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Determination of the effects of cover crops on yield and pomological characteristics of 'Meyer' lemon

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Abstract

The shift towards high-density citrus orchards necessitates sustainable weed management strategies that maximize yield without compromising environmental health. Conventional methods, such as herbicide application and mechanical tillage, pose risks to soil structure and root systems, particularly in the heavy clay soils of the Mediterranean. This study evaluated the efficacy of common vetch (*Vicia sativa* L.) as a cover crop for weed management in a 'Meyer' lemon (Citrus meyeri Yu. Tanaka) orchard in Adana, Turkey, and compared it to chemical herbicide application, weed cutting, and an unmanaged control. A three-year field experiment (2020-2022) employed a randomized complete block design to assess the impact of these four treatments on tree yield and fruit quality characteristics (Fruit weight (g), Fruit length (mm), Fruit diameter (mm), Peel thickness (mm), Fruit segment number, seed number, TSS (%), Total acidity (%), TSS/TA, Fruit juice (%)).The results indicated that while annual yield was statistically similar across all treatments, cover crop application significantly enhanced key fruit quality characteristics in the second year. Fruits from the vetch treatment exhibited a greater weight (98.74 g), length (65.87 mm), and width (54.0 mm) than those from the chemical application. Furthermore, the vetch and weed cutting treatments produced fruit with significantly thicker rinds ($p<0.0044$). Total Soluble Solids (TSS) were highest in the weed cutting treatment, while juice content remained unaffected by the management strategy.

Keywords: Citrus, Fruit quality, Weed control, Mulching, Cover crop

INTRODUCTION

In recent years, citrus orchards have been increasingly established using high- or medium-density planting systems. The objective of these systems is to maximize yield per unit area. To achieve yield optimization, various horticultural practices have been employed, including fertilization, pruning, and disease and pest control. However, significant yield losses in citrus production are attributable to various plant-protection agents. Specifically, research indicates that these losses are distributed as follows: 45% due to competitive weeds, 30% to insect pests, 20% to disease pathogens, and 5% to other harmful agents (Hançerli and Uygur, 2021). Conventional weed management in citrus orchards typically involves the use of mechanical equipment, herbicide application, or a combination of both.

Heavy clay-textured soils predominant in the Mediterranean region pose a significant challenge to citrus cultivation. Due to these compact soil conditions, citrus root systems are unable to penetrate deeply and instead become concentrated near the soil surface. Consequently, mechanical weed control using tractors can damage delicate capillary roots. This root injury creates wounds that increase the risk of soil-borne infections (Tuzcu, 2000). In contrast, many modern fruit-producing countries have adopted no-till or reduced tillage agricultural practices (Derpsch et al, 2010; Şeker et al., 2024). Given the intensity of citrus cultivation in our region, implementing sustainable soil management practices is imperative. Conventional agricultural practices, including intensive tillage, monoculture systems, and excessive use of inorganic fertilizer, have led to a marked decline in environmental quality, biodiversity, and long-term agricultural productivity (Adetunji et al., 2020).

To ensure the long-term viability of citrus production, we must adopt sustainable weed management strategies that simultaneously provide effective control of yield-limiting weeds and maintain the vital ecological balance of the agroecosystem. Ideally, these practices should enhance local biodiversity, thereby facilitating the natural regulation of other pest organisms that affect fruit trees. Among the most successful methods are cover crop applications (Brandsaeter and

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Roen., 2004; Bugg et al., 1991; Macit et al., 2020; Hançerli and Uygur, 2021; Fernando and Shrestha., 2023, Rosa et al., 2021; Singer et al., 2008; Şeker et al., 2024). The use of cover plants is one of the most profitable and beneficial practices adaptable to citrus cultivation. Cover crops are protective organic plant layers that spread across the soil surface (Hançerli and Uygur, 2021). Their cultivation is not intended for harvest but rather to serve multiple ecological functions. These purposes include acting as living mulch, providing a source of organic matter, creating a multifaceted surface ecosystem, conserving soil, regulating soil temperature and moisture, suppressing diseases and pests, and inhibiting the germination and emergence of weeds (Özeker and Ulutürk, 2006; Adetunji et al., 2020; Şeker et al., 2024).

Commonly used cover crop species include common vetch (*Vicia sativa* L.), hairy vetch (Vicia villosa Roth.), red clover (Trifolium pratense L.), white clover (Trifolium repens L.), field pea (Pisum sativum ssp. arvense L.), and cowpea (Vigna unguiculata (L.) Walp.) (Chapagain et al., 2020; Kitiş, 2009; Kitiş, 2010; Ntshidi et al., 2021; Perkus et al., 2022; Şeker et al., 2024). Previous research has highlighted that common vetch is a particularly effective species (Mennan et al. 2020; Ramírez-Parra, and De la Rosa, 2023) such as Avena sterilis L., Sinapis arvensis L., Amaranthus retroflexus L., Echinochloa colonum (L.) Link., Chenopodium album L., Cochorus olitorus L., Setreia verticillata (L.) P. Beauv. (Kitiş et al., 2016). It forms a dense surface cover that creates intense shading and rapidly utilizes available environmental resources. Owing to its competitive nature, it possesses superior traits that outperform a wide range of weed species. Owing to these characteristics, common vetch has been recognized as one of the most preferred plants globally for use as living mulch against weeds (Kitiş et al., 2016). Supporting this, a study conducted by Temel et al. (2011) in an organic citrus orchard demonstrated that areas sown with common vetch exhibited lower weed coverage and density, confirming its efficacy as a successful cover crop. In citrus orchards (Anthemis arvensis L., Avena sterilis L., Bromus tectorum L., Calendula arvensis L, Chenopodium album L., Lolium temulentum L., Malva sylvestris L., Melilothus officinalis (L.) Lam., Phalaris brachystachys Link., Polygonum aviculare L., Ranunculus arvensis L., Raphanus raphanistrum L., Rumex obtusifolius L., Senecio vernalis Waldst. & Kit, Sisymbrium officinale (L.) Scop, Sonchus oleraceus L.weeds can be seen (Hançerli and Uygur, 2021).

Further research is needed to develop environmentally sound weed control methods that actively boost biodiversity while maintaining overall ecological equilibrium. Based on those findings, we conducted an investigation under the ecological conditions of Adana in order to evaluate the effects of four distinct weed control methods—(i) chemical application, (ii) weed cutting, (iii) cover crop (vetch) application, and (iv) control—on the yield and fruit quality of a 'Meyer' lemon orchard.

MATERIALS AND METHODS

Plant Material and Orchard Conditions

The study was conducted using 'Meyer' lemon trees (Citrus meyeri Y. Tan.) grafted onto sour orange (Citrus aurantium L.) rootstocks. The trees were planted in 2010 at a spacing of 6.0 m × 3.0 m at the Research Station of the Çukurova University Faculty of Agriculture Citrus Experiment Station in Adana, Turkey (35°23' N, 36°50' E, at an altitude of 27 m). The soil in the experimental area was classified as clay loam (57% clay, 21% silt, 22% sand) with a calcium carbonate (CaCO3) content of 12%. The soil pH at a depth of 0-90 cm ranged from 6.85 to 7.05, and the electrical conductivity (EC) was 0.20 mmhos/cm, indicating low salinity. The regional climate features mean maximum and minimum temperatures of 26°C and 14.5 °C, respectively, with an average annual rainfall of 465 mm. The trees were irrigated weekly from May to October using a drip-irrigation system.

Experimental Design and Treatments

The experiment was conducted over three years from 2020 to the end of 2022, with fruit sampling for analysis carried out in 2021 and 2022. 'Meyer' lemon orchard was divided into four parcels of one hectare. each with three rows of safety strips between them. A randomized complete block design was employed, with four weed management treatments, and ten replicates were used per treatment for yield and fruit sampling. The treatments were as follows:

1. Chemical Application: This plot simulated standard farming practices, involving the application of herbicides for weed control. Touchdown (active ingredient: Glyphosate-Acid; Syngenta) herbicide was applied twice a year for weed control (5.0 L ha-1), and weed growth was not allowed.

2. Weed Cutting Application: The second plot was chosen as "the parcel where in-row mulching and inter-row weed cutting applications are made" (Weed cutting). Weeds were moved when they were 5 cm tall. No herbicide was applied in this plot.

3. Cover Crop Application: The third plot was chosen as "in-row mulching and inter-rows covering plant with vetch, (*Vicia sativa* L. (Fabaceae: Leguminosae)" (Vetch). Cover crop, vetch, was inter-row planted by plowing the soil. Vetch was planted twice a year as 10 kg per decar (March and September) as a cover crop, and when the vetch was blooming, it was incorporated into the soil.

4: Control: No weed management practices were applied, and the plots were left to natural weed growth.

Data Collection and Measurements

The fruit yield for each tree was determined annually during the harvest period (September-October). All fruits were harvested and weighed at the optimum maturity stage from each plot. Furthermore, a random sample of 25 fruits was collected from each replicate for quality analysis.

The following fruit quality parameters were measured:

Fruit yield was determined by weighing the fruit produced by each tree. Fruit weight was recorded for each sample fruit. The number of seeds was determined by counting the seeds in the fruit. The number of segments was determined by counting the segments in the fruit. Fruit diameter was measured at the equator using a digital caliper (Mitutoyo CD-15CPX). Rind thickness was measured with the same digital caliper after the fruit was cut in half transversely. Juice percentage was determined by weighing the fruit, extracting the juice using a standard juicer, and then weighing the juice. The result was expressed as a percentage of the total fruit weight. Total soluble solids (TSS) content was measured using a few drops of juice with a portable refractometer (FG-103/113) and expressed as Brix. Titratable Acidity (TA) was determined by titrating 1 mL of juice with 0.1 N sodium hydroxide (NaOH) using phenolphthalein as an indicator. The results were expressed as a percentage of citric acid.

Statistical Analysis

Data from the 2021 and 2022 growing seasons were subjected to analysis of variance (ANOVA) using SAS statistical software (version 9.0). Treatment means were separated using the Least Significant Difference (LSD) test at a significance level of $P< 0.05$. Graphical representation was performed using SigmaPlotv. 14.0 (Systat Software Inc.).

RESULTS AND DISCUSSION

Result

Yield

The effects of the four treatments on yield were found to be statistically non-significant in 2021 and 2022, as well as in the average yield. Yield per tree varied between 14.41-17.05 kg/tree in 2021 and 13.60-17.45 kg/tree in 2022 (Figure 1).

Pomological Characteristics

The effects of the different treatments on fruit weight, length, and diameter were not statistically significant in the first year of the trial (2021) (Table 1) or in the combined annual average (Table 3). However, in the second year (2022), the differences between the treatment means for all three characteristics were statistically significant (Table 2). In 2022, the highest fruit weight (98.74 g) was obtained from trees in the vetch cover crop treatment. This was followed by the weed cutting (88.29 g) and control (84.24 g) treatments, while the lowest fruit weight (74.05 g) was recorded in the chemical application treatment (Table 2). Similarly, the highest fruit length (65.87 mm) and fruit diameter (54.0 mm) were observed in the Vetch treatment, consistent with the trend in fruit weight. The lowest values for fruit length (59.45 mm) and diameter (49.26 mm) were found in the chemical application treatment (Table 2). The fruit index (diameter to length ratio) ranged from 0.78 to 0.81 in 2021 (Table 1), 0.80 to 0.83 in 2022 (Table 2), and 0.80 to 0.81 for the average across years (Table 3). The differences between treatments for this parameter were not statistically significant in any year (Tables 1, 2, and 3).

Peel thickness was found to be statistically significant in 2022, and the combined annual average (Tables 2 and 3). In 2022, the thickest peels were observed in the vetch (2.94 mm) and weed cutting (2.78 mm) treatments (Table 2). A similar pattern was observed for the annual average, with the thickest peels in the weed cutting (3.03 mm) and vetch (2.96 mm) treatments (Table 3). In both 2022 and the annual average, the control and chemical application treatments produced fruits with the thinnest peels (Tables 2 and 3). The number of fruit segments and the number of seeds were not significantly influenced by the treatments (Tables 1, 2, and 3). The number of segments ranged from 9.92 to 10.26 in 2021, from 10.26 to 10.77 in 2022, and averaged 10.09 to 10.48 per year (Tables 1, 2 and 3). The number of seeds ranged from 3.67-5.09 in 2021, 2.70-3.55 in 2022, and an average of 3.37-3.89 per year (Tables 1, 2 and 3).

The treatment effects on the annual average of total soluble solids (TSS) content were non-significant in 2021 but statistically significant in 2022. In both 2022 and the average of 2021 and 2022, the highest TSS content was detected in fruits from the weed cutting treatment, with values of 12.02% and 9.89%, respectively. The effect of treatments on acidity and TSS/acidity ratio was non-significant in all years. Total acidity ranged from 6.32 to 6.59 in 2021, from 6.90 to 8.05 in 2022, and averaged 6.71 to 7.29 per year (Tables 1, 2 and 3).The juice content, a critical harvest criterion for lemons, was not significantly affected by the treatments in any of the experimental years (Table 1, 2, and 3). Juice yield ranged from 32.2% to 34.33% in 2021 (Table 1), from 36.73% to 43.08% in 2022 (Table 2), and from 35.53% to 37.77% (Table 3) for the combined annual average.

Discussion

This study evaluated the use of mulching and cover crops as alternatives to chemical weed control. The results indicated that fruit yield in the alternative treatments was comparable to, and in some aspects superior to, the chemical control. This finding is consistent with research on other fruit species, including kiwifruit (Demir and Işık, 2019), persimmon (Demir and Işık, 2019), hazelnut (Işık et al., 2014), apple (Bould and Jarrett, 1962), peach (Fang et al., 2022; Şeker et al., 2024), apricot (Demir et al., 2019), guava (Bhattacharjee et al., 2020), mango (Wei et al., 2021), and vineyards (Muscas et al., 2017), which demonstrate that specific cover crops can serve as viable alternatives to herbicides without compromising yield or fruit quality.

In the present study, fruit size in the second year (2022) was significantly greater in vetch (*Vicia sativa* L.) treatment compared to others. Similar improvements in fruit size following cover crop application have been reported for Valencia orange (Mulinge et al., 2018), mandarin (Selim et al., 2020), and apricot (Demir et al., 2019). Peel thickness in the second year (2022) was significantly higher in vetch (*Vicia sativa* L.) (2.94 mm) and weed cutting (2.78 mm) treatments compared to others. However, Economides (1976) observed a reduced fruit rind thickness on plotswith a cover crop compared with plots without a cover crop. Given the rising costs of inputs and the detrimental effects of herbicides on environmental and human health, transitioning away from their use is imperative. Cover crop systems that alleviate yield concerns for producers represent a viable path toward sustainable agriculture. Various cover species have been successfully trialed in citrus, including common vetch in Valencia orange (Economides, 1976), lupine in Valencia orange (Henfy et al., 2020), and soybean in mandarin (Selim et al., 2020). As Silwana et al. (2023) noted, legume cover crops are recommended and for enhancing fruit quality in citrus orchards.

This study, conducted under the ecological conditions of Adana with 'Meyer' lemon, demonstrated that the use of common vetch resulted in fruit yield and quality comparable to chemical methods, with a notable advantage in fruit size. These findings provide preliminary evidence that citrus cultivation using cover crops can be practiced without loss in yield or quality. However, further research is warranted, incorporating a greater variety of cover species and extending trials to other major citrus types such as mandarins, oranges, and grapefruits. The study area, Adana, is a region of intensive citrus production where herbicide use is prevalent. The adoption of environmentally friendly cover crops as an alternative would not only make citrus production more economical but also significantly enhance its sustainability for environmental and human health. In addition, more information needs to be obtained on the long-term agronomic and economic impacts of cover crops in citrus farming under specific Turkish growing conditions.

Table 1. Effects of control, weed cutting, vetch, and chemical treatments on the pomological characteristics of 'Meyer' lemon in 2021.

	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)	Index	Peel thickness (mm)	Fruit segment number	Seed number	TSS (%)	Total Acidity (%)	TSS/TA	Fruit Juice (%)
Control	94.82 ± 9.83	68.71 ± 4.02	53.64 ± 1.40	0.78 ± 0.03	3.11 ± 0.47	10.10 ± 0.43	3.67 ± 0.76	7.74 ± 0.65	6.52 ± 0.54	1.19 ± 0.09	33.25 ± 1.64
Weed cutting	99.31 ± 4.91	68.83 ± 1.16	54.97 ± 0.85	0.80 ± 0.02	3.29 ± 0.08	9.92 ± 0.35	4.22 ± 0.73	7.76 ± 0.26	6.52 ± 0.34	1.19 ± 0.05	32.20 ± 2.98
Vetch	90.24 ± 7.61	66.04 ± 2.39	53.19 ± 1.35	0.81 ± 0.01	2.98 ± 0.07	10.26 ± 0.20	5.09 ± 1.60	7.68 ± 0.38	6.32 ± 0.23	1.22 ± 0.07	32.45 ± 0.88
Chemical	98.98 ± 5.26	70.20 ± 3.57	54.79 ± 1.12	0.78 ± 0.03	3.18 ± 0.26	10.19 ± 0.18	4.20 ± 1.27	7.54 ± 0.11	6.59 ± 0.17	1.14 ± 0.03	34.33 ± 1.67
Prob>F	0.196^{ns}	0.209^{ns}	0.086^{ns}	0.249^{ns}	0.384^{ns}	0.366^{ns}	0.309^{ns}	0.823^{ns}	0.663^{ns}	0.386^{ns}	0.338^{ns}
LSD (p<5%)	9.6287	4.0192	1.6102	0.0297	0.3684	0.4122	1.5422	0.5409	0.4704	0.0858	2.6069

ns: not significant. TSS (Total soluble sugar); TSS/TA (Total soluble sugar/Total acidity)

Table 2. Effects of control, weed cutting, vetch and chemical treatments on the pomological characteristics of 'Meyer' lemon in 2022.

	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)	Index	Peel thickness (mm)	Fruit segment number	Seed number	TSS (%)	Total Acidity (%)	TSS/TA	Fruit Juice (%)
Control	84.24 ± 3.61 ^{b}	62.47 ± 3.04 ^{bc}	51.81 ± 0.45 ^{b}	0.83 ± 0.03	2.45 ± 0.07 ^{b}	10.35 ± 0.44	3.06 ± 0.05	10.70 ± 0.36 ^{b}	6.90 ± 1.21	1.61 ± 0.23	42.07 ± 1.20
Weed cutting	88.29 ± 9.05 ^{b}	64.72 ± 1.82 ^{ab}	51.81 ± 2.29 ^{b}	0.80 ± 0.03	2.78 ± 0.18 ^{a}	10.26 ± 0.24	3.55 ± 1.15	12.02 ± 0.90 ^{a}	8.05 ± 0.28	1.48 ± 0.06	40.67 ± 1.29
Vetch	98.74 ± 8.80 ^{a}	65.87 ± 1.06 ^{a}	54.00 ± 1.53 ^{a}	0.82 ± 0.01	2.94 ± 0.25 ^{a}	10.43 ± 0.10	2.70 ± 0.80	10.76 ± 0.04 ^{b}	7.26 ± 0.27	1.48 ± 0.05	43.08 ± 6.53
Chemical	74.05 ± 3.83 ^{c}	59.45 ± 2.84 ^{c}	49.26 ± 0.86 ^{c}	0.83 ± 0.02	2.42 ± 0.06 ^{b}	10.77 ± 0.49	2.94 ± 0.32	11.14 ± 0.95 ^{ab}	7.11 ± 1.24	1.48 ± 0.05	36.73 ± 1.81
Prob>F	<0.001***	0.003**	0.001**	0.301^{ns}	<0.001***	0.160^{ns}	0.326^{ns}	0.027*	0.231^{ns}	0.343^{ns}	0.053^{ns}
LSD (p<5%)	9.1714	3.1286	1.9570	0.0366	0.2149	0.4759	0.9624	0.9102	1.1924	0.1700	4.6941

Means followed by different letters in the same column are significantly different (Least Significant Difference (LSD) test at a significance level of P< 0.05.) ns: not significant. ***: P ≤ 0.001, **: P ≤ 0.01, *: P ≤ 0.05. TSS (Total soluble sugar); TSS/TA (Total soluble sugar/Total acidity)

Table 3. Effects of control, weed cutting, vetch and chemical treatments on the pomological characteristics of 'Meyer' lemon in average year.

	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)	Index	Peel thickness (mm)	Fruit segment number	Seed number	TSS (%)	Total Acidity (%)	TSS/TA	Fruit Juice (%)
Control	89.53 ± 4.48	65.59 ± 1.76	52.72 ± 0.66	0.81 ± 0.01	2.78 ± 0.21 ^{b}	10.22 ± 0.35	3.37 ± 0.39	9.22 ± 0.43 ^{b}	6.71 ± 0.81	1.40 ± 0.12	37.66 ± 0.93
Weed cutting	93.80 ± 6.42	66.78 ± 0.72	53.39 ± 1.35	0.80 ± 0.01	3.03 ± 0.11 ^{a}	10.09 ± 0.26	3.89 ± 0.90	9.89 ± 0.41 ^{a}	7.29 ± 0.07	1.34 ± 0.05	36.44 ± 1.98
Vetch	94.49 ± 5.61	65.95 ± 1.07	53.60 ± 0.72	0.81 ± 0.01	2.96 ± 0.12 ^{ab}	10.34 ± 0.12	3.89 ± 0.70	9.22 ± 0.19 ^{b}	6.79 ± 0.19	1.35 ± 0.06	37.77 ± 3.32
Chemical	86.51 ± 3.76	64.83 ± 2.18	52.03 ± 0.63	0.81 ± 0.02	2.80 ± 0.14 ^{b}	10.48 ± 0.31	3.57 ± 0.68	9.34 ± 0.42 ^{b}	6.85 ± 0.64	1.31 ± 0.04	35.53 ± 0.75
Prob>F	0.085^{ns}	0.286^{ns}	0.052^{ns}	0.588^{ns}	0.044*	0.175^{ns}	0.571^{ns}	0.036 *	0.344^{ns}	0.344^{ns}	0.282^{ns}
LSD (p<5%)	6.9323	2.0676	1.1939	0.0194	0.2029	0.3657	0.9305	0.5014	0.7078	0.0985	2.7140

Means followed by different letters in the same column are significantly different (Least Significant Difference (LSD) test at a significance level of P< 0.05.) ns: not significant. TSS (Total soluble sugar); TSS/TA (Total soluble sugar/Total acidity)

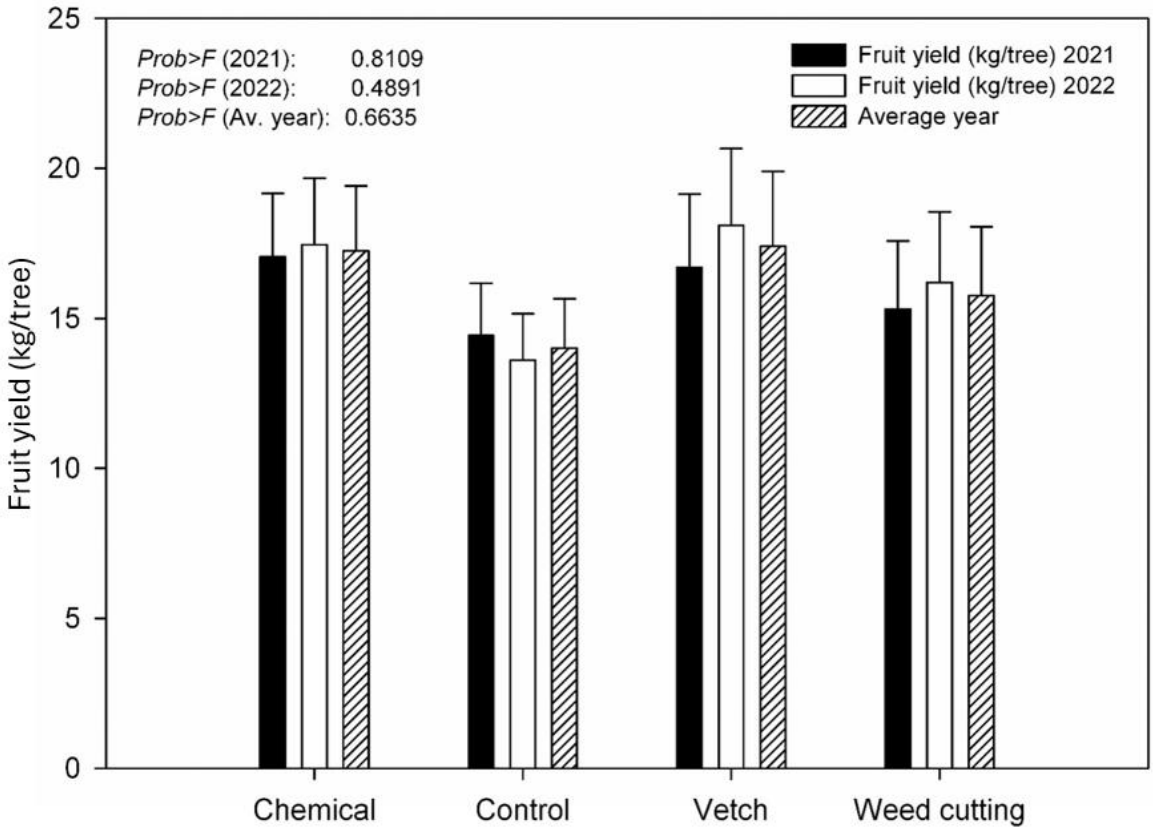


Figure 1. The effect of different weed control strategies on fruit yield in 2021 and 2022.

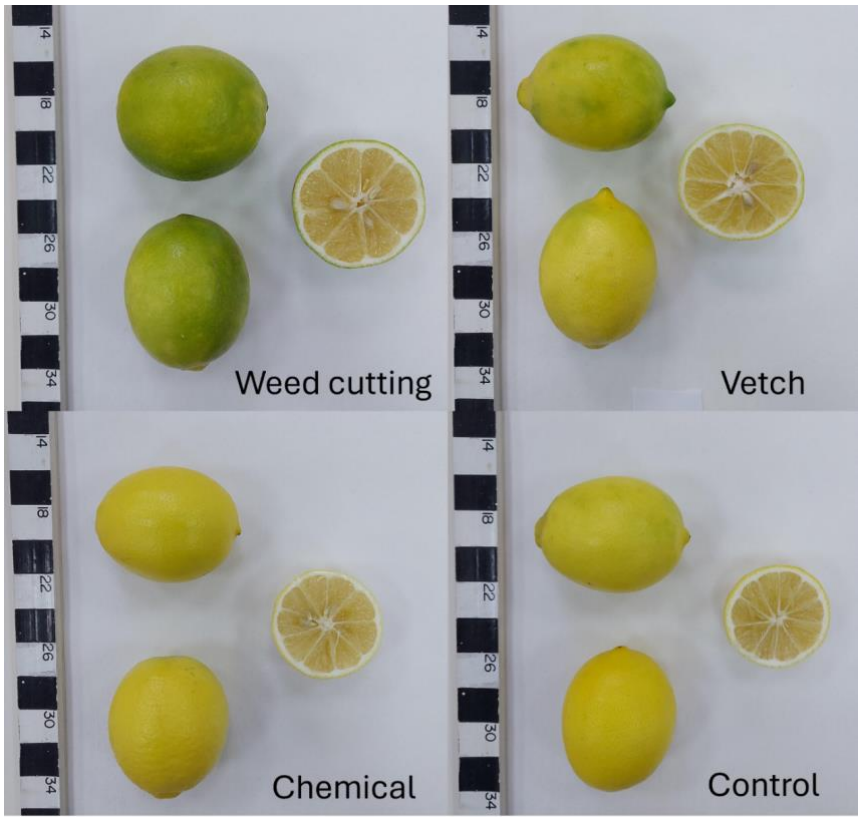


Figure 1. Photo illustrating measurements of 'Meyer' lemon fruit characteristics, including length, width, and rind thickness. Representative 'Meyer' lemon fruits were collected from trees exposed to different weed control strategies.

Ethical Statements and Declarations

Conflict of Interest

The authors declare no competing interests regarding the publication of this paper.

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