Soil & Tillage Research 184 (2018) 52–61

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Managing soil fertility and health for quinoa production and weed control in organic systems

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ARTICLE INFO

Keywords:
quinoa
Inter-crop
Compost

ABSTRACT

Quinoa (*Chenpodium quinoa* Willd.) could provide a high value crop for organic cropping systems in the Intermountain Western US. This study evaluated quinoa in three cover cropping systems [strip crop (SC), undersown clover (UC), or winter cover crop and tillage (T)] with and without compost (+C or −C) in a split-plot with blocks design. Quinoa produced no seed in 2013 and limited seed in 2014, likely due to excessive temperatures during flowering. Compost increased seed yield in 2014, and in both years, increased total biomass and improved soil health measures. Seed and biomass yield was greater in T than UC on a land-equivalent basis but SC was greatest on a per harvest area basis. Cropping system effects on soil health measures were minimal. However, microbial biomass increased in all systems over time, yet was diminished in the tillage system. Quinoa may be an alternative crop for organic systems provided sufficient nitrogen and phosphorous fertility is available, and yields can be stabilized by identifying heat tolerant varieties before widespread adoption of this crop is feasible.

1. Introduction

Quinoa is recognized as a highly nutritious substitute for traditional grains, as it provides a complete gluten free protein (Kozioł, 1992). Growers in South America have been under great pressure to increase production to meet the growing demand, resulting in intensified farming practices and reduced sustainability (Jacobsen, 2011). Quinoa is mostly produced organically and annual imports into the US in 2017 exceed 33 million kg, making the US the largest worldwide importer (United Nations Comtrade, 2017). In South America, quinoa is grown in diverse ecosystems indicating there may be varieties that are well suited to production in the western US (Jacobsen et al., 2003). Organic growers face steep challenges in developing cropping systems to adequately control pests and foster soil health, all while maintaining a profit. The incorporation of quinoa into organic cropping systems in the western US region could provide a novel, and profitable, addition to crop rotations thereby increasing the sustainability of organic farms.

To determine whether quinoa could be a viable alternative crop for organic production in the western US, appropriate cropping systems need to be developed. In organic systems, crop nutrient requirements are frequently met with a combination of cover crops, diverse rotations, and applications of compost or manure while weeds are typically controlled with tillage. Incorporating organic matter increases soil health indicators yet frequent tillage depletes soil organic matter (SOM) and degrades soil health. Compost use can increase soil health indicators such as plant available nutrients, water holding capacity and SOM, which is frequently low in western arid soils (Reeve et al., 2012; Olsen et al., 2015). The application of compost can be cost prohibitive and if applied at heavy rates over the long-term, may become an environmental concern due to elevated levels of other nutrients such as phosphorous (P). Alternatively, some organic growers rely on cover crops or intercropping alone to address soil fertility and suppress weed populations.

Using a nitrogen (N) fixing green manure crop as a cover, relay, or intercrop can provide significant inputs of N while also suppressing weeds and others pests (Altieri, 1999; Altieri and Letourneau, 1982; Wang et al., 2011). Cover crops do not contribute other nutrients to the system, such as P and potassium (K), and may not adequately replace nutrients removed at harvest but can aid in cycling nutrients from deeper layers in the soil (Cherr et al., 2006; Dabney et al., 2001). Intercropping can increase the productivity of a cropping system by increasing plant-available nutrients, resulting in increased tissue nutrient content and yield (Gao et al., 2009; Li et al., 2001). However, interactions between cash crops and cover or inter-crops are species

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https://doi.org/10.1016/j.still.2018.07.001
Received 16 December 2017; Received in revised form 11 June 2018; Accepted 1 July 2018

dependent and may instead result in detrimental competition to the main crop, which can impact N uptake and water use efficiency and reduce yields (Zhang et al., 2008, 2007; Gao et al., 2009). Therefore, crop selection and timing of establishment and termination of growth must be skillfully managed. Establishing cover crops earlier enough to produce sufficient biomass, especially in cold climates with short growing seasons, also presents challenges. Strip cropping with a green manure, relay cropping, or intercropping may extend the growing season and increase nutrient contributions, thereby offsetting any interspecific competitive effects and simultaneously reducing tillage.

The goal of this research was to measure the growth response of quinoa and soil health indicators in three organic cropping systems designed to supply N and reduce tillage through various configurations of cover crops with and without added compost. Cover crop systems tested were: (1) a winter cover crop of 70% hairy vetch (*Vicia villosa* Roth.) and 30% winter wheat (*Triticum aestivum* L.) incorporated with tillage prior to seeding quinoa (tillage, T); (2) the same hairy vetch and winter wheat cover crop terminated with tillage followed by undersowing clover once quinoa was established (undersown clover, UC); and (3) a cover crop of hairy vetch and winter wheat strip cropped with quinoa where mowed residue of the cover crop was blown onto the quinoa row (strip crop, SC). Hypotheses tested were (1) quinoa grown with compost in an intercropped system will have greater growth and yield than in a tillage-only system and (2) intercropping will increase soil health indicators compared to tillage-only treatments.

2. Materials and methods

2.1. Field design and management

The experimental site was located on the Utah State Greenville Experiment Station Organic Research Farm in North Logan, UT (41°46′ N, 111°49′W). The soil was a Millville silt loam (coarse-silty, carbonatic, mesic Typic Haploxeroll, USDA Web Soil Survey). The site was managed organically since 2005 with a variety of summer and winter cover crops with no additional inputs, and was certified organic in 2011. Field corn was grown in 2010 and pumpkins in 2011. The experimental design was a split-plot in four blocks, for a total of 24 plots. Blocks were derived from equal sections of a larger field separated by a 1.5 m alley between blocks. The whole plot factor was cropping system [three levels: strip crop mow and blow (SC), under-sown clover (UC) and winter cover crop tillage (T)], and the split-plot factor was fertility [compost added (+C) or no compost added (−C)]. Cropping system was randomly assigned to a plot within each block. Compost was randomly assigned to subplots within plots. Plots were adjacent to each other within blocks with no spacing between plots or subplots. With the exception of initial site preparation all tillage was accomplished with a three point mounted rotary tiller to a depth of approximately 10 cm.

Initial field preparation was done on August 29, 2012, by disking the soil to a depth of approximately 15 cm. The site was then planted with a cover crop consisting of a mix of hairy vetch and winter wheat (78/34 kg ha^{-1}, respectively) prior to establishment of all plots and treatments in the spring of 2013. Plots for T and UC measured 21.4 m long by 5.2 m wide and consisted of six rows of quinoa centered within the plot. Quinoa rows were spaced 0.46 m apart with a seeding rate of 13.4 kg ha^{-1}. Strip-crop plots were also 21.4 m long and consisted of three 1.0 m-wide sections containing two rows of quinoa flanked by four 1.2 m wide alleyways containing the hairy vetch/winter wheat cover crop. Within the plot, split-plot compost treatments were assigned randomly to halves of each plot so the length of each subplot was 10.7 m.

On May 17, 2013, the winter cover crop mix was terminated with tillage to a depth of approximately 10 cm except for the 1.2 m wide strips within the SC treatments. Steer manure compost was applied on June 3, 2013 prior to planting the first crop of quinoa. The compost application rate of 11.2 metric tons ha^{-1} (dry weight) of composted steer manure (Table 1) was based on providing readily available P for 2 years using published yield response data for P in quinoa (Darwinkel and Stolen, 1997; Oelke et al., 1992; Peterson and Murphy, 2015). On June 4, 2013, shallow tillage (approximately 2.5 cm) was used to incorporate the compost and kill emerged weeds in all plots, except the cover crop strips in the SC, immediately prior to planting quinoa variety Oro de Valle (Washington State University) with a HEGE model 500 small plot seeder. After quinoa emergence, the remaining strips of cover crops (SC plots) were mowed and the residue raked onto the quinoa rows to simulate a side discharge mower.

Table 1
Composted steer manure nutrient analysis (analysis on air-dried compost).

Parameters	Value
Moisture %	4.9
pH (2:1)	8
EC(2:1) dS/m	4.32
N %	1.54
C %	24.5
P %	0.6
K %	1.32
Ca %	3.72
Mg %	0.74
S %	0.33
Na mg/kg	3410
B mg/kg	17.3
Zn mg/kg	212
Cu mg/kg	31.2
Fe mg/kg	5980
Mn mg/kg	254

Clover in the UC plots was broadcast seeded (13.4 kg ha^{-1}) and lightly incorporated with a rake once quinoa was well established (approximately late June) to avoid excessive competition. After harvest on September 3, 2013, the field was tilled to a depth of 10 cm with the exception of the UC plots. The clover remained as the overwintering cover crop in the UC plots while a second hairy vetch/winter wheat cover crop was planted in the SC and T treatments.

In April 2014, all winter cover crops were incorporated approximately 1 week prior to spring planting, except for the strip-crop alleys as described above. The location of strips of quinoa and cover crop in the SC treatment were switched from the previous year to maximize above- and below-ground nutrient contributions from the cover crops and minimize tillage events over the course of multiple years. The variety Oro de Valle was planted on April 25, 2014. Poor germination required a second, shallow tillage and re-seeding on May 28 with the variety Cherry Vanilla due to a shortage of Oro de Valle seeds with acceptable germination rates.

Overhead sprinkler irrigation applied approximately 5–8 cm of water per week from June through mid-September each year, depending on weather conditions monitored through the Greenville Station AGWX weather station located in North Logan, UT (approximately 0.2 km from research plots). Weeds were controlled with a combination of shallow hoeing and hand rogueing twice per season within 60 days of seeding.

2.2. Plant analyses

A single row, 3 m length, within the center of each subplot was harvested (September 3, 2013 and September 16, 2014). Weeds in the quinoa row were harvested at the same time as quinoa to assess weed growth. In 2013, quinoa did not set seed, likely due to high air temperatures during flowering (Murphy and Matanguihan, 2015). Quinoa plants were cut at ground level and sectioned into stems and panicles. Plant components were weighed wet, dried at 60 °C and weighed again. The sum of stem and panicle (including seed weight in 2014) is referred to as total biomass. In 2014, dried panicles were manually threshed to