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# Integrated weed management along tree row in high density fruit orchards

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**Abstract:** Despite the productivity, achieving long-term sustainability and maintaining plant biodiversity become the pivotal goals in orchard floor management, especially along tree rows. Thus, the paradigm of eradicating weeds in the tree row using chemical herbicide or repeated soil tillage needs to be substituted with more sustainable alternatives. This study was conducted in two commercial apple and peach orchards in Marche region (Italy). Two integrated mechanical approaches, integrated mowing (mower + brush or disc) and integrated tillage (blade weeder + integrated mowing), were compared with standard herbicide system in a 2-years trial. Weed species abundance, soil coverage rate, and weed biomass productions, including gas exchange parameters, tree growth, fruit yield and quality were measured. Both integrated practices had significant effects on the number of weed species, total vegetation coverage, and dry weed biomass production. No significant differences were found in terms of tree gas exchange parameters, growth and fruit yield. However, a few fruit quality parameters such as fruit firmness, solid soluble content and dry matter content responded positively to the integrated practices. These results suggest that the integrated mechanical approaches of weed management increased orchard biodiversity, and they had no adverse effects on tree growth, fruit yield, and quality.

**Keywords:** weed management, integrated tillage, integrated mowing, herbicide, biodiversity and fruit production

## 1. Introduction

Sustainable tree-row management in the fruit orchard is not only crucial for healthy tree growth and quality fruit yield but also for sustaining soil quality and promoting orchard biodiversity. Tree-row management entails the management of orchard weeds as they can compete aggressively, with fruit trees for available nutrients and water, essential for plants growth. Fruit trees are poor competitors because of their low root density per unit of soil compared to weeds [1]. Therefore, proper weed management is vital in the fruit orchard to minimize weeds competition against fruit trees, for assuring quality fruit yields [2,3] and to support biodiversity in orchards [4]. A common management method is to eradicate weeds, either permanently, or temporarily, through herbicide use, or traditional tillage along the tree row, or inter-row [4,5]. Maintaining bare soil from 0.6 to 2.0 m along the tree row with herbicides [6] has proved to be easy, cost- effective, and favorable for tree growth and fruit yield [7]. However, the continuous use of chemicals is detrimental to human and environmental health. The consequences generated by herbicide applications include declines in weed biomass, weed biodiversity and soil quality [8,9,10]. Also, these practices foster development and evolution of herbicides resistant weed species [11] and favors an insurgence of soil sickness [12,13]

Currently, the concept of weed management has achieved a broader meaning than in past decades, as it regulates the coenoses of orchard agroecosystems and turns into a consistent part of the agroecological approach in the perennial fruit orchard. Hence, a sustainable weed management in the orchard can play a vital role in enhancing biodiversity and soil quality by offering ecological protection [14] and improving nutrient availability and resilience in the soil [15]. Moreover, soil cover with spontaneous vegetation might increase orchard biodiversity with richer food chains, which may lower the incidence of some pests by favoring beneficial organisms [16]. It can also play a crucial role in soil erosion reduction and carbon sequestration with improved organic matter in the soil [17], while opposite results may be found under coverless ground system conditions [18]. In this regard, maintaining soil vegetation, while augmenting biomass production and species diversity can be considered fundamental goals in sustainable orchard management systems. The key is to practice more sustainable strategies that support covered soil with spontaneous, or selected living species by keeping them at a density level that does not cause any negative impact on tree performances [4].

Several alternatives to chemical weed management, such as minimum tillage, mowing, mixtures of living mulching species, distribution of organic mulch, uses of plastic mulch, flaming, and steaming, have been studied with relatively negative results [19]. Therefore, researchers are still seeking a more sustainable strategy that might reduce weed competition and improve orchard biodiversity without compromising the quality of fruit production. Priority has been given to the integrated approach for an enhancement of long-term orchard sustainability [5,19,20].

The variety of sustainable management practices directed us towards seeking more advances in mechanical weed control [4]. These include integrated tillage, integrated mowing and modern finger weeder as sustainable techniques that reduce soil disturbance. Even though, weed control based on traditional soil tillage demonstrated several adverse impacts on tree growth, fruit production and quality [14,21,22], tree roots [23], and soil fertility. However, it might be possible to minimize those problems and optimize orchard biodiversity by integrating advanced shallow tillage implements. In this study, two integrated mechanical practices: (i) integrated mowing (mower with brush or disc), (ii) integrated tillage (blade weeder + integrated mowing) were compared to chemical herbicide (glyphosate) with the aim of investigating the effects of sustainable alternative weed management methods on orchard biodiversity, fruit yield, and quality. We hypothesized that two integrated treatments would bolster species number, biomass production and vegetation coverage, without declining tree growth, fruit yield and quality in fruit orchards, managed with drip irrigation and a usual fertilization regimen.

## 2. Materials and Methods

### *2.1. Experimental sites and management practices*

The experiment was started in March 2018 in two commercial fruit orchards (apple and peach) at Valdaso in the Marche region (central Italy, 43°00′13.70″ N, 13°35′45.98″ E; average annual precipitation 750 mm). A three years old apple (*Malus* × *domestica* Borkh., cv. Crimson Crisp; rootstock M9) orchard was spaced at 4 x 1 m (2,500 trees/ha) on an alkaline (pH=8.25) sandy clay loam soil (sand 55% + silt 16.7% + clay 28.3%) with 1.29% soil organic matter. The trees were trained to spindle system and covered with a white high-density polyethylene net to protect them from insects and hailstorms. Three years-old peach (*Prunus persica* L. Batsch cv. Royal Sweet; rootstock GF677) orchard, located on a nearby farm, was planted at the distance of 4 x 3 m (833 trees/ha) between row to row and plant to plant respectively, on an alkaline (pH=8.04) sandy clay loam soil (sand 46.7% + silt 26.7% + clay 26.7%) with 1.16% soil organic matter, where plants were trained to a palmette system. Both orchards were drip irrigated in the summer and fertilized in the winter/spring, as per protocols used in the area.

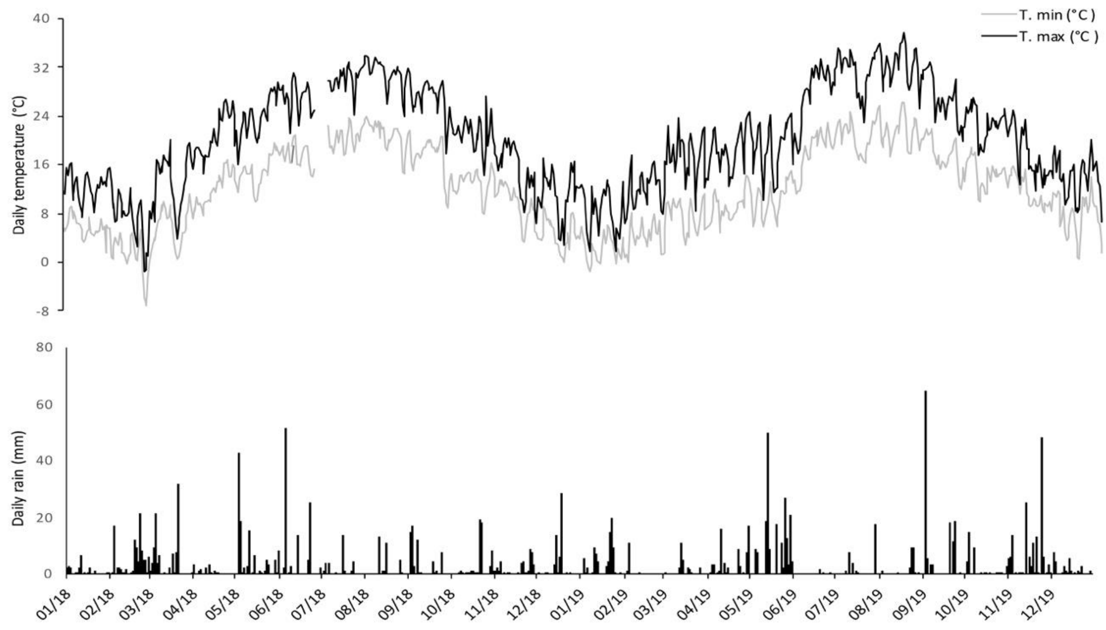


**Figure 1**. The daily rain (mm), and minimum and maximum temperature (°C) measured during the experiment (2018-2019) by a meteorological station located 3 km from the experimental field (Sistema Informativo Regionale Meteo-Idro-Pluviometrico).

The study was laid out in Randomized Complete Block Design (RCBD) with three treatments applied in both orchards (Table 1): (1) Integrated mowing (mower with polypropylene brush mounted on a horizontal axis or disc, Falconero company), (2) Integrated tillage (Single blade weeder, mounted on Kubota M5091 tractor, ID-David S.L.U. company + integrated mowing), and (3) Herbicide (mixing 1 L glyphosate with 100 L of water, applied 3.2 L/ha). Each treatment was replicated three times at each orchard with three plots, which included 32 trees each (288 trees in total), where three trees were sampled for the measurement from each replication of all the treatments (total of 27 sampled trees per orchard).

**Table 1.** Treatments applied in the tree row over 2 years (2018-2019)

| Treatment | 2018 | 2019 |
|---|---|---|
| Herbicide | Herbicide sprayed 2 times | Herbicide sprayed 2 times |
| Integrated tillage | Tilled with blade weeder 1-time, integrated mowing 4 times | Tilled with blade weeder 1-time, integrated mowing 5 times |
| Integrated mowing | 5 times | 7 times |

*2.2. Tree growth, fruit yield and quality*

The tree growth was measured as the cross-sectional area of the trunk (TCSA) at 20 cm above the graft union on both apple and peach. Measurements were taken in March 2018, January 2019, and December 2019. Results are presented as the percent increase over 2 years. Fruits were harvested by hand, the total numbers of fruit from each plant were counted separately for each treatment, then fruits were weighed using a digital balance to measure the fruit yield (kg/plant). Three similar size fruits per plant (total twenty-seven fruits per treatment) were collected to measure fruit quality parameters: individual fruit weight, fruit firmness, dry matter content (DMC), and soluble solids content (SSC). The firmness was measured on two peeled sides in the equatorial plane of the fruit with a penetrometer (model 53200, Turoni, Italy), equipped with 11 mm plunger for apple and 8 mm for peach. For the soluble solids content (SSC) determination, the pulp from three fruits from each selected plant was crushed and the intact juice was analyzed immediately, with an optical refractometer (model-53000 C, Turoni, Italy). For the determination of fruit dry matter content, 5g of fruit flesh were collected from each fruit and kept in the oven at 60°C until a constant weight was reached. The fresh and dry weights of fruits flesh were measured with a digital balance, only in 2019.

### *2.3. Orchard biodiversity assessment*

Weed biomass production, the total number of plant species present in the tree row and their soil coverage rate were considered to assess orchard biodiversity in this study. Weeds were collected during the summer season (July- August) of each year, prior to a weed control event from three random locations per treatment, with a frame of 0.50 $m^2$ (1m x 0.5m). Collected weeds were placed in a separate paper bag with a tag for each treatment, then the fresh weight of weed was recorded. For drying, weeds were kept in the oven for 48 hours at 65°C temperature. The fresh and dry weight of weeds were measured with a digital balance. Species abundance and their coverage rate in the tree row were estimated using the Braun-Blanquet method [24]. Visual weed ratings for each plot were recorded the day before the treatment application by randomly selecting 10 $m^2$ (4 m x 2.5 m) area in the tree row.

### *2.4. Gas exchange parameters*

Gas exchange parameters such as the net photosynthetic rate (A, μmol $CO_2$ $m^{-2}$ $s^{-1}$), the transpiration rate (E, mmol $H_2O$ $m^{-2}$ $s^{-1}$), the stomatal conductance (gs, $H_2O$ $m^{-2}$ $s^{-1}$), and the intercellular $CO_2$ concentration (Ci, μmol $CO_2$ $mol^{-1}$) were measured using gas exchange measurement system (LCpro, ADC Bioscientific Ltd., UK), under environmental light (PAR ranging 1300-1650 μmol $m^{-2}$ $s^{-1}$). Measurements were carried out on 2 leaves from each randomly selected 6 plants per treatment from 9-11 am to avoid the midday depression of photosynthesis and respective changes in stomatal conductance [25]. The parameters were measured when the system reached equilibrium on July and August in 2018 and June, July, and August in 2019.

### *2.3. Statistical analysis*

All the experimental data were subjected to analysis of variance (ANOVA); significant differences were compared using mean separation with the Tukey-Kramer HSD test ($p \leq 0.05$). Statistical analysis was conducted using JMP Software (Release 8; SAS Institute Inc., Cary, NC, USA, 200).

## **3. Results**

### *3.1. Orchard biodiversity assessment*

A total of 48 weed species belonging to 22 families were identified with the abundance of annual species in both orchards over two years timeframe of the experiment (Table 2). None of them were listed in the red and blue list of Italian flora (composed of endangered and defended species). The most dominant weed species present in the tree row were the perennial dandelion *(Taraxacum officinale Weber)*, especially under integrated mowing plot, the annual sow thistle *(Sonchus oleraceus L.*) under integrated tillage, and both broadleaved species of the Asteraceae family, and the annual birdeye speedwell *(Veronica persica Poir.)* under the herbicide plot, forming prostrate ground cover. Where white clover *(Trifolium repens L.)* was abundant in the inter-row area along with other perennial grasses, including bermudagrass *(Cynodon dactylon (L) Pers.)* and ryegrass *(Lolium perenne L.)*. In the peach orchard, presence of cockspur *(Echinochloa crus-galli (L.) Beauv., Poaceae)*, plant that can grow up to 1 m tall), was abundant in June and July, especially under herbicide and integrated tillage plots.

**Table 2.** Weed species identified in the orchards over 2 years (2018-2019)

| | Apple | | | | | | Peach | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2018 | | | 2019 | | | 2018 | | | 2019 | | |
| **Species** | **H** | **IT** | **IM** | **H** | **IT** | **IM** | **H** | **IT** | **IM** | **H** | **IT** | **IM** |
| **Annuals** | | | | | | | | | | | | |
| *Amaranthus retroflexus* L. | | | | | | | x | x | x | | x | x |
| *Anagallis arvensis* L. | x | x | x | | | x | x | x | x | | | |
| *Anthriscus cerefolium* (L.) Hoffm. | | | | x | | | | | | | | |
| *Avena sativa* L. | | | | | | | x | x | x | | | x |
| *Cardamine hirsuta* L. | x | x | x | x | x | x | x | x | x | x | x | x |
| *Conyza canadensis* (L.) Cronq. | | x | | x | | | | | | | | x |
| *Digitaria sanguinalis* (L.) Scop. | x | x | x | x | x | x | x | x | x | x | x | x |
| *Diplotaxis erucoides* (L.) DC. | x | | | | | | | | | | | |
| *Echinochloa crus-galli* (L.) Beauv. | x | x | x | x | x | x | | x | x | x | x | x |
| *Fumaria officinalis* L. | x | x | x | x | x | x | x | x | x | | | |
| *Geranium pusillum* L. | | | | x | | | | | | | | |
| *Lamium purpureum* L. | | x | x | | x | x | x | x | x | x | x | x |
| *Lolium multiflorum* Lam. | | x | x | | | | x | x | x | | x | |
| *Matricaria chamomilla* L. | | | | | | | x | x | x | | x | x |
| *Mercurialis annua* L. | | | | | | | | | x | | | |
| *Oxalis corniculata* L. | | | | | | x | | | | | | |
| *Papaver rhoeas* L. | x | | x | | | | x | x | x | | | |
| *Picris echioides* L. | x | x | x | x | x | x | x | x | x | x | | x |
| *Poa annua* L. | | | | | x | x | x | x | x | x | x | x |
| *Polygonum aviculare* L. | x | x | x | x | x | x | | x | x | x | x | x |
| *Portulaca grandiflora* Hooker | x | x | x | x | x | x | x | x | x | x | x | x |
| *Ranunculus arvensis* L. | | | x | | | | | | | | | x |
| *Scandix cerefolium* L. | | x | x | x | | | | | | | | |
| *Senecio vulgaris* L. | x | x | x | x | x | x | x | x | x | x | x | x |
| *Setaria glauca* (L.) Beauv. | | | x | | x | x | | x | x | | x | x |
| *Setaria viridis* (L.) Beauv. | x | x | x | x | x | x | x | x | x | | | |
| *Solanum nigrum* L. | | | | | | | x | | | x | x | |
| *Sonchus oleraceus* L. | x | x | x | x | x | x | x | x | x | x | x | x |
| *Stellaria media* (L.) Vill. | | | x | x | x | | x | x | x | x | | x |
| *Veronica persica* Poiret | x | x | x | x | x | x | x | x | x | x | x | x |
| **Perennials** | | | | | | | | | | | | |
| *Calystegia sepium* (L.) R.Br. | | | x | | x | | | | x | x | x | x |
| *Capsella bursa pastoris* (L.) Medicus | x | | | x | x | x | x | x | x | x | x | x |
| *Hyoseris radiata* L. | | | x | | x | | | | | | | |
| *Lolium perenne* L. | | | | x | x | x | | | | | x | x |
| *Malva sylvestris* L. | | | | | | | | x | x | | | x |
| *Plantago lanceolata* L. | | | | | | | x | x | x | | | x |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Plantago major L.* | x | x | x | x | x | x | x | x | x | | x | x |
| *Poa trivialis L.* | | | x | | | | | | | | | |
| *Potentilla reptans L.* | | x | x | x | x | x | x | x | x | x | x | x |
| *Ranunculus ssp.* | | x | | | x | | | | | | | |
| *Rumex obtusifolius L.* | | x | x | | x | x | x | x | x | | x | |
| *Taraxacum officinale Weber* | x | x | x | x | x | x | x | x | x | x | x | x |
| *Trifolium repens L.* | | x | x | x | x | x | | | | | x | x |
| *Urtica dioica L.* | | | | | | | | | | | x | x |
| **Geophytes** | | | | | | | | | | | | |
| *Cirsium arvense (L.) Scop.* | x | x | x | x | x | x | x | x | x | x | x | x |
| *Convolvulus arvensis L.* | x | x | x | x | x | x | | x | x | x | x | x |
| *Cynodon dactylon (L.) Pers.* | x | x | x | | x | x | x | x | x | x | x | x |
| *Sorghum halepense (L.) Pers.* | | | | | | | x | x | x | | | |

Abbreviations–Herbicide (H); Integrated Tillage (IT); Integrated Mowing (IM).

The orchard floor management practices had a strong impact on the number of plant species present in the tree row, which was consistent both in the apple and peach orchards (Figure 2). Over the two years of experiment, the plots managed with integrated practices showed a higher number of plant species compared to plots that were treated with herbicide, whereas integrated mowing demonstrated a greater species number followed by integrated tillage in both sites.

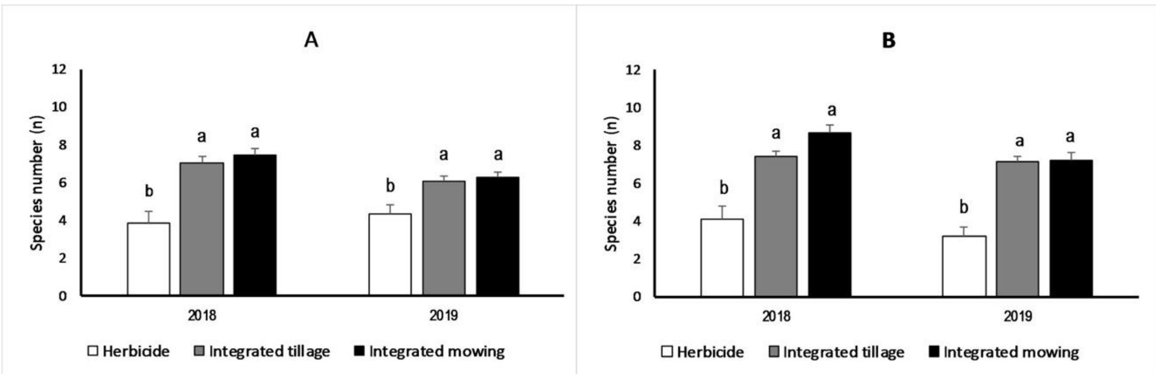


**Figure 2.** Effect of integrated orchard floor management on species number (n) in apple **(A)** and peach **(B)** orchards. Columns with the same letter are not significantly different ($p \leq 0.05$).

Likewise, the percentage of soil coverage with spontaneous vegetation was affected significantly by different tree row management strategies (Figure 3). Integrated mowing and integrated tillage treatments demonstrated approximately 85% to 90% soil coverage, compared to standard herbicide system (around 45% to 50%), at both apple and peach.

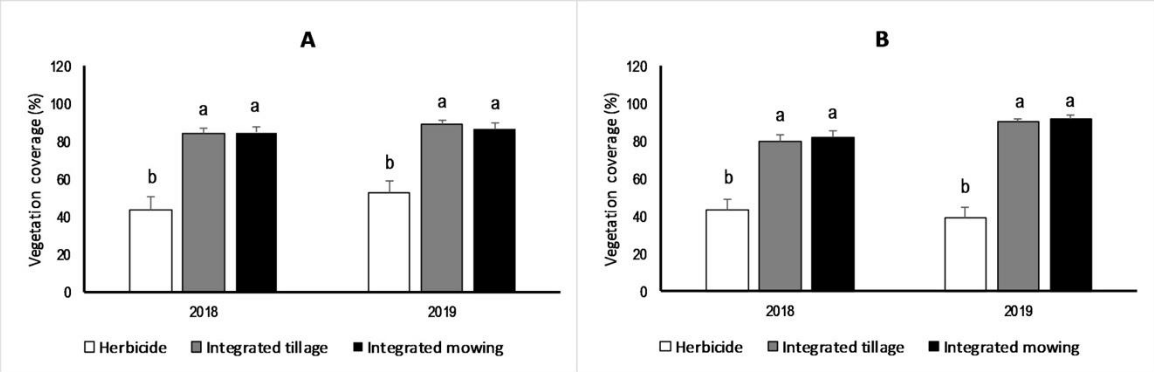


**Figure 3**. Effect of integrated orchard floor management on vegetation coverage (%) in apple **(A)** and peach **(B)** orchards. Columns with the same letter are not significantly different (p≤0.05).

The above-ground dry weed biomass production was heavier in the plots managed by integrated approaches than those in the herbicide system (Figure 4). In 2018, daily dry weed biomass production during the summer season varied significantly among the treatments in the apple orchard in 2018 ($p$= 0.0026) and peach in 2019 ($p$= 0.0167), while statistically insignificant results were obtained from the remaining year in both sites. Even though integrated methods yielded higher dry weed biomass production in both apple and peach fields relative to the herbicide treatment, these did not indicate any significant difference between them.

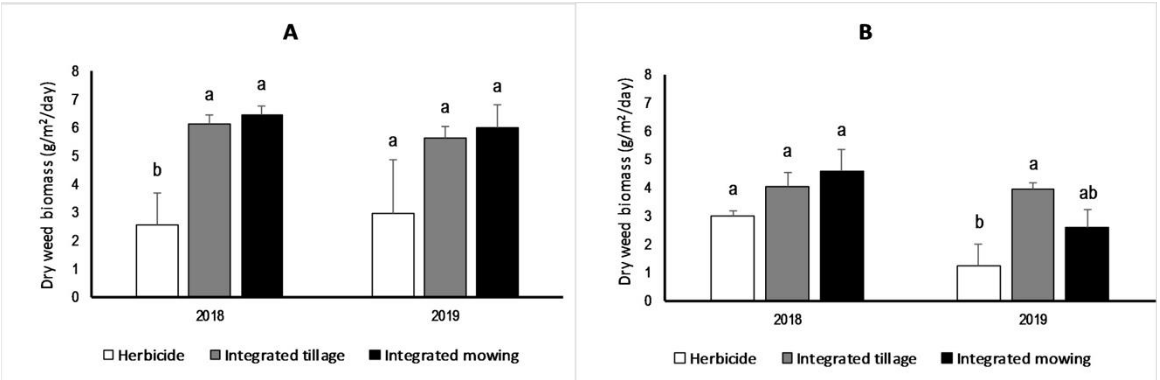


**Figure 4.** Effect of integrated orchard floor management on dry weed biomass production (g/m²/day) in apple **(A)** and peach **(B)** orchards. Columns with the same letter are not significantly different (p≤0.05). Bars represent standard error

*3.2. Tree growth, fruit yield and quality*

There were no significant treatment effects on tree growth, as measured by percent increase in trunk sectional area (TCSA) at either orchard. The apple trees showed highest tree growth increment (46%) in the herbicide plots and lower in integrated mowing plots (38%). Similar tree growth (45%) was measured under all the treatments at the peach orchard, too (Table 3).

The average apple yield did not differ significantly among treatments (Table 3). In the first year, slightly higher apple yield were obtained from the herbicide plot (6 kg/plant), followed by integrated tillage (5.7 kg/plant) and integrated mowing (5.4 kg/plant). The next year, integrated tillage showed higher fruit yield when this was compared to other treatments. This indicates that the average apple yield was comparable among the treatments in both years. In peaches, there was no significant treatment effect on fruit yield. In 2018, the herbicide plot obtained better yield (28.5 kg/plant) than integrated tillage (25.8 kg/plant) and integrated mowing plots (23.1 kg/plant), whereas all the treatment showed an increase in fruit yield in 2019.

Tree row management practices showed a significant impact on fruit firmness (*p*=0.02), and individual fruit weight (*p*=0.02) of apple in 2018 (Table 3 and 4), whereas fruit firmness was higher in integrated mowing and lower in herbicide. However, apples harvested from the herbicide plot had higher individual fruit weight compared to others. In 2019, apple fruit firmness was comparable among the treatments and was lower under all the treatments than the first- year. There were no significant differences recorded among the treatments for SSC, although fruit from integrated mowing plot showed higher SSC levels at harvest in both cropping seasons. Fruit dry matter content (2019) showed no treatment effect for apple. Among the peach quality parameters, a statistically significant treatment effect was found for SSC (*p*=0.014) and fruit dry matter content (*p*=0.007) in 2019, where integrated mowing resulted in more SSC and fruit dry matter than other treatments (Table 4). Peach firmness and individual fruit weight were comparable among the treatments, even though integrated tillage yielded the highest value for both variables.

**Table 3**. Impact of integrated weed control methods on tree growth and fruit production in the apple and peach orchard.

| Treatments | TCSA -2 years (% Change) | Individual fruit weight (g) | | Fruit yield (kg/plant) | |
|---|---|---|---|---|---|
| | | 2018 | 2019 | 2018 | 2019 |
| | **Apple** | | | | |
| Herbicide | 45.6 ± 4.6 | 222.8 ± 3.24 a | 214.1 ± 5.42 | 6.1± 0.40 | 6.9 ±1.02 |
| Integrated tillage | 45.1 ± 7.44 | 210.6 ± 4.09 ab | 205.6 ± 3.97 | 5.7± 0.53 | 7.1 ± 0.70 |
| Integrated mowing | 45.3 ± 4.08 | 200.2 ± 4.61 b | 212.8 ± 4.66 | 5.4 ± 0.40 | 5.7 ± 0.98 |
| p-value | 0.998 | 0.0007 | 0.3929 | 0.614 | 0.497 |
| | **Peach** | | | | |
| Herbicide | 45.6 ± 5.75 | 252.6 ± 4.31 | 238.1 ± 3.90 | 28.4 ± 1.47 | 30.9 ±1.50 |
| Integrated tillage | 45.1 ± 5.73 | 256.3 ± 5.1 | 251.0 ± 5.31 | 25.8 ± 1.49 | 29.4 ± 1.05 |
| Integrated mowing | 45.3 ± 6.70 | 250.8 ± 5.07 | 237.2 ± 4.14 | 23.1 ± 1.75 | 27.1 ± 1.98 |
| p-value | 0.998 | 0.7144 | 0.0548 | 0.076 | 0.241 |

Data are expressed as mean ± standard error of the mean. Means with the same letter in a column are not significantly different at p≤0.05 (Tukey-Kramer HSD test)

**Table 4.** Impact of integrated weed control methods on fruit quality variables in the apple and peach orchard

| Treatments | Fruit firmness (kg/cm²) | | SSC (°Brix) | | Fruit dry matter (%) |
|---|---|---|---|---|---|
| | 2018 | 2019 | 2018 | 2019 | 2019 |
| | **Apple** | | | | |
| Herbicide | 10.0 ± 0.09 b | 9.1 ± 0.09 | 13.8 ± 0.23 | 13.8 ± 0.13 | 15.4 ± 0.15 |
| Integrated tillage | 10.1 ± 0.16 ab | 9.4 ± 0.13 | 13.9 ± 0.21 | 13.7 ± 0.15 | 15.3 ± 0.21 |
| Integrated mowing | 10.6 ± 0.14 a | 9.5 ± 0.16 | 14.0 ± 0.21 | 14.0 ± 0.13 | 15.7 ± 0.26 |
| p-value | 0.018 | 0.143 | 0.803 | 0.152 | 0.455 |

| | | | | | |
|---|---|---|---|---|---|
| | **Peach** | | | | |
| Herbicide | 5.3 ± 0.13 | 5.4 ± 0.1 | 13.6 ± 0.25 | 13.1 ± 0.2 b | 13.7 ± 0.22 b |
| Integrated tillage | 5.5 ± 0.11 | 5.4 ± 0.1 | 13.4 ± 0.20 | 13.7 ± 0.15 ab | 14.5 ± 0.19 a |
| Integrated mowing | 5.3 ± 0.13 | 5.2 ± 0.1 | 13.9 ± 0.33 | 13.9 ± 0.22 a | 14.6 ± 0.27 a |
| p-value | 0.516 | 0.210 | 0.40 | 0.0146 | 0.007 |

Data are expressed as mean ± standard error of the mean. Means with the same letter in a column are not significantly different at $p \leq 0.05$ (Tukey-Kramer HSD test)

### *3.3. Gas exchange*

Gas exchange data in both orchards did not significantly differ among the treatments. Intercellular CO2 concentration (Ci), transpiration (E), stomatal conductance (gs), and net photosynthetic rate (A) were statistically similar among all treatments (Figure 5). The results showed that maintaining a weed free strip in the herbicide plot did not induce any physiological improvement of trees compared to alternative plots, under the same supplied cultural inputs.

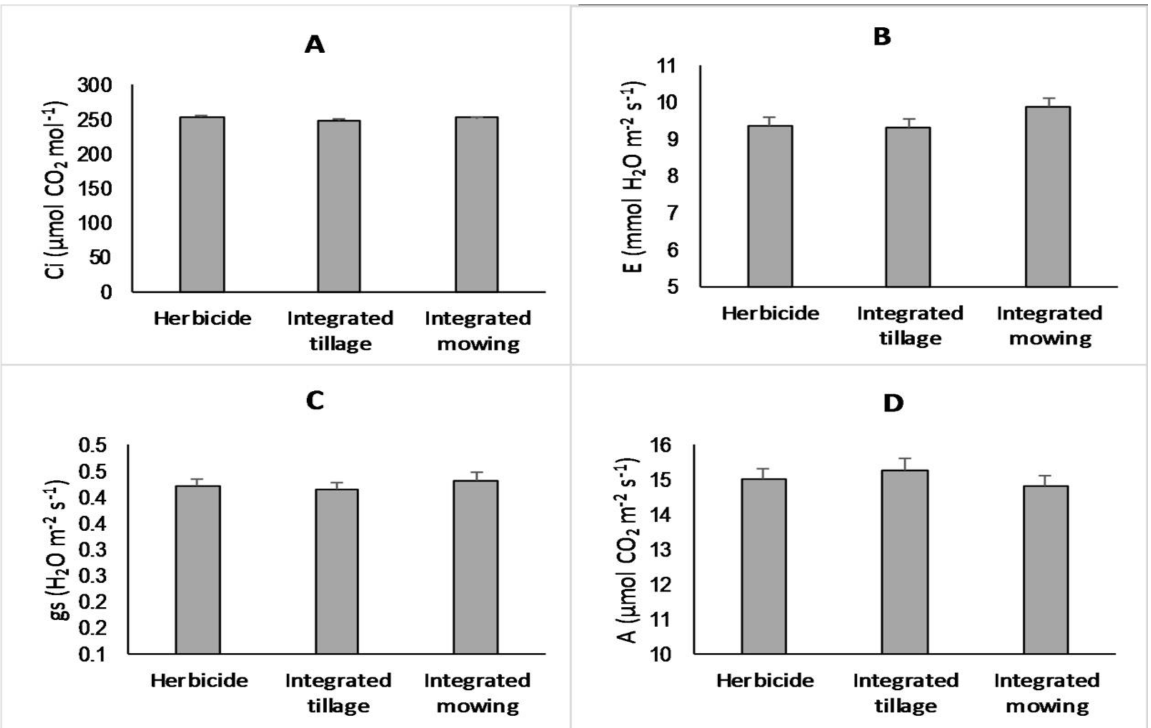


**Figure 5**. Effect of integrated orchard floor management on different gas exchanges : **(A)** intercellular CO2 concentration (Ci), **(B)** transpiration rate (E), **(C)** stomatal conductance (gs), and **(D)** net photosynthetic rate (A) in leaves of apple and peach trees. Bars represent standard error.

## 4. Discussion

This research demonstrated that sustainable integrated weed management practices along the tree row enhanced understory species abundance, vegetation density and dry weed biomass , which led to an improvement of orchard biodiversity, in comparison with the conventional herbicide application. This is presumably due to the maintenance of spontaneous vegetation in both alternative plots, which was mowed frequently, with integrated mowing system. In this system, two advanced types of equipment, a rotary brush weeder and a mower, were used simultaneously. A rotary brush weeder helps to bend down the weeds near the tree trunk without causing any trunk damage, while the mower can cut and chop weeds above the soil surface, without disturbing the soil. The chopped weed plant materials served as mulch in the tree rows. In the integrated tillage systems, the first application was conducted with a horizontal blade weeder, which is a shallow tillage implement (3 cm to 4 cm tillage depth), followed by integrated mowing system for the rest of the season. On the contrary, chemical herbicide maintained bare soil in the tree row, resulting in a lower number of spontaneous species, less percentage of soil coverage and reduced weed biomass. While integrated weed management treatments established a substantial number of species with a more significant percentage of soil coverage, approximately two times higher than the herbicide treatment. The daily dry weed biomass during the summer season of each year was higher in the integrated treatment plots than those that were treated with herbicides. More weed biomass in the integrated plots signify their vital role in soil physical and chemical quality improvement [26]. In this study, a similar impact of two integrated practices was observed on overall orchard biodiversity improvement.

Integrated orchard management techniques at the ground level did not impair tree growth, even though herbicide showed slightly better tree development in apple. The divergence was limited among the treatments, which could be the reason for maintaining partial bare ground in the herbicide plot, as this management system offers less competition between herbaceous vegetation and fruit trees. Peach trees in integrated plots reported similar growth increments as trees as in the herbicide plot. However, annual fruit yield was not affected by different ground management systems. All the treatments showed an increased apple yield in the second year, with an increase of 13.8% in herbicide, 24.5% in integrated tillage, and 5.2% in integrated mowing. Integrated tillage demonstrated higher fruit yields in comparison with herbicide treatment. Similarly, there was an increased fruit yield at the peach orchard in 2019. The rates of peach production improvement were higher in the integrated mowing (17.6%), followed by integrated tillage (14.0%), while it was lower in herbicide (8.8%). This rise in fruit yield correlated directly with less weed tree competition [27]. Also, it is worth noting that weed tree competition was under control in both orchards due to the consideration of different numbers of weeding interventions, based on the weather conditions and rain distribution during the summer season (Figure 1). These circumstances resulted in limiting the competition between weeds and fruit trees. In the second year, we had more rain, which accelerated weeds growth. As a result, two additional weeding interventions were done in the second year. Hence, sustainable alternative approaches did not have a negative impact on fruit production. In fact, there was a tendency of fruit yield increment in the integrated treatment plots. In this study, different ground management techniques affected apple and peach quality attributes to some extent. Despite the individual fruit weight in apple, integrated mowing and integrated tillage fruits were firmer compared to the herbicide, which can play an important shift towards sustainability, by increasing consumer preferences in the marketplace [28,29]. In the peach orchard, no fruit quality attributes varied significantly, among the management systems except fruit dry matter content. The integrated tillage alongside with herbicide exhibited a higher value of peach firmness than integrated mowing. Even though differences were comparable among the treatments. However, sweeter apple and peach fruit with more dry matter content were harvested from integrated mowing plots. The overall results of this experiment illustrated a positive intent towards apple and peach quality improvement under both integrated approaches. Moreover, they had no negative impact on gas exchange parameters, which proved trees ability to maintain similar physiological function, as the trees do under chemical herbicide system.

## 5. Conclusions

The worldwide eco-friendly guidelines, especially in the European Union, raise the popularity of embracing more sustainable orchard floor management practices. It is a challenge for researchers to find proper alternatives to chemical herbicide. This study supported that either integrated mowing and integrated tillage performed as viable alternatives to herbicide, without impairing tree growth, fruit yield, quality, and photosynthetic performances of trees. Additionally, they demonstrated a significant increase in plant diversity, ground coverage rate and weed biomass productions. Those are the pivotal goals in achieving orchard biodiversity, improving soil quality, and eventually lead towards long-term sustainability. In sum, as an alternative to chemical herbicide (twice a year), integrated mechanical strategies with blade tillage (once a year) followed by the repeated constraints with brush and disk mower (5–7 times) depending on the orchard stage and environmental conditions, can be a more sustainable solution for intra-row management in the high-density fruit orchards of central Italy.

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