peanut fields. Radwan and Hussein (2001) reported that broadleaf weeds were more susceptible to mulching treatments than grassy weeds. Ligneau and Watt (1995) showed that a 3-cm layer of mulch was enough to prevent the emergence of annual weeds. The application of glyphosate proved the most efficient and maintained broadleaf and grass weed control up to 3 months (Table 3). The highest efficacy control of broad leaf weed (94% reduction in dry weight) was observed after 4 months from glyphosate treatment compared with unweded control treatment, where regrowth of grass had started. Variable glyphosate efficacy has been reported on different weed species.

| Table 1. Weed control treatments used in the 2-year experiment. |
|----------------|----------------|----------------|
| Treatments | Abbreviations | Application |
| 1. Unweeded control | UW | Allowing weeds to grow with mandarin trees |
| 2. Hand hoeing | HH | Orchard floor was weeded twice by hand hoeing annually (second week of May and August) |
| 3. Cultivation | Cul | Orchard floor was disked in two directions (east-west and north-south) with a standard orchard disk twice annually (second week of May and August) |
| 4. One layer of rice straw (Oryza sativa L.) mulch | 1LRSM | 3 cm deep; 8 tons/ha |
| 5. Two layers of rice straw mulch | 2LRSM | 6 cm deep; 15 tons/ha |
| 6. Three layers of rice straw mulch | 3LRSM | 9 cm deep; 23 tons/ha |
| 7. One layer of cattail (Cyperus articulatus, L.) weed mulch | 1LCWM | 4 cm deep; 10 tons/ha |
| 8. Two layers of cattail weed mulch | 2LCWM | 8 cm deep; 20 tons/ha |
| 9. Three layers of cattail weed mulch | 3LCWM | 12 cm deep; 30 tons/ha |
| 10. Wild oat (Avena fatua, L.) mulch | WOM | 6 cm deep; 15 tons/ha |
| 11. Black plastic mulch | 80 μm BPM, 150 μm BPM | 80 μm thickness, 150 μm thickness |
| 12. Black plastic mulch | 200 μm BPM | 200 μm thickness |
| 13. Black plastic mulch | Gly. | Glyphosate (Roundup) at 850 g a.i/ha was applied to the orchard floor in the second week of May. Source of Roundup, Monsanto Company, 800 North Lindbergh Boulevard, St. Louis, MO 63167. |
Weed control (%)

| Treatments | June 10 | Aug. 10 | Oct. 10 | Dec. 10 |
|------------|---------|---------|---------|---------|
| UW         | 25 c    | 17 f    | 9 f     | 11 g    |
| HH         | 96 b    | 78 c    | 63 d    | 49 e    |
| Cul        | 89 c    | 67 d    | 52 e    | 37 f    |
| 1LRSM      | 73 d    | 68 d    | 58 ed   | 38 f    |
| 2LRSM      | 98 ab   | 92 db   | 74 b    | 69 ed   |
| 3LRSM      | 100 a   | 99 a    | 97 ab   | 94 ab   |
| 1LCWM      | 74 d    | 66 d    | 55 ed   | 49 e    |
| 2LCWM      | 96 b    | 95 ab   | 90 b    | 85 c    |
| 3LCWM      | 100 a   | 98 a    | 97 ab   | 95 a    |
| WOM        | 74 d    | 53 e    | 53 c    | 42 ef   |
| 80 cm BPM   | 100 a   | 96 ed   | 74 c    | 69 d    |
| 150 μm BPM  | 100 a   | 100 a   | 100 a   | 98 a    |
| 200 μm BPM  | 100 a   | 100 a   | 100 a   | 100 a   |
| Gly.       | 92 c    | 76 c    | 56 d    | 41 f    |

cv% 2.4 15 7.3 4.6

*UW: unweeded, HH: hand hoeing, Cul: cultivation, 1LRSM: layer of rice straw mulch, 2LRSM: layer of cattail weed mulch, WOM: wild oat mulch, BPM: black plastic mulch, Gly: glyphosate.

Rating scale (0 = no effect and 100 = complete control).

Treatment means within a column followed by the same letter do not differ significantly (P = 0.05, Student–Newman–Keuls) probability.

Table 2. Influence of organic and synthetic mulches, hand hoeing, cultivation, and glyphosate on the dry weight of weeds (g/m²) grown in mandarin orchards.

Table 3. Influence of organic and synthetic mulches, hand hoeing, cultivation, and glyphosate on the dry weight of weeds (g/m²) grown in mandarin orchards.
of fruit per tree by 21%, 25%, and 48%, respectively, compared with hand hoeing (Table 4). Similar results were reported by Sabbah et al. (1994), Santinoni and Silva (1995), and Lima et al. (2002).

The reduction in fruit yield per tree from weeds was 62% (Fig. 1). This may be unjustified speculation because of the diffusion of toxic root exudates into the soil which affected mandarin tree growth (Aharoni et al., 1969). Kalita and Bhattacharyya (1995) reported that controlling weeds in lemon (Citrus limon Burm.f.) orchards improved flowering, fruiting, and fruit yield. MacRae et al. (2007) reported that interference from weeds with peach (Prunus persica) trees would reduce the availability of water and nutrients, and limited the amount of cell division thus affecting the final size of the fruit. These studies may explain the decrements of number, diameter, and weight of fruits in unweeded control treatment. Data in Table 4 also indicate that all weed control treatments had a significant increment in fruit criteria, in most cases, than unweeded control. Using one mulch layer of rice straw resulted in more yield than that of one layer of cattail by 22% (Fig. 1). The application of two layers of rice straw resulted in more yield per tree by 8% than did three layers, whereas two layers of cattail gave 9% more than three layers. However, using three layers of mulch resulted in higher levels of weed control than two layers (Tables 2 and 3). We conclude that two layers of rice straw mulch (6 cm deep) or cattail mulch (8 cm deep) are sufficient to control weeds in mandarin groves. Advantages of effective control by these mulches include lower weed management costs, more yield per tree, and less competition for irrigation water and nutrients. Previous studies found a pronounced effect of mulch on soil moisture by (reduced evaporative loss) and weed growth (substantially reduced with mulch; Faber et al., 2001). Using plastic mulches at 200 and 150 μm, two layers of cattail or rice straw mulch, and hand hoeing for controlling weeds resulted in the highest yield per tree without significant differences between these treatments. Soil mulching with rice straw or cattail at three layers, as well as mechanical hoeing, glyphosate, and plastic mulch (80 μm) treatments caused a significant reduction in weed density and weed biomass, but gave a lower yield compared with superior treatments. This result may be because of a short period of effective control and less efficacy control on grass (Table 3) of these previous treatments. Tworskosi and Glenn (2001) reported that the grasses in a peach grove were one of the most competitive species and reduced vertical water sprout length by 15% to 27% and lateral shoot length on fruit-bearing branches by 19% to 30% compared with herbicide treatments. MacRae et al. (2007) reported that maintaining the orchard floor weed-free for 12 weeks after peach tree bloom resulted in the greatest fruit size (individual fruit weight and diameter), total yield, and fruit number.

![Fig. 1. Yield of mandarin trees as affected by organic or synthetic mulch, hand hoeing, cultivation, and glyphosate treatments. Bars labeled with the same letter are not significantly different (P = 0.05, Student–Newman–Keuls) probability.](image)

Table 4. Influence of organic and synthetic mulches, hand hoeing, cultivation, and glyphosate on yield components and fruit physical and chemical properties of mandarin fruits.

| Treatments | Fruit length (cm) | Fruit diam (cm) | Length/diameter ratio | Fruit wt (g) | No. of fruit/tree | Total soluble solids (%) | Total acidity (%) | V.C (mg/100 ml) |
|------------|------------------|----------------|-------------------|-------------|------------------|------------------------|-------------------|-----------------|
| UW         | 5.5 cd           | 4.9 f          | 1.1 a             | 127 g       | 255 f            | 10 a                   | 0.7 d            | 41 d           |
| HH         | 5.8 eb           | 6.2 a          | 0.9 c             | 170 dc      | 494 abc           | 11 a                   | 0.8 bcd          | 47 abcd         |
| Cul        | 5.6 cd           | 6.1 a          | 0.9 c             | 166 dce     | 448 bc            | 12 a                   | 1.0 abc          | 49 ab           |
| 1LRSM      | 5.1 f            | 5.7 eb         | 0.9 c             | 171 bc      | 357 ed            | 12 a                   | 0.9 bcd          | 47 abcd         |
| 2LRSM      | 5.4 edf           | 5.7 cb         | 1.0 b             | 157 df      | 490 abc           | 11 a                   | 0.8 cd           | 50 ab           |
| 3LRSM      | 5.6 cd           | 5.3 ed         | 1.1 a             | 154 ef      | 322 ef            | 11 a                   | 1.1 ab           | 43 bcd          |
| 1LCWM      | 5.6 cd           | 5.3 ed         | 1.0 b             | 163 dce     | 545 a             | 10 a                   | 0.7 cd           | 43 bcd          |
| 2LCWM      | 5.6 cd           | 5.8 b          | 1.0 b             | 161 edcf    | 506 ab            | 11 a                   | 0.8 bcd          | 46 abcd         |
| 3LCWM      | 5.5 ed           | 5.8 b          | 1.0 b             | 161 edcf    | 506 ab            | 11 a                   | 0.8 bcd          | 46 abcd         |
| WOM        | 4.8 g            | 5.1 ef         | 0.9 c             | 148 f       | 341 e             | 12 a                   | 1.3 a            | 49 ab           |
| 80 μm BPM  | 6.3 a            | 6.2 a          | 1.0 b             | 166 dce     | 424 ed            | 11 a                   | 0.7 d            | 41 d            |
| 150 μm BPM | 5.2 ef           | 5.5 cd         | 0.9 c             | 184 ab      | 466 abc           | 10 a                   | 0.7 d            | 40 d            |
| 200 μm BPM | 5.5 cd           | 5.6 cb         | 1.0 b             | 185 a       | 495 abc           | 10 a                   | 0.9 bcd          | 49 ab           |
| Gly.       | 6.0 b            | 5.7 cb         | 1.0 b             | 162 ced     | 444 bc            | 11 a                   | 0.8 cd           | 51 a            |

\[ ^{\text{a}}\] UW: unweeded, HH: hand hoeing, Cul: cultivation, LRSM: layer of rice straw mulch, LCWM: layer of cattail weed mulch, WOM: wild oat mulch, BPM: black plastic mulch, Gly: glyphosate; *0: did not occur.

\[ ^{\text{b}}\] Treatment means within a column followed by the same letter do not differ significantly (P = 0.05, Student–Newman–Keuls) probability.
et al. (2002) reported that no significant difference in total soluble solids of mandarin fruits was observed among mulch treatments (black plastic mulch, soybean straw, local grasses, and paddy straw), but acidity was least with a black polyethylene sheet and was highest with unweeded treatment.

Generally, controlling weeds led to an increase in the fruit chemical properties of mandarin compared with the unweeded control.

Conclusion

Evaluation of mulching with rice straw, wild oat, and cattail weed for controlling weeds in mandarin orchards indicated that tree growth and yield of fruit was the same among the types of mulches tested. Differences in yield and quality of the fruit were significant among the regrowths from the same orchard. A difference in total soluble solids of mandarin fruit was observed among mulch treatments with the highest yield for the mulch treatments. Further studies are needed to evaluate their effectiveness on beneficial organisms, diseases, and insects.

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