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REVIEW

Ecosystem services of organic versus inorganic ground cover in peach orchards: A meta-analysis

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Abstract

Several organic (e.g., compost, hay, straw, grass) and inorganic (e.g., plastic film) ground cover (GC) forms are used in peach orchards worldwide. Yet, there is a lack of quantitative studies on peach orchard ecosystem services comprising fruit yields and quality, soil health indicators, and biological pest control. To fill this knowledge gap, we performed a meta-analysis of 55 peer-reviewed research. Overall, inorganic GC increased peach yields by 7.7 ± 1.8%, while organic GC reduced it, though not statistically significant ($p > 0.05$), by 1.7 ± 3%. Both forms of GC have enhanced single fruit mass, with a greater increase in inorganic (4.2 ± 1.7%) than in organic GC (1.2 ± 1.2%), and soluble solids content by 5.9 ± 0.9% and 3.2 ± 0.7%, respectively. Inorganic GC did not significantly affect titratable acid and fruit hardness, while organic GC reduced titratable acid (13.7 ± 2.1%), and fruit hardness (89 ± 2.9%). Soil temperature has increased in orchards with inorganic GC (2.8 ± 2.9%) and reduced with organic GC (8.3 ± 2.4%). Inorganic GC marginally increased soil water storage, while organic GC increased it by 9.3 ± 2.1%. Both organic and inorganic GC increased soil water content by 13.1 ± 2.4% and 26.1 ± 3.4%, respectively. Unlike inorganic GC, organic GC increased soil organic matter, available nitrogen, available phosphorus, and available potassium by 28.3 ± 3.3%, 25.1 ± 2.7%, 23.5 ± 4.6%, and 30.9 ± 3.3%, respectively. Equally significantly, organic GC increased predator abundance (47.5 ± 5.9%) and reduced pest incidence (2.4 ± 1.8%). Overall, inorganic GC systems slightly increased peach yield but are not sustainable due to their negative soil health and environmental impacts. In contrast, organic GC systems delivered an acceptable yield level while providing numerous ecosystem services, enabling sustainable long-term peach production.

KEYWORDS
ground cover, nutrient cycling, peach, pest abundance, soluble solids content, yield

1 | INTRODUCTION

In recent decades, agrobiodiversity has been threatened by various factors, including industrial agriculture, urbanization, and climate change. As a result, many ecosystem services linked with agrobiodiversity have deteriorated, negatively impacting human well-being and agricultural system sustainability (Landis et al., 2000; Tscharntke et al., 2005). For example, agricultural intensification in monoculture cropping systems has been associated with excessive use of agrochemicals, which has resulted in problems such as loss of agrobiodiversity, a decline in natural pest control, and environmental pollution (Batáry et al., 2017; Gagic et al., 2012). To this end, there is growing interest in promoting agrobiodiversity to improve ecosystem services and agricultural system sustainability. This has resulted in the adoption of ecological intensification practices like agroforestry, conservation agriculture, crop rotations, intercropping, trap crops, ground cover (GC), etc., all of which aim to enhance agrobiodiversity to provide numerous ecosystem services (Bowles et al., 2017; Harvey et al., 2014; Wan, Ji, et al., 2019). Several research on these approaches have proven that they increase multiple ecosystem services in various ways. Diverse cropping strategies such as crop rotation and intercropping, for example, have been shown to boost crop yield and land use efficiency (Mudare et al., 2022; Zhao et al., 2022). Meanwhile, trap cropping has been found to provide a natural habitat for predators, lowering pest outbreaks while enhancing arthropod community variety and stability (Wan, Ji, Gu, et al., 2014).

The selection of GC in managed agroecosystems significantly impacts the quantity and quality of agricultural ecosystem services, especially in orchards (Swinton et al., 2007). The peach (*Prunus persica*) fruit production industry contributes largely to agriculture development, rural economic growth, and poverty reduction worldwide (Guo et al., 2018; Reeve et al., 2017). Peach production can provide various agroecosystem services, which are broadly classified as provisioning, supporting, and regulatory services (Millenium Ecosystem Assessment, 2005; Zhang et al., 2007). Peach orchard provisioning services include peach fruits as a source of food and nutrients (Corollaro et al., 2015). In addition to food provision, peach orchards provide regulating services (water regulation, pest regulation, weed suppression, etc.) and supporting services such as soil nutrient cycling (Gordon et al., 2010). However, the type and extent of these ecosystem services depend on orchard management practices, which ultimately affect soil nutrient supply, water use efficiency, soil stability, and general agrobiodiversity (Montanaro et al., 2017; Robertson et al., 2007). Ground cover as a management practice in peach orchards can result in trade-offs between food and nutrient provision and other ecosystem services and disservices (Power, 2010). As such, a desirable outcome would be having a sustainable GC strategy with increased ecosystem services and reduced disservices, or at least increasing other services without compromising provisioning services.

Italy, the United States, Greece, Spain, France, and Russia are the world's largest producers of peaches (Gupta et al., 2016). North America produced the highest peach yield (20.1 t/ha) in 2020, followed by Asia, Europe, South America, Africa, and Oceania with 19, 17.9, 15.7, 14.5, and 7.4 t/ha, respectively (FAOSTAT, 2022). However, intensive peach production systems under conventional soil management are an important source of greenhouse gas emissions and their carbon footprints are high across major peach-producing regions (Michos et al., 2012). Therefore, there is an urgent need to improve or even replace these practices with more environmentally sustainable systems. The use of an appropriate GC represents one of the sustainable orchard management practices that can play an important role in mitigating greenhouse gas emissions and environmental pollution (Gao et al., 2019). Ground cover can be of organic (composts, hay, straw, grasses, etc.) or inorganic forms (e.g., plastic film mulch) (Forge et al., 2003). The inorganic form of GC includes white transparent film, black plastic film, biodegradable plastic film, and water-permeable plastic film (Li et al., 2012). Organic forms of GC reduce soil temperature fluctuations (Nagy et al., 2013) while increasing soil total nitrogen, microbial biomass, and soil available nitrogen (Nikiema et al., 2012). The use of organic GC, in combination with other orchard management practices, reduces pest pressure in peach orchards thereby reducing reliance on conventional pesticides while increasing fruit size, yield, and quality (Bussi et al., 2016; Johnson et al., 2002). In contrast to the benefits of organic GC, mostly related to soil health indicators, inorganic GC such as plastic film mulch in fruit orchards have been reported to increase fruit quality parameters (e.g., soluble solid content, better fruit color, early ripening) (Layne et al., 2001; Meinhold et al., 2010), especially with the use of reflective film mulch (Funke & Blanke, 2004).

In recent years, plastic film for mulching has been increasingly used worldwide, given its direct reported impact on fruit yield and quality parameters. India has the most mismanaged plastic waste (12.99 million tons per year), followed by China (12.27 million tons per year), while Brazil, the Democratic Republic of the Congo, and Egypt have about 1.4 million tons per year (Our World in Data, 2022). China alone consumes 60% of the world share of agricultural plastic film (Yang et al., 2015), which has resulted in a heightened level of "white pollution" (Liu, He, & Yan, 2014), including deterioration of soil physical properties as well as reduction of water and fertilizer use efficiency (Li et al., 2004). The persistent use of plastic mulch has been linked to significant changes in soil chemical properties, such as lowering soil pH (Dale & Polasky, 2007) and adverse human health effects (Halden, 2010). It has recently been estimated that without control measures, the concentration of microplastics in agricultural soils in Germany will more than triple the current 30 mg/kg dry weight in at least 2% of the agricultural areas used (Henseler et al., 2022). China's national film residue standard is 75 kg ha^{-1} with in some areas reaching very high levels (e.g., Xinjiang with a maximum residue amount of 502 kg ha^{-1}), which is not environmentally sustainable. Each hour, in crop fields in the same region, approximately 50–269 kg of residual plastic film accumulates per square meter in the topsoil (Liu, Wang, et al., 2014; Zhang et al., 2016). Studies from mulched fields in India have reported that plastic mulch residues in the form of films, fiber, and microplastic occupied the top 30 cm of the soil profile (Kumar & Sheela, 2021). Meta-analysis has shown that agricultural productivity is dramatically reduced in soils with plastic residues larger than 240 kg ha^{-1} (Gao et al., 2019). Therefore, there is a need for organic forms of GC as alternatives to plastic film mulching. Understanding how organic and inorganic GC management drives agroecosystem services, such as in peach orchards, is critical in determining the best sustainable option based on relative economic and environmental merits.

Quantitative synthesis of global data across agroecosystems, forests, marine, grasslands, and wetlands has proven that plant genetic diversity influences plant performance by lowering pressure from antagonists across trophic levels of different plants (Wan, Cavalieri, et al., 2022). Similarly, meta-analysis studies have indicated that the abundance of plant species promotes pest regulatory services by enhancing predator and parasitoid abundance, predation, and parasitism (Wan et al., 2021). Field studies in orchard management revealed that organic GC boosted fruit yield by 10% while decreasing pesticide use by 51% (Ji et al., 2022). In addition, using border crops in urban agriculture has shown that insecticide use reduced while crop yields increased (Wan, Cai, et al., 2018). Another study in peach orchards found that ecological engineering of ground cover by *T. repens* promoted biocontrol services in peach orchards when compared to bare orchards (Wan, Ji, & Jiang, 2014). Pest populations in peach orchard ecosystems were reduced in similar research employing sunflower and maize as trap crops (Wan et al., 2016). Although several meta-analysis studies have demonstrated that plant diversity enhances pest regulatory services, it remains unknown to what extent GC promotes biocontrol services as well as other ecosystem services in peach orchards.

The results of individual field experiments on ecosystem services and the mitigation of the disservices driven by organic and inorganic forms of GC in peach orchards are often contradictory. This is probably due to environmental conditions and orchard management practices that differ greatly worldwide. Furthermore, short-term studies may not provide a clear picture of changes in agroecosystem support services such as soil nutrients, especially since soil carbon requires at least 8–10 years to detect meaningful changes (Birkhofer et al., 2015). Therefore, more research is needed to determine whether organic GC has the potential to drive levels of ecosystem services comparable to or greater than inorganic GC forms in a wide range of environmental conditions and orchard management practices. Quantifying ecosystem services provided by agroecosystems such as peach orchards is critical in policymaking and management (Dale & Polasky, 2007). To fill this knowledge gap, here we used a meta-analytical approach to quantify and synthesize results from individual studies as this approach allows us to elicit an overall pattern at global, or regional scales (Hedges et al., 1999). We hypothesized that (1) organic GC might promote comparable or higher levels of peach fruit yield and quality than inorganic GC (i.e., provisioning services); (2) organic GC has the potential to improve soil physical characteristics and nutrient cycling (i.e., supporting services), lowering the requirement for less sustainable GC techniques; and (3) organic GC enhances agrobiodiversity by regulating soil water, soil temperature, and insect biocontrol (i.e., regulatory services) at a similar or higher level than inorganic GC. This study has important implications for fostering agrobiodiversity not only in peach orchards, but all orchard management and diverse agroecosystems.

2 | MATERIALS AND METHODS

2.1 | Data collection

An extensive literature search was conducted to collect relevant information from two databases, Web of Science (WOS) and China National Knowledge Infrastructure (CNKI) published until 2021. In the Web of Science in the topic field, we used various combinations of keywords such as “peach” AND “mulch*”; “peach” AND “grass cover*”; “peach AND “ground cover*” and finally “peach” AND “groundcover*”. The combinations resulted in a total of 387 articles published in English for further screening. We excluded many articles on different GC forms in peach orchards published in other languages around the world by selecting only WOS articles published in English. In order to carry out the search procedure in the CNKI database, we translated the keywords used in the WOS. In the CNKI database, we searched for a combination of keywords “覆盖” OR “覆膜” OR “覆秸秆” OR “生草” AND “桃”. The search produced 81 articles, which were then screened. We excluded 231 articles from both English and Chinese publications that did not address GC in peach orchards, including press articles, conference papers, reviews, and meta-analyses. To be eligible for selection, an article had to meet the following criteria: (i) The experiment had to be conducted in a field or orchard rather than a greenhouse or pot experiment. (ii) The study reported data on both the control (bare ground, tilled ground, or herbicide-controlled mulch) and the treatment, which included any type of GC such as plastic film mulch (all colors), biodegradable film, straw mulch, natural or planted grass or residues. The residues included sawdust, pine bark, manure, or small rotten branches. (iii) The experiment included replications. (iv) An article was chosen that described field trials on GC effects in peach orchards and the effects on soil physical, chemical, and biological properties, as well as fruit yield quantity and quality indices.

Finally, we chose 55 peer-reviewed articles that met the selection criteria, including 22 in Chinese and 33 in English publications. Multiple data records were extracted from multiple experiments in each study and multiple treatments in each experiment. This study used 177 observations on peach yield, 133 on peach quality, and 449 on soil physiochemical properties. When data were presented in the form of tables, we extracted the data directly for each observation consisting of paired data on the mean of treatment and control under the same site and year. Most studies did not include a measure of error (standard deviation, standard error, etc.). Limiting our dataset to studies that provided a measure of error would drastically limit the number of publications and may impact the results. Data presented in form of figures were extracted using WebPlot Digitizer (Version 4.3). Most studies were published in Asia, with China dominating followed by the United States of America, with only one study reported from Africa and another from Australia (Methods A-B, Figure S1). Even though the selected papers report on a variety of response variables, we recognize their limitations in the absence of sufficient information on important explanatory variables. For example, the effect of climate and anthropogenic factors, such as fertilizer input, pruning, and bagging, on the selected response variables was significantly small to estimate due to the small sample sizes. Understanding how these components interact and ranking their importance is critical for orchard design and management. We found 15 studies on soil organic matter, six studies on soil total nitrogen, eight studies on available nitrogen, four studies on available phosphorus, and 10 studies on available potassium in our database. Only eight studies reported the nitrogen input rate, while six reported both the phosphorus and potassium input rates. Because these factors were not reported evenly for each response variable, conducting a robust meta-regression for all variables was impossible. Only three of the seven studies reporting on plant densities were specific to peach yield, so the combined effect of plant density and GC forms was not included in the analysis. A global map was created with QGIS (Version 3.16.1) using the experimental location information reported in the selected publications (Methods C, Figure S2).

2.2 | Response variables

We categorized the response variables into three major groups of ecosystem services, which included; (i) provisioning, (ii) supporting, and (iii) regulatory services, and used models to estimate the GC effects on these services (Table. 1). The model selection and grouping of response variables were based on the availability of data for the required variable. For the provisioning services, we studied the influence of GC on peach yield, single fruit mass, soluble solids content, titratable acid content, and fruit hardness. Some GC-supporting services were considered, either as soil formation that is, soil pH, soil organic matter, soil bulk density, etc., or nutrient cycling. The latter included soil-available nitrogen, soil-available phosphorus, and soil-available potassium. We also considered the regulatory effect of GC in three subgroups, that is, (1) water regulation, for example, soil water storage, soil water content, and water infiltration rate. (2) soil temperature regulation and finally (3) pest regulation, for example, pest abundance and predator abundance.

2.3 | Explanatory variables

These variables included two broad categories of GC practices, that is, organic and inorganic GC. Organic GC consisted of various materials such as wild grass (weeds), artificially planted grasses, and plant residues (straw, branches, and other living mulch). Inorganic GC consisted of plastic film mulch (either in black, white, or others). Various GC forms were reported on various response variables in the selected studies. As a result, the sample size required to determine an effective effect size for specific GC forms was small in some cases. Therefore, whenever possible, GC forms were classified as organic or inorganic to ensure an appropriate analysis from a sufficient sample size. The effects of the duration of the experiment and the texture of the soil on peach yield and the mass of the single fruit were investigated. Data were collected in the form of paired observations that demonstrated the effect of control and GC forms on a specific response variable. Furthermore, the data were treated separately when an article contained multiple experiments recorded in different years or locations.

TABLE 1 Specification of the mixed-effects models fitted to the data

Model	Equation	Data
1	Yield $ijk = \beta_0 + ai + bij + \varepsilon ijk$	All data on yield
2	Yield $ijk = \beta_0 + \beta_1$*Materials $i^2 + ai + bij + \varepsilon ijk$	All individual materials used as ground cover
3	(SFM, SSC, TA, hardness) $ijk = \beta_0 + \beta_1$*Ground cover$i^2 + ai + bij + \varepsilon ijk$	Only for records with full information (no missing data) quality parameters
4	(AN, AP, AK) $ijk = \beta_0 + \beta_1$*Ground cover$i^2 + ai + bij + \varepsilon ijk$	Only for records with full information (no missing data) on nutrient cycling
5	(pH, SOM, porosity, BD) $ijk = \beta_0 + \beta_1$*Ground cover$i^2 + ai + bij + \varepsilon ijk$	Only for records with full information (no missing data) in either organic or inorganic ground cover
6	(SWS, SWC, IR) $ijk = \beta_0 + \beta_1$*Ground cover$i^2 + ai + bij + \varepsilon ijk$	Only for records with full information (no missing data) soil water changes
7	(Pest, predator abundance) $ijk = \beta_0 + \beta_1$*Ground cover$i^2 + ai + bij + \varepsilon ijk$	Only for records with full information (no missing data) on pest control
8	Yield $ijk = \beta_0 + \beta_1$*Ground cover$i^2 + \beta_2$*Duration $+ ai + bij + \varepsilon ijk$	All ground cover forms and their length of experimentation

Note: The indices *i*, *j*, and *k* represent publication, experiment, treatment ID, respectively. In all mixed effect models, a*i* is a random publication effect. b*ij* is a random experiment effect nested within the i^{th} publication. a*i* and b*ij* are assumed normally distributed with constant variances. ε*ijk* is a residual error assumed normally distributed with a constant variance. The variance terms a*i*, b*ij* and ε*ijk* are all assumed independent. Superscript 2 in model 2 represent different GC materials and different GC situations in models 3–7.

Abbreviations: IR, infiltration rate; SFM, single fruit mass; SOM, soil organic matter; SSC, soluble solids content; SWC, soil water content; SWS, soil water storage; TA, titratable acids.

2.4 | Effect size

We calculated the natural logarithm of the response ratio as the effect size to quantify the influence of various forms of GC on a given variable:

$$\ln \mathrm{E} = \ln \mathrm{Xt} - \ln \mathrm{Xc}$$

where Xt and Xc are the treatment (i.e., under specific GC) and corresponding control value, respectively, for the given variable. The effect of GC in the treatment over the control was considered statistically significant ($p < 0.05$) only when the 95% confidence interval did not overlap with 0 (Hedges et al., 1999). The same concept was applied when the data were analyzed for different categories of GC (Xia et al., 2017). The response ratio was converted to a percent change (E^+) to represent the impact of different forms of GC on various response variables in order to better express the results:

$$\mathrm{E}^+ = \left(\exp^{\ln \mathrm{E}} - 1\right) \times 100$$

A positive percentage value indicates an increase in the variable due to GC, while a negative percentage represents a decrease in the value of the variable. Based on the integrity of the precision measures reported in the database, the effect size can be weighted either using the inverse of pooled variances (Yang et al., 2016) or the number of replications (Lam et al., 2012). In our analysis, the weights were calculated using the replication-based method (Lam et al., 2012):

$$\mathrm{Weight} = \frac{\mathrm{Nc} \times \mathrm{Nt}}{\mathrm{Nc} + \mathrm{Nt}}$$

where Nc and Nt represent the number of replicates in the treatment and control groups, respectively. Mean effect sizes and the 95% confidence intervals (CIs) were computed by bootstrapping procedure with 4999 iterations using MetaWin (Version 2.1) software (Rosenberg et al., 2000). To verify the robustness of the meta-analysis, we removed outlier studies and compared them with the results of the original analysis. We then plotted a funnel plot that relates the effect sizes to the sample sizes to determine any publication bias. The results from the funnel plot consisted of a few studies that resulted in a slightly asymmetrical shape, showing the presence of a slight publication bias (Figure S3) (Philibert et al., 2012).

3 | RESULTS

3.1 | Effect of groundcover systems on ecosystem services

3.1.1 | Fruit yield and quality—Provision services

Our results show that in general, yields were not significantly affected by GC. Organic GC reduced peach yields by 1.7 ± 3%. On the contrary, the inorganic system significantly increased peach yield by 7.7 ± 1.8% (Figure 1).

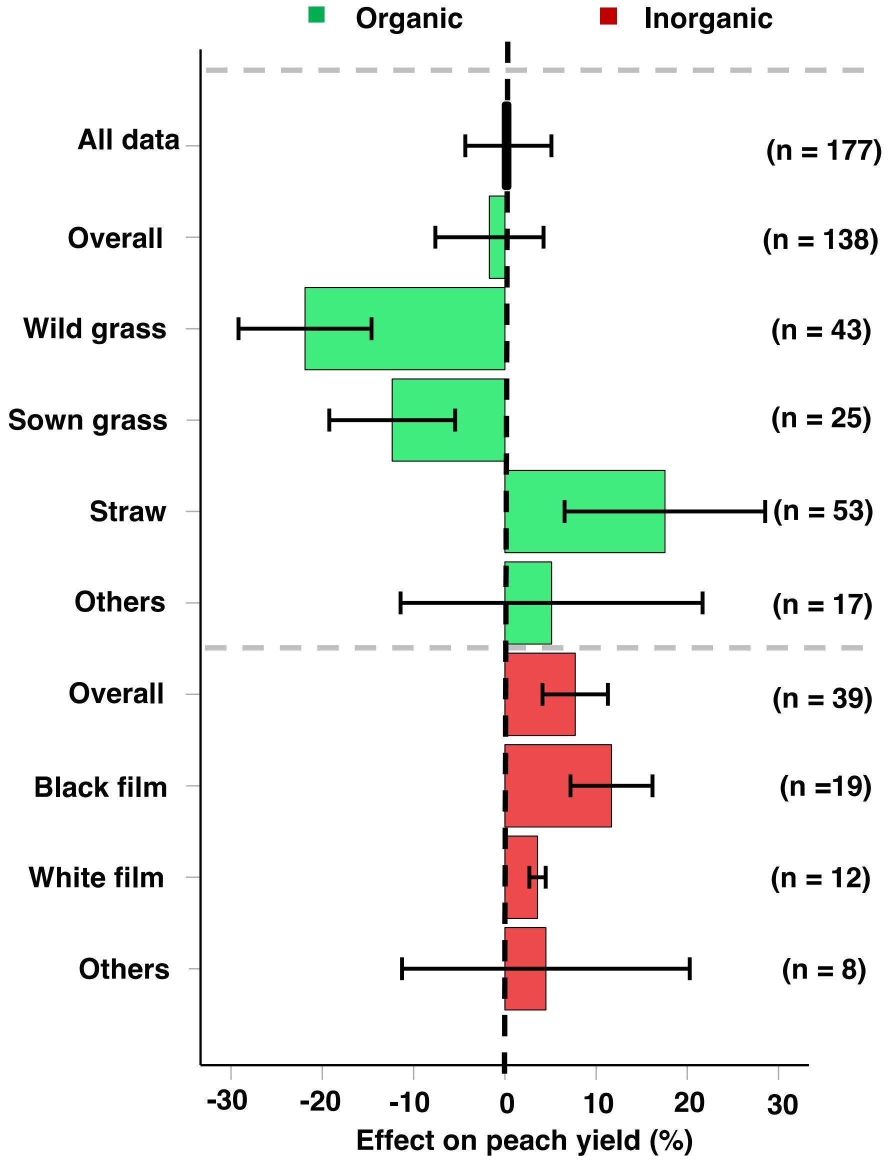

FIGURE 1 Changes in peach yield as influenced by various ground cover forms. The letter "*n*" indicates the number of data points. Horizontal lines represent error bars at a 95% confidence interval.

We observed that individually, the material used as GC affected peach yields differently. We show here that using wild grass or sown grass reduced yields by 21.9 ± 3.6% and 12.3 ± 3.3%, respectively. The best option for the organic GC material used was straw (17.6 ± 5.5%) (Figure 1). The black film mulching had the greatest effect on yield increase for all inorganic materials included in this study. Black film mulching increased yields by 11.7 ± 2.1%, whereas white film mulching increased yields by 3.6 ± 0.4% (Figure 1). Peach yields also varied depending on the duration of the experiment, the GC forms and the texture of the soil, with organic GC in sandy loam soil increasing the yields over time (Figures S3–S5).

Inorganic GC increased the average single fruit mass by 4.2 ± 1.7% compared with the organic GC (1.2 ± 1.2%, Figure 2a). The best option for organic GC material used for single fruit mass was straw with an increase of 8.6 ± 1.4%. Sown and wild grass reduced single fruit mass by 4.8 ± 3.3% and 4.9 ± 1.3%, respectively. Inorganic GC using either black or white film increased single fruit mass by 5.1 ± 3.4% and 6.4 ± 0.6%, respectively, but not significantly different from straw. Single fruit mass was also increased in loam soils with organic GC over time (Figure S3). Our results showed high levels of soluble solid content in both organic and inorganic GC, although no significant effect of inorganic GC on titratable acids was observed. Both organic GC and inorganic GC increased soluble solids content by 3.2 ± 0.7% and 5.9 ± 0.9%, respectively (Figure 2b). However, using straw (6.1 ± 0.6%) was statistically similar to white film (6.4 ± 0.6%). In addition, the black film contributed even lower (4.7 ± 1.1%) to soluble solids content. In general, organic GC reduced the titratable acid content (13.7 ± 2.1%, Figure 2c), and fruit hardness (82 ± 2.9%). Fruit hardness was 1.2 ± 0.7%

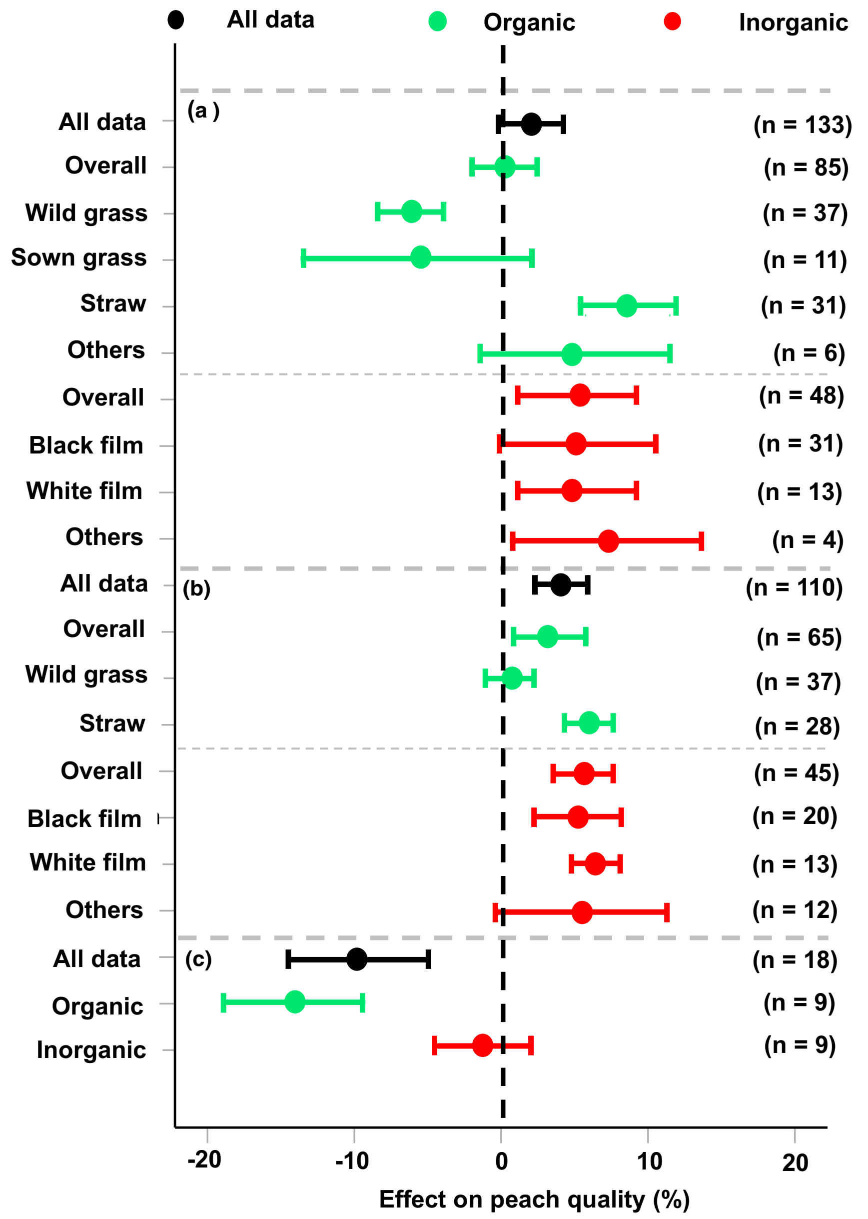

FIGURE 2 Effect of ground cover forms on single fruit mass (a), soluble solids content (b), and titratable acids (c). The letter "*n*" indicates the number of data points. Horizontal lines represent error bars at a 95% confidence interval.

under inorganic GC, although the effect was not significant (Figure S5).

3.1.2 | Physical properties of the soil—Supporting services

Organic GC significantly reduced bulk density by 5.1 ± 1.2% (Figure 3a). Overall, GC significantly increased soil porosity (Figure 3a). The highest increase in porosity was observed in organic GC (3.5 ± 1.4%) than inorganic GC (0.5 ± 0.8%). Inorganic GC increased the soil temperature (2.8 ± 2.9%), although the effect was not significant. In contrast, organic GC significantly reduced soil temperature by 8.3 ± 2.4%, (Figure 3b).

3.1.3 | Soil water, soil nutrient cycling, and pest control services

Soil water storage was not significantly affected by inorganic GC. Organic GC, however, increased soil water storage by 9.3 ± 2.1% (Figure 3b). All systems had significant positive effects on soil water content, with higher levels observed in inorganic GC (26.1 ± 3.4%) than in organic GC (13.1 ± 2.4%) (Figure 3b). We also estimated the GC effect on soil infiltration rate only using organic GC materials due to a shortage in data points for inorganic GC material. The results showed that organic GC increased the infiltration rate by 20.6 ± 6% (Figure S5), although the effect was not significant. The soil pH was not significantly affected by organic GC.

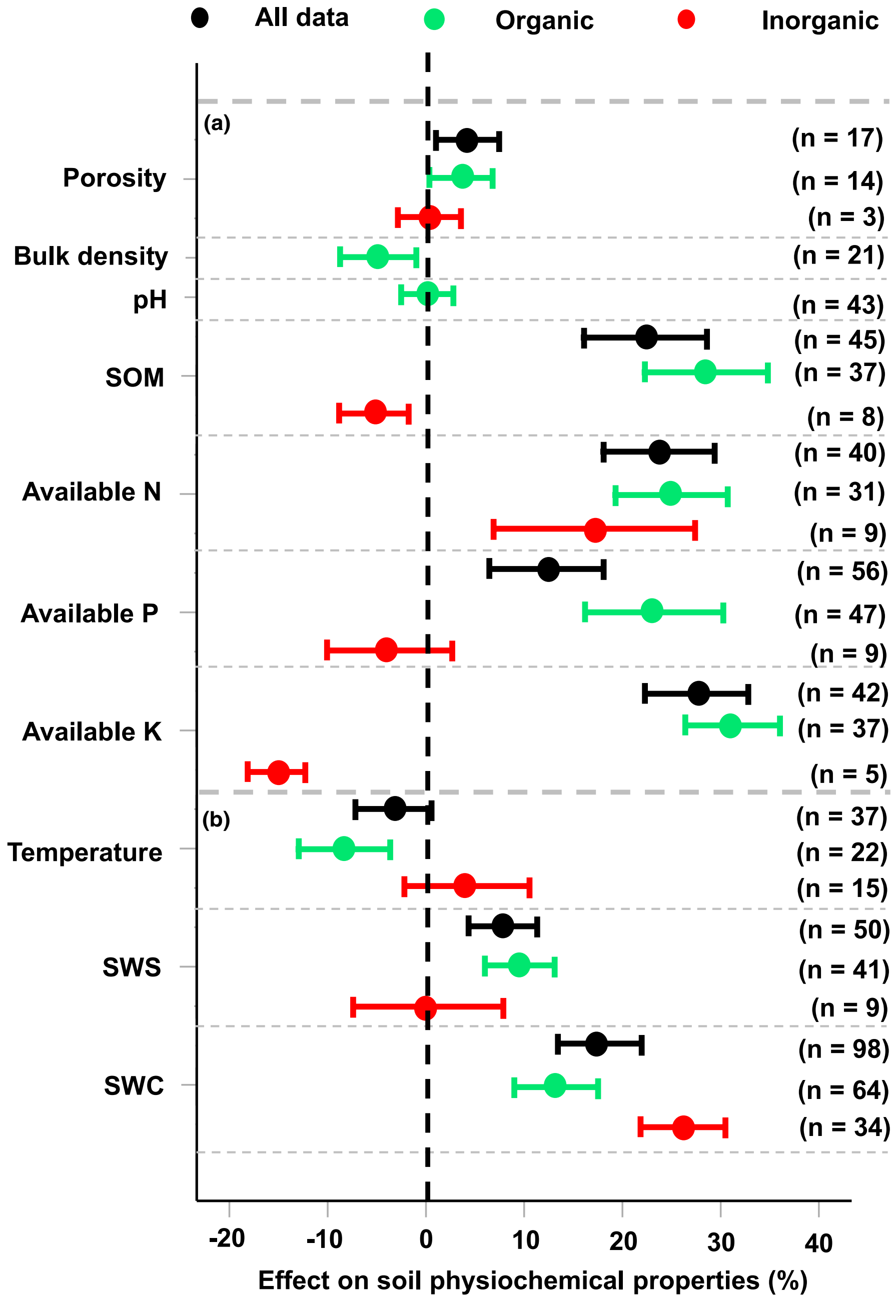

FIGURE 3 Groundcover effects on soil supporting services (a) and soil temperature and water regulation services (b). SWS, SWC and SOM represent soil water storage, soil water content, and soil organic matter, respectively. The letter "*n*" indicates the number of data points. Horizontal lines represent error bars at a 95% confidence interval.

While inorganic GC reduced SOM by 5.5 ± 1.5%, organic GC significantly increased SOM by 28.3 ± 3.3% (Figure 3a). All GC systems had a significant positive effect on soil available nitrogen (Figure 3a). The effect was much more pronounced in organic GC (25.1 ± 2.7%) than in inorganic GC (17.2 ± 5.6%). Organic GC also increased both available phosphorus and available potassium by 23.5 ± 4.6%, and 30.9 ± 3.3%, respectively. However, inorganic GC reduced available phosphorus (3.6 ± 3.6%), but not significantly, and increased available potassium (16.2 ± 1.1%). The data on GC effects on pest management were available only from the organic systems. The results showed that organic GC reduced pest abundance by 2.4 ± 1.8%, though not statistically significant, while the abundance of predators increased significantly increased by 47.5 ± 5.9% (Figure S5).

4 | DISCUSSION

4.1 | Implications of groundcover on peach orchard production services

Our results indicate that GC in peach orchards increased peach fruit yields, even though the overall effect was not statistically significant. Organic GC reduced peach yields, particularly wild grass or sown grass. The explanation could be that both wild grass and sown grass compete with peach trees for resources such as water and nutrients, decreasing peach yield (Zhang et al., 2010). Weeds that grow naturally compete for resources with peach trees, and their negative effects are magnified in drought conditions. This corroborates the results by Tu et al. (2021), who reported fruit yield reduction of ~32.2–41.7% in a long-term organic GC using full grass mulching. However, using straw increased peach yields more than wild grass and sown grass. Straw has been suggested as a viable alternative to plastic film mulching (Shah & Wu, 2020). Our results were in line with those of Wang, Wang, Zhao, Chen, and Wang (2015), who reported that GC increases single fruit mass when organic forms such as straw are used. The use of straw in orchards may affect peach yields in many ways, especially in arid conditions. First, straw mulching reduces the rate of surface runoff, thus increasing soil water infiltration which in turn ensures water availability for peach trees. Second, in cold weather, straw mulch functions as an insulator, decreasing temperature changes in the soil (Liu, Zhu, et al., 2014). Finally, straw mulching improves soil quality as nutrients are released from straw during decomposition. The decomposition of straw increases the available nitrogen, available phosphorus, and available potassium in the soil which consequently improves peach productivity (Huang et al., 2021).

Overall, inorganic GC boosted peach yield more than organic GC forms evaluated in this study. Several reports indicate the advantages of film mulching in terms of improved crop yields, especially across arid regions (Yan et al., 2014). More importantly, in our study, black film mulch had a greater effect on peach yield than white film. This could be because black film mulching enables weed suppression by smothering germinated weed seedlings and depriving them of sunlight. Second, black film mulch can raise soil temperatures to levels where disease-causing pathogens cannot survive, hence reducing the incidence of viral and bacterial diseases that would otherwise lead to flower and fruit abortion, fruit rot, and fruit drop which ultimately reduces peach yields (Campi et al., 2020; Shah & Wu, 2020). In addition, in the soil, black film increases soil temperature and water-holding capacity and decreases water loss through evapotranspiration, thus improving peach productivity. Gupta et al. (2022) discovered that black polythene mulch outperformed white polythene mulch or atrazine-controlled treatments in terms of fruit yield and volume. Despite having a lower effect than black film mulch, white film mulch was found to be more effective on peach yield than other GC forms such as wild grass or sown grass in our study. The white film, like black film, has been widely adopted by peach farmers due to its positive yield effects. White film mulching, like black film mulch, has similar mechanisms for weed and pest control and moisture conservation. According to research conducted in India, both black and white polythene mulch can produce high yields (Gupta et al., 2016). While some researchers, for example, Suo et al. (2019) found that film mulching reduced yield, and Losciale et al. (2020), observed no effect of reflective plastic film on yield, our study has shown that, in general, plastic film mulch greatly increases peach yield.

Parameters such as the content of soluble solids and titratable acids are largely related to the quality of the fruit and indicate the levels of sweetness and sourness in the fruit (Antonucci et al., 2011; Belisle et al., 2018). Gupta et al. (2022) found that in terms of soluble solids content, vitamin C, and sugars, black polythene mulch outperformed white polythene mulch or atrazine-controlled treatments. However, in this study, white film mulch outperformed black film mulch in terms of single fruit mass and soluble solids content. In general, white or reflective film has high reflectivity and also cools the tree basins, which improves fruit quality (Amare & Desta, 2021; Parshant et al., 2015). Inorganic GC with reusable reflective mulching has been reported to increase fruit size (Losciale et al., 2020). Studies have reported that reflective mulching results in higher soluble solids content, and significantly lower firmness than the control in the first season. Previously, Pande et al. (2005) discovered that apples with organic mulch had lower soluble solids content than apples with black polythene mulch. In Greece, for example, a study found that the use of reflective mulching under deficit irrigation increased peach quality, particularly the content of soluble solids (Pliakoni & Nanos, 2010). Although both wild grass and sown grass reduced single fruit mass, our study demonstrated that the use of straw can increase single fruit mass. Furthermore, it has been suggested that fruits grown under black polythene mulch have low acid levels because they are converted to sugars in this system (Gupta et al., 2022). Inorganic GC did not affect titratable acids in our study. Others have reported that total acidity in both mulched and unmulched peaches was insignificant (Andreotti et al., 2009, 2010). Similar levels of straw to both black and white film mulch on fruit quality suggest that using straw in peach orchards to improve fruit quality may be sustainable. As previously stated, notwithstanding the yield gains, plastic film still poses significant environmental concerns due to the repeated fragmentation of plastic mulch (Ramos et al., 2015).

Even though our study was not designed to investigate the levels of plastic film pollution, their presence in the soil facilitates the absorption of heavy metals and pesticides, which can have negative consequences when absorbed by soil microbes (Avio et al., 2015). The use of dead organic mulch in orchards can help with weed suppression, soil moisture retention, and, most importantly, the diversity of beneficial insects, reducing the need for herbicides and pesticides while not compromising yield or increasing it, as straw mulch does (Arvidsson et al., 2020). Plastic film mulching can also severely affect long-term crop yield (Gao et al., 2019), as it does not readily degrade in soil (Briassoulis et al., 2015). The use of biodegradable film in combination with organic GC forms such as straw may represent an alternative to plastic film mulching for improved environmental sustainability (Han et al., 2013; Zhang et al., 2021).

4.2 | Organic ground cover materials affect soil physiochemical properties

Peach orchards with plastic film mulching hinder vegetation growth, thus limiting agrobiodiversity and affecting the supply of SOM into the soil, resulting in soil structure deterioration and impoverished soil fertility. In contrast, organic GC significantly improves soil formation when the material decomposes, thereby increasing SOM content and soil porosity. This was evident in our study, where inorganic GC did not affect both porosity and bulk density, and organic GC increased porosity while reducing bulk density. A soil structure with increased compactness and reduced porosity is not ideal for peach production as it promotes excessive surface runoff and reduced infiltration (Jiang et al., 2017). Soils with high bulk density generally limit root expansion as well as optimal air circulation. To promote soil formation with a good structure and improve soil fertility, the adoption of organic GC in orchards, particularly using both live and dead vegetative material since 1990 has been recommended (Wilson et al., 2010). Both live and dead vegetation (grass or straw) readily decompose into the soil, adding SOM stock which is important for soil fertility. However, one major disadvantage of living grass cover is that they compete with the crop for nutrients and water, particularly in the early phases of crop growth (Zhang et al., 2010). While there are notable disadvantages of sown grass or natural weeds on peach yield in this study, diverse plant communities still support pollinators such as bees, butterflies, and birds, which are essential for crop pollination. Some plant species help maintain soil health by fixing nitrogen, reducing erosion, and improving soil structure. Identifying plant species which may be used as trap crops, or border crops to promote agrobiodiversity without compromising yield is still an area to be explored. We showed that organic GC significantly reduced soil temperature, affecting various functions in the soil, including microbial activities, enzyme functions, plant root respiration, etc. Organic GC in the form of straw has been associated with low soil temperatures in the early stages of plant growth (Chen et al., 2007; Wang, Wang, Zhao, & Wang, 2015) and this generally slows the soil formation processes. However, diverse plant communities can help to mitigate climate change by sequestering carbon in the soil and reducing greenhouse gas emissions. In contrast, similar to bare soils, plastic film mulching in orchards has been reported to increase soil temperature compared to orchards with wild grass. Generally, as opposed to freezing or excessively hot soil temperatures, higher soil temperatures aid in faster soil formation. However, the use of inorganic mulch such as plastic film is still unsustainable as it adds less value to soil fertility. Therefore, we recommend the use of organic GC for soil improvement and to ensure the long-term sustainability of peach fruit production.

Organic material mulching is a method for recoupling nitrogen, phosphorus, and potassium pools in agroecosystems (Drinkwater & Snapp, 2007; Power, 2010). The choice of GC material to be used determines the soil quality, as it changes the composition of microbial communities (Chen et al., 2014; Zheng et al., 2018). Soil microorganisms are important in maintaining soil fertility and productivity, thanks to their role in plant residue decomposition, soil organic carbon, and nitrogen retention (Liang et al., 2017; Verzeaux et al., 2016; Wang, Huang, et al., 2020). We found that, unlike inorganic GC, organic GC increases the microbiological functional diversity of the soil linked to the carbon and nitrogen cycle as high soil microfauna is available (Birkhofer et al., 2019; Huang et al., 2021). Besides increasing available nitrogen, inorganic GC did not affect soil available phosphorus and reduced available potassium. This finding partly contradicts the results of Gu et al. (2018), who reported higher enzyme activity, available nitrogen, available phosphorus, and available potassium as a result of plastic film mulching. However, the presence of similar levels of available nitrogen with the use of inorganic GC, compared to organic GC, is not surprising. Ma et al. (2018) reported that plastic film mulching increased nitrate concentration in the 0–20 cm of topsoil while slightly decreasing soil organic carbon in the 0–10 cm of the topsoil layer. Even though inorganic nitrogen is higher in plastic mulch due to high mineralization, this comes at a cost of accelerated escape of carbon monoxide and nitrous oxide into the atmosphere (Cuello et al., 2015). Potassium deficiency can lead to limited growth, metabolism, and stress defense (Wang et al., 2013). Plants that have potassium deficiencies are more susceptible to pest damage (Wang et al., 2013; West & Nansen, 2014). Our results show that organic GC enhances available potassium in peach orchards boosting the crop defense against pests. Nonetheless, this study demonstrated that organic GC improves soil structure and nutrient cycling, implying the possibility of achieving both high nutrient cycling and good soil structure.

4.3 | Effects of ground cover systems on soil water regulation

We found in our study that overall, GC increased both soil water content and soil water storage more than when no GC was used. This reduces irrigation costs and improves water use efficiency in arid or semi-arid areas by minimizing soil evaporation (Zribi et al., 2015). Although our results indicated that inorganic GC did not affect soil water storage, other studies have reported that reusable reflective mulching increased water use efficiency and productivity in peach orchards (Losciale et al., 2020). Biodegradable plastic mulching has been found to have positive effects on soil and overall groundwater quality (Sintim et al., 2021) than polythene mulch (Flury & Narayan, 2021). Plastic film mulch, when compared to paper, straw, or grasses, can save 25–30% of water in crop production by inhibiting evapotranspiration (Ingman et al., 2015), and this may explain why soil water content was higher in inorganic GC than organic GC. Even though soil water content was high for inorganic GC in our study, others have reported that an increase in soil water content due to plastic film mulching adversely affected fruit yield and water use efficiency (Suo et al., 2019). Under plastic film, the soil can become ultra-dumped allowing fungi growth. Furthermore, the availability of plastic mulch may result in inefficient rainwater use. As the amount of residual plastic film in the soil increases, so does the bulk density of the soil, resulting in uneven water movement. As a result of poor soil quality, plant growth slows and nutrient uptake is hampered, resulting in low crop productivity (Zhang et al., 2007). Wang, Wang, Zhao, Chen, and Wang (2015) concluded that soil water content increased significantly when organic GC was used in peach orchards compared to without GC, similar to our findings. We found no overall significant effect of GC on water infiltration rate except for sown grass and straw, which conforms to the finding of (Lordan et al., 2015). While both organic and inorganic GC forms had a high soil water content in our study, for sustainable peach production, adopting organic GC is preferable owing to its water-saving and other environmental benefits. Natural weeds, on the other hand, compete for water with peach trees and their negative effects are exacerbated in drought conditions. As a result, dead organic mulch would be the best option for water conservation as moisture competition is one of the ecosystem's disservices.

4.4 | Effects of ground cover forms on peach orchard pests

Organic GC reduced the pest population while enhancing that of predators. The natural enemy hypothesis, which suggests that biodiversity can promote ecosystem services by increasing the diversity and effectiveness of natural enemies, such as predators and parasites, which can help control populations of herbivores or other pests could explain this phenomenon (Letourneau, 1987; Staudacher et al., 2013). One mechanism is temporal and spatial heterogeneity, that is, diverse plant communities create diverse and complex natural habitats, in which natural enemies may be better able to persist and reproduce (Collins et al., 2018; Vinatier et al., 2011), which can lead to more effective and long-term pest control (Wan, Fu, et al., 2022). Insect pest populations generally reduce in peach orchards due to an increase in the population of natural predators, facilitated by diversified groundcover vegetation compared to non-diversified annual groundcover vegetation (Wan, Ji, et al., 2018; Wan, Li, et al., 2019). Pest control by predators such as birds, spiders, wasps, and mantis not only reduces pest damage but also increases peach yield or limits pest yield losses in the short term. Unlike inorganic GC, biological GC forms in peach orchards have been linked with enhanced diversity and stability of peach canopy arthropod communities (Tebeau et al., 2017; Wan, Ji, Gu, et al., 2014). Facilitation is another mechanism which helps to improve peach productivity. First, organic GC facilitates the growth and peach trees by providing shade on the tree basement which reduces excessive evapotranspiration, providing nutrients through decomposition as well as maintaining soil health by promoting the life of soil-dwelling organisms like earthworms. Second, organic GC may indirectly affect other ecosystem services by altering microbial and other abiotic properties of the soil (Wang, Liu, et al., 2020). The abundance of natural enemies in peach orchards, especially with annual vegetation, has previously been reported (Wan, Gu, Ji, et al., 2014; Wyss, 1996). Long-term regulatory benefits also include the preservation of an ecological balance, which prevents herbivorous insects from becoming pests (Zhang et al., 2007). Taken together, organic GC using vegetation promotes biocontrol in peach orchards by shaping the niche of herbivores and natural enemies (Wan, Li, et al., 2019). Organic GC thus has the potential to improve above- and below-ground biodiversity and the environmental benefits of organic GC may outweigh those of inorganic GC.

4.5 | Limitations and future perspectives

Our study provides evidence on how different forms of GC drive the ecosystem services in agroecosystems like peach orchards. Due to a lack of sufficient information on soil fertility, chemical fertilizer management, plant densities, pruning, and irrigation among others, we could not determine how the interaction of GC and these other management factors influence various ecosystem services or disservices. Future research is needed to fill these knowledge gaps that may offer new insights into the overall sustainability of peach production. Furthermore, we stress the need for more research on biodegradable plastic film mulch combined with organic GC, as both can help reducing the environmental impact of plastic mulching (Li et al., 2012; Shen et al., 2012). Our study had only a few observations on this GC combination, and therefore we could not conclude its effect on ecosystem services.

5 | CONCLUSION

The purpose of this meta-analysis was to investigate how organic and inorganic GC management affects the various ecosystem services provided by the peach orchard agroecosystem. For provisioning services, we found that inorganic GC is more effective in increasing peach yield compared to organic GC. Inorganic GC increased peach yield by 7.7%, but there was no significant yield reduction with organic GC. Also, inorganic GC positively affected fruit quality, particularly single fruit mass and soluble solids content. Our study confirms that inorganic GC promotes soil water content and thus water regulation in peach orchards. Inorganic GC can be useful in achieving high peach yields while promoting a few supporting and regulatory services, depending on resource availability and production requirements. Nonetheless, our research shows that, while inorganic GC promotes provisioning services, it does so at the expense of both supporting and regulatory services. This was evident in this study, as inorganic GC did not significantly improve porosity, reduced SOM, available phosphorus, and available potassium, and was ineffective in increasing soil temperature and soil water storage. Our study also reported that, despite having no overall significant effect on peach yields, the use of straw is a good alternative for achieving high peach yields in contrast to inorganic GC forms. The soluble solids content of the fruits was also raised by 3.2% under organic GC forms. Straw, in particular, was found to be effective in increasing single fruit mass, as much as 8.6%. On the other hand, organic GC forms were important in promoting soil fertility characteristics such as available nitrogen (25.1%), available phosphorus (23.5%), and available potassium (30.9%). Additionally, organic GC increased soil organic matter by 28.3%, while inorganic GC reduced it by 5.5%. Furthermore, organic GC promoted regulatory services such as soil water content and soil water storage. Finally, natural predators can be used to reduce the overuse of chemical pesticides in peach production, which was increased by 54.4% under organic GC in this study. Thus, organic GC can be used to enhance ecosystem services while still maintaining acceptable yields. Based on this evidence, this study concludes that organic GC is a promising practice for long-term sustainable peach production. However, future research should focus on how other factors, such as inorganic fertilizer management, irrigation, soil physiochemical characteristics, and GC, interact to impact multiple ecosystem services.

AUTHOR CONTRIBUTIONS

Wen-Feng Cong, and J.J. carried out conceptualization. Shingirai Mudare, Mengqi Li, Jasper Kanomanyanga, and Wen-Feng Cong carried out methodology. Mengqi Li, Shingirai Mudare, and Jasper Kanomanyanga were involved in investigation. Shingirai Mudare wrote the original draft. Wen-Feng Cong, Shingirai Mudare, Prakash Lakshmanan, and Jay Ram Lamichhane were involved in supervision. Wen-Feng Cong, Jasper Kanomanyanga, Shingirai Mudare, Prakash Lakshmanan, and Jay Ram Lamichhane carried out writing—reviewing and editing. Wen-Feng Cong carried out resources, project administration, and funding acquisition.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data used in this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

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