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Biochar Return on Investment in Fruit and Nut Orchard Production

By Kelpie Wilson

Biochar is a form of highly stable carbon produced by the thermal degradation of biomass that creates value when used as a soil amendment. Biochar also provides climate benefits by transferring carbon from the atmosphere to highly stable soil carbon pools. As a soil amendment, biochar can address production bottlenecks while stimulating higher yields of an improved product that fetches a premium price. Farmers can incorporate biochar into current cultural practices for the production of walnuts, almonds, filberts, avocados, citrus, stone fruits, olives, apples, pears, pomegranates and other tree crops at a small additional cost, with variations in application methods depending on the irrigation system used. This paper discusses common nut and fruit production bottlenecks and how biochar can address these. It also proposes a method of partial budget analysis for determining whether biochar is economically viable as a soil amendment for orchards.

How Biochar Addresses Fruit and Nut Orchard Production Bottlenecks

Propagation and disease control

Control of tree crop pathogens begins in the nursery where rootstocks and cuttings are propagated. Biochar has been shown to induce resistance to a variety of pathogens and to encourage strong root growth in many different horticultural crops[1]. Activated carbon (with many similar properties to biochar) has long been used in tissue culture to encourage growth and root vigor[2]. Recommended formulations for grafting wax use powdered wood charcoal to protect against disease[3].

Water management – physical effects

Biochar increases soil water holding capacity (WHC), reducing irrigation needs. In one sandy loam, biochar increased WHC by 23%[4]. Many researchers have found similar results in a variety of soil and biochar combinations and have shown that the effect on WHC increases linearly with biochar application rate[5]. Biochar can increase total field capacity for better retention of both irrigation water and winter and spring rainfall.

Water management – biological effects

Biochar buffers soil water availability and the flooding/drying cycles that cause problems with fungal diseases such as *Phytophthera*. Evidence shows that biochar can make water more available to plants under water stress conditions and increase water use efficiency (WUE)[6,7]. This is an important benefit for young trees as they are especially sensitive to water stress. Declining snow packs in the West are forcing land managers to consider deficit watering strategies for some crops, but this approach leads to an increased potential for problems such as reduced fruit size, greater pest problems and decreased tree health[8]. Biochar-mediated improvements in WHC and WUE can help make the most of scarce water resources. Maintaining consistent soil water can also help avoid calcium uptake fluctuations that cause fruit diseases like apple bitter pit. Water availability buffering also benefits nutrient cycling by maintaining more consistent nutrient levels. This can improve yields with less fertilizer. Researchers in California are recommending biochar for increasing yields of avocado, especially under drought conditions[9].

Nutrient leaching and salinization

Biochar has been shown to prevent leaching of nitrogen into groundwater in diverse cropping systems, including orchards[10, 11, 12]. As a result, producers can safely apply less fertilizer and they will avoid pollution problems in the face of proposed surcharges on nitrogen fertilizers. Cutting back fertilizer use will also reduce fertilizer salt accumulation in soil.

Fruit quality, size and yield

Biochar applications can result in bigger, healthier fruits and nuts. A five-year biochar trial of apples in Australia has produced fruits that are up to 20 grams heavier than fruits from untreated trees, with no decrease in fruit firmness or sugar content[13]. In a Costa Rican trial, using cacao, researchers observed that biochar alone increased the fresh weight production of cacao fruits (pods) per tree and per hectare and also increased the height and stem diameter of seedlings after planting. Biochar reduced the incidence of *Monilia* pod rot.[14]. Biochar can also lead to earlier production in new orchards. Field trials in Belize have seen a 2.5-year-old cacao tree producing fruits 18 months after a top-dressing of biochar. Most cacao orchards in the area do not produce fruit until trees are 5-7 years old[15].

Trees, biochar and vesicular-arbuscular mycorrhizae

Vesicular-arbuscular mycorrhizae (VAM) are especially important for tree crops, promoting significant increases in plant productivity and survival[16]. Biochar supports the growth of healthy communities of beneficial microbes such as VAM that enhance soil nutrient cycling and plant nutrient uptake[17]. UC Davis researchers studying biochar use in a walnut orchard have found that populations of soil microorganisms increased in the biochar amended plots[18]. In a Japanese study, two year-old citrus trees in root boxes were used to evaluate three types of biochar as VAM inoculant carriers. All three biochars showed increased VAM infection along with increased root and shoot growth in the trees (at least 150% greater than an unamended control)[19]. One of the biochar types used also produced significantly higher phosphorus concentration in leaves. A second experiment by the same researchers applied biochar in trenches around 15 year-old trees in an established orchard. Root samples taken a year later found a much higher percentage of VAM in biochar-amended trees as compared to controls. In general, beneficial microbial inoculants are likely to be better supported and provide benefits over a longer period in biochar-amended soils[20,21].

Disease and pest resistance

Biochar has been shown to induce plant resistance to a broad spectrum of pathogens and parasites, including bacteria, viruses, molds, mildews, soil-borne fungal pathogens, mites, flies and nematodes. This induced resistance is partly due to biochar promoting the growth of beneficial fungi and bacteria that outcompete soil-borne pathogens, and partly due to induced systemic resistance in plants, possibly from increased populations of plant-colonizing microbes. There may be abiotic resistance mechanisms as well, related to organic chemical compounds present in biochar[22]. Two studies have demonstrated the effectiveness of biochar in suppressing bacterial wilt (*Ralstonia solanacearum, Pseudomonas syringae*) in tomatoes[23,24]. One of these studies also reported a decrease in whitefly populations on greenhouse tomatoes grown in biochar-amended soil that was inoculated with *Trichoderma harzianum* and *Bacillus subtilis*, two beneficial microbes. A study of three different strawberry fungal diseases with three different infection mechanisms found that biochar was effective in suppressing all three (Grey mold caused by *Botrytis cinerea,* Strawberry black spot caused by *Colletotrichum acutatum* and Strawberry powdery mildew caused by *Podosphaera apahanis*)[25]. An experiment to assess resistance to *Phytopthera cinnamomi* in oak and maple seedlings found that not only did biochar induce systemic resistance to canker expansion; it also reduced water stress in infected plants[26]. Another study measured parasitic nematode abundance in a wheat field and found that biochar altered the species composition of nematodes (without reducing overall nematode abundance) toward more beneficial species and fewer plant parasites[27].

Plant establishment

Biochar-mediated improvement in WHC helps to maintain the higher soil moisture levels that are needed for adventitious root development and successful plant establishment, while avoiding waterlogged conditions that promote fungal infections. Biochar can also protect sensitive young trees from damage related to residual herbicides in the soil. Root dips of activated carbon have been recommended to protect young plants from herbicide toxicity since the 1950s[28]. Biochar can be added to other amendments and fertilizers that are placed directly in tree planting holes[29].

Revitalizing older orchards

Some tree diseases of older orchards may respond to a biochar soil revitalization treatment. Fungal pathogens of walnuts, almonds and stone fruits in California are developing resistance to fungicides. Root aging and browning are caused by warm, dry soils and the presence of phenolic compounds. Biochar can improve soil moisture and it adsorbs phenolic compounds. If the orchard has a re-development budget, it will likely be cost effective to utilize techniques developed in Japan to successfully restore root systems of declining trees by adding biochar, phosphorus and VAM inoculant to holes or trenches around a tree's drip line[30].

Replant preparation

When orchards are replaced, producers are often faced with replant rejection due to an "unfriendly" soil ecosystem caused by high levels of soil pathogens that were tolerable to mature trees, but overwhelming to saplings. To restore a more balanced soil microbial environment, extension agents recommend fallowing with a cover crop for a year or more, but this may not be economical. The alternative of soil fumigation is also problematic. Methyl bromide is a Class I stratospheric ozone-depleting chemical under the Montreal Protocol, and fumigation with methyl bromide is scheduled for phase out in California[31]. Other fumigation chemicals come with water quality and health concerns. Researchers are looking for ways to quickly re-establish a friendly microbial community that can induce systemic resistance to disease[32]. Two recent studies confirm the potential of biochar soil amendments to mitigate replant disease. Using replant soil from an apple orchard, researchers found that biochar adsorbed phenolic acids in the soil and increased plant height, fresh weight, and several measures of photosynthesis while promoting higher enzyme activity[33]. A study of disease-susceptible peach rootstock in replant soil found that total biomass production was significantly higher with biochar[34].

Interactions with herbicides and pesticides

Soil organic matter in all its forms is known to adsorb soil-applied herbicides[35]. Depending on the amount of biochar in soil and its adsorption characteristics, biochar may also reduce the effectiveness of soil-applied herbicides[36,37,38,39]. Those biochars with less surface area will adsorb herbicides less strongly. Researchers have found that soil applied herbicides were still effective at killing weeds in biochar-amended soil, but only at the higher label application rates. Once available sorption sites on biochar are filled, biochar-amended soils behave like control soils in herbicide adsorption[40]. Biochar can also beneficially reduce leaching of both soil and foliar applied herbicides and pesticides, retaining them in place where they degrade over time[41].

How Biochar Produces Higher Yields of Fruits and Nuts

Higher Yields of Marketable Fruits and Nuts

Increased resistance to pests and diseases combined with better use of nutrients and water can result in greater yields, as shown by the results cited previously for apples and cacao.

Earlier and Longer Production

Orchards require a considerable investment to establish. Producers cannot afford to let poor establishment, early decline or disease reduce their returns. Biochar can produce stronger transplants that can be moved to the field earlier and survive better. Biochar may also bring on high yield production at an earlier date. Biochar can help to maintain vigor and productivity in mature and older orchards, while biochar soil improvement can make replanting more efficient as well. Longer total production time results in a reduced unit cost of production and an improved return on investment.

Biochar Impacts on Economic Returns

In order to determine the return on investment for biochar, a partial budget analysis may be used. A partial budget analysis distributes costs and benefits into four quadrants that account for additional costs and returns as well as reduced costs and returns. The net return is calculated by combining the results from each quadrant. Below are some items that should be considered when evaluating the return on investment from adding biochar to orchard soil.

Additional Costs

- Cost of biochar – Biochar can be purchased from suppliers or it can be produced on site using orchard prunings. Several low cost methods are available to produce biochar from material that might normally be burned on site to dispose of it[42].
- Application amount - In some cropping systems biochar can be applied in small annual increments until the desired soil saturation is reached. For tree crops it will be most effective to apply all the biochar at one time in the tree row with the cost spread over the orchard's lifetime. A small additional amount of biochar is applied in the planting holes.
- Application cost - Biochar will be applied along with other soil amendments during regular land preparation, or it can be added to planting holes when replacing trees in an older orchard. It can also be added to compost or other amendments that are surface applied in established orchards
- Propagation – adding biochar to the propagation system will incur a small additional cost for trees.

Reduced Costs

- Biochar may result in significant water use reduction based on a combination of increased water holding capacity and increased plant water availability and water use efficiency.
- Biochar may reduce the amount of NPK fertilizers required based on biochar impacts on soil nutrient cycling and retention.
- Biochar may reduce losses to disease.

Additional Returns

- Yield increase – To start with, it is reasonable to assume a yield increase of 15% based on average yield increases reported for a number of crops using biochar[43]. Actual yield increases will depend on a number of factors, including the type of crop and soil type as well as disease pressure, climate, fertilization regime and many other factors.

Reduced Returns

- No reductions in returns are anticipated from properly applied biochar.

Conclusions

This economic model for tree crop production using biochar is based on reasonable assumptions. Biochar is new to modern agriculture, but it has a long history of use in many cultures, including 19th century farming in Europe and the United States[44]. This long history of use gives assurance that biochar will provide a net benefit when added to farm soils. Actual economic returns and assumptions about specific costs and benefits will need to be proven through extensive, well-documented field trials.

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