Improving Soil Health Through No-Till Organic Vegetable Production

Anne Pfeiffer (Graduate Student Applicant), Graduate Student, Department of Horticulture, University of Wisconsin, 1575 Linden Dr., Madison, WI 53706, (608) 630-4343, acpfeiff@wisc.edu

Partners on the Project:

Eric Bietila, Graduate Student, Agroecology Program, 1630 Linden Dr., Madison, WI 53706, (608) 354-2462, bietila@wisc.edu

Erin Silva, Assistant Professor, Department of Plant Pathology, University of Wisconsin, 1630 Linden Drive, Madison, WI 53706, (608) 890-1503, emsilva@wisc.edu

Abstract

No-till techniques have gained attention as a means to reduce the negative impacts of intensive tillage, which is routinely used by organic farmers for weed control. Significant questions remain about the viability of no-till techniques in organic vegetable systems. This research compared cover crop species that could be used in organic no-till vegetable systems, measuring impacts on vegetable quality, yield, and soil health. Outcomes included the assessment of best management practices for organic no-till vegetable production in the upper Midwest. Long-term impacts include more effective no-till adoption among vegetable growers, leading to more effective organic weed management and improved soil health.

Introduction

Building healthy soils, integrating cover crops, and minimizing weeds are key management issues on organic vegetable farms. Unfortunately, organic weed control is often achieved with intensive tillage that can be damaging to soil health. Use of no-till and cover cropping has been shown to provide a wealth of soil benefits while effectively controlling weeds and reducing farm labor inputs. However, with high land prices, farmers face increasing pressure to keep greater portions of land in cash crops at the expense of cover cropping. Cover-crop based no-till practices allow farms to gain the benefits of cover crop rotations while still earning a financial return from the land.

Though no-till systems offer a multitude of soil building and weed control benefits, implementation remains variable for organic farmers. Skilled management of cover crops used in no-till practices is critical; mismanagement can lead to undesired consequences, including serious weed issues rather than effective control. Relatively cooler, wetter soils that occur using mulch can impede seed germination, slow crop growth, and delay harvests. Unfortunately, thus far, the majority of no-till research has focused largely on conventional systems incompatible with organic practices. Research is particularly limited on the use of no-till management in organic fresh market vegetable applications.

The goals of this research included:

1) **Improve organic farm systems**: The use of no-till and cover cropping practices have been shown to increase soil organic matter, improve soil biology and soil health, reduce erosion, and improve soil aggregate structure. Research to identify successful

applications of no-till on organic farms will allow increased implementation of this technique, resulting in improved soil health and reduced erosion and nutrient run-off.

2) **Facilitate the transition of conventional farms to organic methods**: Improved no-till management strategies will allow farmers a more cost effective and environmentally sustainable tool for weed management, one of the primary hurdles to organic transition. This research will provide data, education and outreach that will support farmers in adopting organic no-till practices and increase the use of mulches in successful system for weed management and a low-cost source of slow release soil organic carbon.

3) **Help make existing organic farms more productive and profitable**: Adapting no-till systems to organic vegetable production will allow farmers to benefit from the demonstrated reduced labor costs associated with successful no-till management by reducing the need for time spent on tillage, weed management, and spreading mulch. In addition to reducing labor requirements and associated costs, no-till retains soil nutrients on-farm, minimizing the need for off-farm fertility and weed management inputs and fuel.

Conservation and no-tillage, which are recognized as important tactics for improving agricultural sustainability and economic performance for conventional grain production, have increased dramatically in the U.S. in the past two decades. Conservation tillage systems are known to increase soil fertility, reduce soil erosion and conserve soil moisture (Hoyt et al. 1994). The benefits of reduced tillage that have been documented in conventional systems include weed suppression, moisture conservation, and soil tilth enhancement (Green et al. 2005; Carrera et al. 2004; Teasdale et al. 2006).

No-till grain production systems often have reduced machinery, labor, and fuel costs compared to intensive tillage systems. However, research on alternative tillage methods for organic farmers is still considered limited (Carr et al. 2012).

Cover crop based no-till has been developed as an alternative to traditional no-till methods. Pioneered by the Rodale Institute, this technique involves using non-chemical strategies to convert standing cover crops into weed-suppressing, soil-building mulches using innovative roller/crimper technology. The blades crimp or crush but do not cut plant stems, thereby improving efficacy of the termination method while also maintaining intact plant residue on the soil surface, creating a mulch to smother weeds. This technique has been the focus of multiple university-led research projects across the country, demonstrating its positive impacts on soil health and quality and its potential to decrease soil erosion (Carr et al., 2012). Various cover crops, including cereal grains and nitrogen-fixing legumes, have been successfully used.

In addition to use in a cash grain system, cover crop based no-till has been used successfully in vegetable production systems. In 1995, experimentation began with stalk-choppers, rollers, and other implements to convert cover crops into mulch and reduce tillage for weed management in organic horticultural crops (Creamer and Bennett 1995). Creamer et al. (1996) demonstrated comparable organic tomato yields in an undercut cover crop mixture of hairy vetch, rye, crimson clover and barley to conventionally fertilized tomatoes. Dr. Ron Morse, who has experimented with different cover crop kill strategies for no-till vegetable production for many years (Morse 1998), has obtained positive results with the roller/crimper in organic systems. In California, organic tomato yields were equivalent in no-till and tilled treatments (Madden et al. 2004) and, in Brazil, lettuce yields were similar in tilled and no-till organic systems (Oliveira et al. 2006). No-till vegetable systems have produced increased or equivalent yields of snap bean (Abdul-Baki and Teasdale 1997), sweet corn (Griffin et al. 2000), squash (Hoyt 1999), and tomato (Herrero et al. 2001). Carrera et al. (2004) found that cover crops increased no-till sweet corn yields by reducing weed biomass and improving crop competitiveness.

The greatest benefit from organic no-till systems has been demonstrated through soil improvements. Mäder and Berner (2012) found that soil organic carbon, microbial activity and soil structure improved in the upper soil layer under reduced tillage organic systems compared with tilled soils. Additional benefits from cover crops include lower pest insects, diseases and nematodes (Andow 1991; McSorley 1998; Thurston 1992) including lower Colorado potato beetle on potatoes grown with killed vegetative mulches, as the mulch provided habitat for predatory ground beetles (Weber et al. 2006).

Method and Materials. All experiments were conducted on certified organic land (MOSA), using organic practices at the University of Wisconsin West Madison Agricultural Research Station. Research plots were seeded in the fall with four cover crop treatments (cereal rye, hairy vetch, winter wheat, and a rye/vetch mix) and a control plot of no cover in randomized complete block design including four replications. Cover crops were hand sown and lightly incorporated with a tractor mounted tiller at rates of 3 bushels/acre for winter wheat (variety not specified) and winter rye (variety not specified), 40 pounds/acre for hairy vetch (variety: 'Purple Prosperity'), and rye-vetch mix (3 bushels/acre rye plus 40 pounds/acre vetch). Each plot measured 15 feet x 20 feet.

Fall plant density counts were collected after cover crop emergence, counting all plants within a 0.25 square meter quadrat at two random locations in each plot.

In early May, prior to the cover crops exceeding 6 inches in growth, a 9-inch wide band was tilled using a walk-behind cultivator in each treatment plot where the vegetable crops will be sown. Strip tillage was necessary in this system to prevent the cereal grain cover crops within the planting zone from becoming too dense, thus inhibiting planting activities. Additionally, strip tillage facilitated soil warming, thus promoting crop growth. Cover crop biomass samples and soil samples were collected immediately prior to cover crop termination (Figures 1 and 2). Cover crops were terminated with a sickle-bar mower (at anthesis/pollen shed for the cereal grain crops, and at 100% bloom for the vetch crop) prior to vegetable planting. Bell peppers, snap beans, and potatoes were planted into the cultivated strips in each cover crop treatment in early June at 30 inch centered row spacing.

Crops were fertilized with granulated chicken manure (Chickity-Doo-Doo, OMRI) (snap beans 44.8 kg N/ha, bell peppers and potatoes 89.7 kg N/ha) (Bussan et al. 2012) in the case of the snap beans, along the entire row, and for potatoes and peppers concentrated in a circle around the plant. Crops were watered in by watering can immediately after planting, and drip irrigation was installed to water as needed throughout the season. Pest and disease control was applied as follows in accordance with Organic Standards. EF400 fungicide/bactericide (active ingredient clove and citrus oils) was applied to potatoes at a concentration of 1 oz/gallon by backpack sprayer on three occasions, two weeks apart, as a preventative measure against late blight. Pyrethrum extract (Pyganic) was applied as needed to control leaf-hopper damage to potatoes, at a concentration of 1 oz/3 gallons with acetic acid used to bring pH to 5.5 per company recommendation applied by backpack sprayer.

Throughout the growing season, weed variety counts and biomass samples were collected. Soil samples were sent to the University of Wisconsin Soil Testing Laboratories for phosphorous, potassium, nitrate and total nitrogen (N) analysis. All biomass samples were harvested into paper bags and dried at 70 degrees for one week.

Soil fertility tests were conducted at the UW Soil and Plant Analysis Lab using their standard techniques, measuring soil total carbon/total nitrogen, inorganic N (NH4 + NO3), phosphorus and potassium pH, EC, CEC + exchangeable cations (Ca, Mg, K, Na), micronutrients (Zn, Mn, Cu, Fe), nitrate-nitrogen and soil organic matter. Soil respiration (measured using the SOLVITA assay (solvita.com) will be measured as an indicator of soil microbiology and soil health.

Peppers were harvested in late August at the green-ripe stage. All peppers from each plot were harvested. All beans from twenty row feet within each plot were harvested when > 80 % of beans are at maturity. Potatoes were harvested in September. All produce was harvested by hand. Produce from each plot was sorted into marketable and non-marketable groups, counted, weighed, and assessed for quality.

Soil and root samples from pepper and bean plants were taken in both cover crop rye plots and control plots to examine soil microbial populations, an indicator of soil health. These samples were taken from both the strip-tilled areas (representing the rhizophere/root zone of the crop) as well as in the no-till/cover cropped areas between the rows. In addition to overall impacts on soil ecology, plant-growth promoting phenotypes of bacteria involved in nutrient-solubilization and cycling, as well as modulation of plant hormones, were specifically examined. Laboratory assays are currently being conducting comparing the frequency with which these phenotypes are expressed between field treatments, vegetable crops, and location relative to the plant roots (bulk soil in proximity to the roots, on the root surface, and colonizing root tissue). Assays being conducted include tests for production of protease and pectate lyase enzymes, production of the potential plant-growth promoting compounds acetion, 2,3-butanediol, indole-acetic acid, and ACC deaminase, ability to solubilize phosphorus, and production of siderophores to bind soluble iron. This research will help to assess whether no-till cover cropping and soil conservation contribute to the presence of beneficial soil bacteria.

Results Hairy vetch germination and survival through the winter was extremely poor and this treatment was replaced by a straw mulch treatment using straw obtained from off-farm as a positive control. Comparing the 2013 and 2014 biomass, more cover crop biomass was produced in 2013 versus 2014. Across treatments, in 2013, biomass ranged from approximately 1,050 to 1,350 g per meter sq, with wheat producing more biomass than the rye crops (Figure 1). Conversely, in 2014, overall biomass ranged from 850 – 950 g per meter sq., with no significant difference in biomass production between the rye and wheat cover crops (Figure 2). Greater numbers of weeds were found in the wheat mulch as compared to the cereal rye in 2013 (Figure 3). Early season weed density was significantly greater in the control plots than in the rye plots, although later in the season density was comparable (Figure 3). This impacted the in-season labor required for weed management, with wheat plots requiring the most labor and rye plots having management needs similar to the control plots (Figure 4). Later in the 2013 season, weed densities were more similar among treatments (Figure 5). Thus, weeding times were more similar among treatments later in the season, although the control plots required, on average, less labor time to manage weeds (Figure 6). In 2014, weed density in the rye plots was less that of the control plots in the early part of the season (Figure 7). However, labor time required for early season weed management was still greater in the rye plots than in the control plots (Figure 8). Similar to 2014, later in the season, weed densities in the rye and control plots were similar (Figure 9), although labor time for weed management was less in the control plots than in the no-till plots (Figure 10).

Pepper plants in the no-till rye plots yielded similarly to the control plots in both 2013 in 2014 (Figure 11). In both seasons, peppers from the wheat plots yielded less than in the rye plots. Pepper yields from the straw mulch plots varied; in 2013, the peppers in the straw mulch had greater yields than the other treatments, while in 2014, peppers from the no-till plots out-yielded the straw mulched plots (Figure 11). Bean yield was greater in the control plot relative to the no-till and mulch treatments (Figure 12). In 2014, weed pressure due to volunteer oats in the straw mulch probably impacted this treatment so as to significantly decrease yield (Figure 12).

Potato yields were not significantly different among treatments in 2013 (Figure 13). Wheat treatments showed a lesser potato yield than the other mulch treatments, although yields were not significantly different than other treatments. In 2014, however, there was a greater yield of potatoes from the control plot (Figure 13). Although weed pressure may be a factor, damage caused by potato leafhoppers and rodents decreased the harvest of marketable potatoes in 2014. There was a greater incidence of loss due to these factors in the mulched plots, probably due to their providing a preferable habitat for pests.

These results suggest the fruitfulness of future work with winter rye as a cover crop, together with other varieties of winter hardy vetch or red clover to add nitrogen fixation to the benefits of this system. Overall, adequate cover crop biomass production was found to be a key factor in determining the extent of weed suppression and productivity of this system. One shortcoming of this experiment was that it only ran for two seasons, in adjacent but different fields, limiting the assessment of long-term impacts on soil health. Given the high weed density both years, we would recommend that farmers manage the initial weed seed bank before attempting this method for long-term weed control. Cooler soil, production of allelopathic compounds by rye, and slower cycling of organic matter from the cover crops to replenish soil nutrients may also impede growth in cover cropped plots. Future research should take into account the impacts of these factors. It would also be helpful to experiment with other vegetable crops.

One measurement of soil health that we pursued was the assessment of the impact of organic no-till production on soil biology. Our initial bacterial assays do not show a significant difference in enzymatic activity or production of plant-growth promoting compounds between rye and control plots. As expected there is greater incidence of these phenotypes in samples taken from the root surface (the rhizophere) than in the bulk soil. Laboratory work with bacterial samples is ongoing and will be completed by this summer. Impacts of no-till production on mycorrhizal growth, longer term effects, once the organic matter of the cover crops is fully broken down and corroboration with other techniques to measure impacts on the microbial community, would be advisable for future research.

Outreach

This research is part of a larger cover crop project that includes on-farm trials at organic farms and is overseen by a 10-member organic farmer advisory panel (including representatives from Troy Community Gardens and the FairShare Community Supported Agriculture Coalition). Initial findings were presented at a 2013 Organic Field Day at the West Madison Agricultural Research Station and incorporated into a larger no-till organic presentation at the 2014 Organic Field Day. Feedback on this research was solicited from farmers interested in utilizing cover-crop based reduced tillage in urban areas at the Growing Power Small and Urban Farmer's conference in Milwaukee and from several organic vegetable farmers in southeastern Wisconsin. This research was presented at the 2014 American Society of Agronomy-Crop Science Society of America-Soil Science Society of America meetings in Long Beach, CA and discussed with from organic researchers working with these methods within the Organic Management Systems Community. A poster presentation of soil microbiology aspect of this work was presented at the 2014 American Phytopathological Society-Canadian Phytopathological Society meeting in Minneapolis. Although the research was led by Anne Pfeiffer as a core part of her graduate thesis, the support from Ceres Trust was further leveraged and incorporated the involvement of a second graduate student, Eric Bietila.

Figure 1. Cover crop biomass at anthesis (g per meter sq.), 2013.

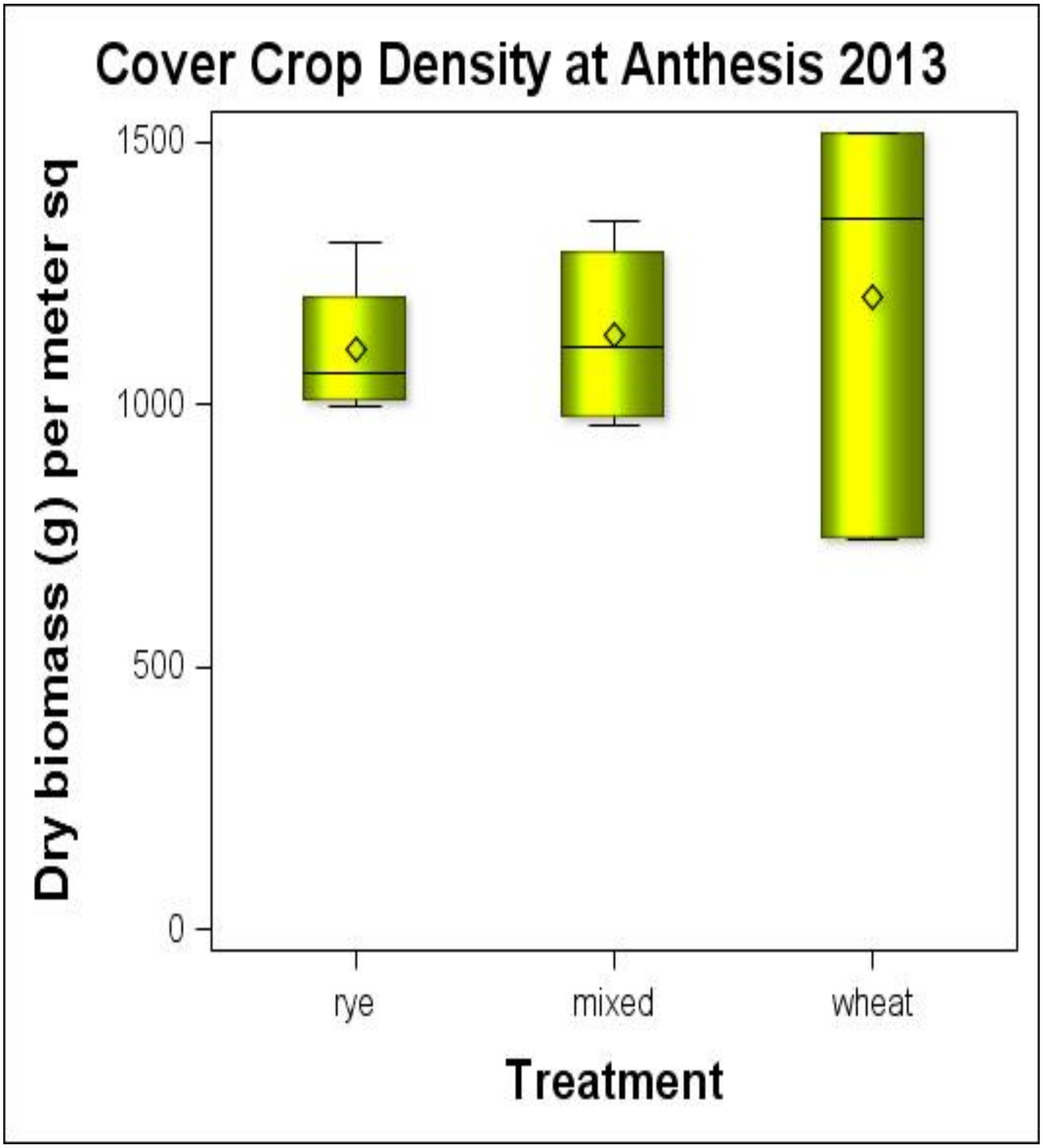

Figure 2. Cover Crop biomass at anthesis (g per meter sq.), 2014.

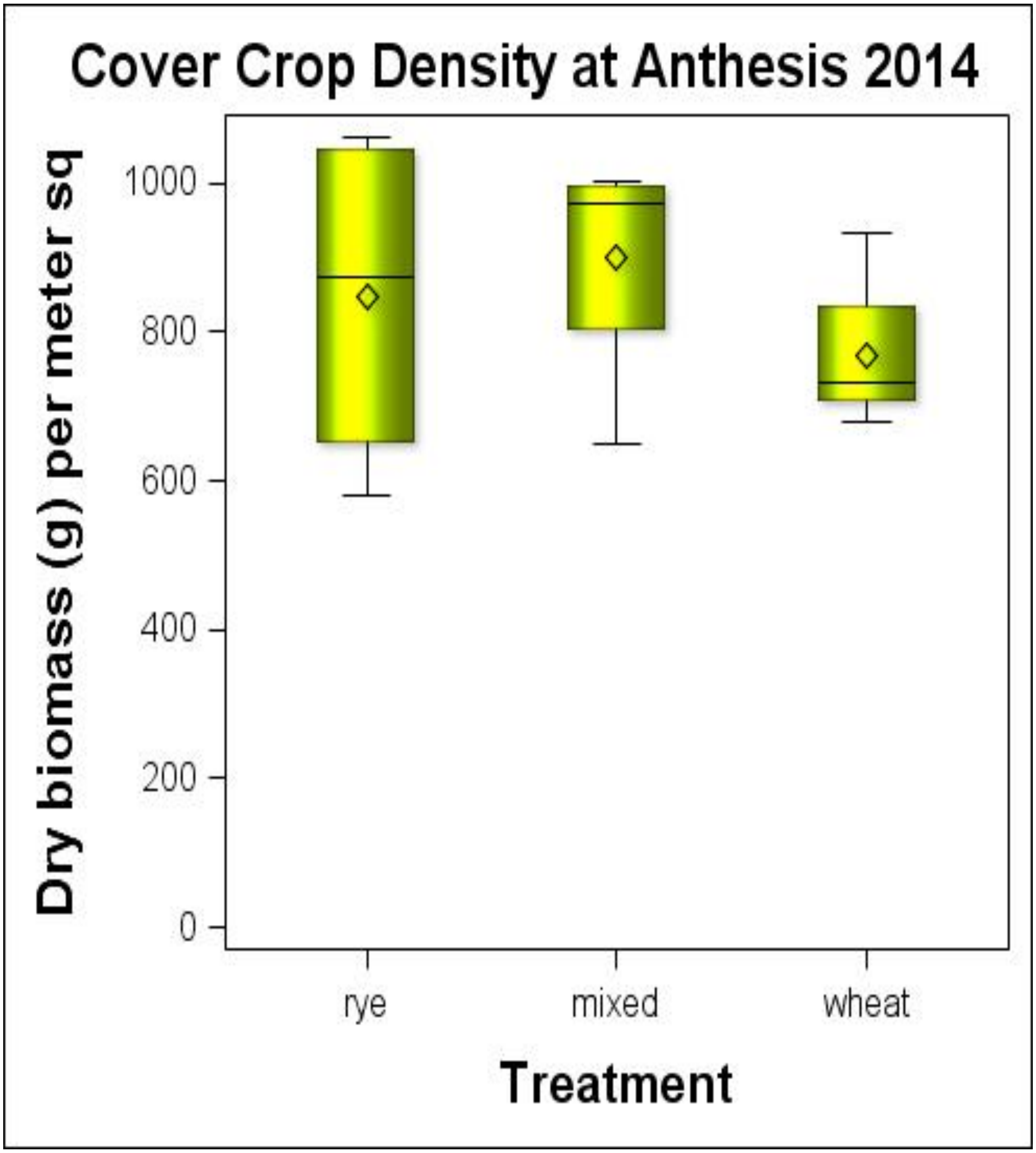

Figure 3. Weed density in treatments early in the production season, 2013.

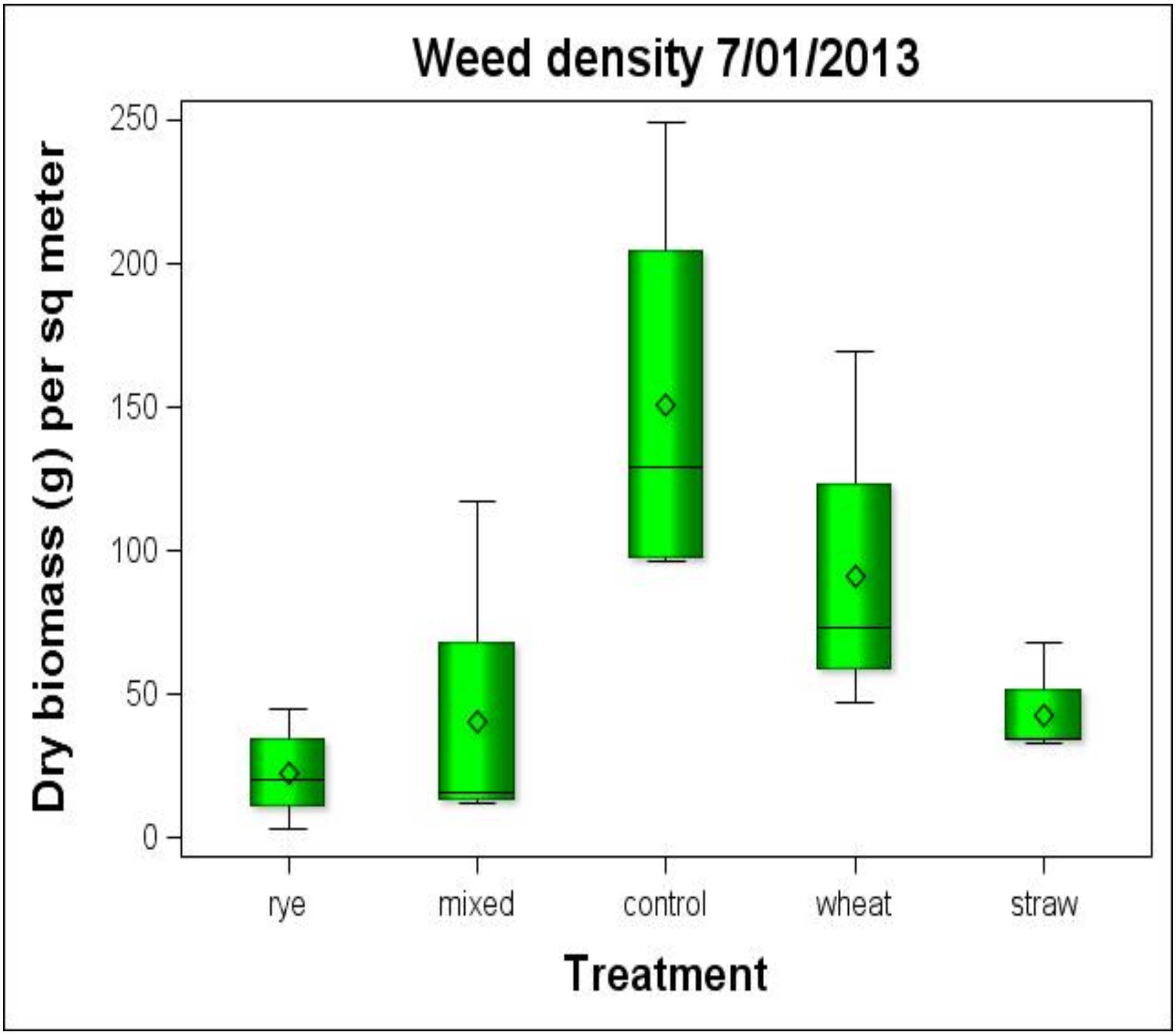

Figure 4. Labor time required for weed management in each of the treatments early in the production season, 2013.

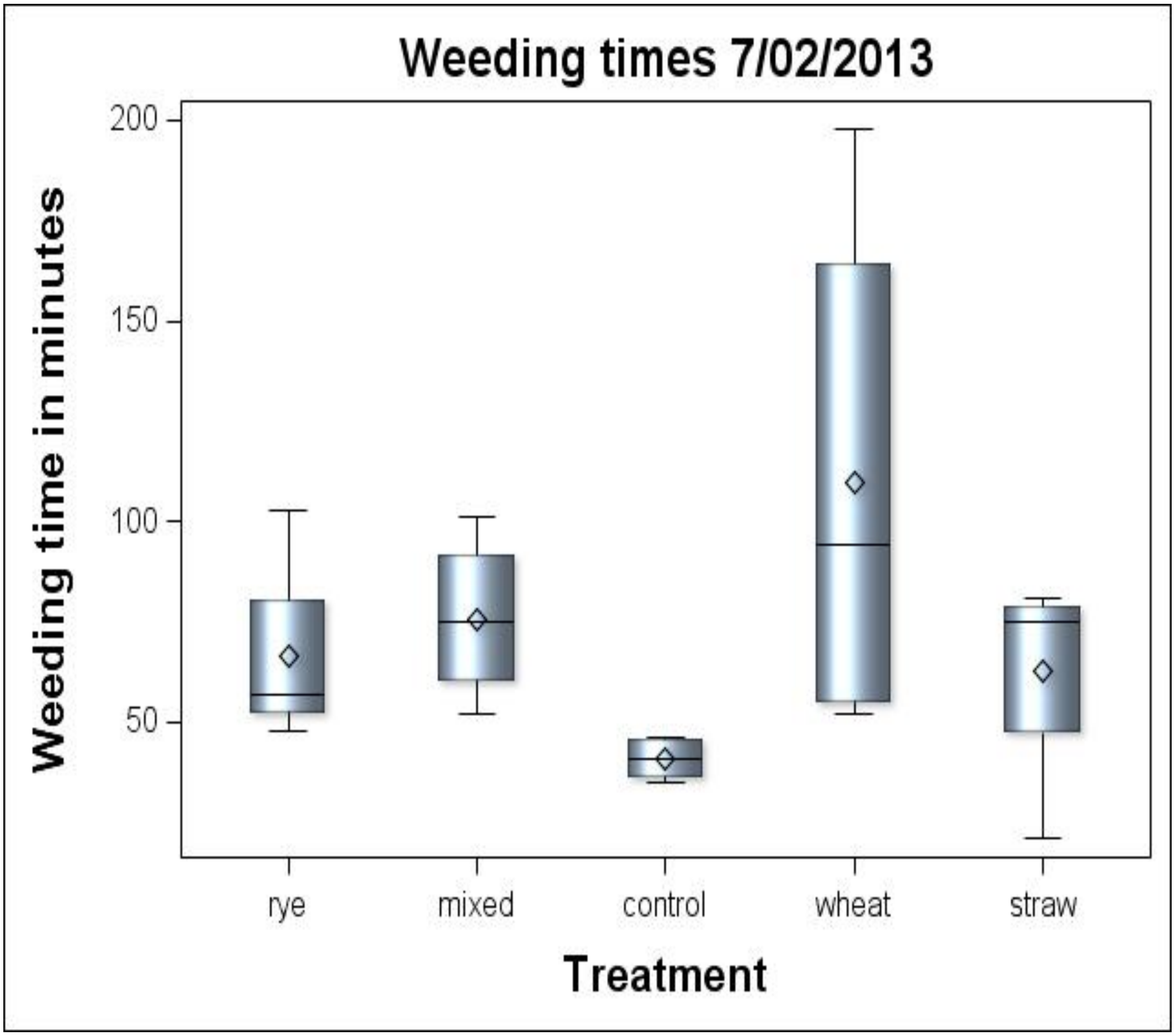

Figure 5. Weed density in treatments in mid-production season, 2013.

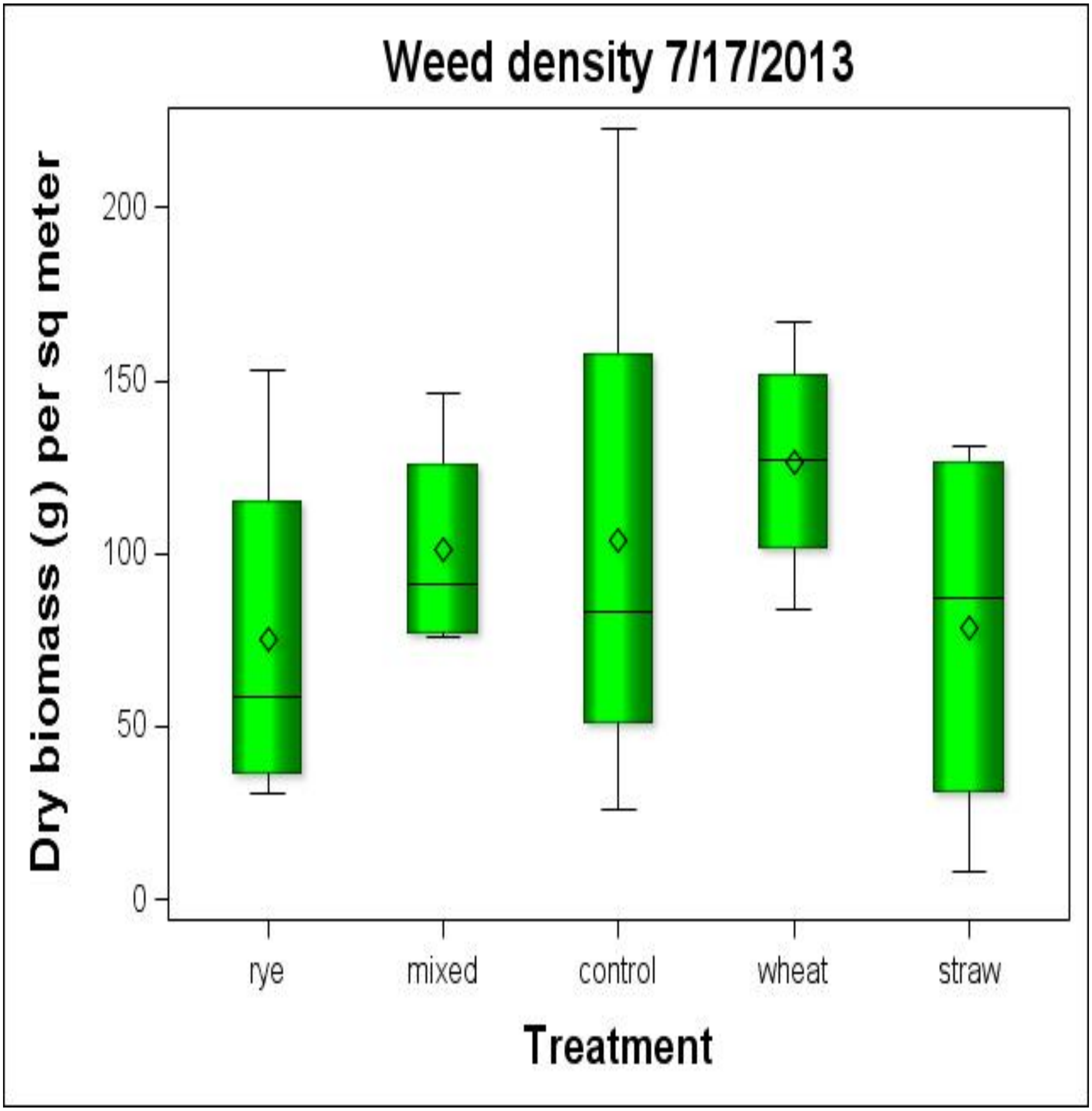

Figure 6. Labor time required for weed management in each of the treatments in mid-production season, 2013.

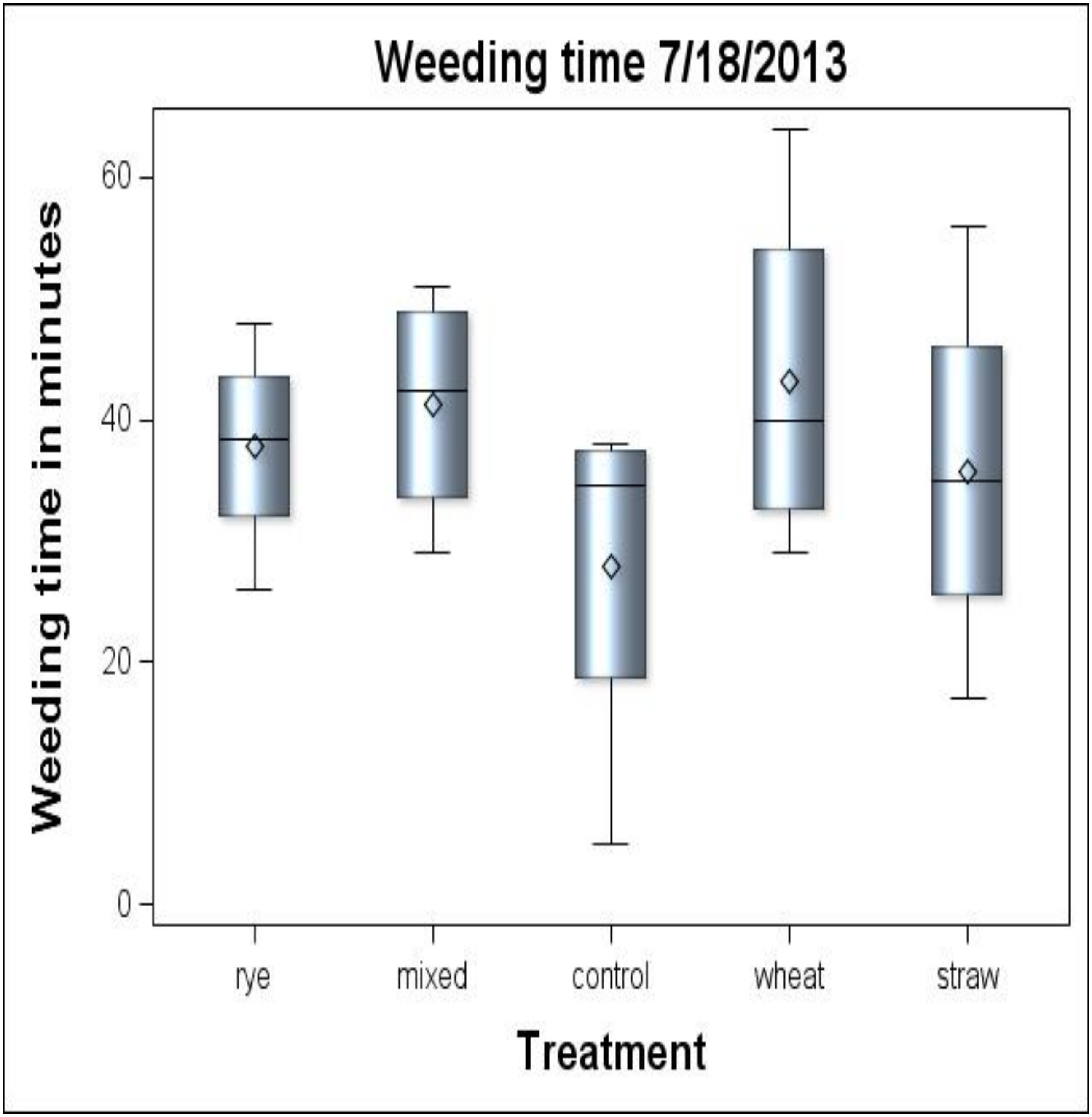

Figure 7. Weed density in treatments early in the production season, 2014.

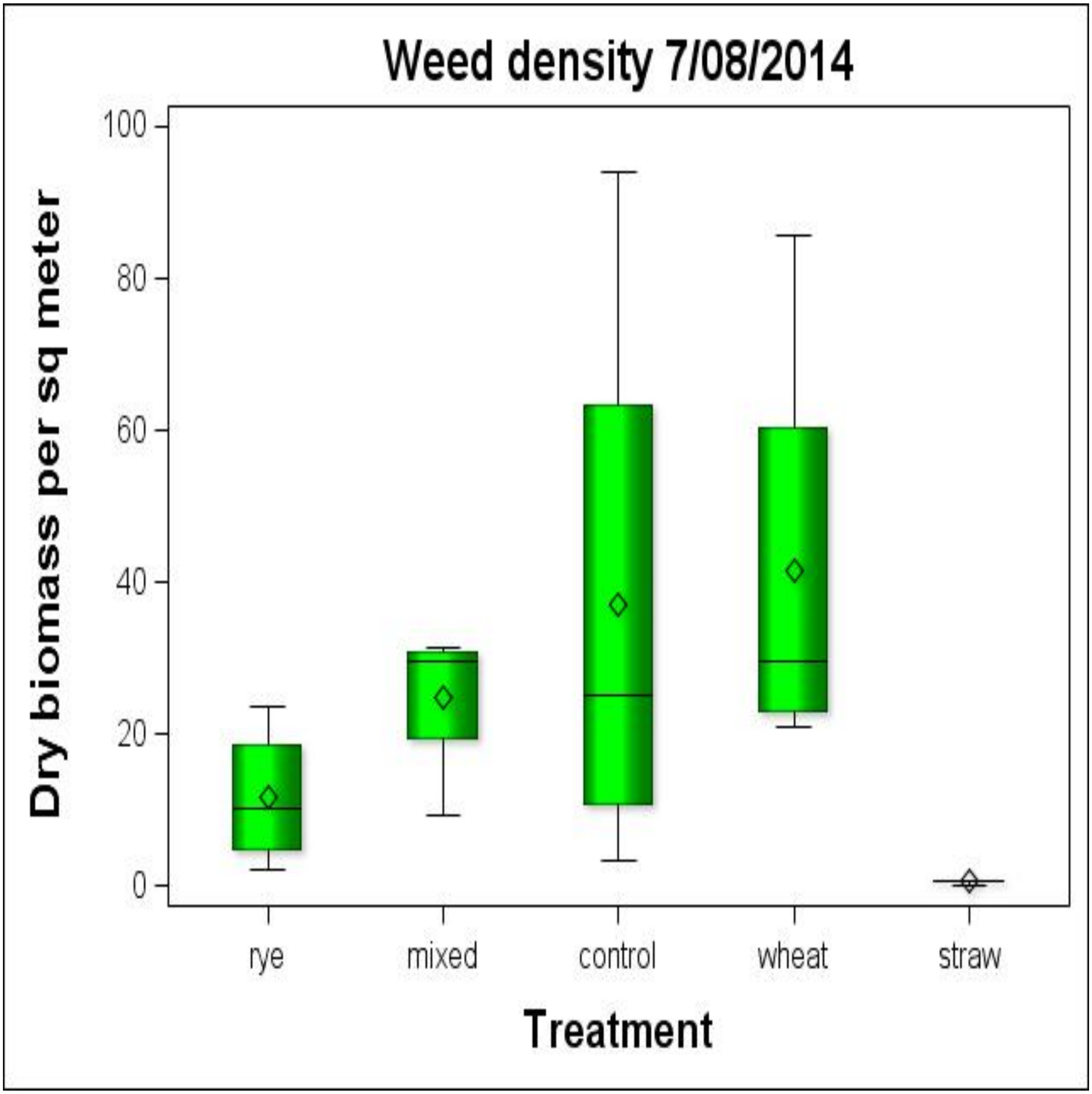

Figure 8. Labor time required for weed management in each of the treatments early in the production season, 2014.

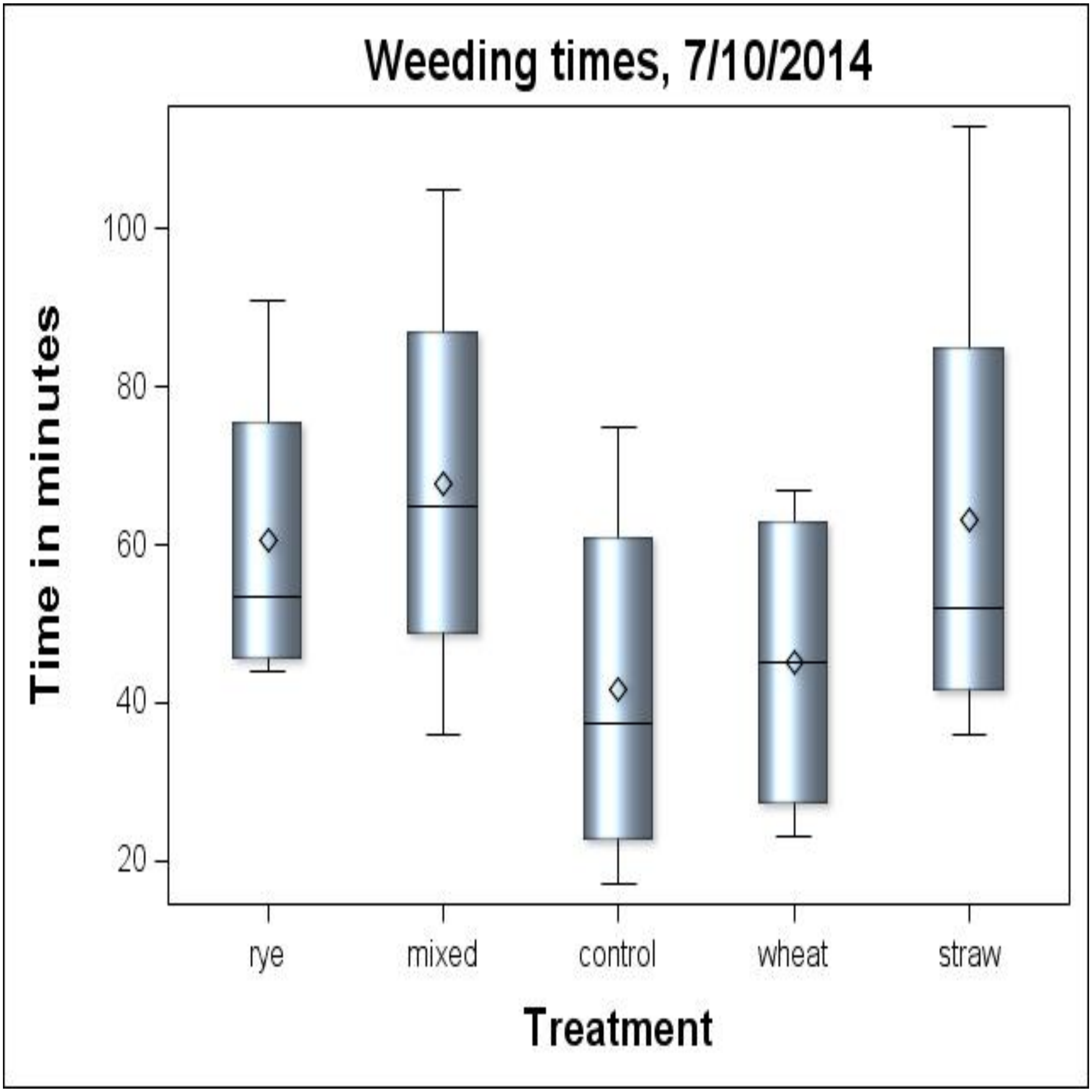

Figure 9. Weed density in treatments in mid-production season, 2014.

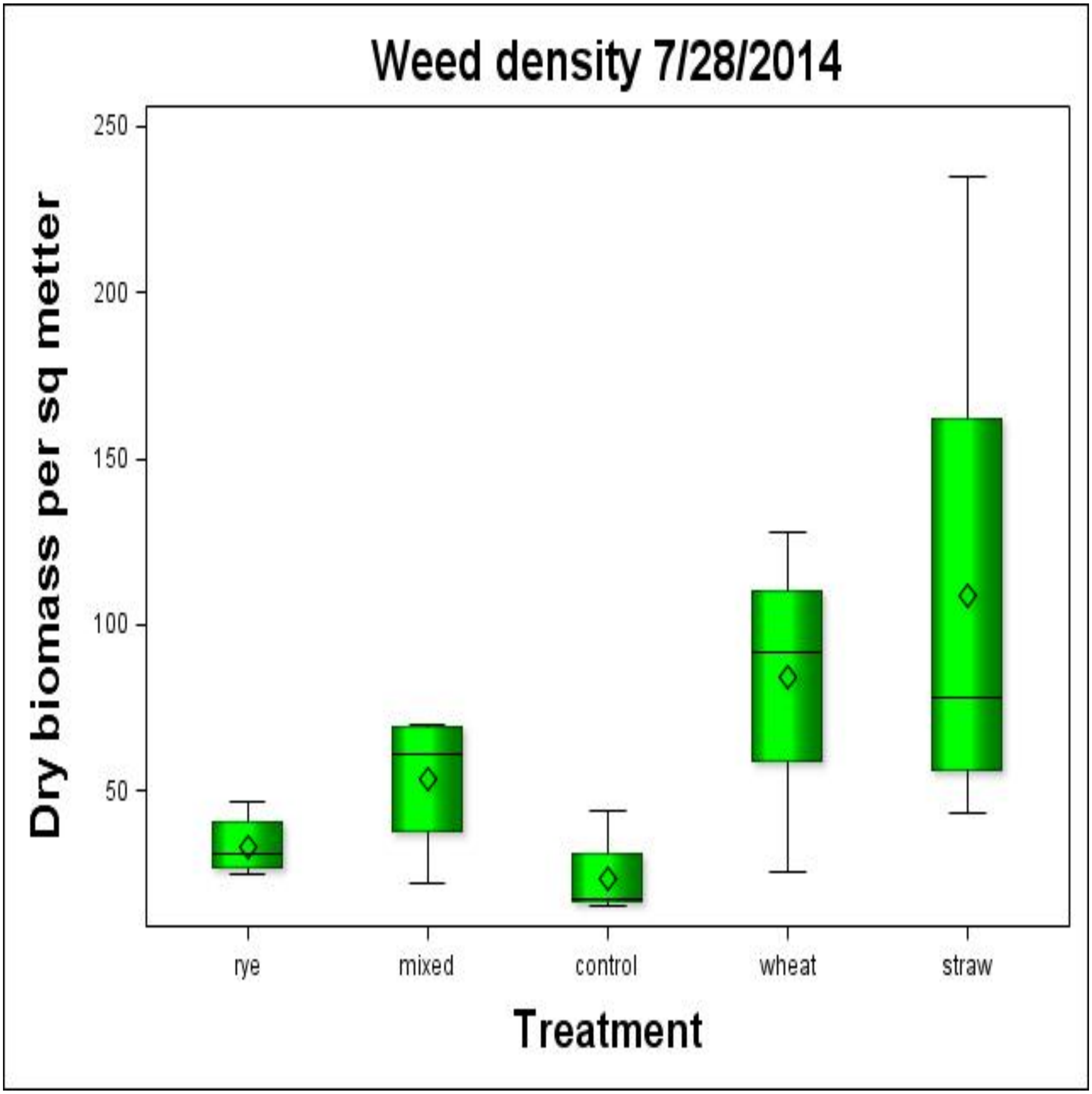

Figure 10. Labor time required for weed management in each of the treatments in mid-production season, 2014.

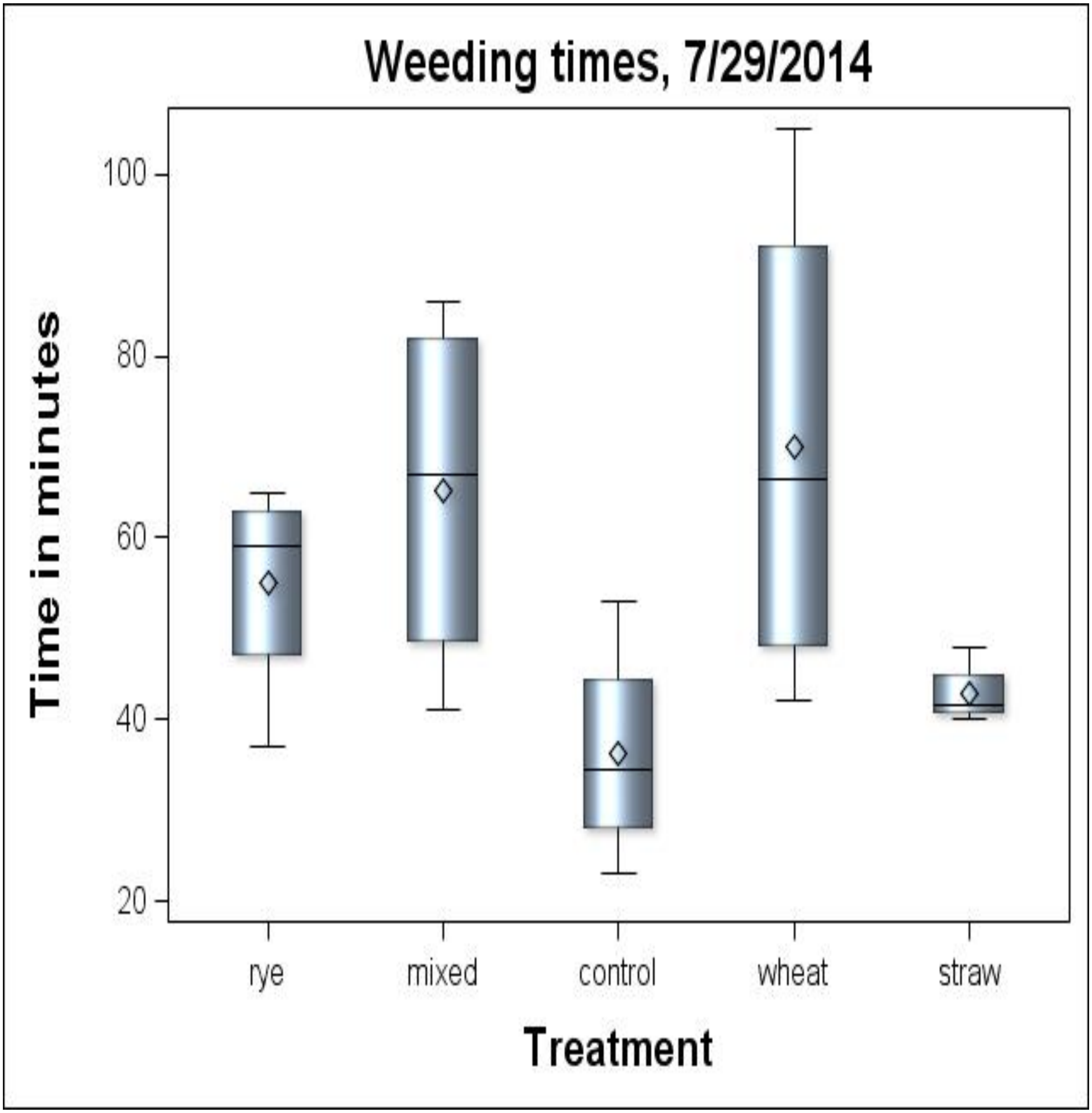

Figure 11. Pepper yields in no-till and control treatments, 2013 and 2014.

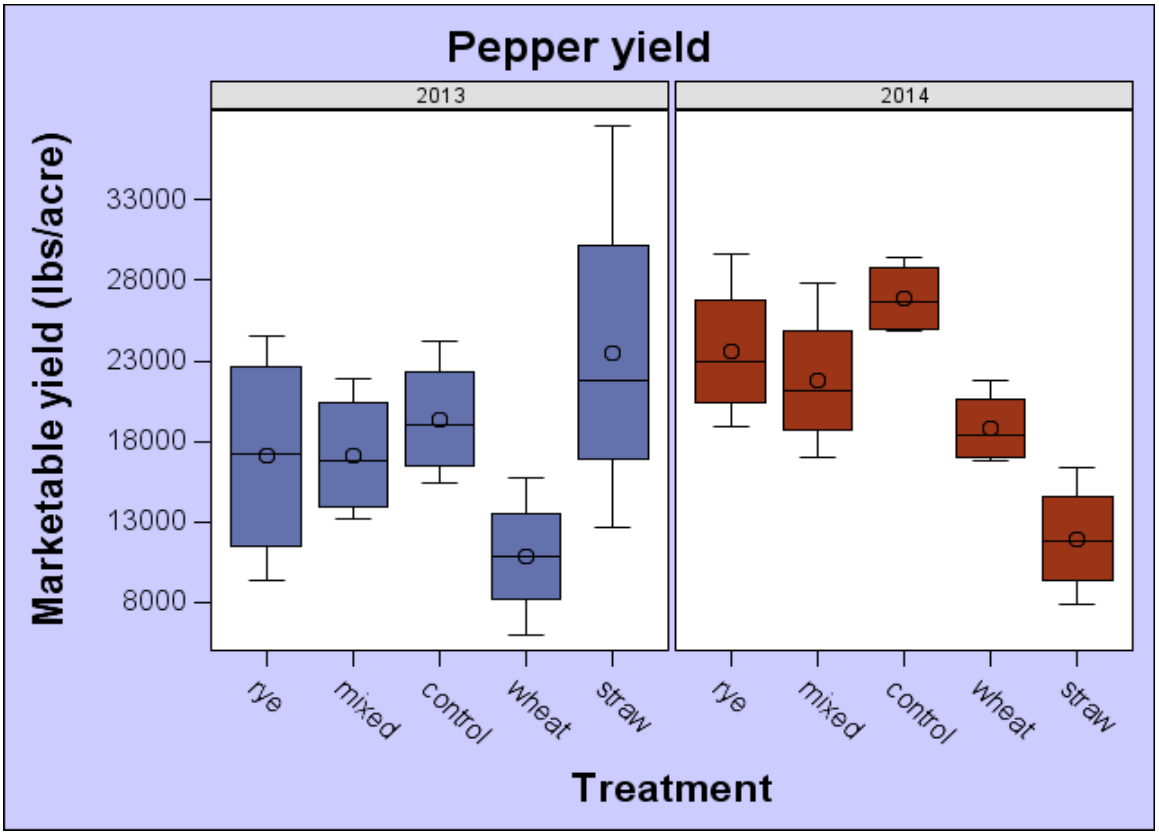

Figure 12. Bean yields in no-till and control treatments, 2013 and 2014.

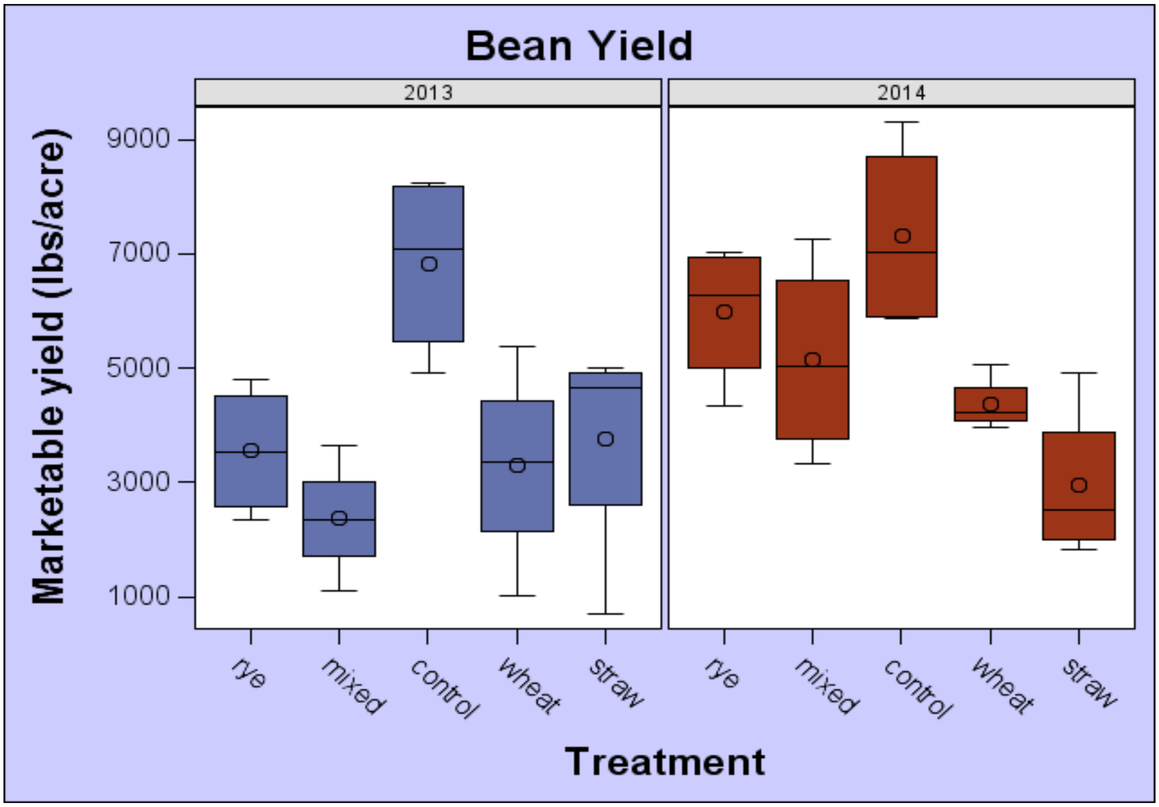

Figure 13. Potato yields in no-till and control treatments, 2013 and 2014.

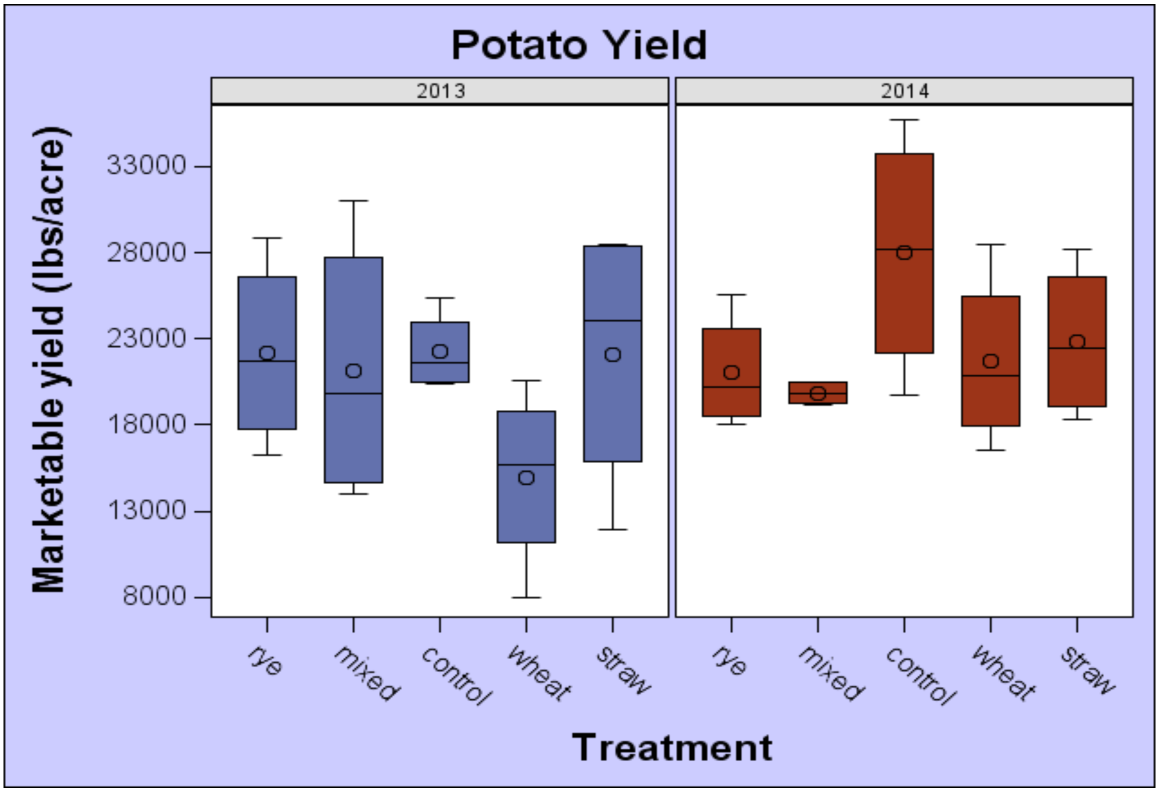

Figure 14. Photograph of equipment similar to that used to mow plots in this experiment.

Figure 15. Photograph of potato plants growing in no-till rye plots, 2014.

Figure 16. Photograph of potato plants growing in no-till rye plots, 2014.

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