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Locally produced wood biochar increases nutrient retention and availability in agricultural soils of the San Juan Islands, USA

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ABSTRACT

Biochar additions to agricultural soil have been shown to result in numerous potential benefits; however, most studies have been conducted in greenhouse or laboratory trials with few being conducted in the field and particularly in association with organic farming systems. Herein, we address this gap by conducting on-farm studies on the efficacy of locally produced biochar as a soil amendment in small-scale organic agriculture on ten farms in San Juan County, WA. Biochar produced from local timber harvest residues in the San Juan Islands was applied in factorial combination with a poultry litter based fertilizer to replicated plots on all ten farms. Dry beans (*Phaseolus vulgaris* L.) were grown on eight of the farms with green beans and cauliflower being grown on the other two. Soils were examined for nitrogen (N), phosphorus (P), and carbon (C) pools during the growing season. Dry bean samples were evaluated for metal and nutrient uptake. Biochar additions increased soil total C by 32–33%, soil available NH_4^+ by 45–54% through mid-season, pontentially mineralizable N by 48–110%, and citrate extractable P by 29%; biochar additions enhanced soil NO_3^--N, NH_4^+-N, and P retention in the rooting zone by 33%, 53% and 39% respectively. Increased availability of soil P, Fe, Mg, Zn was reflected in the nutrient concentration of harvested dry beans. Our study demonstrates that locally produced wood biochar has the potential to increase soil nutrient availability and uptake. By producing biochar from timber harvest residues and applying them on neighboring organic farms on the San Juan Islands, WA, this study leveraged the local resources and community readiness to drive forest restoration and sustainable agricultural practices in addition to the demonstrated potential short-term benefits of biochar additions for organic farms on the sandy soils of the San Juan Islands.

1. Introduction

Wood biochar has been identified as a potentially effective soil amendment in temperate agricultural systems in North America; however, few studies have directly linked locally produced biochar feedstocks to on-farm applications and fewer studies yet have been conducted on organic farms. In western forest ecosystems fire is a major form of ecosystem disturbance; however, active fire suppression and a shift in forest management objectives has resulted in the occurrence of heavily stocked forests (Naficy et al., 2010; Hessburg et al., 2015) that are subject to stand replacing wildfire. Fuel reduction and forest restoration treatments have been promoted as a means of reducing fire hazard and returning forest stand structure and composition to a more resilient form (Hessburg et al., 2015). Forest residues from timber harvests and fuel reduction treatments are normally piled and burned resulting in generation of air pollutants (CO_2, CO, NO_x and particulate matter), loss of nutrients, and incursion of exotic plant invasion (Kauffman, 1990).

In San Juan County, WA, approximately seventy percent of the land cover is considered to be overstocked second growth forests (San Juan Conservation District, personal communication). Thinning treatments geared toward improving forest health result and reducing fire generate forest harvest residues that require disposal which normally involves pile burning. Pile burning of residues creates air quality problems and is an expense to the land owner. Importantly, a critical part of San Juan County's economy is agriculture and organic farming on well drained sandy loam soils formed in glacial till and outwash. Growing seasons are relatively short and dry due to the "rain shadow" effect created by Olympic Mountains and Vancouver Island. Therefore, biochar production from local timber harvest residues in San Juan County may offer a

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sustainable means of reducing wildfire hazard fuel loading while improving soil health and reducing nutrient loss on neighboring organic farms.

Biochar or charcoal obtained from the thermochemical conversion of forest residues have been studied as a means of creating a low emission, value added product from forest residuals while offering an innovative approach to improving soil fertility and crop productivity (Lehmann and Joseph, 2015). Biochar is a C rich, recalcitrant solid material that is generated from the pyrolysis or thermochemical decomposition of organic material in an oxygen limited environment under controlled conditions.

The application of biochar to soils has been shown to increase soil nutrient retention and microbial biomass, improve N_2 fixation in cover crops, decrease the need for irrigation, and sequester C from the atmosphere (Lehmann and Joseph, 2015). Studies in Midwestern soils, for example, illustrate that biochar decreased N and P leaching by 11% and 69% respectively (Laird et al., 2010). More recently, Ventura et al. (2013) reported a 72% reduction of NO_3^- leaching in sub-alkaline soils in an apple orchard (Ventura et al., 2013). Studies have demonstrated that biochar addition to soils can increase soil microbial biomass, and may also affect the soil biological community composition, which in turn will affect nutrient cycling and plant growth (Zhang et al., 2014). Some biochar studies have illustrated even greater benefits with calcium (Ca) and magnesium (Mg), increasing uptake by between 77 and 320% (Major et al., 2012). Biochar has also been reported to help decrease irrigation demands by increasing soil-water retention (Karhu et al., 2011).

Biochar has been identified as an effective soil C sink as it has high proportion of recalcitrant C with stability measured in hundreds to thousands of years (Lehmann and Joseph, 2015). Its highly porous structure, large surface area may offer appropriate habitat for beneficial microorganisms to flourish; other physico-chemical properties such as high ion-exchange capacity can also impact a number of processes in the soil N cycle associated with enhanced soil fertility (Clough et al., 2013).

The response of soil fertility and plant productivity to soil application of biochar has been highly variable. Fertility responses can vary with the nature of the biochar feedstock, application of an activation or inoculation step, total application rate, crop species, soil type and other soil inputs, as well as combination of these factors (Jeffery et al., 2015). A meta-analysis of biochar effects on crop production by Jeffery et al. (2011) suggests that a biochar application rate lower than 1–5 $Mg\,ha^{-1}$, or more than 150 $t\,ha^{-1}$, did not simulate significant yield increases (Jeffery et al., 2011), but crops such as rice, wheat, maize and soybean grown in acidic, OM poor soils often showed increases in crop yield and production when growing with biochar additions of 10–100 $Mg\,ha^{-1}$.

Enhancement of crop production by biochar addition is generally attributed to the alteration of soil nutrient availability, liming effect, soil hydrological effects, as well as biotic interactions such as enhanced biological N_2 fixation or mycorrhizal fungi colonization (DeLuca et al., 2015b; Jeffery et al., 2015). However, the majority of biochar trials have been conducted as short-term studies in the greenhouse or growth chamber limiting the validity of the findings. Longer-term field trials have often been conducted at agricultural experiment stations using conventional agricultural production approaches. To date, very few studies have been conducted in the field in active organic farming operations and as a part of a holistic closed loop system. Herein, we address this gap by

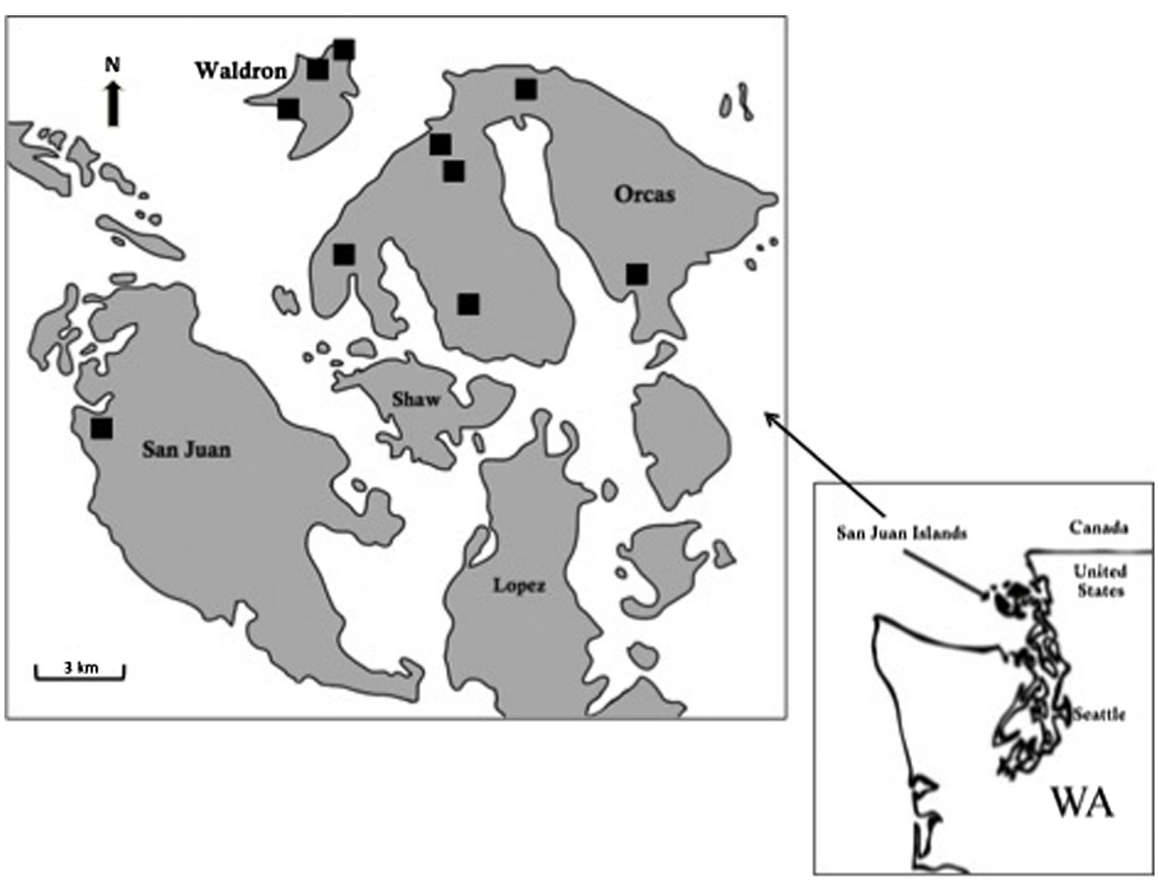

Fig 1. The location of ten organic farms (black squares) in San Juan County, WA, USA.