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Air-propelled abrasive grits reduce weed abundance and increase yields in organic vegetable production

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ABSTRACT

Abrasive-weeding is a novel weed management tactic with potential to reduce tillage and hand-weeding in organic agriculture. However, abrasive-weeding has not been tested in vegetable cropping systems and growers are interested in the potential for using organic fertilizers as abrasive grits to control weeds and supplement crop nutrition in one field pass. A two-year field study was conducted at the University of Illinois Sustainable Student Farm to determine the effect of air-propelled abrasive grit type, including organic fertilizers, and application frequency on weed density and biomass and crop yield and marketability in organic tomato (*Solanum lycopersicum* L.) and pepper (*Capsicum annuum* L.) cropping systems. Abrasive-grits, including granulated walnuts shells and maize cobs, greensand fertilizer, and soybean meal, were applied via compressed air between one and four times within planting holes of plastic mulch. Weed density was quantified 25 or 37 days after the first application and weed biomass was harvested at the end of the growing season. Tomatoes and peppers were harvested ripe and graded for marketability. Two applications of abrasive grits, regardless of grit type, reduced weed density by 63% and 80% in tomato and pepper, respectively. Broadleaf weeds were more susceptible to abrasive-weeding than grass weeds. Abrasive-weeding reduced final weed biomass by 69–97% compared with the weedy control, regardless of grit type or application frequency. Total tomato yield was up to 44% greater in treated plots compared with the weedy control, whereas total yield gains in pepper (up to 33%) were only approaching significance ($p = 0.09$). Yield and the marketability of fruit was not negatively affected by grit application, despite minor stem and leaf tissue damage after applications. Organic fertilizers used as abrasive grits in this study could contribute between 35 and 105 kg N ha^{-1}, which may improve the functionality and economic feasibility of abrasive-weeding.

1. Introduction

Most organic vegetable growers rely heavily on intensive soil tillage or plastic films to control weeds within crop rows. Recent technological advances have improved post-planting precision tillage options for intra-row weed management in organic vegetables (Rafaelli et al., 2010, 2011), but the efficacy of tillage often depends on ideal soil conditions and is time-sensitive (Gunsolus, 1990). Similarly, recent development of new plastic and biodegradable mulches (Kasirajan and Ngouajio, 2012) has improved weed control in vegetable crops, but weeds can still emerge through planting holes or tears in plastic mulch (Schonbeck, 1999; Miles et al., 2012). Despite their effectiveness, tillage and mulching may not provide season-long weed suppression when used alone. Instead, successful organic or ecological weed management requires a diversity of tactics that target a broad range of weed species, especially those that emerge early in the growing season (Liebman and Davis, 2000). Beyond tillage and mulching, common organic weed control tactics in vegetable production include flame-weeding (Melander et al., 2005), natural-product herbicides (Baker and Mohler, 2014), crop rotation and cover crops (Wang et al., 2008; Wortman et al., 2014), and hand-weeding. Optimum weed suppression is typically achieved when a combination of these tactics (e.g., flame-weeding + precision hoeing + straw mulch) are deployed within the same growing season (Fontanelli et al., 2013). However, not all combinations of tactics are compatible. For example, flame-weeding could not be used to control weeds growing through the planting hole or rips in a plastic or biodegradable plastic mulch because the plastic would burn and melt. Thus, continued innovation is needed to develop physical weed management tactics that are compatible with a broad range of

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other organic weed strategies. Moreover, despite these recent advances in physical weed management, organic growers are not satisfied with the tactics available to them and the level of weed suppression achieved (Baker and Mohler, 2014).

Abrasive-weeding, or "weed blasting," is a novel management tactic where air-propelled abrasive grits are used to physically abrade and kill weeds emerging within crop rows (Forcella, 2009). Forcella (2009) first demonstrated that granulated walnut shells could be used to kill small *Chenopodium album* L. seedlings. This initial proof-of-concept has led to rapid development of the technology. Early field research on abrasive-weeding demonstrated the possibility for selective post-emergence control of small broadleaf weed seedlings within maize (*Zea mays* L.) and soybean (*Glycine max* L.) rows using granulated maize cobs as the abrasive grit (Forcella, 2012, 2013). Most research on abrasive-weeding had been focused in maize and soybean, but Wortman (2014) recently demonstrated that air-propelled abrasive grits did not negatively influence the growth of tomato (*Solanum lycopersicum* L.) or pepper (*Capsicum annuum* L.) in a greenhouse study (Wortman, 2014). However, the potential for abrasive-weeding in organic vegetable crops has not been confirmed in field cropping systems.

Tomato and pepper may be ideal crops for abrasive-weeding because they have an erect, upright stem growth habit. Abrasive-weeding indiscriminately abrades stem and leaf tissue of both weeds and crops and the success of the tactic depends on a size differential between weeds (small) and the crop (large) (Wortman, 2014). Grit applicator nozzles can be targeted at the base of a crop stem to minimize crop tissue damage to the apical meristem, but this strategy is most effective in reducing crop injury if the crop is taller than the emerged weeds. Tomatoes and peppers are typically transplanted, which provides the needed size differential between the crop and weeds. In addition, these crops are often vertically trellised, which may help minimize leaf tissue damage during grit application and plant lodging after application (Wortman, 2014). Vining and leafy crops, where a majority of the vegetative or marketable portion of the plant is on or near the soil surface at the time of grit application, will be less compatible with abrasive-weeding. Similarly, direct seeded vegetable crops will be less compatible due to size similarity between crops and weeds, resulting in increased damage to the crop during grit application.

Abrasive-weeding is an exciting new tactic because of the additional possibility of using organic fertilizers as abrasive grits, which would allow growers to control weeds and supplement crop nutrition in one field pass. Granulated maize cobs and walnut shells, which are common abrasive grits, have a high carbon (C): nitrogen (N) ratio and will provide negligible crop nutritional benefits. In contrast, organic fertilizers (e.g., soybean meal) typically contain between 4 and 15% N, and when added to soil release this N over a period of at least three months (Stadler et al., 2006; Sexton and Jemison, 2011). Previous greenhouse and pot studies suggest that organic fertilizers applied as abrasive grits can be just as effective as maize cob or walnut shell grits in reducing grass and broadleaf weed biomass (Forcella et al., 2011; Wortman, 2014). Applying organic fertilizers at the time of post-emergence abrasive-weeding may also reduce in-row weed competition by delaying N availability until periods of peak crop demand (Liebman and Davis, 2000). Moreover, some seed meal fertilizers may have allelopathic properties that can aid in the inhibition of weed seed germination and growth after grit application, similar to a pre-emergence herbicide (Bingaman and Christians, 1995; Boydston et al., 2011; Webber et al., 2008).

The objective of this study was to determine the effect of air-propelled abrasive grit type, including organic fertilizers, and application frequency on weed density and biomass and crop yield and marketability in organic vegetable cropping systems.

2. Materials and methods

2.1. Study site and experimental design

Two trials were conducted at the University of Illinois Sustainable Student Farm in Urbana, Illinois (40.08 N, 88.22 W; elev. = 221 m) in 2013 and 2014. The test crop in 2013 was fresh market tomato (cv. Big Beef) and in 2014 was green bell pepper (cv. Revolution). Test crop was different between years to provide additional information about crop species tolerance to abrasive-weeding. Experimental design was a factorial randomized complete block design with four replicate blocks and two factors. Factors included abrasive grit type and grit application frequency. In 2013, abrasive grit types included maize cob and walnut shell grits (Kramer Industries, Inc., Piscataway, New Jersey, USA), greensand fertilizer (Greensand, 0-0-3 NPK; Down to Earth Distributors, Inc., Eugene, Oregon, USA) and soybean meal (Phyta-Grow Leafy Green Special, 7-1-2 NPK; California Organic Fertilizers, Inc., Hanford, California, USA). Greensand fertilizer was omitted in the 2014 trial due to practical concerns about the heavy weight of the product and the fine particulate dust created during application. Application frequency ranged from one to four applications in 2013, but the number of applications was reduced in 2014 based on ambient weed populations and 2013 results. A hand-weeded weed-free control and a weedy control plot were included in each replicate block. This design resulted in 72 plots in 2013 (4 grit types × 4 application frequencies + 2 controls in 4 blocks) and 44 plots in 2014 (3 grit types × 2 possible application frequencies + 2 controls in 4 blocks [the experiment was originally designed for 3 application frequencies, but crop canopy cover and low ambient weed seedbank abundance eliminated the need for a third application; thus, 3× plots were pooled with 2× plots resulting in twice as many 2× experimental units compared with the 1× and control treatments]). Each plot was 3.72 m^2 (1.22 m wide × 3.05 m long) and included five tomato plants spaced 0.61 m apart or nine pepper plants spaced 0.33 m apart. Experimental plot size was limited in part by the amount of abrasive grit available because greensand fertilizer and soybean meal had to be hand-sieved to remove particles greater than 0.85 mm.

2.2. Site and crop management

The experimental sites were roto-tilled in early spring, and raised-beds were shaped (approximately 0.61 m bed tops) and spaced 1.83 m apart measuring from the row centers. Drip tape irrigation line with 15 cm emitter spacing was laid down the middle of each raised-bed and beds were covered with 0.025 mm black polyethylene mulch film. Eight-week old greenhouse grown crop seedlings were transplanted into 10 by 15 cm planting holes in the plastic mulch on 6 June 2013 and 19 May 2014. Tomatoes were trellised vertically using the basket-weave method on 24 June 2013 and peppers received no physical support. Weeds between rows of plastic mulch were controlled with mowing and hand-weeding. Crops were drip-irrigated regularly to maintain soil moisture in the top 7.5 cm of the profile above 20% volumetric soil moisture. Crop nutrition was supplemented during the growing season with water soluble fish emulsion delivered via drip irrigation lines. Plants were sprayed with a copper sulfate solution to manage fungal pathogens. All cultural practices followed USDA National Organic Program guidelines.

2.3. Abrasive grit application

Abrasive grits were applied 14 and 33 days after transplanting (DAT) in 2013. All plots (1×–4× frequency treatments) were