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EVALUATING FERTILIZER RATE, CROP ROTATION AND TRAP CROPS FOR EFFECTS ON ONION
GROWTH AND YIELD, SOIL HEALTH, THRIPS DENSITIES AND IRIS YELLOW SPOT VIRUS INCIDENCE

by

Kristine R. Buckland

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Plant Science

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2011

ABSTRACT

Evaluating Fertilizer Rate, Crop Rotation and Trap Crops for Effects on Onion Growth and Yield,
Soil Health, Thrips Densities and Iris Yellow Spot Virus Incidence

by

Kristine R. Buckland, Master of Science

Utah State University, 2011

Major Professor: Dr. Jennifer R. Reeve
Department: Plants, Soils, and Climate

Onion production in the United States is seriously affected by the tospovirus Iris Yellow Spot (IYSV), whose symptoms include lenticular-shaped lesions that reduce photosynthesis and bulb yield. *Thrips tabacai* Lindeman, onion thrips (OT), is the only known vector of the disease and a primary arthropod pest of onion. Frequent insecticide applications, increasing resistance in OT populations to insecticides, high nitrogen (N) fertilization rates and loss of yield to disease and insect pressure threaten sustainable onion production. The objectives of this study were to identify crop management strategies to enhance onion productivity while suppressing OT and IYSV. Three fertilizer rates and two crop rotations were assigned to replicated plots to assess effects on onion growth, yield, bulb storage quality, soil quality, thrips populations and IYSV incidence. Trap crops of carrot, buckwheat and lacey phacelia were established in commercial fields to evaluate impact on thrips populations and IYSV occurrence. Reduced nitrogen (N) rates, one-third the standard grower rate ($133.8 \text{ kg N ha}^{-1}$), resulted in no yield loss as compared with the standard N rate, despite slower crop maturation. Onions treated with a standard N rate

(401.8 kg N ha⁻¹) had greater numbers of adult and immature OT than other treatments. Soil nitrate levels were lower and microbial activity measured as dehydrogenase and biomass were greater in reduced N treatments. Plots with buckwheat and phacelia had greater numbers of both adult and immature OT when trap crop apparancy was high (i.e. when onion plants were relatively smaller). There was no observed effect of trap crops on IYSV levels. Results suggest that reduced rate N applications lower numbers of OT while enhancing the microbial population, reducing potential for nitrate leaching while still maintaining yields. Potential for trap crops of buckwheat and lacey phacelia to attract onion thrips from onions exists with successive stands of highly apparent trap crops.

(132 pages)

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Kristine R. Buckland

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CHAPTER I

GENERAL INTRODUCTION

Onion production in the western US has been negatively affected by Iris Yellow Spot Virus (IYSV). Symptoms were first recorded in the late 1980s in the Treasure Valley region of Idaho and Oregon (Gent et al., 2006). The virus was formally identified and the genome mapped in the late 1990s as a Tospovirus, family *Bunyaviridae*, with different strains thought to have arisen in Europe, South America and Asia. Rate of onion infection has increased rapidly and the main focus of slowing its spread is effective control of the only known vector, *Thrips tabaci* Lindeman, onion thrips. Besides the direct feeding injury caused by onion thrips, the IYSV infected adult may transmit the disease to numerous plants in its adult life span of 20-40 days (Jones, 2005). In neighboring Colorado, IYSV incidence rates skyrocketed from 5.6% to 73.2% of survey fields in only 3 years and caused an estimated yield loss of 5%-10% (Gent et al., 2004; Gent et al., 2006). Manifestation of IYSV symptoms includes elongated or lenticular-shaped lesions. These lesions reduce effective photosynthetic leaf area and may coalesce to completely girdle the leaf (Gent et al., 2006). It is not uncommon, however for onion tissue to test positive for the virus while the plant is asymptomatic (Gent et al., 2004; Hsu et al., 2010). The reason for differential manifestation of disease symptoms is not well understood, but is thought to be a factor of plant stress. Recent research suggests a possible link between cultural practices and reduced exposure to IYSV and thrips damage (Gent et al., 2006). Reducing overall nitrogen (N) inputs, encouraging natural predatory insect populations, and effective use of thrips trap crops could provide significant advantages in overall health of the onion crop (Trdan et al., 2006; Malik et al., 2009).

Onion is a high value crop and typically treated with high rates of synthetic fertilizers to ensure acceptable yields and large bulb size (Drost and Koenig, 2002). Nitrogen (N) applications typically exceed 300 kg N/ha. The result is that nitrogen use efficiency in onion can be as low as 15% in some systems (Halvorson et al., 2002). Low N use efficiency coupled with irrigation and seasonal precipitation risks moving the excess N below the root zone of the subsequent rotation crop. Halvorson et al. (2002) showed only a 24% recovery of excess N in a corn succession in SE Colorado which produced a total recovery for two seasons of just 39%. The unrecovered N poses a significant threat to ground water. Nitrate contamination has been well documented as a by-product of intensive agricultural practices with significant health risks and environmental impacts (Doran and Zeiss, 2000). Concerns of excessive $\text{NO}_3\text{-N}$ leaching have stimulated many researchers to re-evaluate nitrogen fertilizer application rates and timing (Drost and Koenig, 2002). Halvorson et al. (2002) suggest delaying N application to coincide with increased demand in late June before a period of rapid leaf development and the onset of bulbing in July. Drost and Koenig (2002) note that a carefully structured N application in conjunction with plant growth stage can minimize N loss. Another possibility is use of slow release N as a more suitable supply to the onions with less environmental risk (Drost and Koenig, 2002).

Besides the potential for environmental impacts, research suggests high-N fertilization may produce attractive conditions for onion thrips. Previous research on herbivorous insects shows a strong tendency to favor plant tissue where soluble N is increased (White, 1984). Numerous stressors such as drought or nutrient stress increase the amount of soluble N within the plant (Mattson, 1980). The same effect can be achieved through provision of excess readily available soil N (White, 1984). A field study conducted in Pakistan compared the impact of N

rate on thrips populations as well as overall yield. Over 70% increase in thrips numbers was observed at high levels of N (200 and 250 kg ha⁻¹) when compared to moderate and low N inputs (0, 50, 100, or 150 kg ha⁻¹). These results suggest that low and moderate N amendments have no effect on thrips populations whereas a high rate significantly increases populations (Malik et al., 2009).

Onion thrips, the main pest species in onion, have a large host range including other crops and some weed species common in the western US (Gent et al., 2006). Besides vectoring IYSV, onion thrips reduce yields, shorten bulb storage life and reduce overall quality (Kendall and Capinera, 1987; Larentzaki et al., 2007). Onion thrips prefer overwinter in the soil of non-rotated fields, in onion cull piles or on volunteer onions (Larentzaki et al., 2007). This persistence in and around the onion cropping system may promote insecticide resistance in addition to providing a source of early season infestation (Larentzaki et al., 2007). Growers currently rely on poorly to modestly effective insecticides which require application as frequently as every 7-10 days from June through August. As onion thrips reproduce quickly and eggs are laid inside the leaf tissue, many traditional contact insecticides are limited in their effect. These costly insecticide applications provide varied levels of control in a thrips population that has become increasingly resistant. In New York, over the course of about 40 days, one insecticide showed a reduction in mortality rate from 80.9 to 6.1%. A single season gain in tolerance of this level is incredible (Shelton et al., 2006).

The practice of integrating trap crops into a system takes advantage of the inherent preference of thrips to feed on flowering, attractive plants. By luring the pests into a non-crop species, overall damage to the crop and potential to transmit disease may be reduced (Buitenhuis and Shipp, 2006). Little research has been conducted to evaluate intercropping

possibilities and the possible re-distribution of thrips. Trdan et al. (2006) showed that onion thrips were highly attracted to *Phacelia tanacetifolia* Benth., lacey phacelia, and *Fagopyrum esculentum* Moench., buckwheat, with limited attractiveness to *Dactylis glomerata* L., orchard grass, and *Trifolium repens* L., white clover. However, the competition between onions and the intercrop negatively impacted onion yield (Trdan et al., 2006). Perhaps a more useful system would include these attractive species as trap crops, therefore limiting their competitive effect on the onion crop, generally a poor competitor. A greenhouse study on *Fankliniella occidentalis* Pergande, western flower thrips, suggested not only is the species of trap crop critical but also the stage of development of the potential trap crop (Buitenhuis and Shipp, 2006).

Other key factors in the dispersal of thrips into and within an onion field include wind and distance between attractive plants (Buitenhuis and Shipp, 2006). Environmental factors including degree-days (temperature) and precipitation may account for over half the variation in the initial population peak of onion thrips (Morsello et al., 2008). A study in Sudan, also a semi-arid climate, showed the impact of irrigation on thrips population numbers. The study demonstrated that at longer irrigation intervals there were less thrips present. However, the most frequent irrigation interval of 6 days showed the greatest yield despite high thrips numbers. The authors suggest that stress resulting from longest irrigation intervals made plants less attractive to thrips while the healthy, well irrigated plants were able to tolerate the thrips damage (Kannan and Mohamed, 2001).

The impact of seasonal growing conditions as well as plant nutrient stress can have a major influence on pest populations (Mattson, 1980; White, 1984). Recent research has linked some soil characteristics such as pH and sodium with thrips or IYSV incidence (Schwartz et al., 2010). Overall soil quality is directly affected by management strategy and may have significant

impact on pests and crop production. Doran and Zeiss (2000) expand on this idea, adding “soil condition also impacts water and air quality” with the emphasis of increasing widespread degradation due to intensive management practices. Soil quality is a broad subject that can be assessed through various measurements of physical, chemical and biological attributes.

According to Gil-Sotres et al. (2005), to accurately assess soil health, biochemical properties such as dehydrogenase activity and soil respiration provide essential information on the biological health of the soil. These tests examine the relative efficiency and activity levels of soil microbial populations. Soil microbes play a critical role in nutrient cycling, disease suppression and can even reduce the viability of overwinter pests. While increasing soil organic matter with inputs of compost or manure can enhance microbial populations and nutrient cycling, the cost can be prohibitive on a large scale. As a substitute, there is increasing interest by growers in the use of soil biostimulant amendments in an attempt to increase the microbial populations to enhance these effects. Chen et al. (2002) examined two commercial biostimulants under laboratory conditions for their effect on dehydrogenase activity and soil respiration. Both biostimulants increased respiration at low concentrations (similar to field application rates) but inhibited dehydrogenase activity to differing degrees. The authors suggest that the biostimulant may have increased fungal activity levels but not necessarily bacterial levels (Chen et al., 2002).

Within a cropping system, many common agricultural practices positively impact soil microbial activity. For example, the addition of glyphosate has been shown in some studies to have the potential to increase total microbial biomass, most likely from the herbicide serving as a readily available carbon source (Haney et al., 2002). In general, these effects are heavily dependent on soil texture, crop rotation and residues returned to the soils, and variability of seasonal weather. Microbial response to fertilizer is highly dependent on the source and

amount of carbon (C) available as well as the C:N ratio of resources. Inselsbacher et al. (2010) reported significant microbial reaction to fertilizer input. The two different soils examined showed a strong, short lived, highly competitive response to fertilizer addition measured with ^{15}N tracer. However, within the first 24 hours after fertilizer addition, microbial biomass and N uptake significantly decreased. The authors suggest this resulted from a carbon limitation (Inselsbacher et al., 2010). Similarly, another study on a *Pinus taeda* L., loblolly pine, plantation over a two year period described a negative impact on microbial biomass and activity with addition of urea and diammonium phosphate. These same fertilized plots also showed reduced soil organic matter which the authors concluded was a function of increased microbial C usage (Blazier et al., 2005).

The goal of this study was to take a whole farm approach to the management of onions, onion thrips and IYSV disease. The whole farm approach examines the impact of inputs such as fertilizer not only on crop development and yield, but also on ecosystem status such as insect populations, disease incidence, soil quality, and environmental risk. The study took place in northern Utah, with replicated field trials at the Utah State University Experiment Station in Kaysville, as well as on two commercial onion fields near Corrine, Utah. The experiment station research compared the effect of two crop rotations and three fertilizer treatments on onion growth, yield, and storage quality; thrips populations; soil health and quality; and IYSV incidence. The on-farm research tested the efficacy of three trap crops on attracting onion thrips and reducing IYSV.

This thesis is divided into four chapters. Chapter I provides an overview and goals of the entire project. Chapter II details two seasons of onion production where the effects of prior crop rotation and fertilizer treatments on crop quality, insect pressure, disease and soil quality

were examined. Chapter II is to be submitted to *Agriculture, Ecosystems and Environment* and is formatted according to that journal's submission requirements. Chapter III presents the on-farm trap crop trials. It is to be submitted to *Agricultural Systems* and is formatted accordingly. Chapter IV provides a conclusion and suggestions for further research. Kristine Buckland is primary author on all chapters with Jennifer Reeve, Dan Drost, Diane Alston and Claudia Nischwitz as co-authors.

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CHAPTER II

EFFECTS OF NITROGEN FERTILIZER RATE AND CROP ROTATION ON ONION GROWTH AND YIELD, THIRPS DENSITIES, AND IRIS YELLOW SPOT VIRUS INCIDENCE¹**Abstract**

Onion production in the western United States suffers significant damage from iris yellow spot virus (IYSV) and onion thrips. IYSV is thrips vectored and primary control is from heavy insecticide use, resulting in an increase in pesticide resistance and virus spread. The objective of this study was to identify crop management strategies to enhance onion productivity and suppress thrips and IYSV. Three fertility programs and two crop rotations were tested for their effects on onion growth and yield, soil properties, thrips density and IYSV incidence. Thrips adult, nymph and egg populations were monitored from whole plant and leaf samples of onion. Reduced nitrogen (N) input (133.8 kg N/ha, one-third the standard grower rate), resulted in no significant reduction in yield or storage quality; however time to crop maturity was delayed as compared to the standard rate of N fertilizer (401.83 kg N/ha). Soil microbial¹ activity, as measured by dehydrogenase activity, was decreased by the higher N treatment. Soil biostimulant applications coupled with the low rate N fertilizer showed no effect on microbial activity. The standard N rate treatment also had greater soil nitrate levels and numbers of adult and immature as compared to lower N treatments. Soil microbial biomass and readily mineralizable carbon was greater after wheat than after corn. Results suggest that reduced N treatment, when not coupled with biostimulant application, decreased attractiveness

¹ Coauthored by K. Buckland, J.R. Reeve, D. Alston, C. Nischwitz, D. Drost

of onions to thrips, created a more favorable environment for microbial activity and reduced threat of nitrate leaching while sustaining onion yields.

1. Introduction

Allium cepa L., bulb onion, is a high value crop in Utah and the western United States. From 2000 to 2004, farm-land planted to onions in Utah was over 2,000 acres with a farm value between 4 and 10 million dollars (NAAS, 2006). Due to the high value of the onions, crops are intensively managed, frequently with short rotations, high fertilizer applications and aggressive use of insecticides to suppress *Thrips tabaci* Lindeman, onion thrips (OT). Despite intensive management, yield loss due to thrips and diseases can be severe. Primary thrips control options include pyrethroid or carbamate insecticide sprays, which may be applied as often as every 7-10 days (Shelton et al., 2006). High control cost, removal of beneficial insects and increasing insecticide resistance are causes for concern (Larentzaki et al., 2007; MacIntyre et al., 2005). In addition to economic losses associated with feeding damage, OT also vector Iris Yellow Spot Virus (IYSV). Iris Yellow Spot Virus causes lenticular shaped lesions on leaves and has emerged as a serious threat to onion production world-wide (Pappu et al., 2009). Conservative estimates of 5-10% yield loss to IYSV have been reported in Colorado (Gent et al., 2006). While some varieties appear less susceptible to the virus, no resistant variety is currently known (Gent et al., 2006).

Although OT feeding damage alone may hamper yield by reducing available nutrients during the onion bulbing stage (Kendall and Capinera, 1987), virus transmission remains the largest threat to sustainable onion production throughout the nation (Gent et al., 2004; Gent et al., 2006). A history of onion production in a particular field or region may have dramatic impacts on thrips populations and IYSV due to the presence of overwintering adults in soil, bulb

cull piles or a wide range of alternate weed hosts (Larentzaki et al., 2007). Early season thrips infestations in the fields allow a longer timeline for virus transmission, as well as more exposure to closely related insecticide. Increased insecticide exposure coupled with fast generation times over several years have dramatically increased OT resistance rates (Larentzaki et al., 2007; Shelton et al., 2006). Single season increases in resistance have been recorded at over 70% of population (Shelton et al., 2006).

Not only is pest control a major concern in onion production, nutrient management is difficult due to a shallow rooting depth which often results in applications of high fertilizer rates. Applications of high rates of fertilizer may increase nitrogen in onion tissues as well as crop apparancy to pests. An increase in soluble N in plant tissues can be caused by excessive mineral N applications in a similar manner as nutrient deficiency or moisture stress increase tissue N levels (White, 1984). Onions treated with various levels of mineral N applications showed heaviest OT pressure in plots receiving highest N-fertilizer rates with populations over 70% higher than in untreated control plots (Malik et al., 2009). Other soil parameters may also impact both IYSV severity and thrips pressure. In Colorado onion fields, IYSV symptoms increased with an increase in certain soil characteristics such as pH, organic matter, sodium and other micronutrients. Conversely, in another recent study, soil pH and thrips counts were negatively associated (Schwartz et al., 2010).

Fertilizer use efficiencies (FUE) in highly managed onions can be as low as 15%. Following onion production with highly efficient N users such as corn to maximize nutrient recovery may yield net nutrient capture of only 39% over two seasons (Halvorson et al., 2002). Nitrate contamination has been well documented as a by-product of intensive agricultural practices with significant health risks and environmental impacts (Doran and Zeiss, 2000).

Concern of excessive $\text{NO}_3\text{-N}$ leaching in onion has prompted a re-evaluation of fertilization application rates and timing. Reduced total inputs applied in slow release formulations have proven effective in maintaining high onion yields (Drost and Koenig, 2002).

Not only does N fertilizer rate affect crop growth, but the soil microbial population may be impacted. Soil microbes have been shown to serve important roles in disease suppression and nutrient cycling (Gil-Sotres et al., 2005; Larkin, 2008; Peters et al., 2003). Many physical, chemical and biological measurements can characterize the overall health of soil. Dehydrogenase and respiration analysis focus on the relative size and efficacy of microbial populations in nutrient cycling (Gil-Sotres et al., 2005). Studies examining the health of soil microbial populations point to reduced mineral fertilizer inputs as beneficial (Gunapala and Scow, 1998). Increased mineral fertilization has been associated with a decrease in functional diversity of the microbial population as well as decreased dehydrogenase activity (Shen et al., 2010). Growers seeking to improve the health of the soil sometimes turn to biostimulant applications in lieu of organic matter amendments. Not much is known about the impact of these amendments since the composition between products can vary widely. Russo and Berlyn (1990) found improved root growth and better resistance to environmental stress with an organic biostimulant. However, Chen et al. (2002) compared two commercially available formulations and concluded applications may reduce available nitrogen over time.

Excessive rates of fertilizers, increasing insecticide resistance, and continued crop loss from IYSV threaten the sustainability of onion production in the western United States. In contrast, altering cultural management practices may be an effective method to control disease while maintaining yields. Use of crop rotations has long been used as effective prevention of diseases and pests. Soils under longer crop rotations have been shown to have increased

disease suppression ability (Peters et al., 2003). By interrupting the time or space of pest requisites such as oviposition sites or highly nutritious food sources, rotations limit the success of insect populations. Virus presence may also be reduced through rotations. While modern agriculture is more suited to shorter intervals between cash crops with less variation between crops produced, polyphagous pests such as OT are able to sustain populations between ideal hosts (Milne and Walter, 1998). Successful management of a plant virus may require a broad approach which includes changes in cultural practices (Zitter and Simons, 1980).

A whole farm approach examines system-wide cultural practices for changes in order to enhance production. Much research has focused on a single aspect of production such as reduction in numbers of thrips; however, an integrated approach can examine the complex interactions between thrips populations, IYSV and plant and soil health. A whole farm approach to pest management should seek to optimize production by manipulating crop rotation, integrated pest management, and nutrient cycling. To the best of our knowledge, a whole farm approach to reducing onion loss from thrips and IYSV has not yet been published. The goal of this study was evaluate the effects of N fertilizer rate and crop rotation on onion growth and yield, insect populations, IYSV presence, soil quality and health and environmental risks from excess-N leaching. The study was conducted over three years on replicated plots on an experiment station in Northern Utah.

2. Materials and Methods

2.1 Field Design

Two replicated trials were established in adjacent fields at Utah State University Experiment Station, Kaysville, UT in each of successive years 2008-2010. Each trial consisted of a completely randomized design (CRD) with three replicates and two factors; 1) crop rotation

[wheat (W) or corn (C)] and 2) fertilizer rate [standard (S), reduced (R), or reduced plus biostimulant] (Table 1). The soil was a Kidman fine sandy loam (USDA) that had been fallow for several years prior to the commencement of the trial. In the year prior to onion production, plots measuring 7.62 m by 15.24 m were planted to either corn or wheat with no addition of fertilizer or insecticide. The corn was removed as silage, the wheat harvested and remaining residues incorporated followed by fall fertilizer application and bed preparation (Table 1). Spring application of fertilizer was applied prior to seeding (Table 1). *Allium cepa* var. *vaquero* (Nunhems Seeds, Parma, Idaho), bulb onion, was seeded in 36 inch beds with 4 rows per bed on March 21, 2009 and April 12, 2010. Split fertilizer treatments were also applied in June and July to provide optimal timing and decrease leaching potential. A typical grower management strategy of herbicide applications was planned (Table 2) with pre-emergent glyphosate and delayed pre-emergent application of Prowl was planned for both years. In 2009, poor field conditions immediately preceding emergence did not allow application. Subsequent herbicide applications were Buctril (8 oz/acre) at 2 true-leaves, Buctril (16 oz/acre) and Goal (8 oz/acre) at 4 true-leaves and Goal (16 oz/acre) at 6 true leaves. Due to heavy emergence of *Setaria viridis*, green foxtail, a one-time application of Select (6 oz/acre) was made in late May 2010. Handweeding was conducted throughout the season as needed. No insecticides were applied in any year of the experiment. Plots were sprinkler irrigated in 2009 two times a week with total weekly water application of 5-7 cm. In 2010, plots were drip irrigated (TSX T-Tape Model 506-08-170) on a similar schedule delivering the same total amount of water.

2.2 Soil Analyses

2.2.1 Fertility and N Leaching Potential

Soils were sampled monthly from May to August in 2009 and 2010. Six soil subsamples per plot were taken at 0-30 cm and combined in the field. Soils were sieved through a 4 mm screen, stored in re-sealable plastic bags and refrigerated at 4° C until processed within 10 days of sampling. Nitrate and ammonium was extracted in 1M KCl, and analyzed by Lachat (Quickchem 8500, Hach Company, Loveland, CO). Suction lysimeters (Model 1900 Soil Moisture Water Sampler, Soilmoisture Equipment Corp, Santa Barbara, CA) were installed at 2 and 4 foot depths and leachate was collected during the spring of each year of onion production. In the spring following onion production, soils were collected at depths of 1, 2, and 3 ft and analyzed for nitrate and ammonium as above. Total carbon and nitrogen levels were measured using LECO. Soil pH was measured in a 1:2 soil:water suspension. Soil P and K levels were measured using the Olsen method in July following final field applications of fertilizer.

2.2.2 Quality

Two weeks after field application of fertilizer, soils were sampled at 0-10 cm, sieved and stored as above and the following microbial characteristics assessed. Dehydrogenase enzyme activity, as measured by the reduction of triphenyl tetrazolium chloride (Tabatabai, 1994), was conducted monthly from May to August using 2.5 g oven-dry weight equivalent (od eq) soil at 17% moisture. Respiration was measured in the months of May and July of each year approximately 2 weeks after field application of fertilizer treatments. Sealed vials containing 5 g od eq soil at 17% moisture content were incubated at 25°C. Readily mineralizable carbon, basal respiration and substrate induced respiration were measured by Infrared CO₂ analyzer (MICOR 6251) after 11, 12 and 13 days, respectively (Anderson and Domsch, 1978; Davidson et al., 1987).

2.2.3 Incubation Study

In 2010, a laboratory trial was conducted to determine the effects of fertilizer rate, formulations, and readily available carbon on dehydrogenase activity over time. The trial was conducted as a CRD with two factors (fertilizer and glucose), five levels of fertilizer and two levels of glucose with four replicates. The soil was the same Kidman fine sandy loam sampled in September, sieved and stored as previously described. N application rates were determined to reflect typical concentrations found under onion production in the field. Samples were treated with either ammonium sulfate or urea ammonium nitrate (UAN) at 0, 20, or 200 $\mu\text{gN/g}$ soil and either with or without 1.9 mg glucose g soil^{-1} . Treatments were applied and the final moisture content of all samples was brought to approximate field capacity of 17% before covering vials with parafilm. The soils were stored in the dark and incubated at 25°C for 10 hours, 1 day, 3 days, 6 days or 10 days. Microbial activity was assessed for all treatments at each incubation time using the dehydrogenase method (Tabatabai, 1994).

2.3 Thrips

Onions were sampled at approximately two week intervals for onion thrips from June through August in each 2009 and 2010. Two whole plants in the center two rows of the plots were cut at ground level and immediately submerged in a glass jar containing soapy water. Jars were sealed and transported to the laboratory. In the lab, the onions and soapy water were washed over a 200-mesh sieve and all insects collected with 70% ethanol into a glass vial for storage until counting. During the washing process, the third youngest leaf from each of the two plants was removed and placed into a nalgene bottle to stain thrips eggs for counting. The two leaves were stained with an acid fuchsin technique described by Bowling (1979). The leaves and stain were heated to first boil in a microwave oven to facilitate absorbance of the stain

through the thick, waxy leaf cuticle. The stained leaves were then de-stained in a lactic acid solution to remove stain from leaves while leaving protein in the eggs a darker contrast. Leaves were then sectioned and placed between glass plates. Thrips adults, larvae, and other insects in ethanol and eggs in leaves were counted with the aid of a dissecting microscope at 20-30X magnification.

Thrips hatch from eggs within leaves was also measured. The third youngest leaf from each of two additional plants in each plot was collected, placed in a sealed plastic bag, and transported to the laboratory in a cooler with blue ice. Leaves were rinsed under running water to remove external insects, placed into a sealed plastic bag with a moist filter paper, and placed into an incubator at 25°C for 7 days. At the end of incubation, the two leaves and the inside of the bag were washed with water over a 200-mesh sieve to collect the hatched thrips larvae. The thrips were washed with 70% ethanol into a glass vial for storage until counting as described above.

2.4 IYSV

The presence and severity of IYSV in the plots was measured using a commercially available double antibody sandwich enzyme linked immunosorbent assay (DAS-ELISA) test (Agdia, US). Plots were sampled monthly from June to August in 2009 and at two week intervals from August to September in 2010. One leaf from each of twenty plants per plot was selected at random, individually bagged and stored at -20°C until processing. Samples were considered positive for IYSV presence if results were greater than 2 times the value of the average negative control plus 3 times the standard deviation of the negative control.

2.5 Onion Quality

Onions samples were collected monthly from May to August in each 2009 and 2010. Ten whole plants were removed in the center four rows of each plot, washed, and stored at 4°C. Total number of leaves per plant, total leaf area per plant (LI-3100, LI-COR Biosciences, Lincoln, NE), leaf chlorophyll indexes (CCM-200, Opti-Sciences, Hudson, NH), and total weight were recorded. Tissues were dried at 60°C and processed for total carbon and nitrogen content (LECO). Plots were surveyed in August and September for onion lodging using a visual rating of 1 to 5 which corresponded to 25, 50, 60, 80 or 90 percent of the plant population lodged. Onions were lifted, topped and bagged from two 2.44 m sections and two 1.52 m sections of bed per plot on Sep 26, 2009 and Sep 27, 2010 respectively. Bulbs were sized, counted, weighed and re-bagged for storage under commercial conditions at the Utah Onion storage facility in Brigham City, UT until Feb 11, 2010 and February 10, 2011. Stored onions were visually assessed for loss due to rot and weighed. Ten randomly selected samples were cut in half, measured for overall diameter, number of scales, number of centers and presence of rot or disease.

2.6 Statistical Analyses

The effects of year, crop rotation, fertility treatment and month on onion growth and yield, soil chemical and biological measures and numbers of thrips were assessed using analyses of variance with a 4-way factorial in a mixed model design. Year, crop rotation, and fertilizer treatment comprised a 3-way factorial in a completely randomized design with plot as the experimental unit and month as a repeated measures. Different plots were used in different years therefore year was not a repeated measures factor. The covariance structure for repeated measures was selected using AIC and varied based on the response data set. Responses were square root or log transformed prior to analysis to better meet assumptions of normality and

homogeneity of variance. Statistical analyses were completed using PROC MIXED in the Statistical Analysis System (SAS), version 9.2. Residual analyses were aided by the macro PDMIX800 (Saxton 1998). Data is presented by year when a significant year by fertilizer treatment or year by crop rotation interaction exists. When significant month interactions exist, means are presented by month.

3. Results

3.1 Onion Growth, Yield and Storage

Overall onion yield and onion size at harvest differed between the two seasons of the study. However, patterns in onion growth as measured by onion weight, leaf number and leaf area were similar between years as well as in season responses to fertilizer treatment and crop rotation. Plant growth measured monthly as average onion dry weight was significantly ($p < 0.001$) greater in 2009 compared to 2010 (Figure 1 and 2). Average onion weight was affected by treatment in July and August of 2010 only with SC and SW onions greater than any other treatment combination ($p = 0.003$ and $p = 0.030$, respectively). In August 2010, SC ($p = 0.003$) onions were larger than all other treatment combinations. There was no effect of rotation on onion growth as measured by dry weight in either year.

Other measures of onion growth also reflected the large difference in growth between 2009 and 2010 and a general lack of a treatment response in 2009. Both the number of leaves per plant (Figure 3 and 4) and leaf area (Figure 5 and 6) were significantly greater in 2009 than in 2010. In July of 2010, S fertilizer rate onions had more leaves than both the B and L rate onions ($p = 0.022$). By August 2010, the B onions had the most number of leaves ($p = 0.019$), followed by the L rate onions ($p < 0.05$). Similarly, leaf area in July 2010, SC ($p < 0.001$) and SW ($p = 0.008$) plots were significantly greater than any other treatment and rotation combination. Early to mid

season differences in numbers of leaves (Figure 4) and leaf area (Figure 6) between the high fertilizer rates were largely obscured by the end of the growing season.

The impact of fertilizer treatment greatly affected both the amount of total tissue N (Figure 8 and 9) as well as the timing of onion maturation (Figure 10 and 11) in both years ($p < 0.001$ and $p = 0.002$, respectively). There were no rotational effects observed on either total tissue N levels or onion maturation. In 2009, onions receiving S fertilizer had significantly more total tissue N than either B or L rate onions ($p < 0.005$) in the months of May, June and August. In 2010, the S fertilizer rate onions had higher tissue N than other treatments in May and July ($p < 0.05$) only. In 2010, S rate onion tissue N in August was significantly greater than L rate only with no difference between the B and S treatments. Visual ratings to assess the percent of onion plants that had lodged showed S fertilizer rate plots had a greater rate of lodging than both L and B treatments ($p = 0.008$), which did not differ from each other. In 2009, visual ratings on September 1st showed the standard rate treatment had significantly more onion lodging than both L and B ($p = 0.034$). By 20 Sep, all the treatments were over 90% lodged. In 2010, a greater percentage of onions were lodged in the S treatment on 1 Sep ($p = 0.018$) and 20 Sep ($p = 0.002$).

Crop rotation and fertilizer treatment affected onion yield in various ways over two seasons. In 2009, total yields were not affected by crop rotation. Biostimulant treated onions were notably ($p = 0.089$) lower in yield than S in 2009 (Figure 12). Onion size category did not significantly differ in 2009 with respect to crop rotation (Figure 13) or fertilizer treatment (Figure 14). In 2010, both crop rotation and fertilizer treatment did have significant effects on yield. Corn rotations had greater ($p = 0.0349$) total yields than W while S onions had greater ($p = 0.0034$) total bulb weight than both B and L (Figure 12). Size category of onions (Figure 14) was impacted by fertilizer treatment in 2010 as well. There were greater cull onions in L and B

treatments ($p=0.004$ and $p=0.007$, respectively) than S. Jumbo sized onion bulbs were greater in S than L and B treatments ($p=0.013$ and $p=0.001$, respectively). All other size class categories did not differ. Storage loss data also showed no significant effect of crop rotation or fertilizer treatment (Figure 15).

3.2 Treatment Effects on Thrips and IYSV

Differences in insect populations as a whole were observed between the years of the study, with generally greater counts in 2010. The timing of thrips population peaks also occurred later in the season in 2010 than in 2009. The analysis of biodiversity of insects using a Simpsons Reciprocal Index (SRI) showed effects of crop rotation only (Figure 16 and 17). Treatments planted to wheat prior to onions had significantly or notably greater SRI values in early ($p=0.086$) and mid August ($p=0.006$) in 2009 and at mid June in 2010 ($p=0.021$). All other sample periods showed no significant differences in diversity.

The effects of fertilizer treatment (Figure 18) and crop rotation (Figure 19) had variable impacts on thrips populations throughout the season. For adult OT, the early season treatment effects were similar between the two years of the study (Figure 20). By mid June in both years, adult OT populations were significantly greater in the S rate treatment than in the L rate treatment. Rotational effects were also observed in both years, over a wider time period. In 2009, plots with a prior wheat rotation had more adult OT than corn rotations in mid June ($p=0.036$), early July ($p=0.002$), and early August ($p=0.093$) sample dates. In 2010, there were notably or significantly greater OT after wheat than after corn plots in mid June ($p=0.093$) and mid August ($p=0.040$). Onion thrips at all other sample dates were not significantly different by rotation or fertilizer.

Fertilizer treatment also had a significant ($p=0.042$) effect on number of immature thrips, however this effect was stronger in 2009 (Figure 21 and 22). In 2009, the only difference between treatments was observed in early and mid July with numbers of immature thrips significantly greater in S rate treatments than the L rate treatments ($p=0.047$ and $p=0.028$, respectively). Biostimulant treatments had notably greater numbers of immature thrips than L plots in mid July ($p=0.099$). In 2010, immature thrips counts were greater in mid 15 July in the B treatment compared to the L treatment only ($p=0.0497$). Corn and wheat rotations (Figure 23) did not significantly affect immature thrips except in 2009 in early August ($p=0.001$) where wheat plots had greater immature counts than corn.

While there were greater numbers of adult and immature thrips in the S rate treatment and after wheat as opposed to corn, neither fertilizer rate nor crop rotation significantly affected the number of thrips eggs (Figure 24) or immature thrips hatched (Figure 25). The number of adult Western Flower Thrips (WFT) were notably greater ($p=0.053$) after wheat than after corn (Figure 26).

Neither crop rotation nor fertilizer treatment were significant in the rate of onion plants positive for IYSV in 2010 (Figure 27). Onion samples collected in 2009 for DAS-ELISA testing were not included in analysis due to poor quality after storage.

3.3 Soil Effects

Chemical as well as biological soil properties were affected by treatment and rotation. Crop rotation influenced soil nitrate, phosphorus (P) and potassium (K) levels, mostly in 2009. Plots planted to wheat prior to onions had higher levels of soil nitrate (Figure 28) rather than corn in May, June, July and August 2009 as well as May 2010 ($p=0.003$, $p=0.024$, $p=0.0002$, $p<0.0001$ and $p=0.022$). In 2009 both P (Figure 29) and K (Figure 30) were significantly greater

after wheat than corn ($p=0.002$ and $p=0.003$). There were no other significant rotational effects (Figure 31).

Levels of extractable nitrate (Figure 32) and ammonium (Figure 33) in the soil in both growing seasons were strongly influenced by treatment. Similar patterns were observed between years of the study. In June of both 2009 and 2010, soil nitrate was greater in S treatment than B treatments ($p=0.044$, $p=0.043$). In July and August 2009, soil nitrate was higher in S treatments than both the L and B treatments ($p<0.0001$). Similarly, soil nitrate was much greater in S treatments than B and L in May and July 2010 ($p<0.005$). Differences in soil ammonium levels were noted only in the months of June and July of each year, following fertilizer applications of ammonium sulfate in early June. In June of both years, extractable ammonium was greater in the S treatments than the L or B treatments ($p<0.05$). In July 2009, ammonium was greater in S treatments than the B ($p=0.03$) but not from the L treatments. Soil ammonium in July 2010 was significantly greater in the S rate treatments than the L and B treatments ($p=0.001$ and $p=0.003$).

Not only were differences in soil chemical properties observed, but soil microbial parameters were also influenced by both fertilizer treatment and crop rotation in both years. Dehydrogenase activity (Figure 34 and 35) was significantly greater after wheat than corn in both years ($p<0.001$). Soils showed greatest dehydrogenase activity in both L ($p=0.023$) and B ($p=0.006$) treatments at the end of the season. In the months of May and July, treatment effects were not observed in dehydrogenase activity. In June, soils after wheat, regardless of treatment, showed greatest activity, while by August, SW plots were no different than any corn/treatment combination.

Other measures of microbial activity were also impacted by both crop rotation and fertilizer treatment. Prior crop rotation impacted soil respiration as measured by mineralizable carbon (MinC) and microbial biomass as measured by substrate induced respiration (SIR). Fertilizer treatment also affected MinC and microbial biomass. Basal respiration (BR) was not greatly impacted by either treatment or rotation (Figure 36) except in May 2010 where BR was significantly ($p < 0.001$) greater after wheat than after corn. Soil after wheat had greater MinC (Figure 37) than after corn in May 2009 and July 2010 ($p = 0.013$ and $p < 0.001$). The only fertilizer effects on MinC was in July 2010 where S plots were greater than L plots ($p = 0.0428$). Microbial biomass was also greater after wheat (Figure 38) in May and July of both years ($p = 0.026$, $p = 0.037$, $p = 0.004$ and $p = 0.008$). Treatment effects on microbial biomass were only observed in May 2010 where the S rate was higher in microbial biomass than both L and B treatments ($p = 0.006$). Basal respiration in both L ($p = 0.026$) and B plots ($p = 0.040$) was greater than S rate treatments in July of 2010.

A laboratory incubation was conducted to further examine the effects of fertilizer formulation and carbon availability on dehydrogenase activity. In the laboratory trial, microbial activity as measured by dehydrogenase was greatly impacted by glucose and fertilizer amendments, as well as incubation time. Soils receiving glucose had greater activity than non-glucose treated soils (Figure 39). Treatment effects varied over time (Figure 40). After three days, the high rates of both ammonium sulfate and UAN were greatest ($p < 0.001$). By ten days, the UAN treatments were most active ($p < 0.01$). In the non-glucose amended soils, dehydrogenase activity in the UAN low rate (UL) and UAN high rate (UH) treatments was greater than the ammonium sulfate high rate (AH) and ammonium sulfate low rate (AL) treatments, both of which were lower than the control.

The movement of excess nitrate through the soil profile was captured at three different times. Cumulative nitrate leaching (Figure 41) collected in lysimeters from May through July, 2009 were not significantly affected by crop rotation or fertilizer rate. Following snow melt in the spring of 2010, extractable nitrate levels at 3 ft sample depth were significantly ($p < 0.0001$) greater in S soils than in B or L (Figure 42). Onions following a wheat rotation also had greater ($p = 0.0016$) nitrate at 3ft than corn. In the fall of 2010, extractable soil nitrate (Figure 43) was significantly ($p = 0.048$) greater S than L and B at 1 ft. Also at 1 ft sample depths, corn was greater ($p = 0.045$) than wheat. At 2 ft sample depth, S was significantly ($p = 0.028$) greater than B and notably ($p = 0.065$) greater than L.

4. Discussion

Onion growth data demonstrates the impact of environmental growing conditions on different years. The differences in dry weight, leaf area and overall growth between the seasons are attributed to a later planting date and an unusually cool growing season in 2010. The cold, slow start to the growing season in 2010 most likely resulted in leaching and denitrification of nutrients. Low fertilizer treatments, while still supplying adequate amount of P and K, did not provide sufficient N levels to allow for enough top growth before onions reached genetic physiological long-day triggers in mid-season. Amount of top growth prior to onset of bulbing significantly impacts total yields. In a more ideal growing season, as in 2009, a well timed fertilizer schedule allowed for optimum onion growth with much reduced fertilizer inputs. Drost and Koenig (2002) previously demonstrated the benefits of a reduced input fertilizer management plan for onions using a slow release fertilizer. The difference in growth patterns among fertility treatments, which was observed in both years was more pronounced in 2010 late in the season when the L and B rate treatments were continuing to initiate leaves and

increase bulb size when the S rate treatment was not. Since bulbing response involves a complex interaction of photoperiod, degree days, number of leaves initiated and fertilizer inputs (Lancaster *et al.*, 1996; Milne and Walter, 1998), the delayed maturation observed in L and B onions is probably due to the slower growth rate and lower overall size even though photoperiod requirements were met. While our results indicated a longer time to maturity for L and B rate onions, measurements only accounted for growth up to 15 August. Harvest dates were not until approximately one month later, allowing for a late season catch up in total yield and bulb size between treatments. All treatments were harvested on the same date, in similar timing to local commercial onion production.

Besides affecting onion growth, the impact of fertilizer rate on soil chemical properties was also significant. While the levels of extractable ammonium were only greater in standard plots immediately following the second fertilizer application of ammonium sulfate, the data clearly shows an increase of soil nitrate with increased fertilizer input over the course of the season. In 2010, the total soil nitrate was lower than in 2009 (Figure 27), possibly due to several factors including excessive early season moisture that may have caused leaching of nutrients out of the root zone or significant denitrification. Highest levels of soil nitrate measured between years varied greatly, $378 \mu\text{g g}^{-1}$ soil in 2009 compared with $167 \mu\text{g g}^{-1}$ soil in 2010. Soil K levels were also lower in 2010 than 2009 (Figure 31). However, both N and K availability to onions was not deficient (Hamsom, 1993). Interestingly, in June of both years, there seemed to be a significant influence of the biostimulant on the amount of extractable soil nitrate immediately following the field application of ammonium sulfate. Nitrate in the S and L treatments did not differ; however, B had significantly less nitrate than S. Onion growth does not indicate increased tissue N or more growth in the biostimulant plots during this same period

which could explain reduced soil nitrate. The lower levels of extractable nitrate could be due to slight change in microbial activity which impacted either nitrification of ammonium sulfate fertilizer or the rate of nitrate or ammonium utilization. No differences were noted during this time in dehydrogenase and respiration measures were not conducted in June. No pre-season fertility measurements were conducted on the soils and therefore pre-existing differences in soil nutrients cannot be ruled out. The fields were right next to each other, on the same soil type with the same cropping history, therefore a significant difference in pre-season nutrient status seems unlikely. The difference in field conditions between the years could also explain the reduced influence in rotational effects in year two. The differences in moisture and temperature between the two years most likely affected the rates of decomposition of residues. Also, no direct measurement of the amount of crop residue incorporated each season was made.

Leaching data shows a dramatic impact of seasonal precipitation and loss of residual nitrate. The in-season data collected from lysimeters suggests no difference between treatments. However, by the fall, the residual nitrate is higher in S treatments at upper levels of the soil profile. Following snow melt, the excess nitrate was only observed at 3 ft depths, most likely far below the root zone of a subsequent crop.

Although fertilizer treatment had variable impact on yield, it appears there is some preference of adult OT early in the season to onions with higher rates of fertilizer, followed by increased numbers of immature thrips. Onion size (section 3.1) was greater in S treatments in June of both years and suggests OT may be attracted to larger onions. However, the 2009 data does not indicate onion growth as the only factor attracting early season adult OT (Figure 18 and 20). In 2009, onions were significantly larger in S treatments than B treatments, but there was

no difference in size between S and L treatments. Nevertheless, OT were present in larger numbers on S treatments than the L treatment. There was little evidence of onion leaf area as a determinant of adult OT except for the 1 June 2010 sample date. The timing of the increase in immature thrips within S rate plots follows a reasonable timeline after observed increase in adult thrips, suggesting greater oviposition or fecundity in S rate treatments. However, number of eggs and number of immature thrips hatched were not affected by fertilizer rate or crop rotation. Since immature thrips have limited motility and movement between plants is unlikely, a difference in either fecundity or developmental time is most likely. Generation time in summer months can range from 20-40 days (Jones, 2005). Both fecundity and time to maturity have been linked to quality of diet (Milne and Walter, 1998).

The sample periods throughout the summer show a typical thrips infestation pattern with variable population levels. Mo et al. (2009) attempted to explain the typical seasonal population patterns of OT through a model where the most critical factor in determining pest pressure was the initial date of invasion. This model described an initial invasion into onion fields, followed by a gradual season-long build-up of populations, with multiple population peaks (Mo et al., 2009). Recent research focused on IYSV spread may contradict current early season pesticide applications for thrips control. Hsu et al. (2010) suggests late season vulnerability to IYSV transmission increases from migrating thrips from neighboring fields that have been harvested. That study indicates the density of late season thrips was more predictive of IYSV levels than early season thrips densities (Hsu et al., 2010). However, Mo et al. (2009) suggest maximum thrips populations can be reduced most effectively by strategies that delay the initial infestation date, as perhaps with a low N rate fertilizer. While escaping early season

colonization, onions treated with lower rates of fertilizer may increase susceptibility to late season thrips infestations if harvest dates are later than surrounding fields.

Soil biological properties were exaggerated by both fertilizer treatment and prior crop rotation. The impact of prior crop rotation on soil microbial populations may be a result of differences in readily available C. Wheat had more MinC than corn. There was greater microbial biomass in wheat plots over both years which has been previously correlated with MinC (Reeve et al., 2010). Basal respiration increased in wheat plots early in the season 2010 and was greater in low and biostimulant treatments mid season. Microbial diversity has been shown to decrease with increasing N rates (Shen et al., 2010) perhaps limiting the diversity of the microbial community. Dehydrogenase activity was impacted by both treatment and rotation as the season progressed. Plots receiving high-N rates had the lowest activity at the end of the season. This may indicate a lack of MinC in the high-N plots, however, our data shows no significant impact of fertilizer on MinC. Research has shown a possible link between mineral N additions and a period of reduced microbial health measured as basal respiration and microbial biomass (Gunapala and Scow, 1998) as well as a negative correlation between dehydrogenase activity and amount of N applied (Shen et al., 2010). The formulation of mineral N fertilizers also may contribute to reductions in activity levels.

To further examine the impact of fertilizer amount and formulation on microbial populations, we conducted a lab trial with two levels of UAN and ammonium sulfate. The goal of the trial was to determine whether the depression in dehydrogenase activity observed in the field in S rate treatments was in response to fertilizer amount applied or the formulation. The results indicate a strong effect of fertilizer formulation type on microbial activity (Figure 38). After ten days, the soils receiving ammonium sulfate were lower in dehydrogenase activity,

regardless of glucose addition. It seems there was a repression of dehydrogenase activity with the addition of ammonium sulfate. Since the dehydrogenase assay relies on the reduction of triphenyltetrazolium chloride (TTC) to provide a relative microbial activity level (Tabatabai, 1994), soil additions that interfere with the reduction of TTC can impact the assay. Bremner and Tabatabai (1972) reported a suppression in dehydrogenase activity with nitrate amended soils possibly due to its ability to function as an alternate electron acceptor. Ross (1971) describes the importance of pH in the reaction and reduction of TTC. The addition of high amounts of ammonium sulfate may have altered the solution pH to an unfavorable level despite the addition of calcium carbonate to the assay. This study did not examine the pH of the assay solution. However, since the addition of glucose resulted in similar rates of AL and control soils, the decrease in AH rate may simply be due to an inability to access more recalcitrant C. In order to examine the interaction of fertilizer formulation and dehydrogenase activity further, a study conducted over an extended time including monitoring for changes in pH would be ideal.

5. Conclusions

The benefits of managing onions with split applications of reduced nitrogen are promising. The overall growth and time to maturity may be slightly different between fertilizer treatment levels; however, there was no observed impact on onion size, yield or storage quality as a result of a reduced-N input in an ideal growing season. The reduced N plots also showed an early season reduction in thrips populations. Reduced fertilizer applications led to lower residual soil nitrate suggesting a much reduced risk of nitrate leaching as an environmental concern. The reduced fertilizer inputs also benefited the soil microbial population quantity and possibly diversity as measured by both dehydrogenase activity and respiration.

Although this study observed differences in thrips response to fertilizer treatments, thrips counts and IYSV disease incidence was relatively low in both years. Considering the relatively small size of plots and their close proximity to each other, significant differences in population densities of a motile insect like onion thrips demonstrates interesting results. Clearly, there are complex factors involved in population dynamics and life history timing of OT. The differences in thrips counts between treatments could not fully be explained by differences in onion growth, tissue N levels or soil N values. More likely, there is a combination of factors such as visual cues and quality of food resources that impact the population throughout the course of the season. Since the presence of IYSV within plant tissue may not predict the severity of the expression of the disease, the data observed in this study cannot conclusively determine a preferential fertilizer treatment to thwart crop loss due to IYSV infection. Reduced rate fertilizer applications may provide a period of lower pest pressure, however, this may extend the growing season and increase late season exposure to IYSV transmission. This late season exposure may be a more significant concern in production fields that are in close proximity to additional sources of onion thrips from an early harvest, such as seeded fields planted in close proximity to transplanted fields. Further research on disease expression and the relationship between the time of disease transmission and impact on yield could help discern the most effective timing to evade crop loss.

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Table 1. Fertilizer treatment application rates and timing schedule (rates are expressed as kg ha⁻¹ except MoreLife amendments which are in L ha⁻¹)

	Standard Rate (S)	Reduced Rate (L)	Reduced + Biostimulant (B)
Fall	56.04 N ^A	28.00 N ^A	28.00 N ^A 46.77 L ^B
Spring Pre-Plant	65.57 N ^C 222.94 P ^C 51.28 K ^D	13.11 N ^C 44.59 P ^C 10.26 K ^D	13.11 N ^C 44.59 P ^C 10.26 K ^D 46.77 L ^B
June	140.11 N ^E	79.58 N ^E	79.58 N ^E 46.77 L ^B
July	140.11 N ^A	13.11 N ^C	13.11 N ^C 46.77 L ^B
Total	401.83 N 222.94 P 51.28 K	133.8 N 44.59 P 10.26 K	133.8 N 44.59 P 10.26 K 140.31 L

^A Urea Ammonium Nitrate (UAN), ^B MoreLife, ^C 10-34-0, ^D 0-25-17S, ^E Ammonium Sulphate

Table 2. Herbicide application rate and timing for 2009 and 2010. Pre-emergence herbicides were not applied in 2009 due to unfavorable field conditions.

Year	Pre-emergence	2 true leaves	4 true leaves	6 true leaves	Additional
2009	N/A	Buctril (8 oz/acre)	Buctril (16 oz/acre) Goal (8 oz/acre)	Goal (16 oz/acre)	
2010	Glyphosate Prowl	Buctril (8 oz/acre)	Buctril (16 oz/acre) Goal (8 oz/acre)	Goal (16 oz/acre)	Select (6 oz/acre)

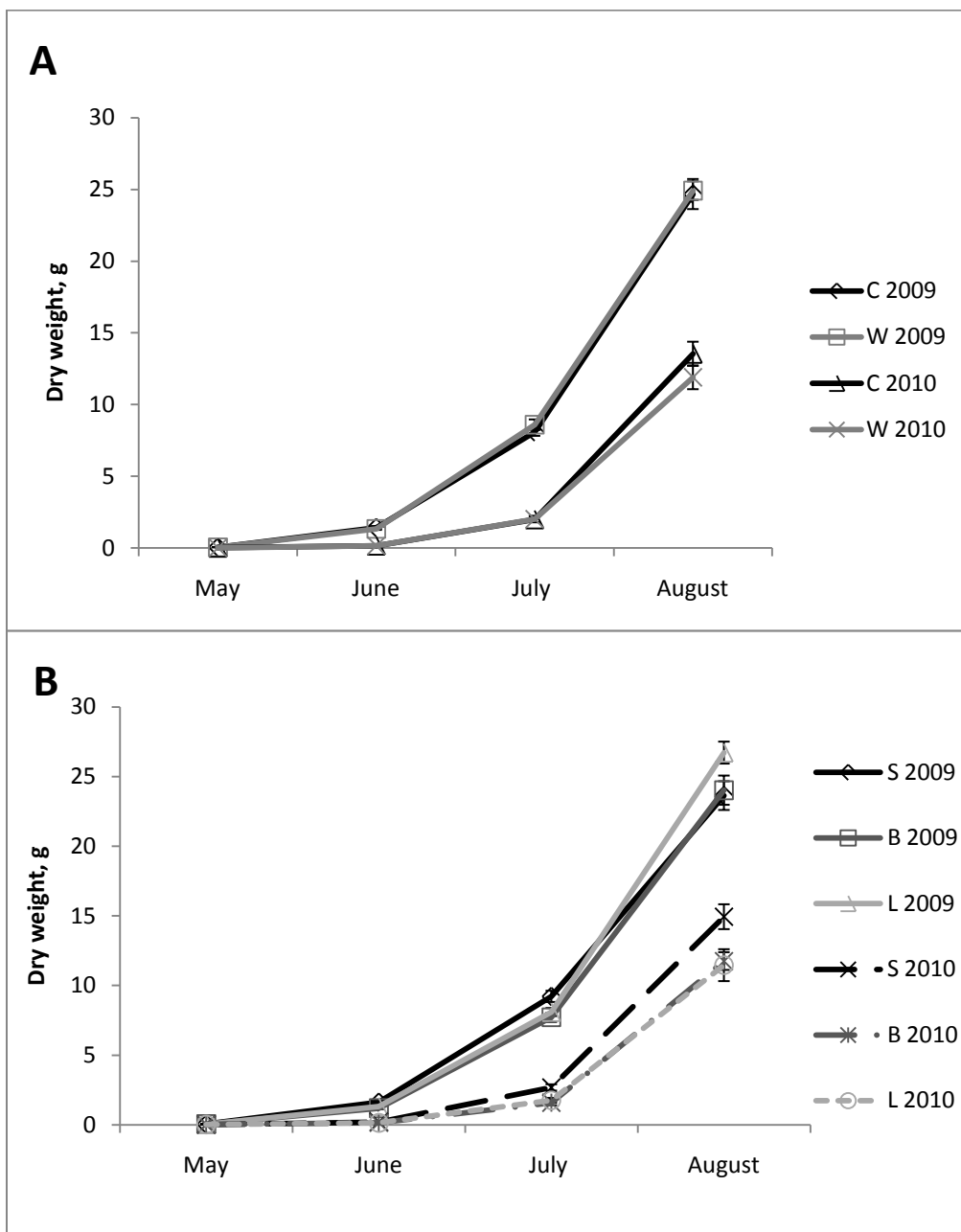


Figure 1. Effects of crop rotation (Panel A) and fertilizer treatment (Panel B) on dry weight of onion measured monthly from May to August in 2009 and 2010. Main effects of year, month and treatment were significant at $p < 0.0001$, $p < 0.0001$ and $p = 0.0003$, respectively. C=corn, W=wheat, S=standard rate, B=biostimulant, L=low rate

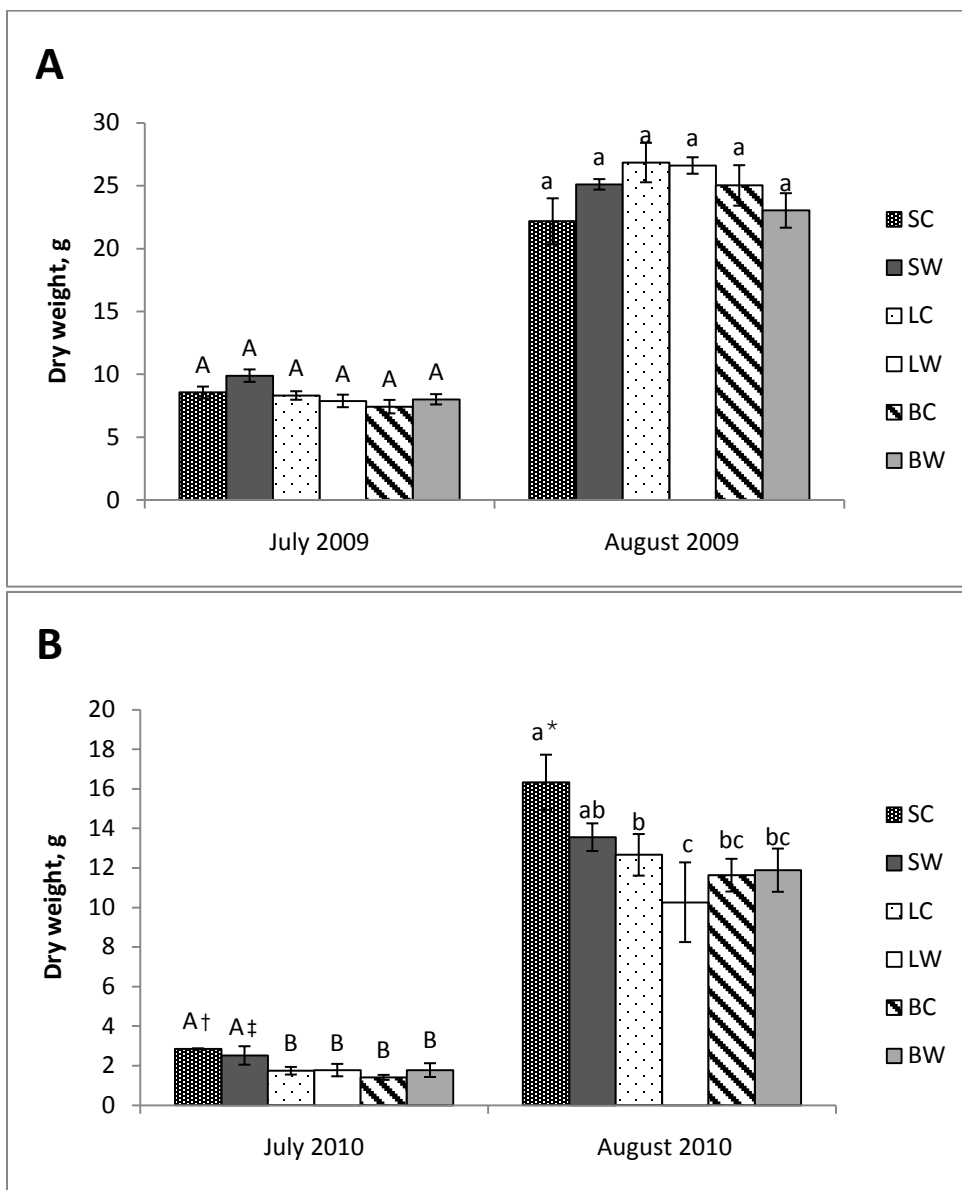


Figure 2. Interaction of crop rotation and fertilizer treatment on onion dry weight from mid to late season in 2009 (Panel A) and 2010 (Panel B). Treatment means (n=4) with different letters are significant within month at p=0.05. Treatment means designated †, ‡, * are significant at p=0.0028, 0.0299 and 0.003, respectively. LW=low wheat, BW=biostimulant wheat, SW=standard wheat, LC=low corn, BC=biostimulant corn, SC=standard corn.

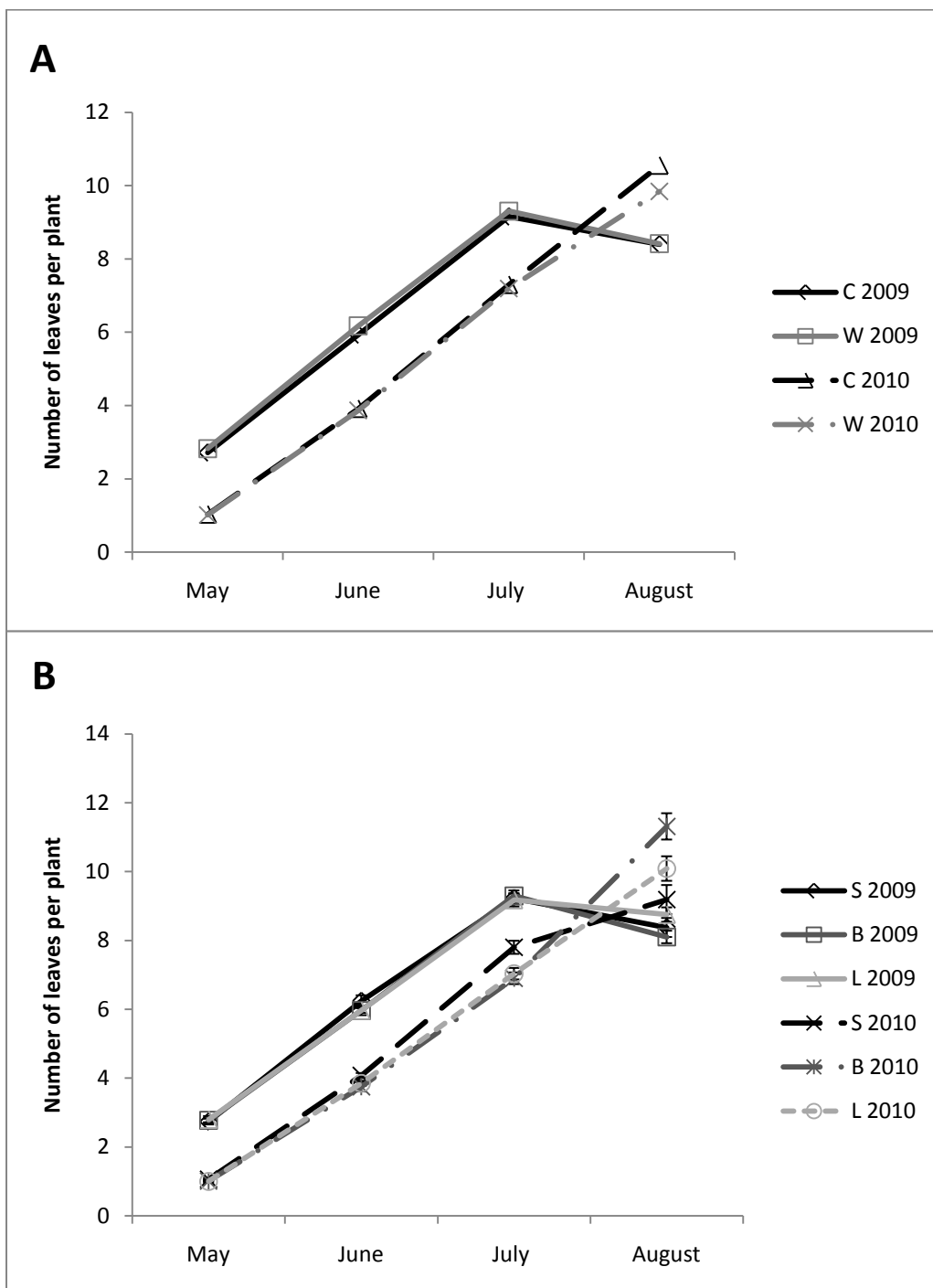


Figure 3. Effects of crop rotation (Panel A) and fertilizer treatment (Panel B) on number of onion leaves per plant in 2009 and 2010. Main effects of year and month were significant at $p < 0.0001$. C=corn, W=wheat, S=standard rate, B=biostimulant, L=low rate

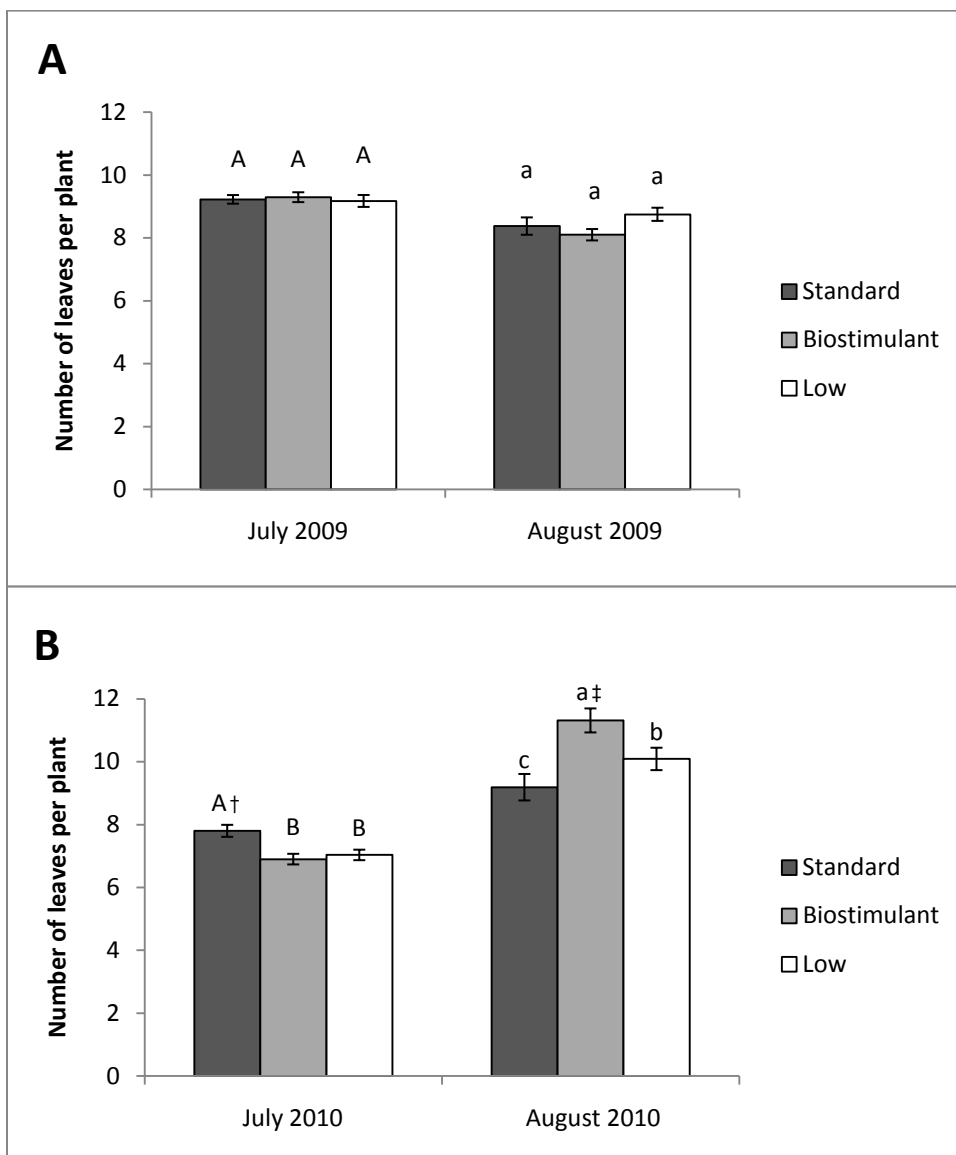


Figure 4. Fertilizer treatment effects on number of onion leaves per plant in 2009 (Panel A) and 2010 (Panel B) mid and late season. Treatment means ($n=4$) with different letters are significant within month at $p=0.05$. Treatment means designated †, ‡ are significant at $p=0.0022$ and $p=0.0189$, respectively.

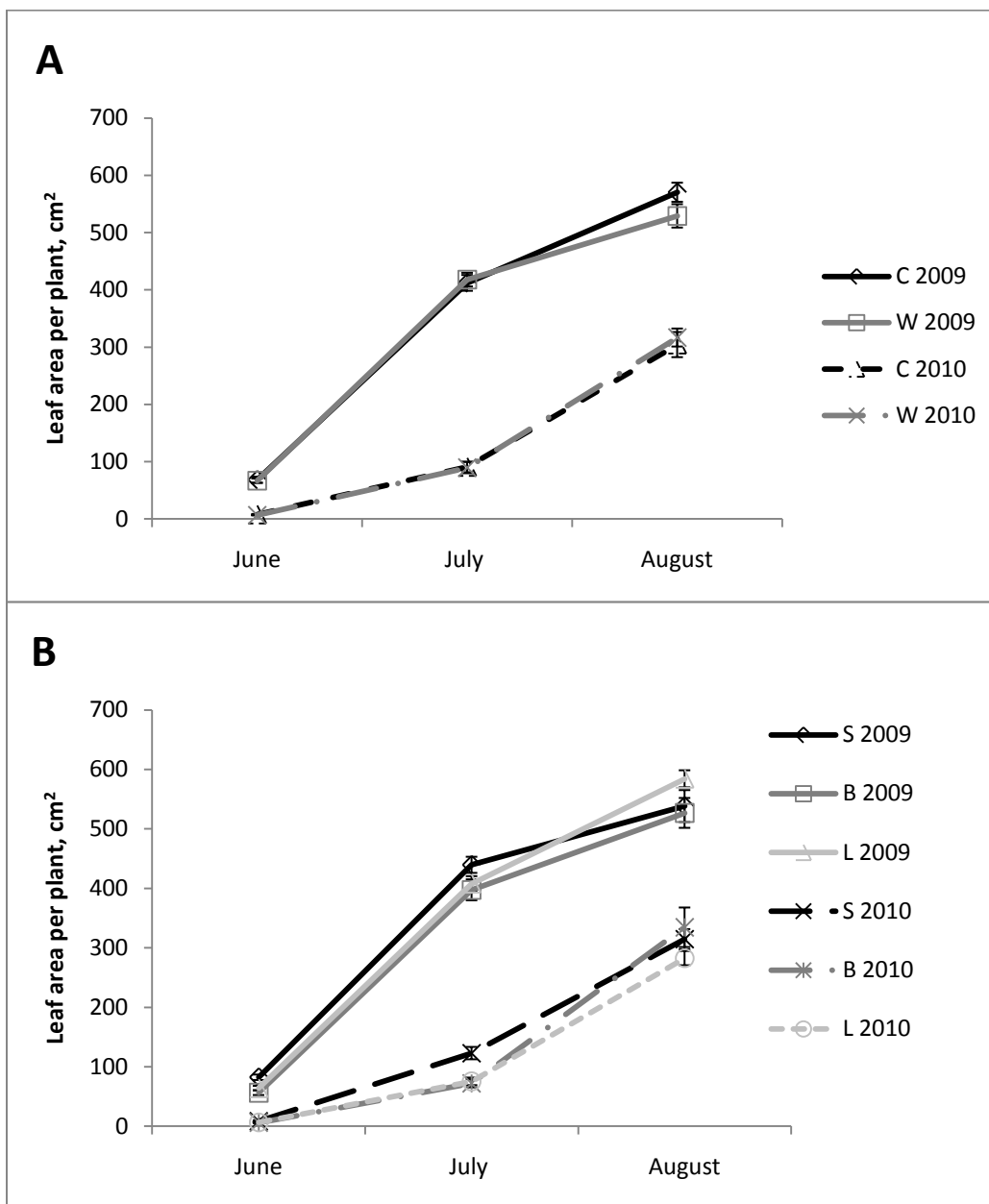


Figure 5. Effects of crop rotation (Panel A) and fertilizer treatment (Panel B) on average onion leaf area per plant in 2009 and 2010. Main effects of year, month and fertilizer treatment were significant at $p < 0.0001$. C=corn, W=wheat, S=standard rate, B=biostimulant, L=low rate

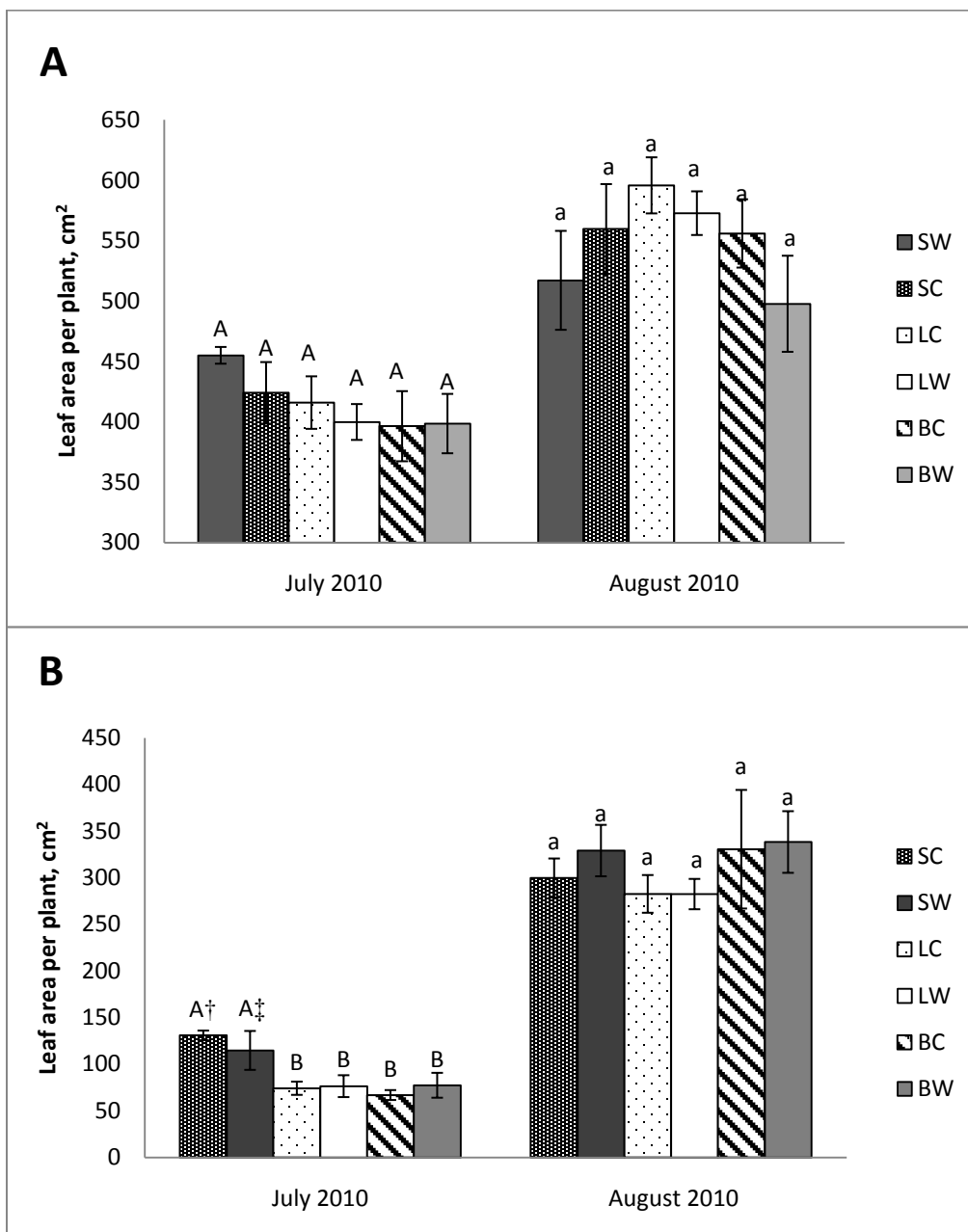


Figure 6. Interaction of crop rotation and fertilizer treatment in mid to late season onion leaf growth for 2009 (Panel A) and 2010 (Panel B). Treatment means (n=4) designated † and ‡ are significant within month at p=0.0003 and p=0.0076, respectively. LW=low wheat, BW=biostimulant wheat, SW=standard wheat, LC=low corn, BC=biostimulant corn, SC=standard corn.

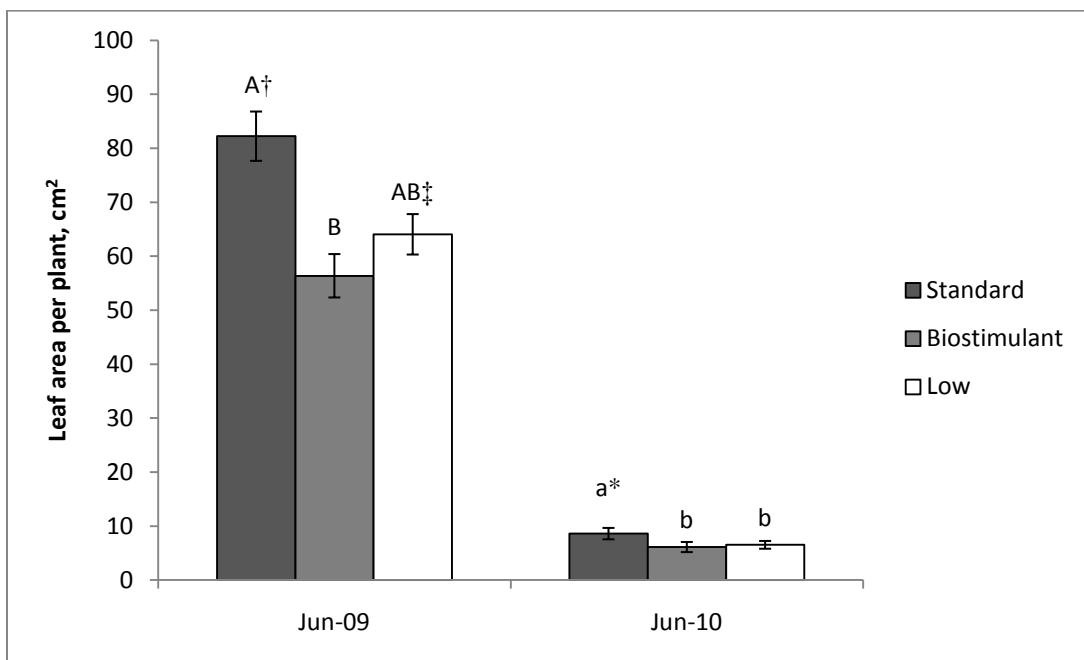


Figure 7. Early season fertilizer treatment effects on total leaf area per onion plant. Treatment means (n=4) designated †, ‡, and * are significant or notable at $p=0.0111$, $p=0.0893$ and $p=0.0156$, respectively.

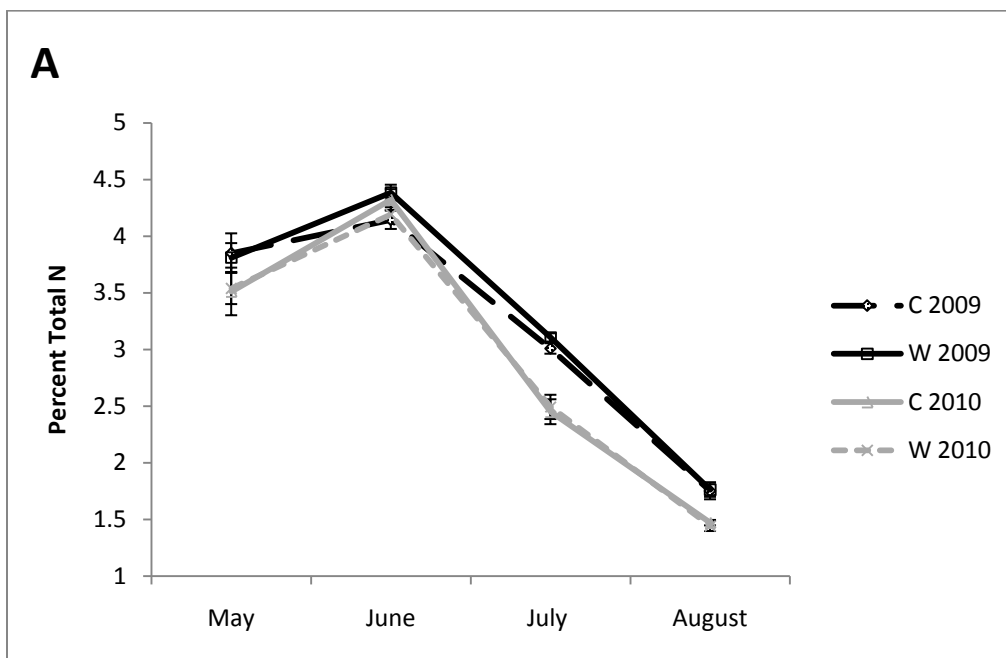


Figure 8. Impact of crop rotation on onion tissue total N in 2009 and 2010. Treatment means did not significantly differ from each other. C=corn, W=wheat

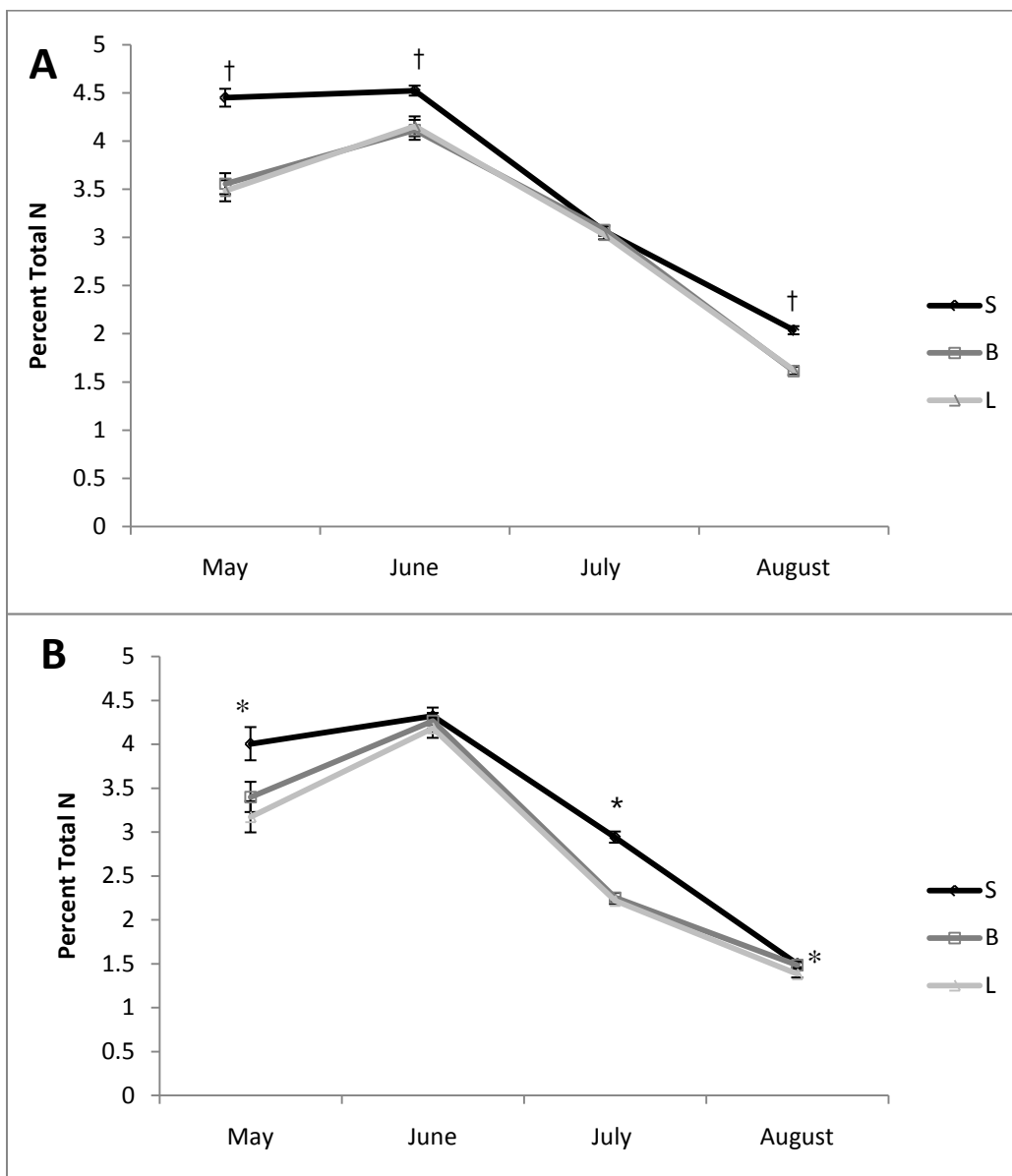


Figure 9. Fertilizer treatment effects on total tissue nitrogen in 2009 (Panel A) and 2010 (Panel B). Treatment means (n=4) designated † and * are significant at $p < 0.005$ and $p < 0.05$, respectively. In August 2010, tissue N was significantly lower in the L fertilizer treatment only from the high treatment at $p = 0.0432$ with no difference between the biostimulant and high treatments. S=standard rate, B=biostimulant, L=low rate

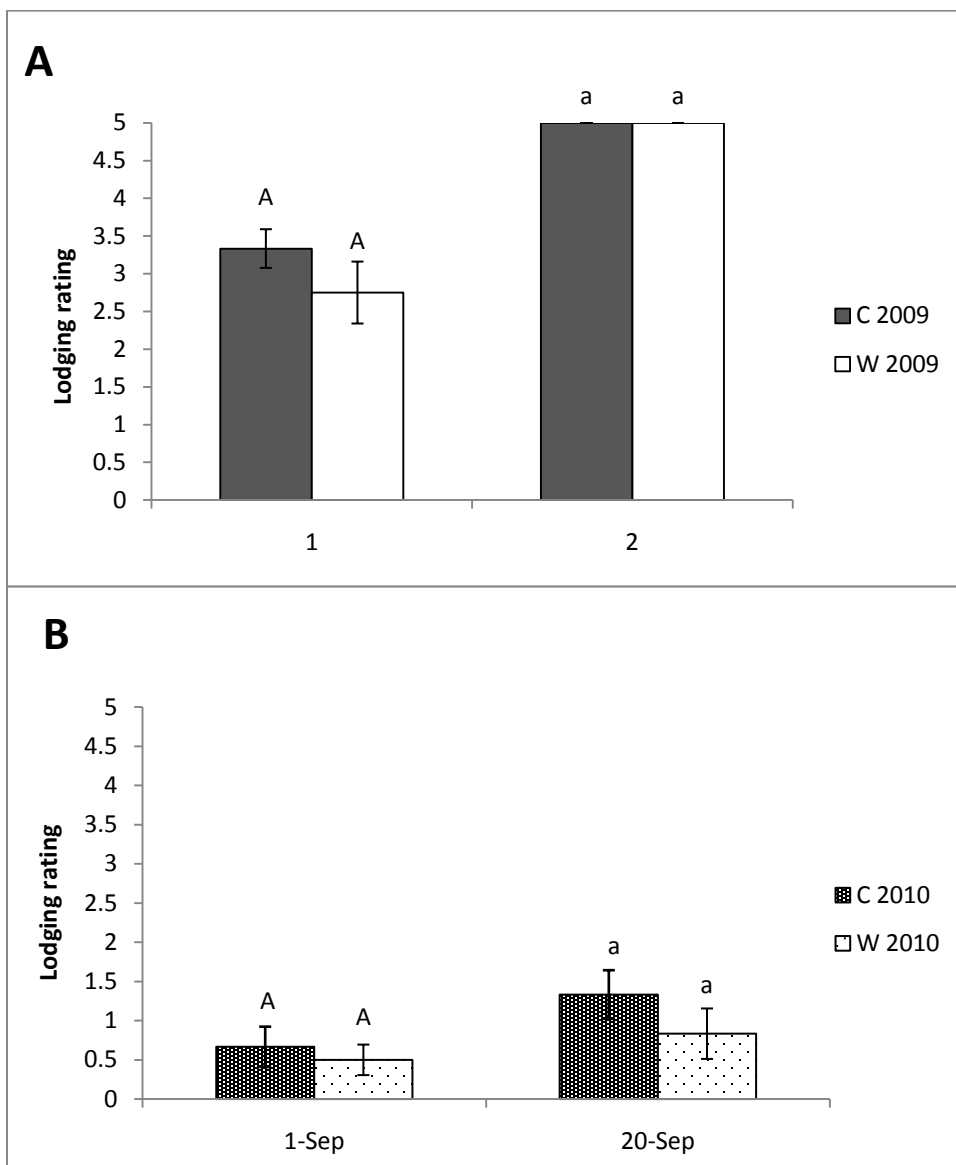


Figure 10. Effects of crop rotation on onion lodging in 2009 (Panel A) and 2010 (Panel B). Visual ratings of onion lodging were assigned as 1 to 5 which corresponded to 25, 50, 60, 80 or 90 percent of the population lodged. C=corn, W=wheat

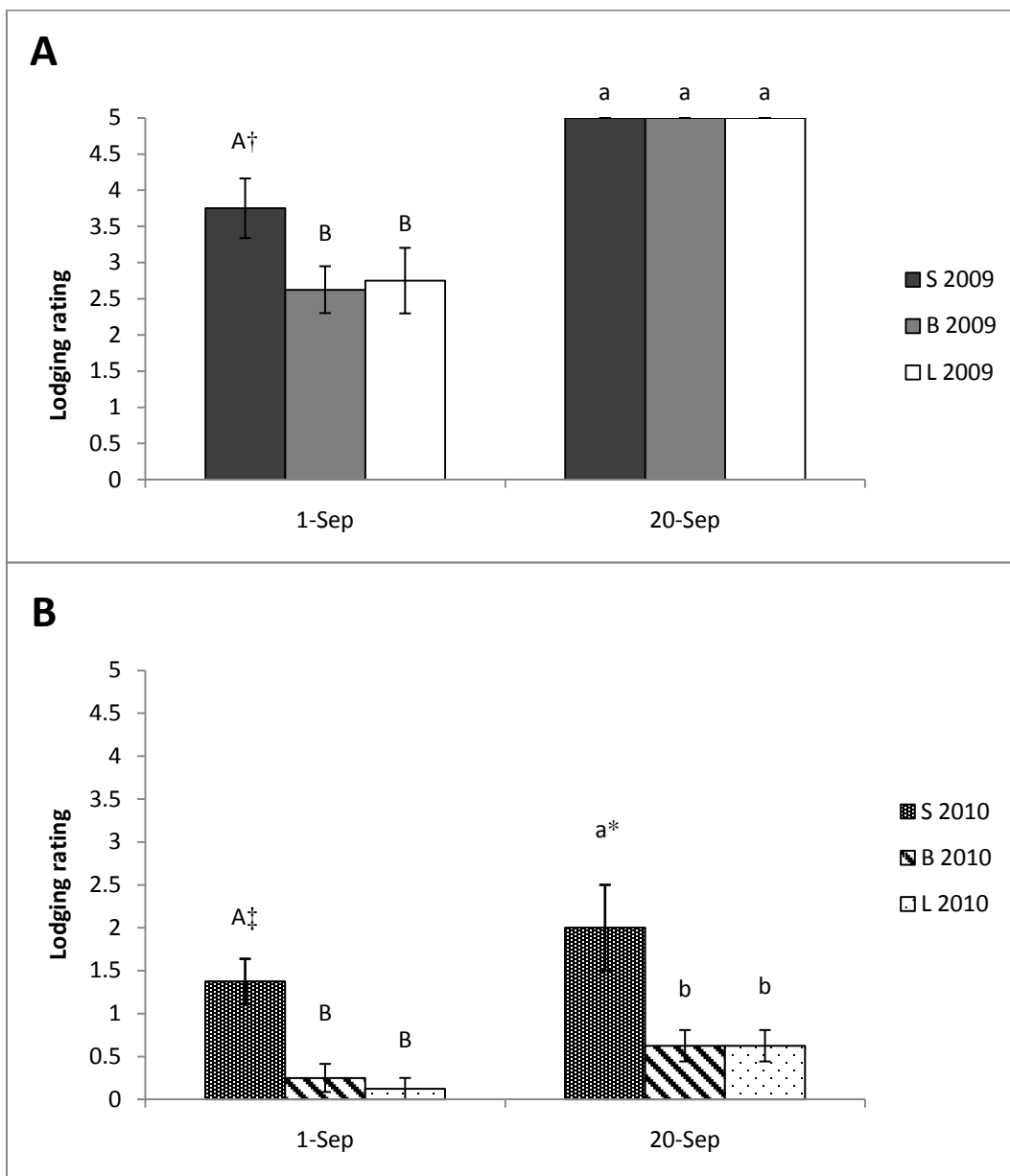


Figure 11. Effects of fertilizer rate on onion lodging in 2009 (Panel A) and 2010 (Panel B). Treatment means (n=4) designated †, ‡, * are significant within month at $p=0.0343$, $p=0.0182$ and $p=0.002$, respectively. S=standard rate, B=biostimulant, L=low rate

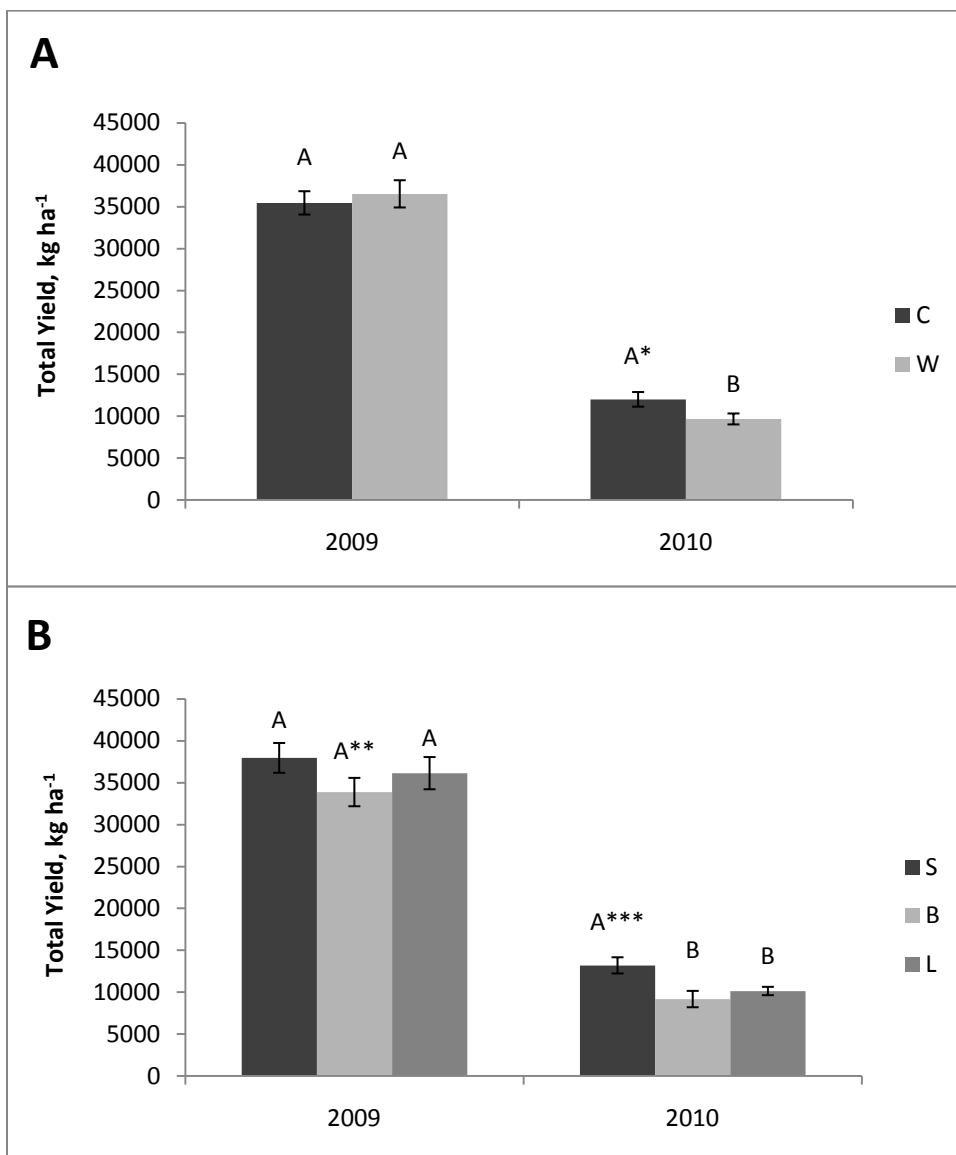


Figure 12. Effect of crop rotation (Panel A) and fertilizer treatment (Panel B) on total yield in 2009 and 2010. Treatment means (n=4) labeled with the same letter did not differ significantly within year. Treatment means designated *, **, and *** are significant or notable at $p=0.0349$, $p=0.089$, and $p=0.0034$, respectively.

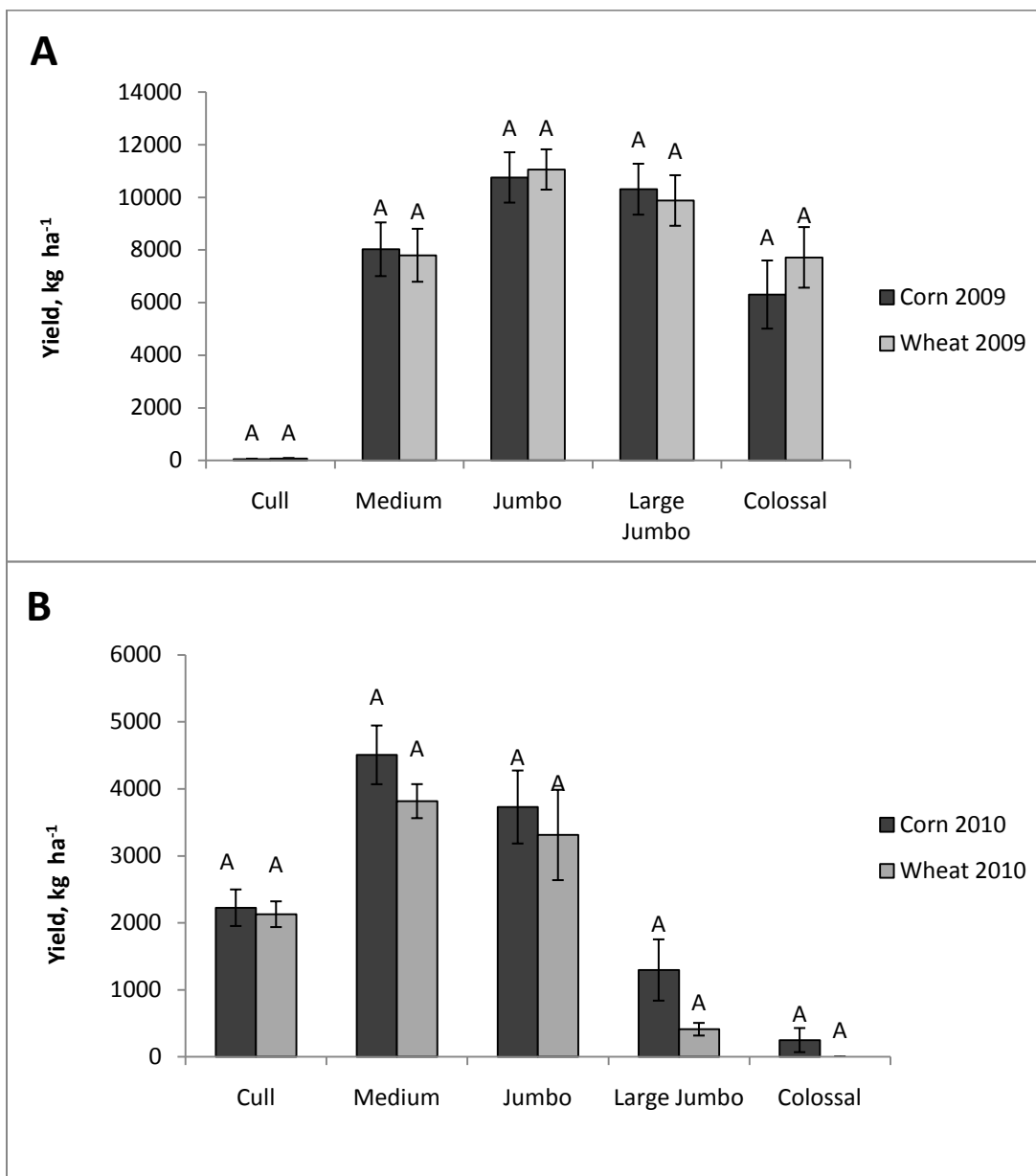


Figure 13. Effect of crop rotation on onion size category yield in 2009 (Panel A) and 2010 (Panel B). Treatment means (n=4) labeled with the same letter did not differ significantly within size category.

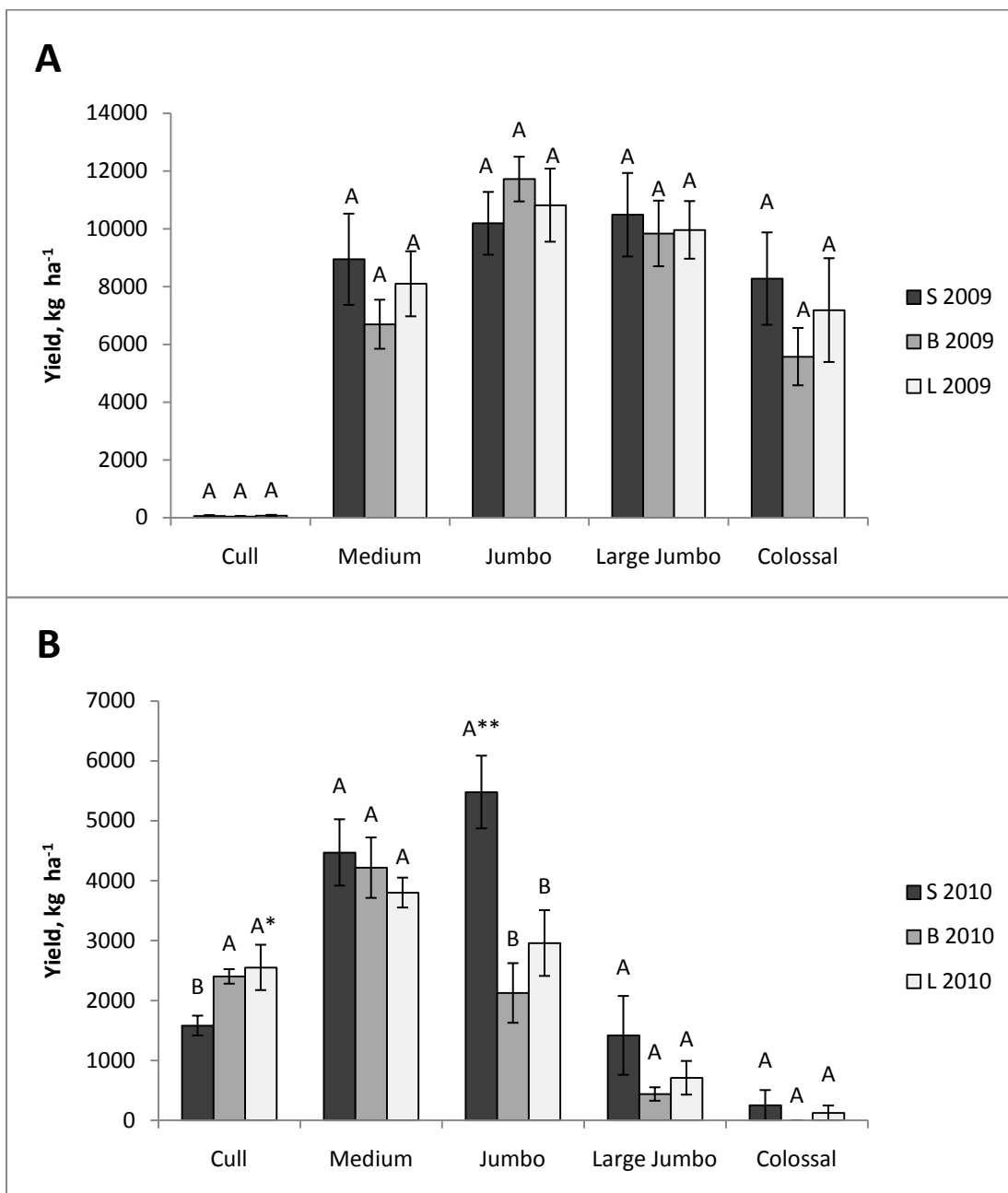


Figure 14. Effect of fertilizer treatment on onion size category and yield in 2009 (Panel A) and 2010 (Panel B). Treatment means (n=4) labeled with the same letter did not differ significantly within size category. Treatment means designated * and ** are significant at $p=0.007$ and $p=0.0133$, respectively.

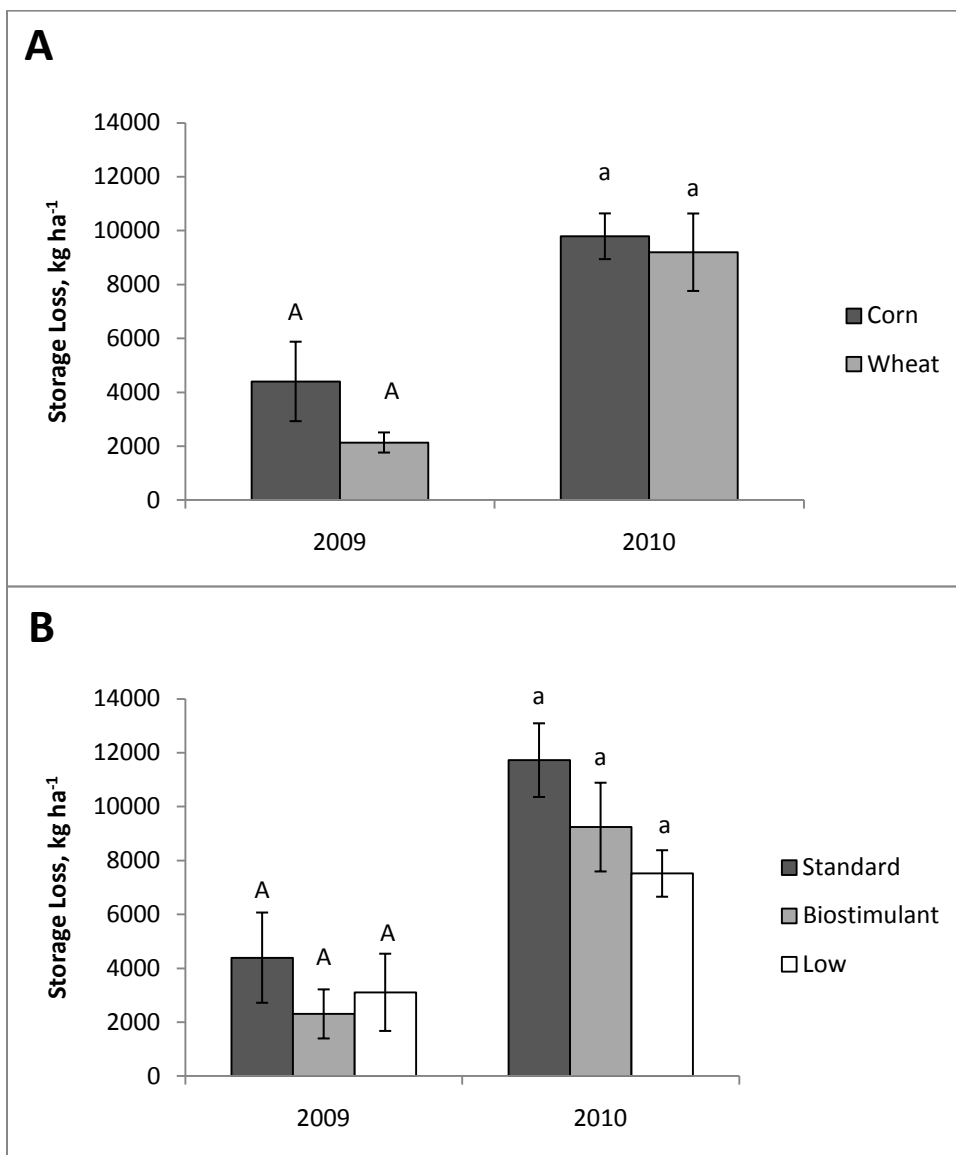


Figure 15. Effects of prior crop rotation (Panel A) and fertilizer treatment (Panel B) on storage loss.

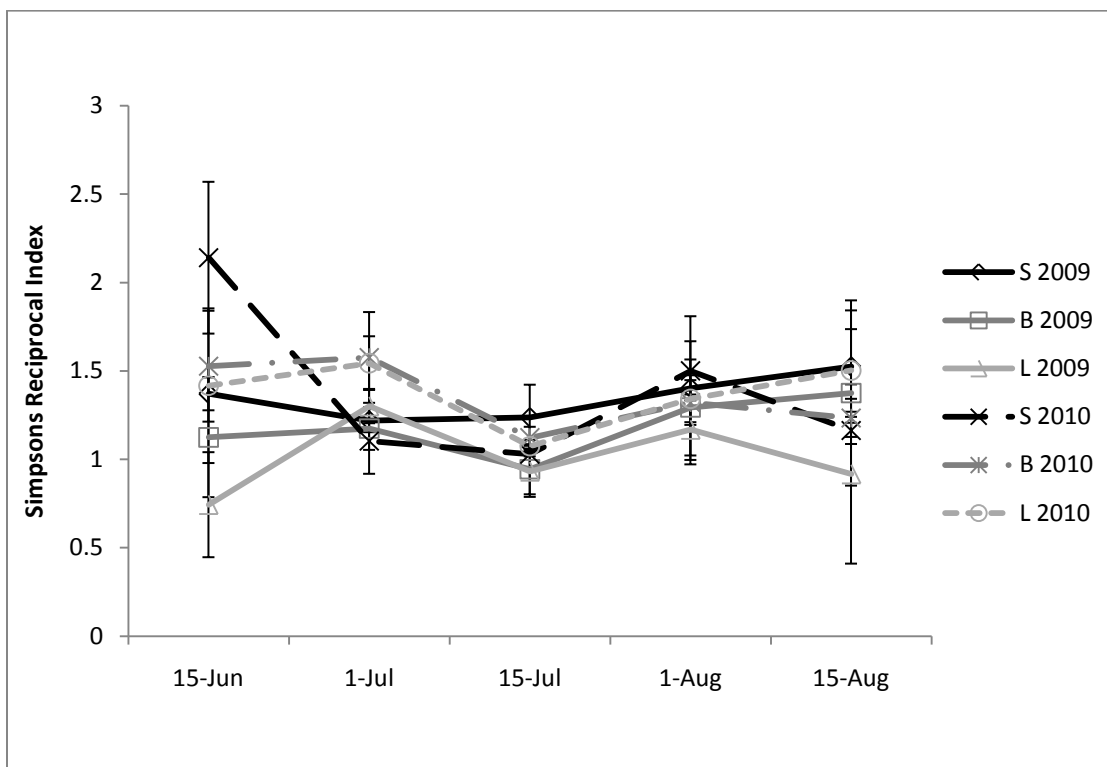


Figure 16. Effects of fertilizer treatment on biodiversity of insects in 2009 and 2010 measured as a Simpsons Reciprocal Index. Treatment means (n=4) did not significantly differ in any sample period. S=standard rate, B=biostimulant, L=low rate

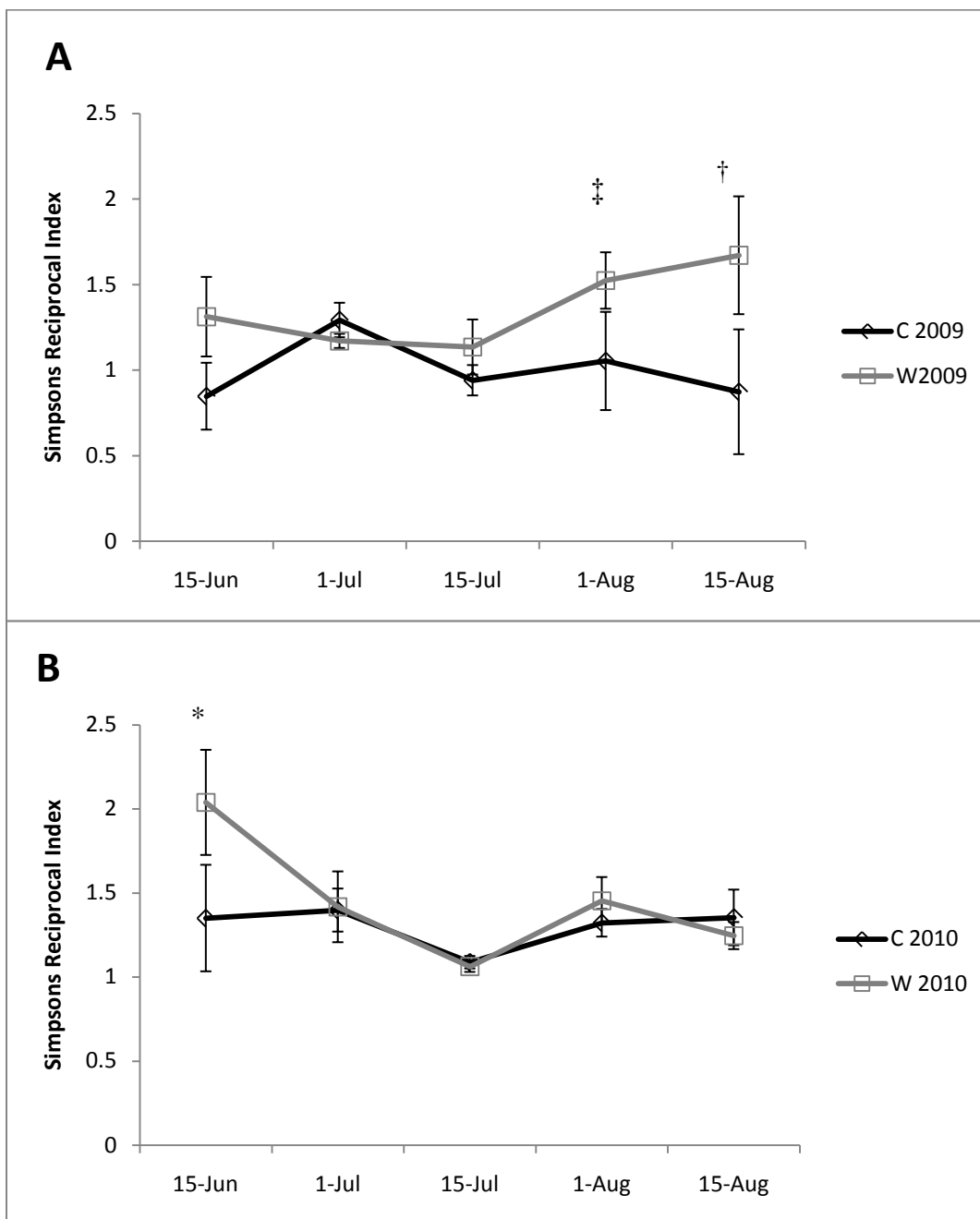


Figure 17. Effects of crop rotation on insect species diversity measured as Simpsons Reciprocal Index in 2009 (Panel A) and 2010 (Panel B). Treatment means (n=4) designated †, ‡, and *, are significant or notable at $p=0.006$, $p=0.086$, and $p=0.021$, respectively. C=corn, W=wheat

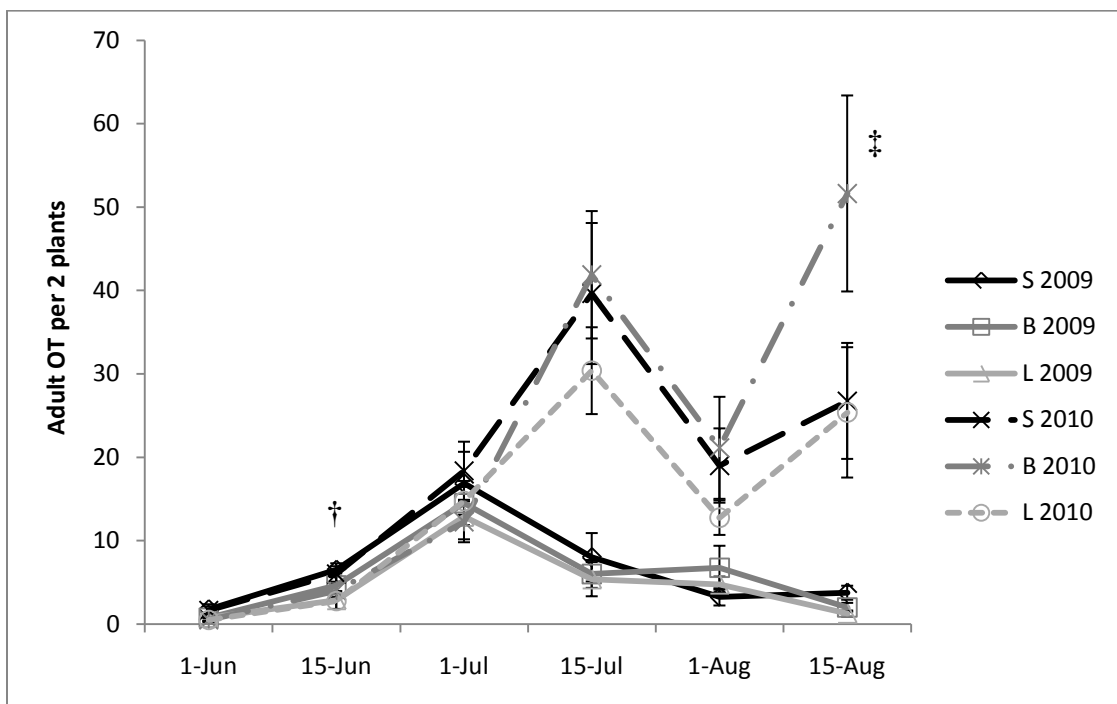


Figure 18. Effects of fertilizer treatment on the numbers of adult OT per two onion plants in 2009 and 2010. Treatment means ($n=4$) designated by a symbol are significant as follows: † further explained in Figure 17 below, ‡ in 2010 only, B treatment greater than both standard ($p=0.0184$) and low ($p=0.0104$). S=standard rate, B=biostimulant, L=low rate

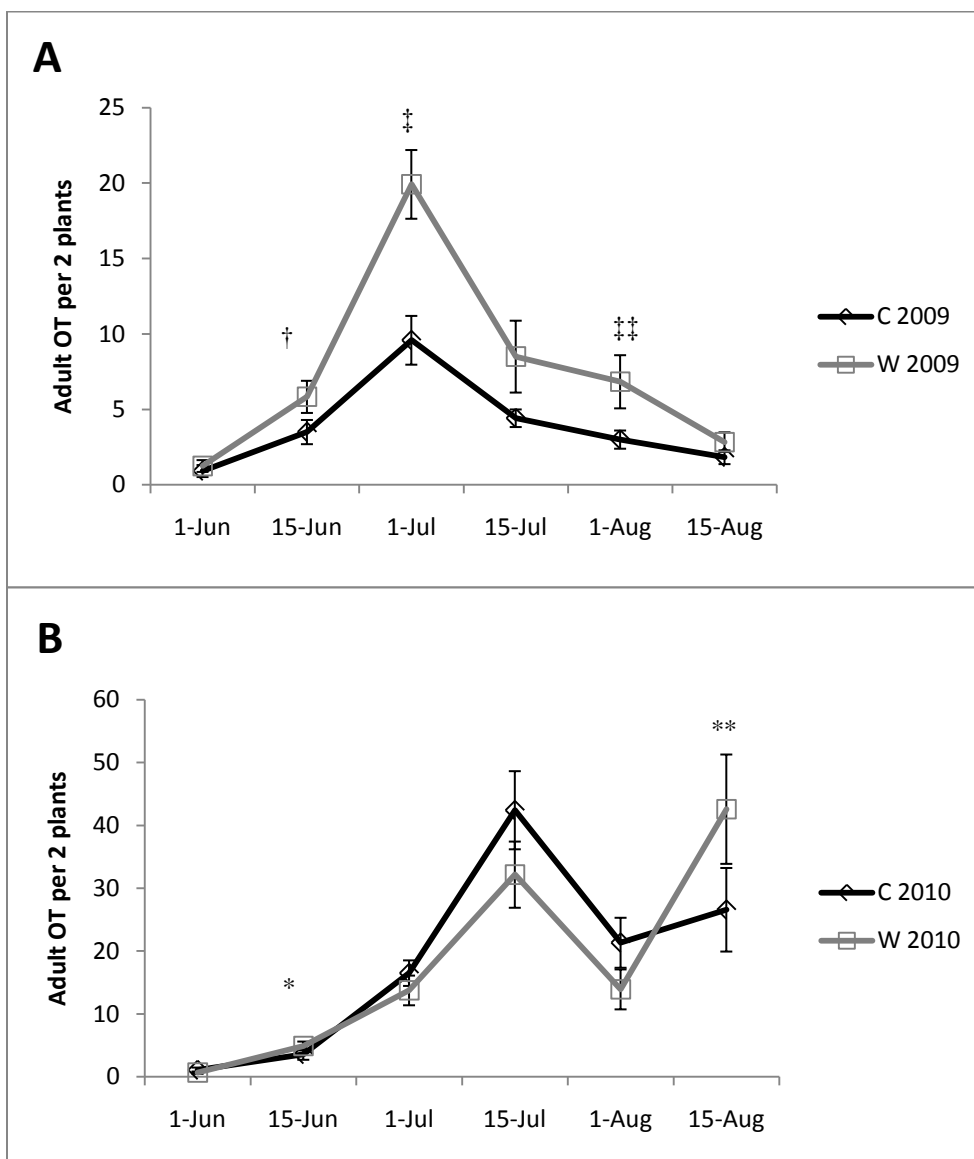


Figure 19. Effects of crop rotation on the numbers of adult OT per two plants in 2009 (Panel A) and 2010 (Panel B). Treatment means (n=4) designated †, ‡, ‡‡, *, ** are significant or notable at $p=0.0358$, $p=0.0024$, $p=0.0931$, $p=0.0933$, $p=0.04$, respectively. C=corn, W=wheat

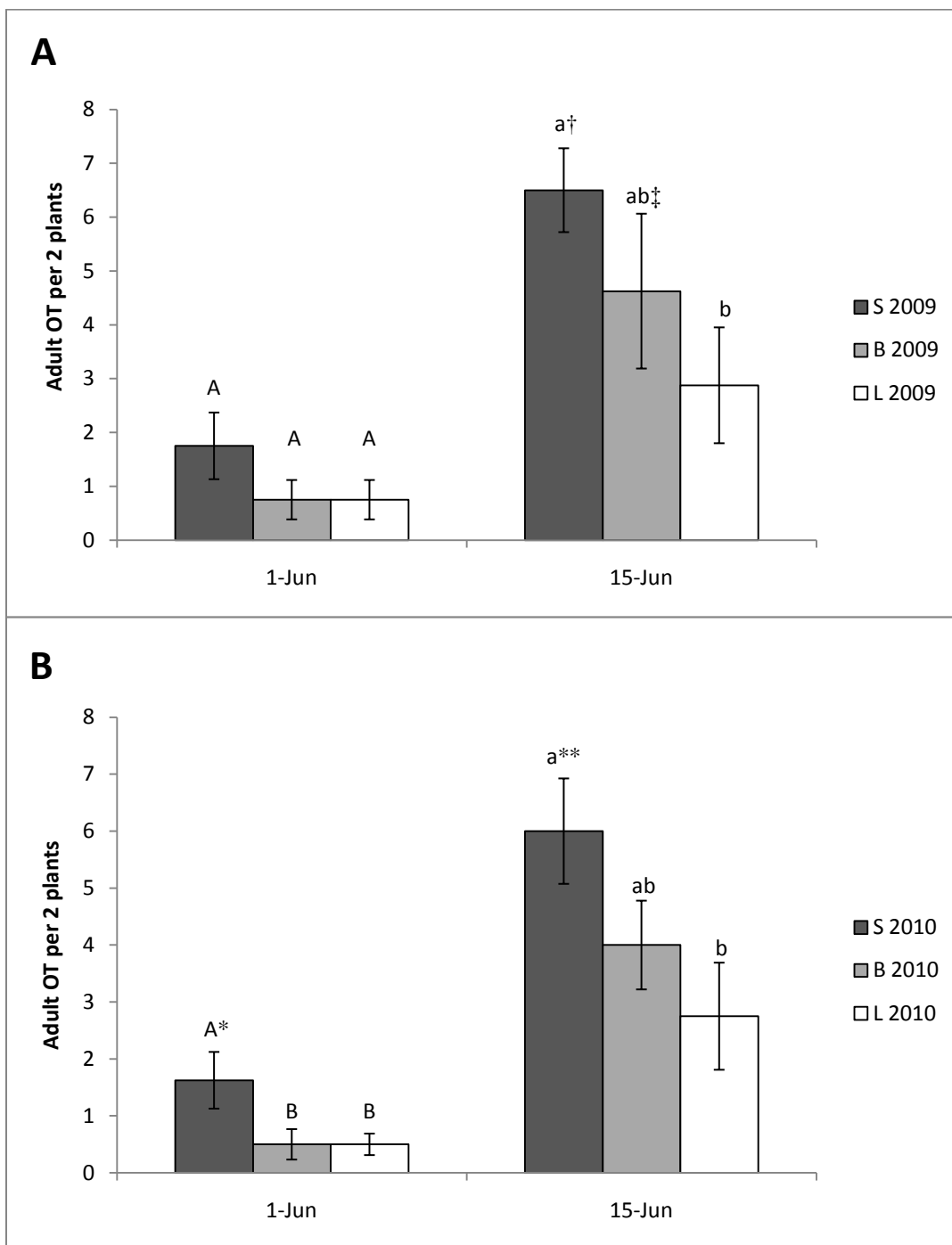


Figure 20. Early season attractiveness of fertilizer treatments on adult OT as seen in 2009 (Panel A) and 2010 (Panel B). Treatment means ($n=4$) designated †, ‡, *, ** are significant or notable within month at $p=0.0033$, $p=0.101$, $p=0.236$, and $p=0.008$, respectively. S=standard rate, B=biostimulant, L=low rate

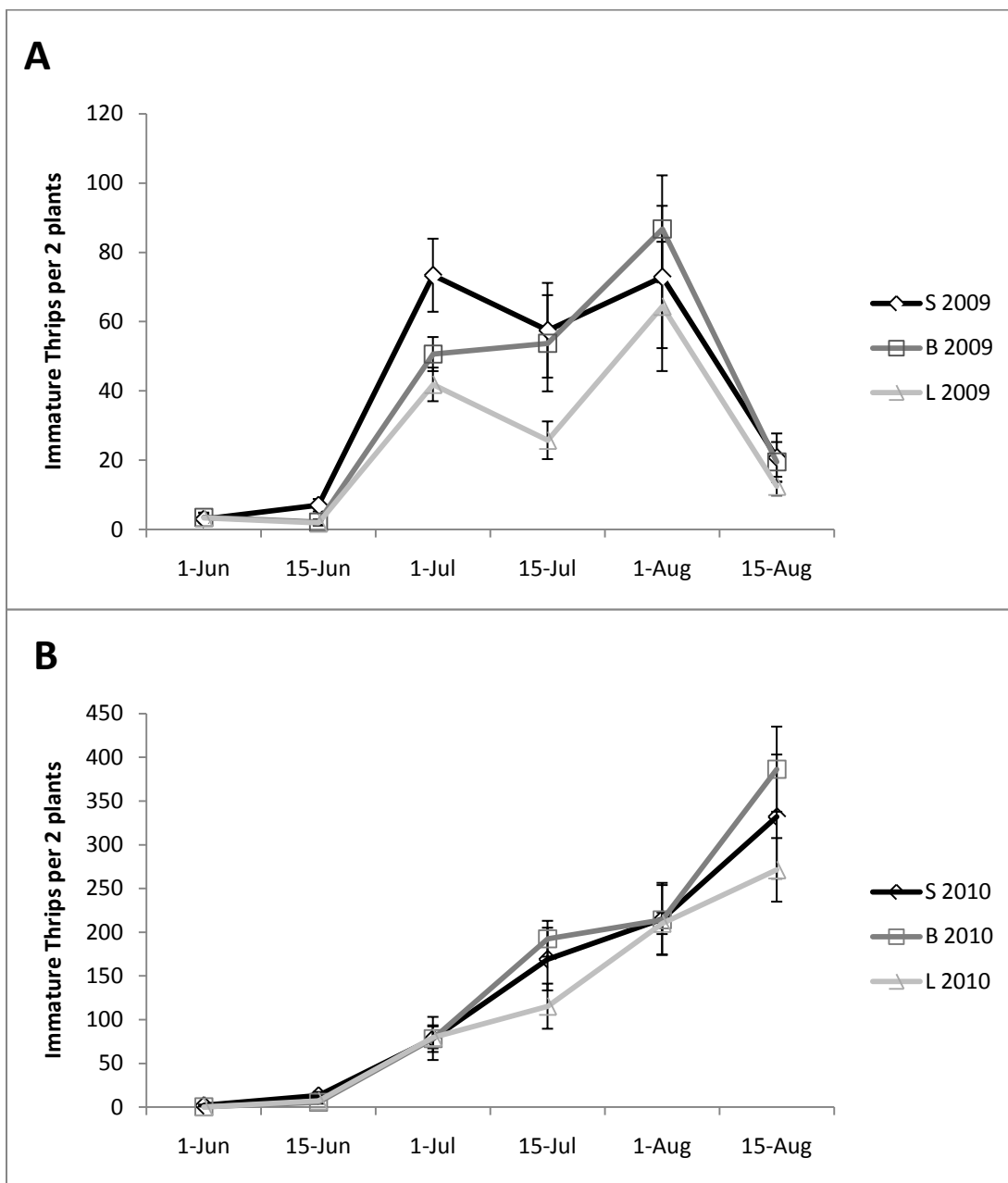


Figure 21. Effects of fertilizer treatment on numbers of immature thrips per two onion plants in 2009 (Panel A) and 2010 (Panel B). Main effects of year and treatment were significant at $p < 0.0001$ and $p = 0.042$, respectively. The interaction of year, sample date and crop rotation was notable at $p = 0.0609$. S=standard rate, B=biostimulant, L=low rate

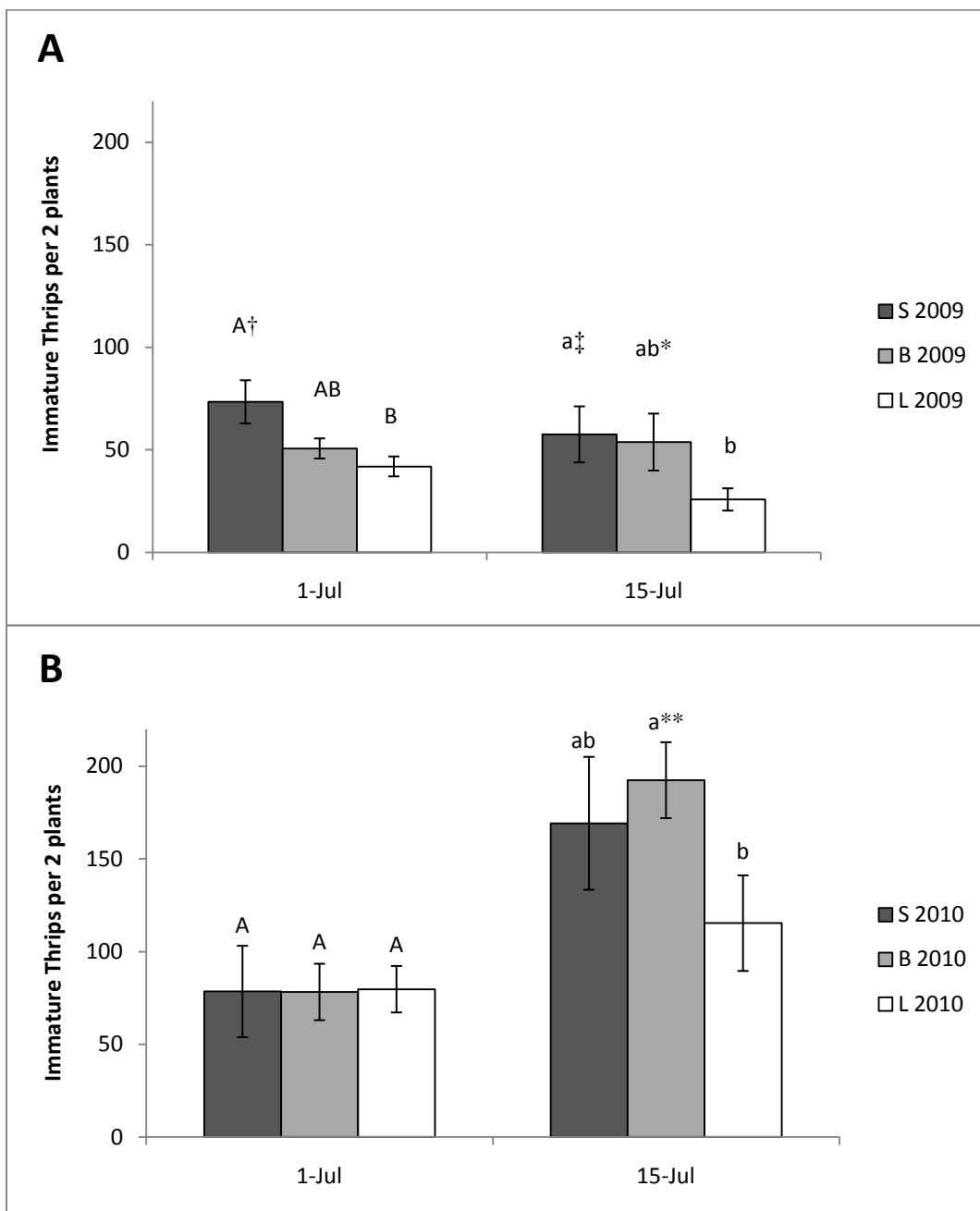


Figure 22. Fertilizer treatment effects on immature thrips counts in early and mid July for 2009 (Panel A) and 2010 (Panel B). Treatment means (n=4) designated †, ‡, *, and ** are significant or notable within month at $p=0.0469$, $p=0.0282$, $p=0.0987$ and $p=0.0497$, respectively. S=standard rate, B=biostimulant, L=low rate

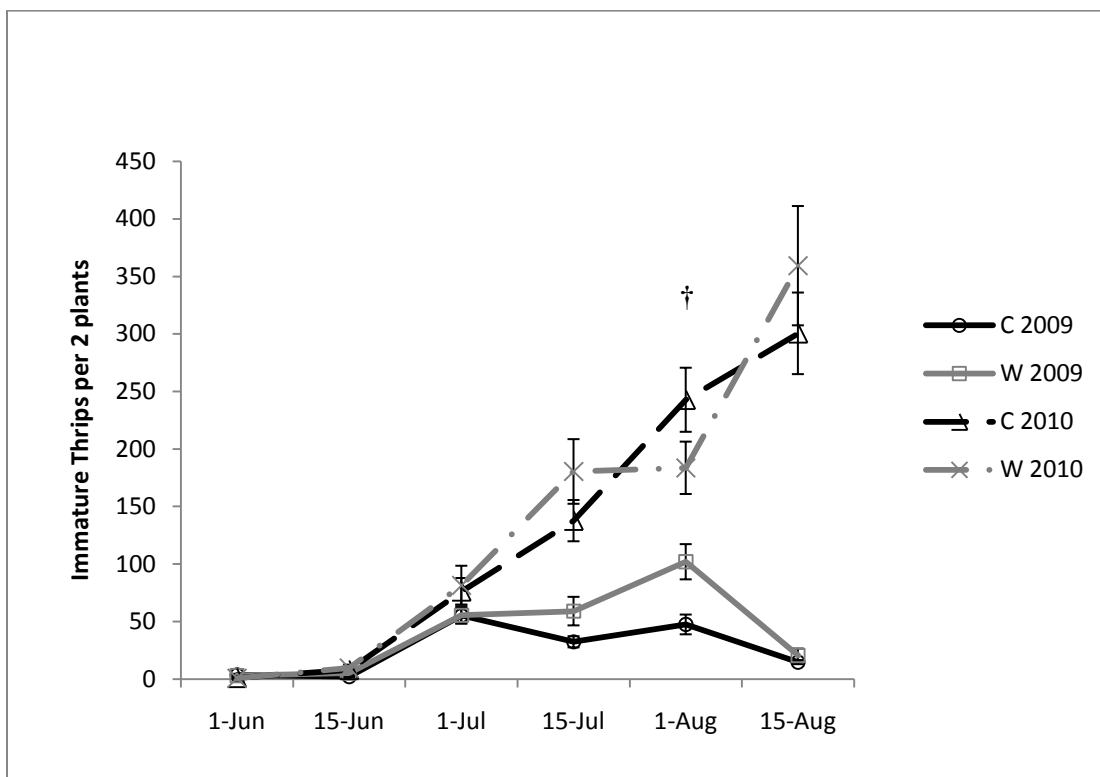


Figure 23. Effects of prior crop rotation on numbers of immature thrips per two onion plants. Treatment means (n=4) designated † denote a significant difference between crop rotations in 2009 only ($p=0.001$). C=corn, W=wheat

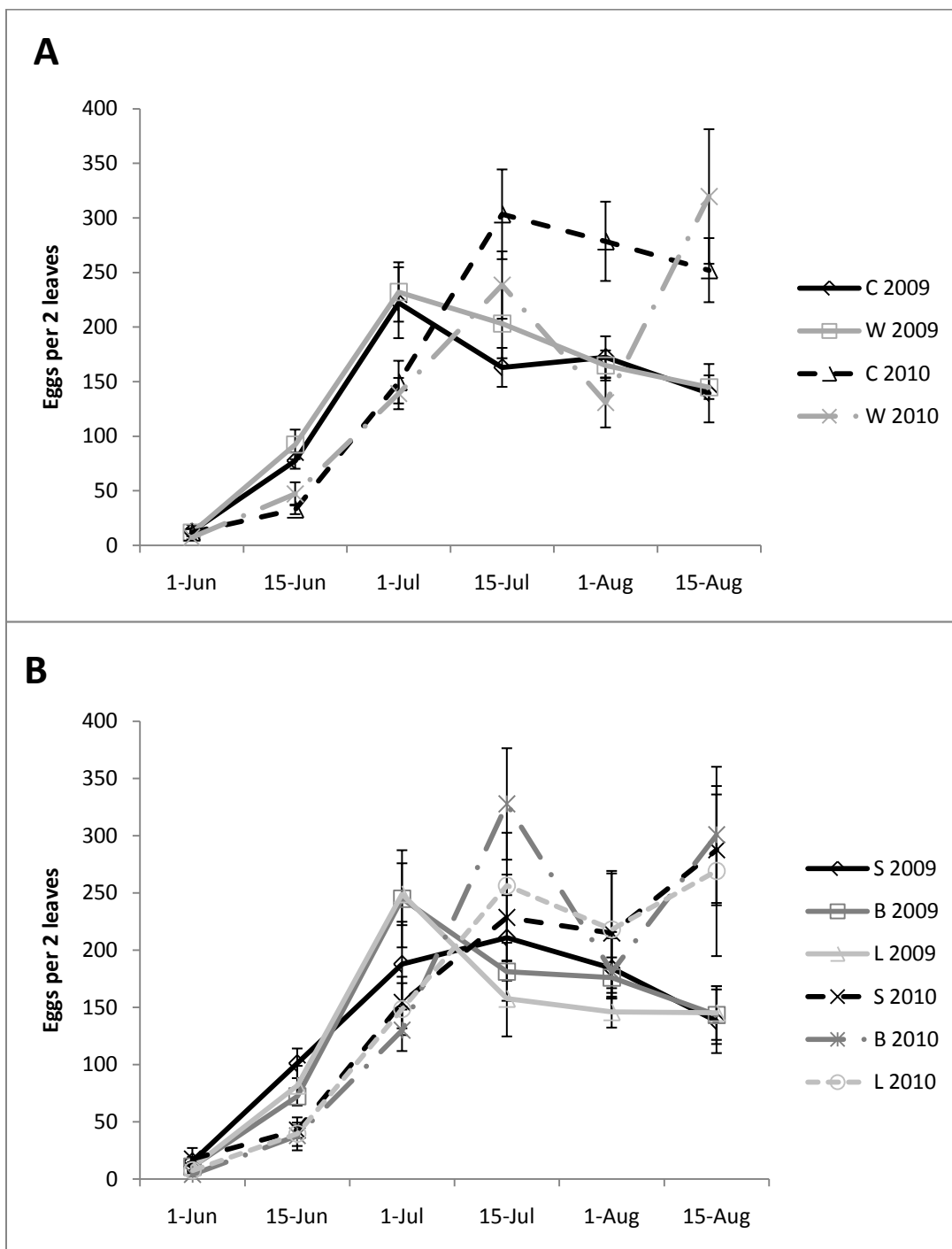


Figure 24. Effect of crop rotation (Panel A) and fertilizer treatment (Panel B) on numbers of thrips eggs per two onion leaves. Treatment means ($n=4$) did not significantly differ in any sample period. C=corn, W=wheat, S=standard rate, B=biostimulant, L=low rate

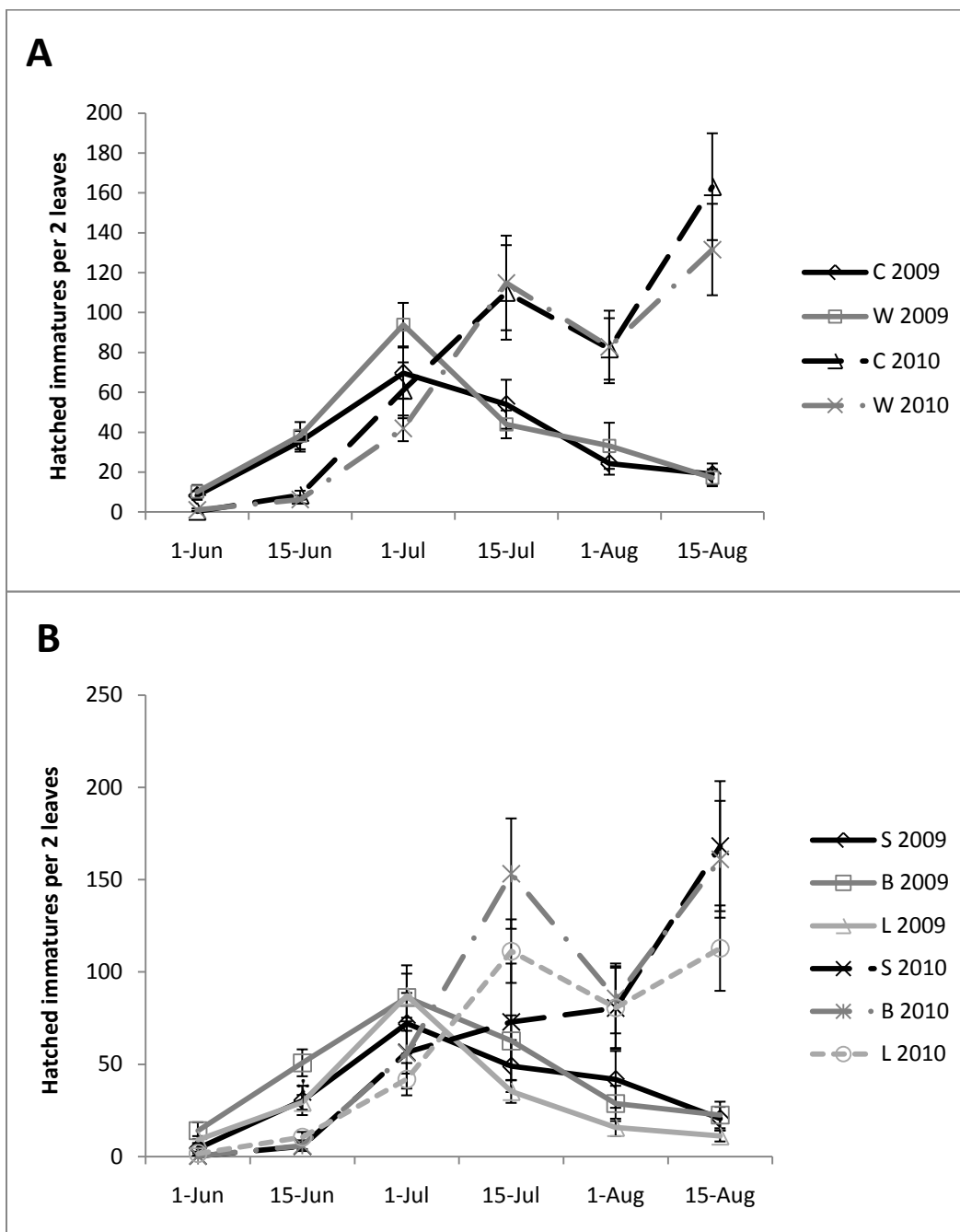


Figure 25. Effects of crop rotation (Panel A) and fertilizer treatment (Panel B) on the number of hatched immature thrips per two leaves.

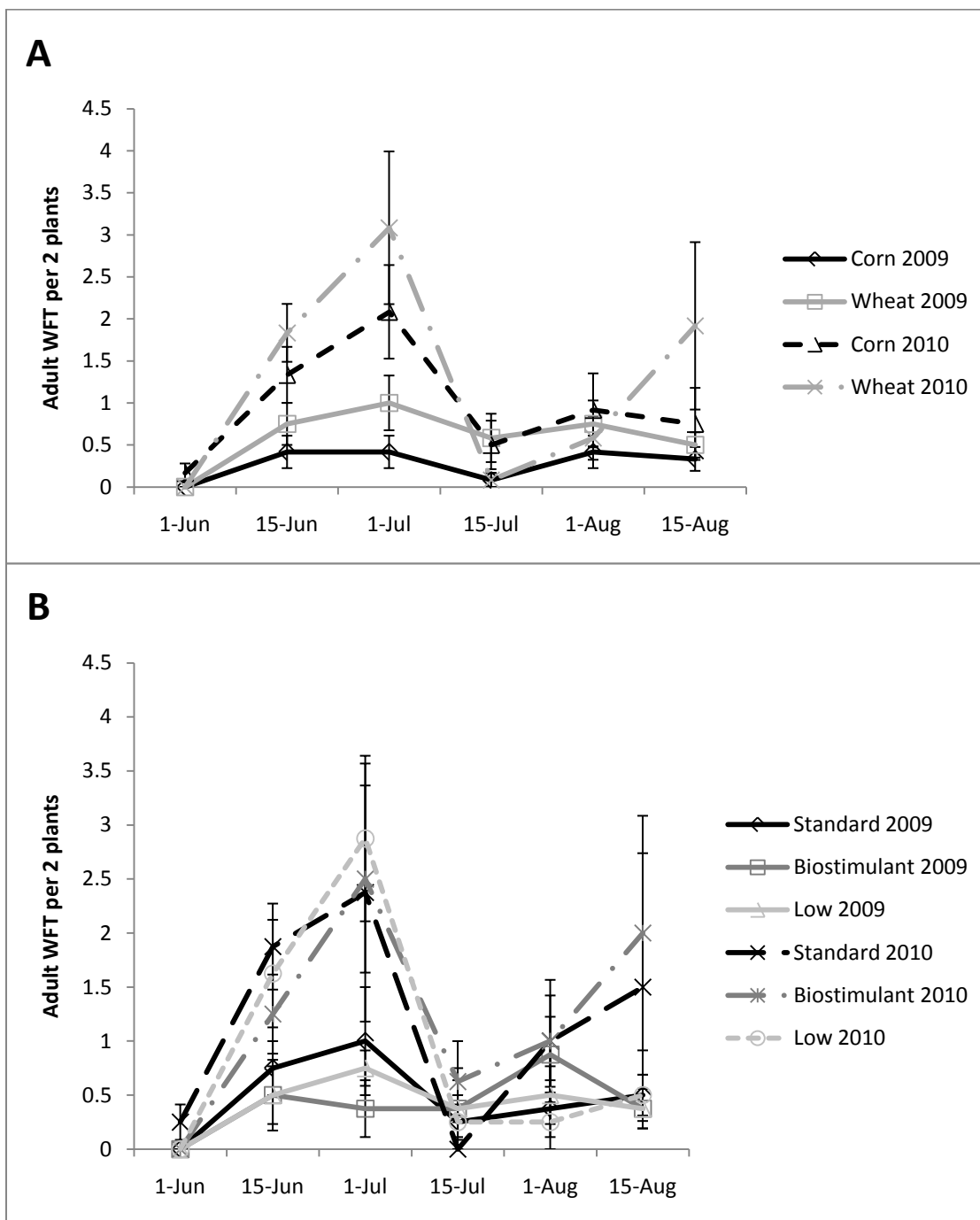


Figure 26. Effects of crop rotation (Panel A) and fertilizer treatment (Panel B) on numbers of adult WFT per two onion plants. Main effects of year and sample date were significant at $p=0.0012$ and $p<0.0001$, respectively. Crop rotation was notable at $p=0.1037$.

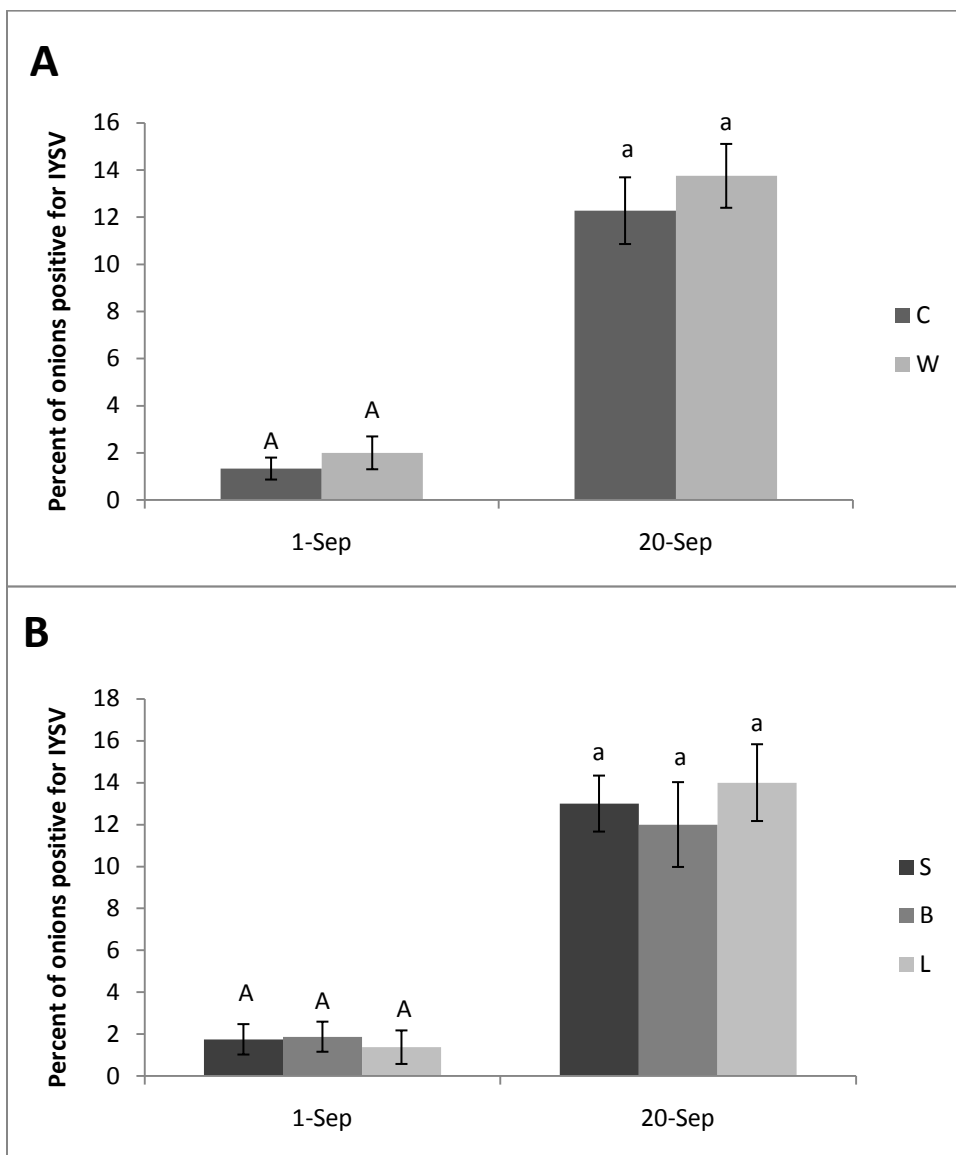


Figure 27. Effects of crop rotation (Panel A) and fertilizer treatment (Panel B) on IYSV incidence on 1 Sep and 20 Sep 2010. Treatment means (n=4) designated by the same letter did not significantly differ within sample date. C=corn, W=wheat, S=standard rate, B=biostimulant, L=low rate

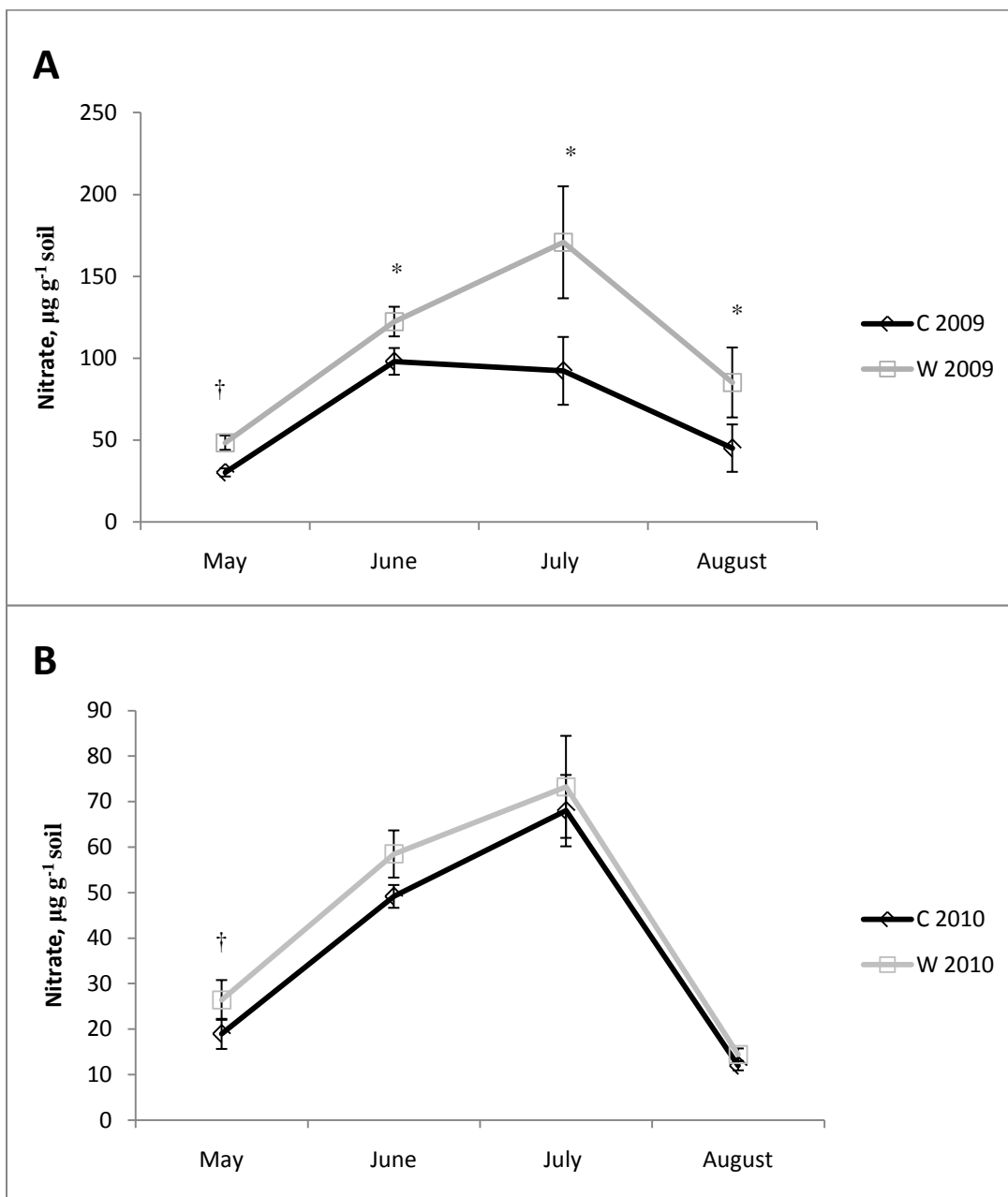


Figure 28. Effects of crop rotation on soil nitrate levels in 2009 (Panel A) and 2010 (Panel B). Treatment means ($n=4$) designated \dagger and $*$ are significant at $p < 0.05$ and $p < 0.001$, respectively. C=corn, W=wheat

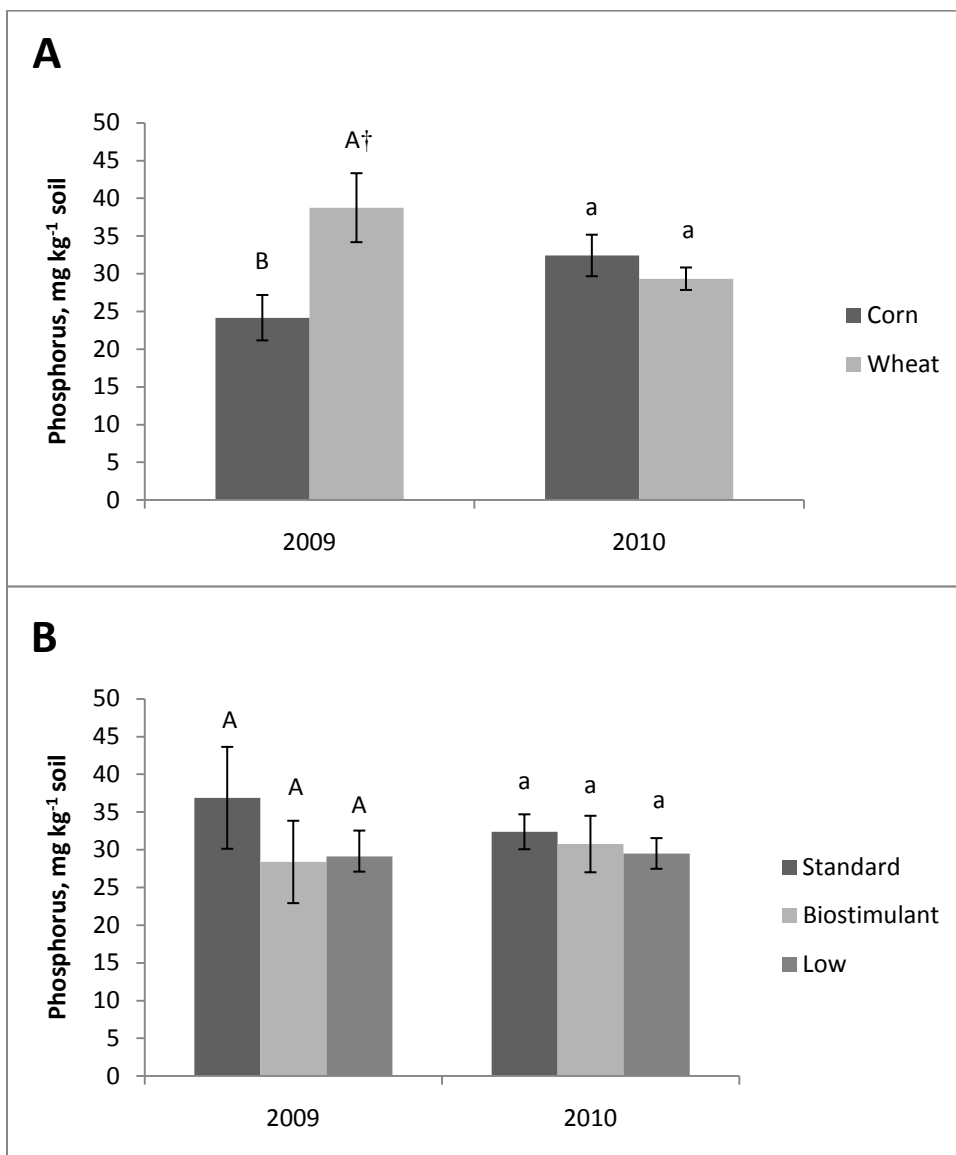


Figure 29. Effects of crop rotation (Panel A) and fertilizer treatment (Panel B) on total soil phosphorus. Treatment mean (n=4) designated † is significant at $p=0.0023$. All other treatment means designated by different letters are significant at $p<0.05$.

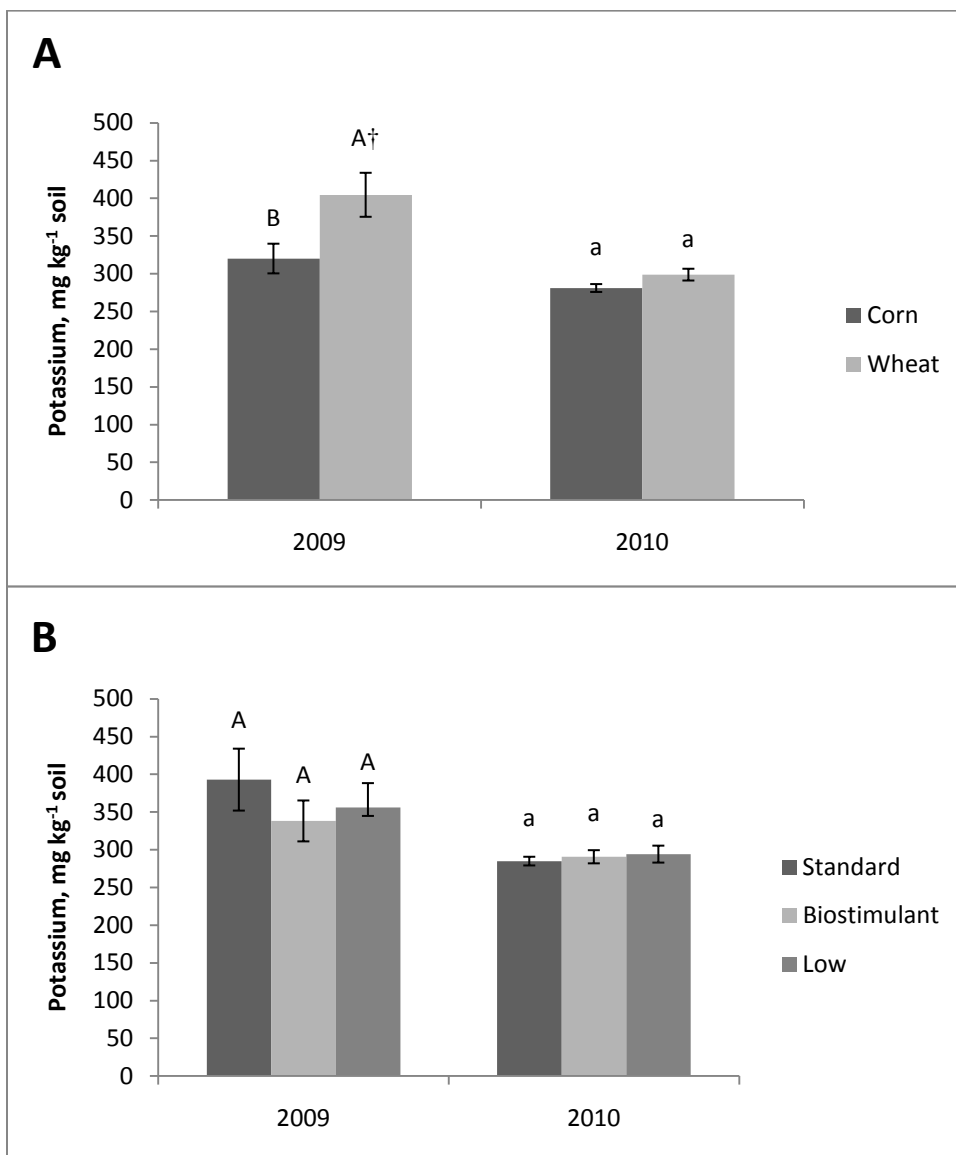


Figure 30. Effects of crop rotation (Panel A) and fertilizer treatment (Panel B) on total soil potassium. Treatment mean (n=4) designated † is significant at p=0.0025. All other treatment means designated by different letters are significant at p<0.05.

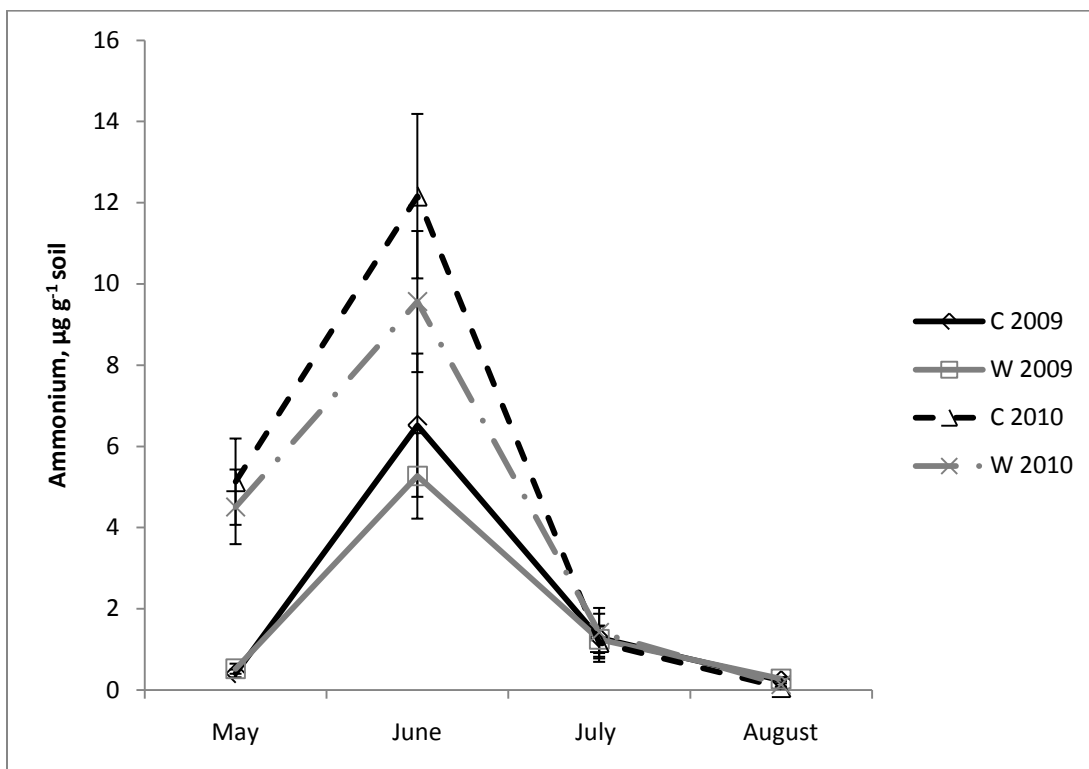


Figure 31. Effects of crop rotation on soil extractable ammonium in 2009 and 2010. Treatment means ($n=4$) did not significantly differ in any sample period. C=corn, W=wheat.

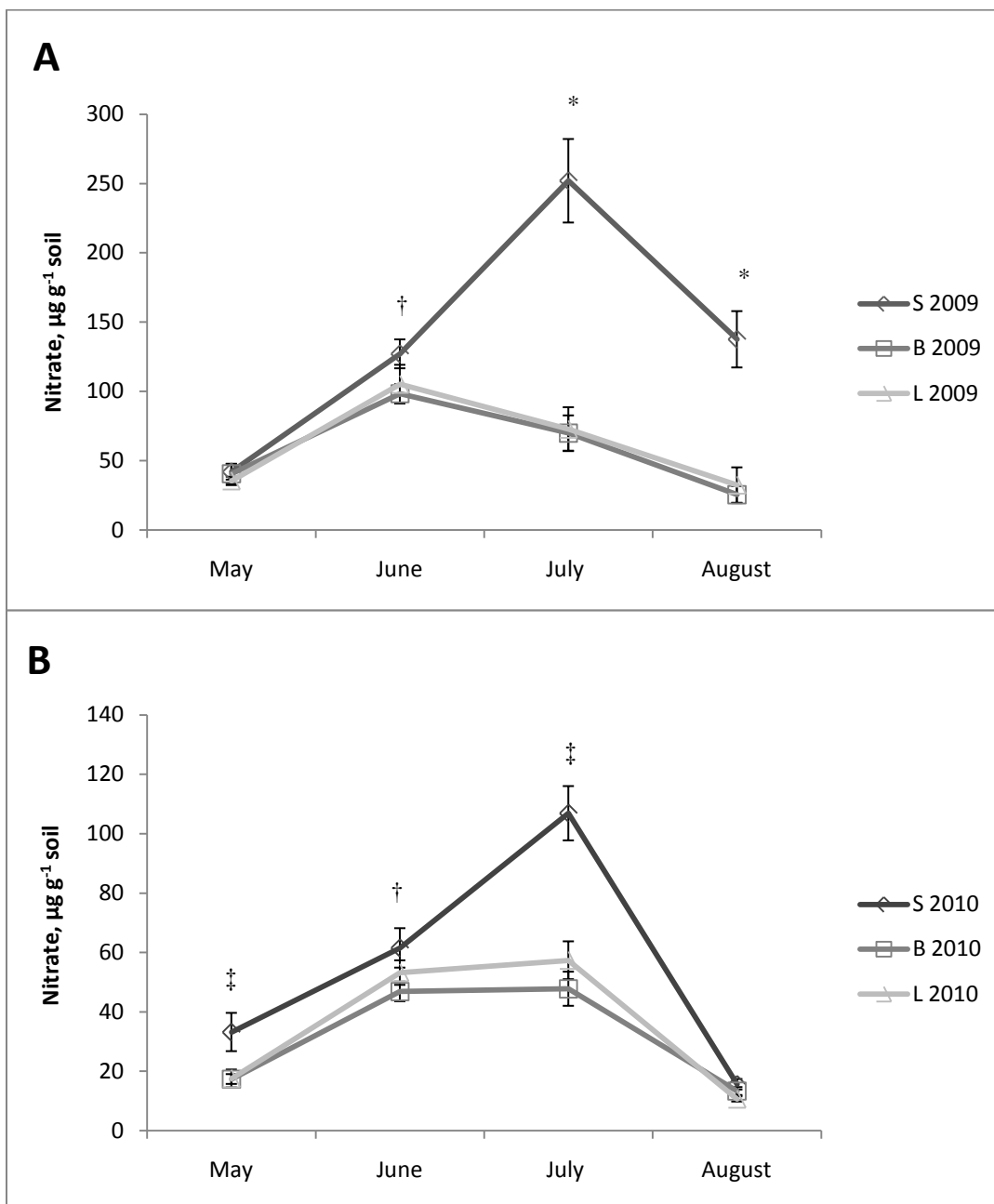


Figure 32. Soil extractable nitrate as a function of fertilizer treatment in 2009 (Panel A) and 2010 (Panel B). Treatment means (n=4) designated ‡, †, * are significant at $p < 0.01$, $p < 0.05$ and $p < 0.001$, respectively. In June 2009 (Panel A), only S and B differed significantly while S and L were notably different at $p = 0.0577$. In June 2010, (Panel B) only S and B differed significantly. S=standard rate, B=biostimulant, L=low rate.

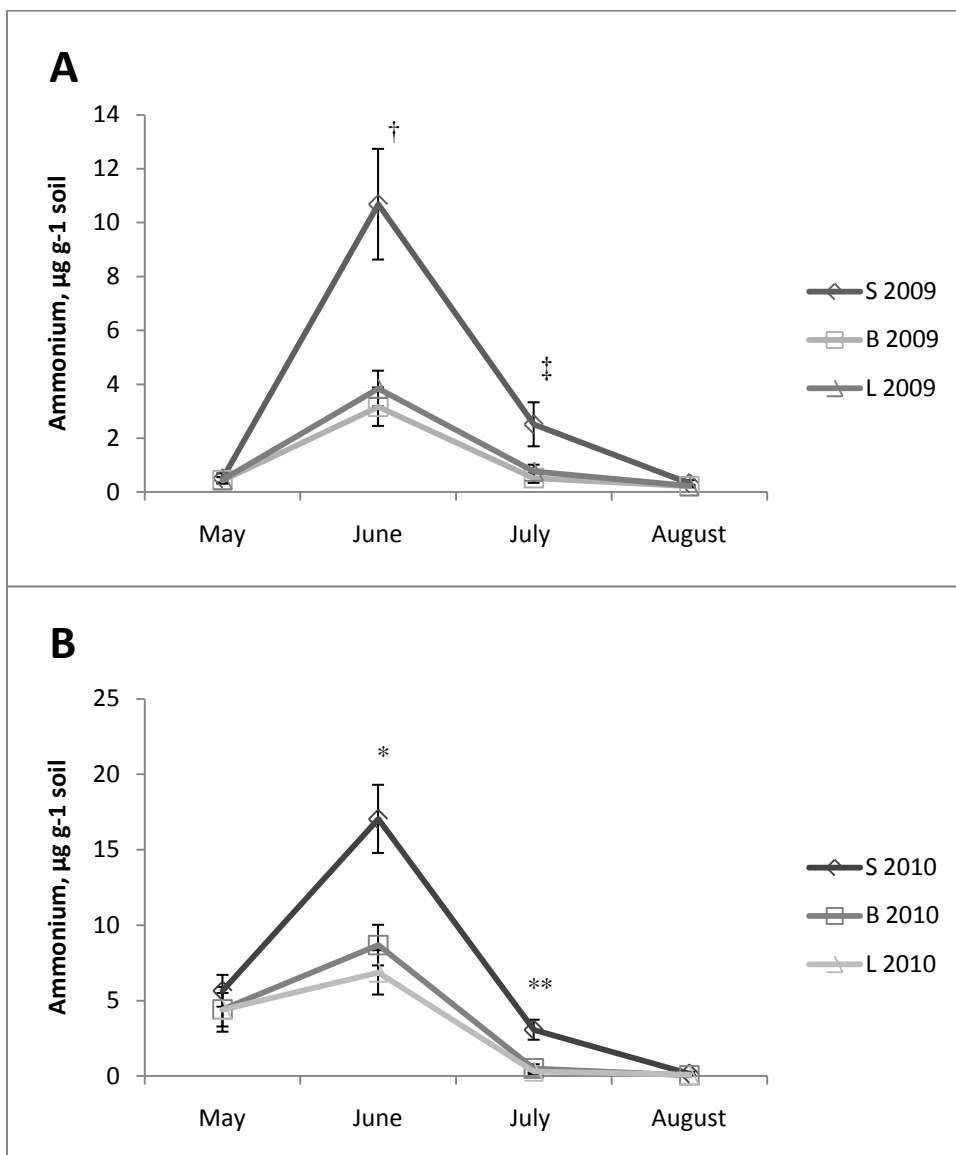


Figure 33. Effects of fertilizer treatment on soil extractable ammonium in 2009 (Panel A) and 2010 (Panel B). Treatment means (n=4) designated **, *, ‡, † are significant at $p < 0.005$, $p < 0.05$, $p = 0.03$ for S and B only and $p < 0.001$. S=standard rate, B=biostimulant, L=low rate.

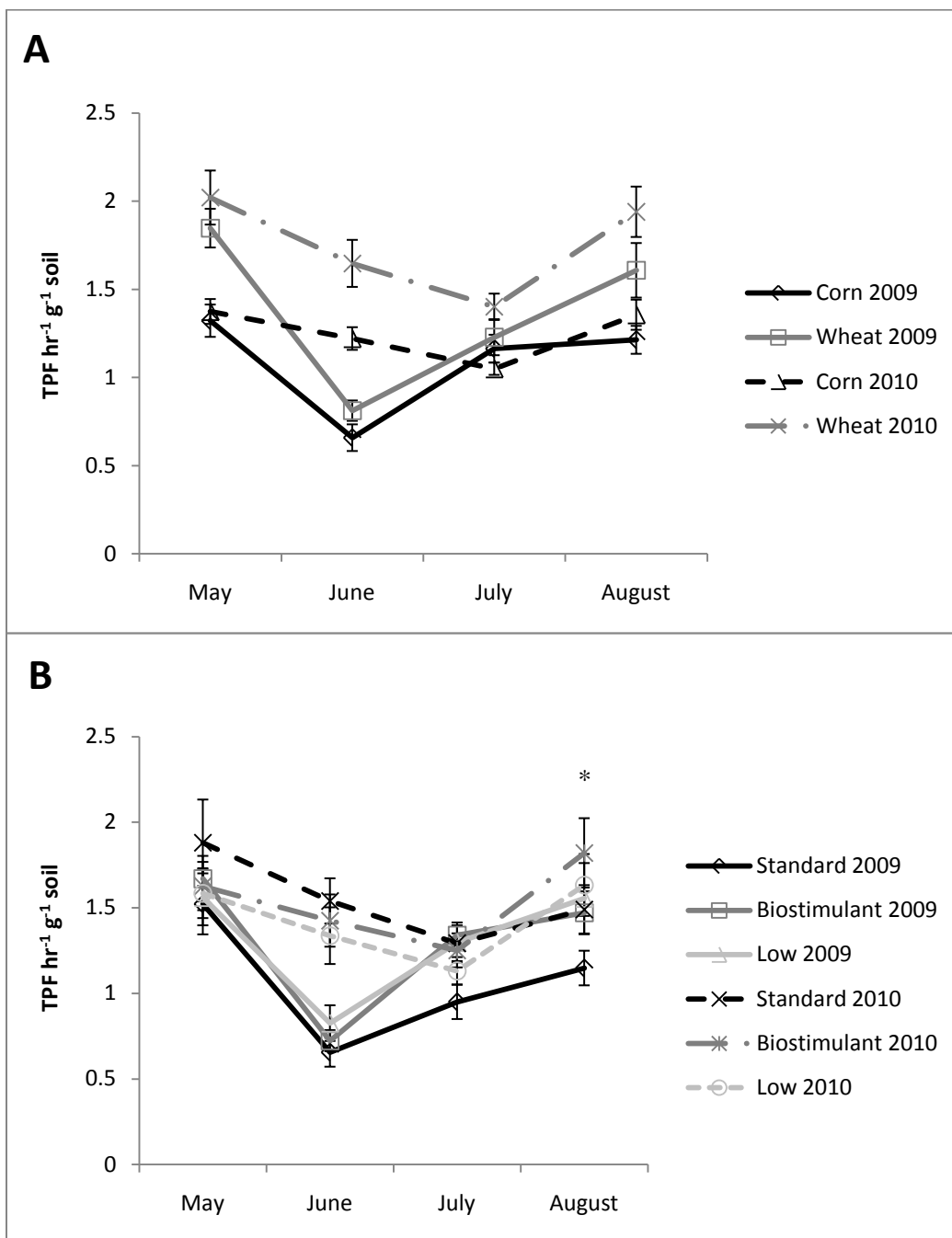


Figure 34. Crop rotation (Panel A) and fertilizer treatment (Panel B) effects on dehydrogenase activity in 2009 and 2010. Crop rotation means (n=4) are significant for May, June, July and August at $p < 0.001$, $p = 0.0079$, $p = 0.0104$, and $p = 0.0012$, respectively. Biostimulant and low treatment means (n=4) are significant in the month of August at $p = 0.0060$ and 0.0225 , respectively. All other treatment means designated by different letters are significant at $p < 0.05$.

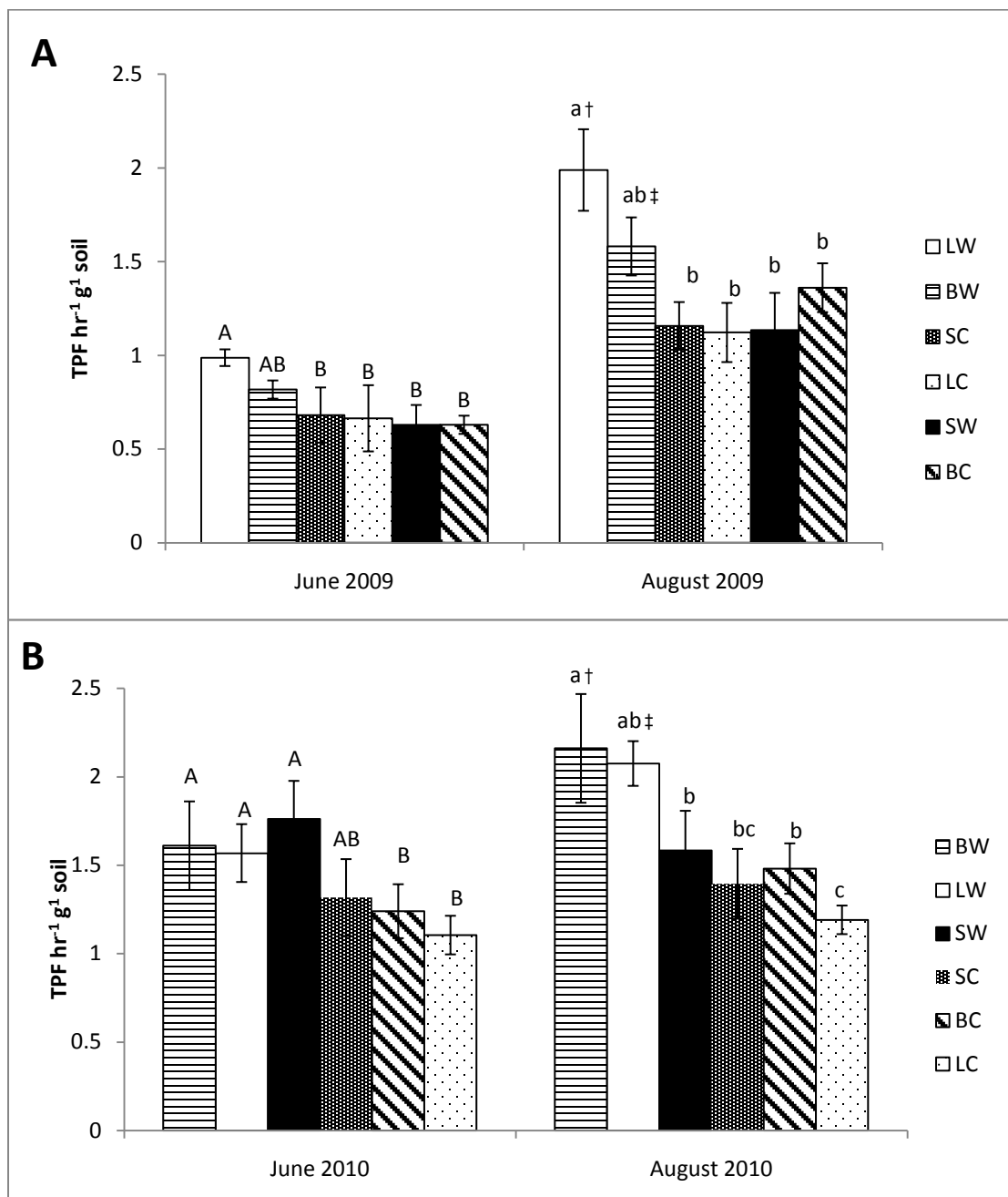


Figure 35. Dehydrogenase activity as measured by reduction of triphenylformazan per hour per gram of soil produced as a function crop rotation and fertilizer treatment for June and August of 2009 (Panel A) and 2010 (Panel B). Treatment means ($n=4$) designated †, ‡, *and ** are significant or notable within month at $p=0.006$, $p=0.0321$, $p=0.0318$ and $p=0.0652$, respectively. All other treatment means designated by different letters are significant at $p<0.05$. LW=low wheat, BW=biostimulant wheat, SW=standard wheat, LC=low corn, BC=biostimulant corn, SC=standard corn.

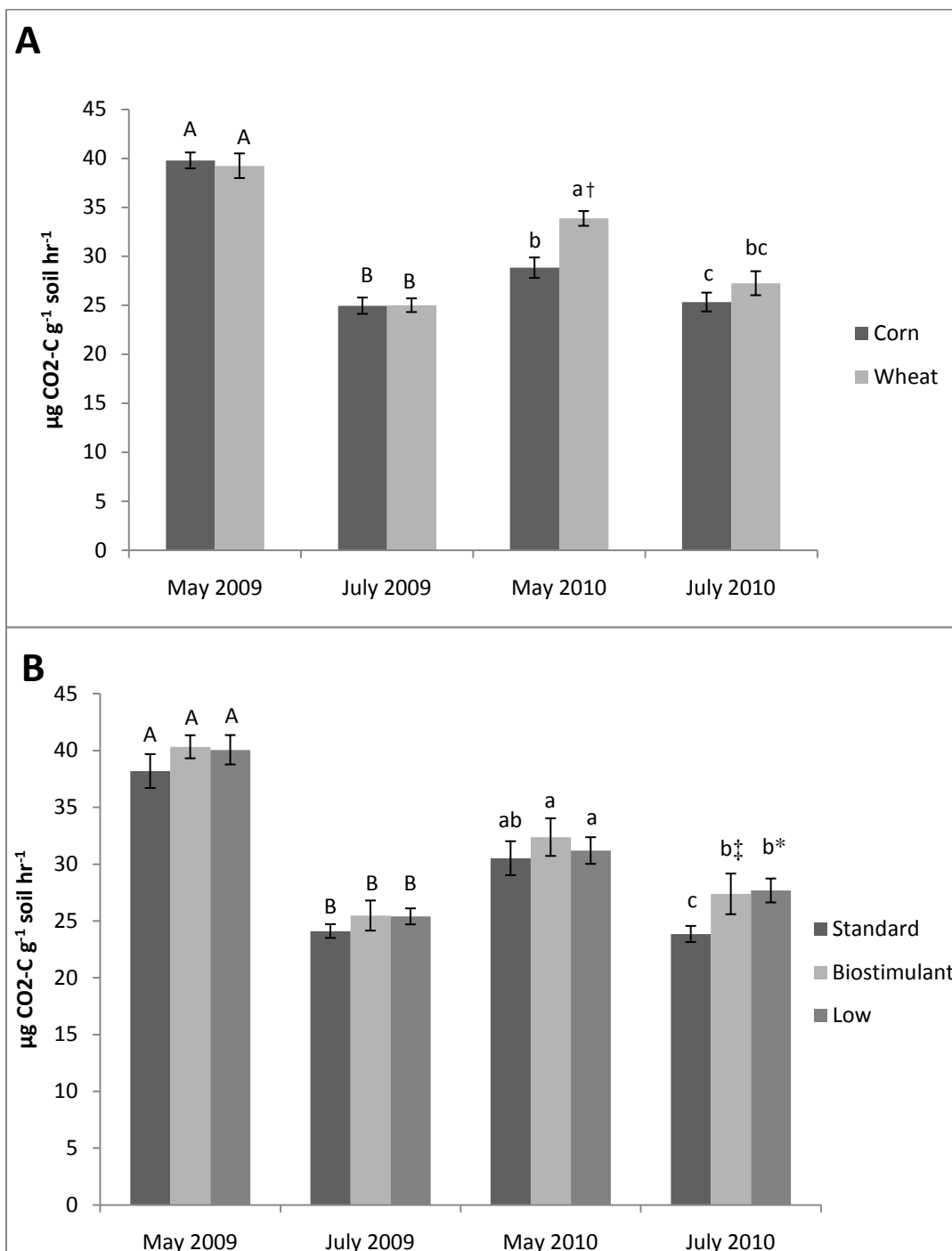


Figure 36. Effects of crop rotation (Panel A) and fertilizer treatment (Panel B) on soil basal respiration in 2009 and 2010. Treatment means (n=4) designated †, ‡ and * are significant within month at $p < 0.001$, $p = 0.0396$ and $p = 0.0259$, respectively. All other treatment means designated by different letters are significant at $p < 0.05$.

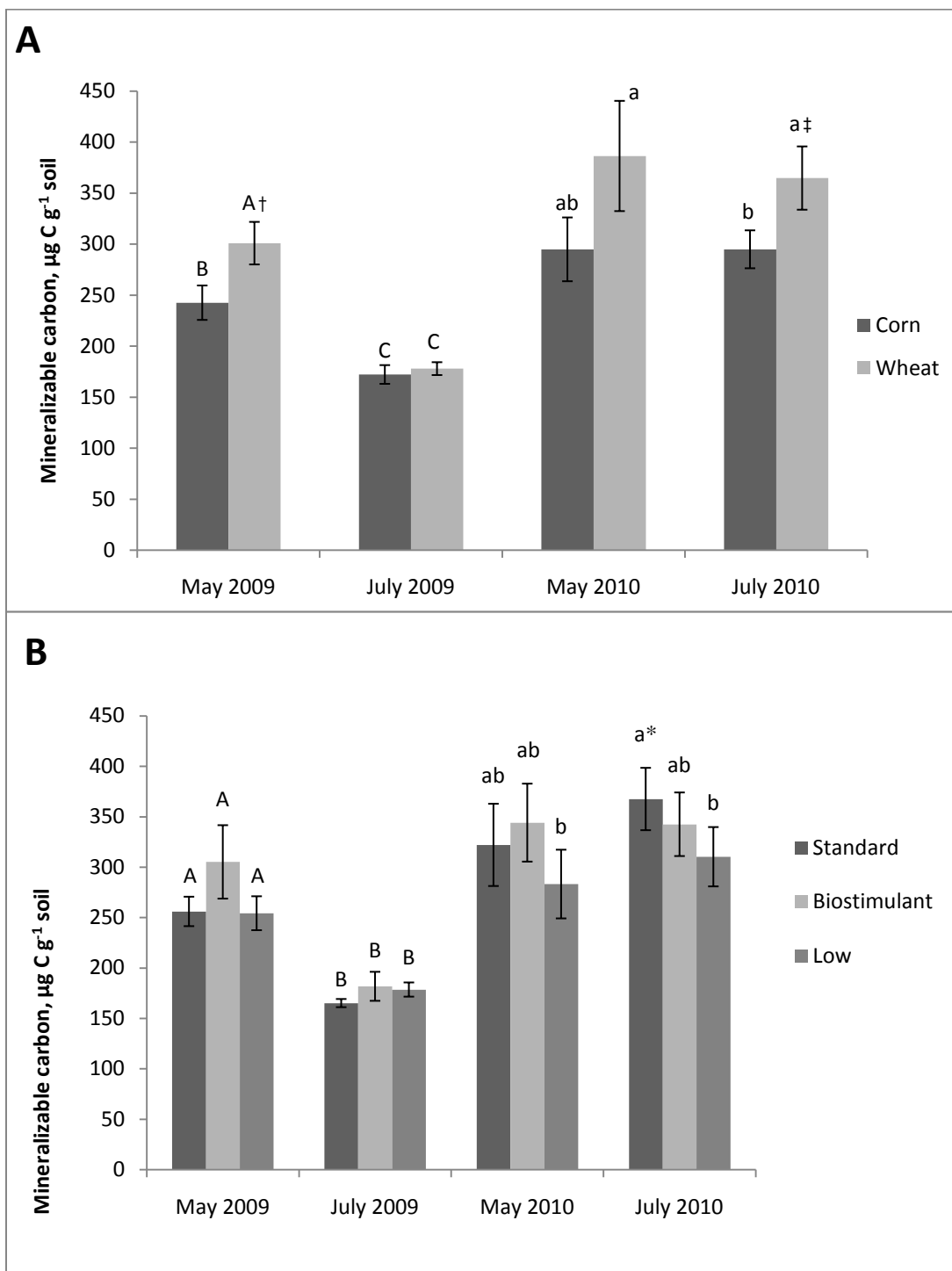


Figure 37. Impact of crop rotation (Panel A) and fertilizer treatment (Panel B) on readily mineralizable carbon over two years. Treatment means (n=4) designated †, ‡ and * are significant within month at p=0.0128, p<0.001 and p=0.0428, respectively. All other treatment means designated by different letters are significant at p<0.05.

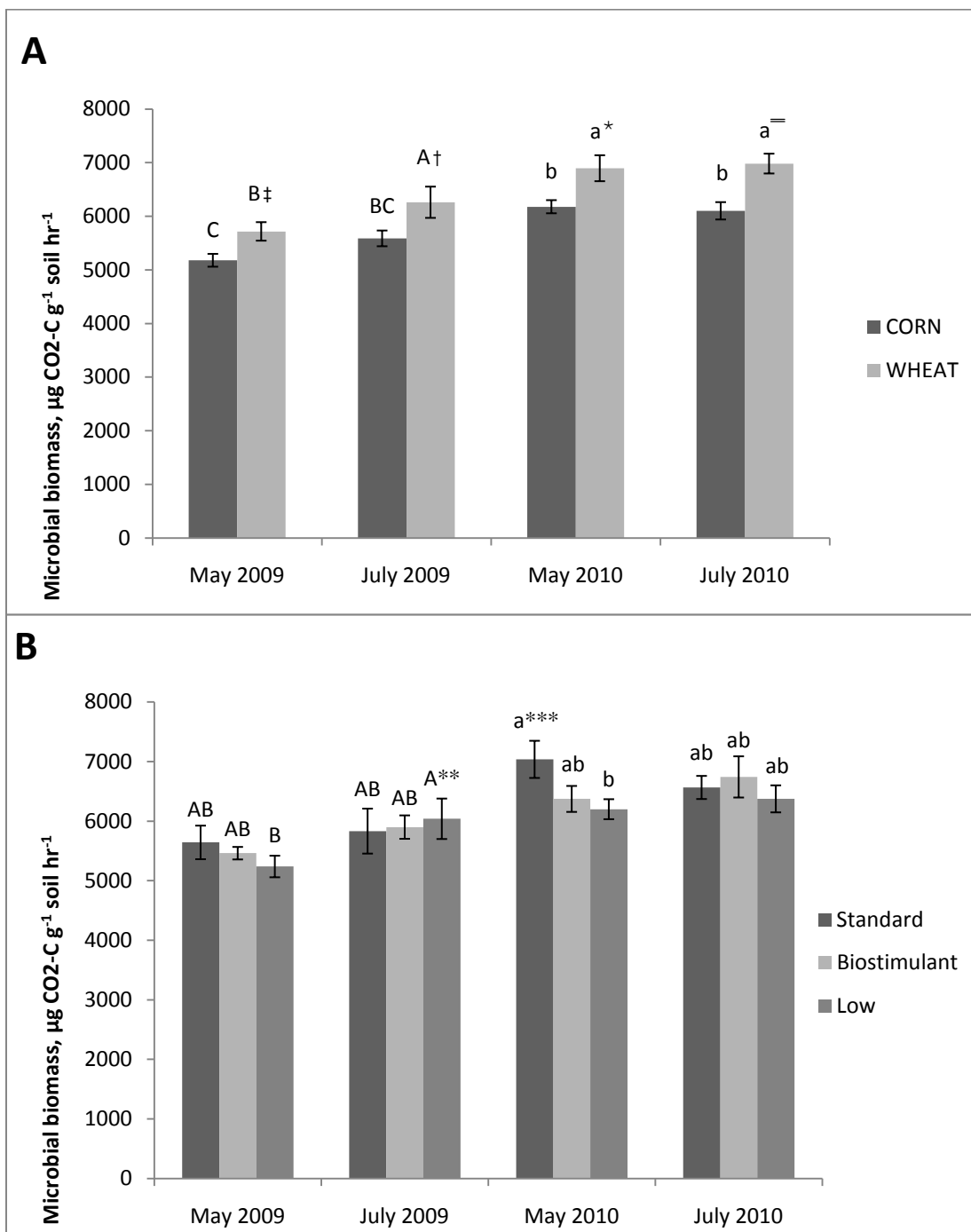


Figure 38. Effect of crop rotation (Panel A) and fertilizer treatment (Panel B) on microbial biomass measured as substrate induced respiration in 2009 and 2010. Treatment means ($n=4$) designated †, ‡, *, =, **, *** are significant within month at $p=0.0374$, $p=0.0260$, $p=0.0038$, $p=0.0083$ $p=0.0003$ and $p=0.0056$, respectively. All other treatment means designated by different letters are significant at $p<0.05$.

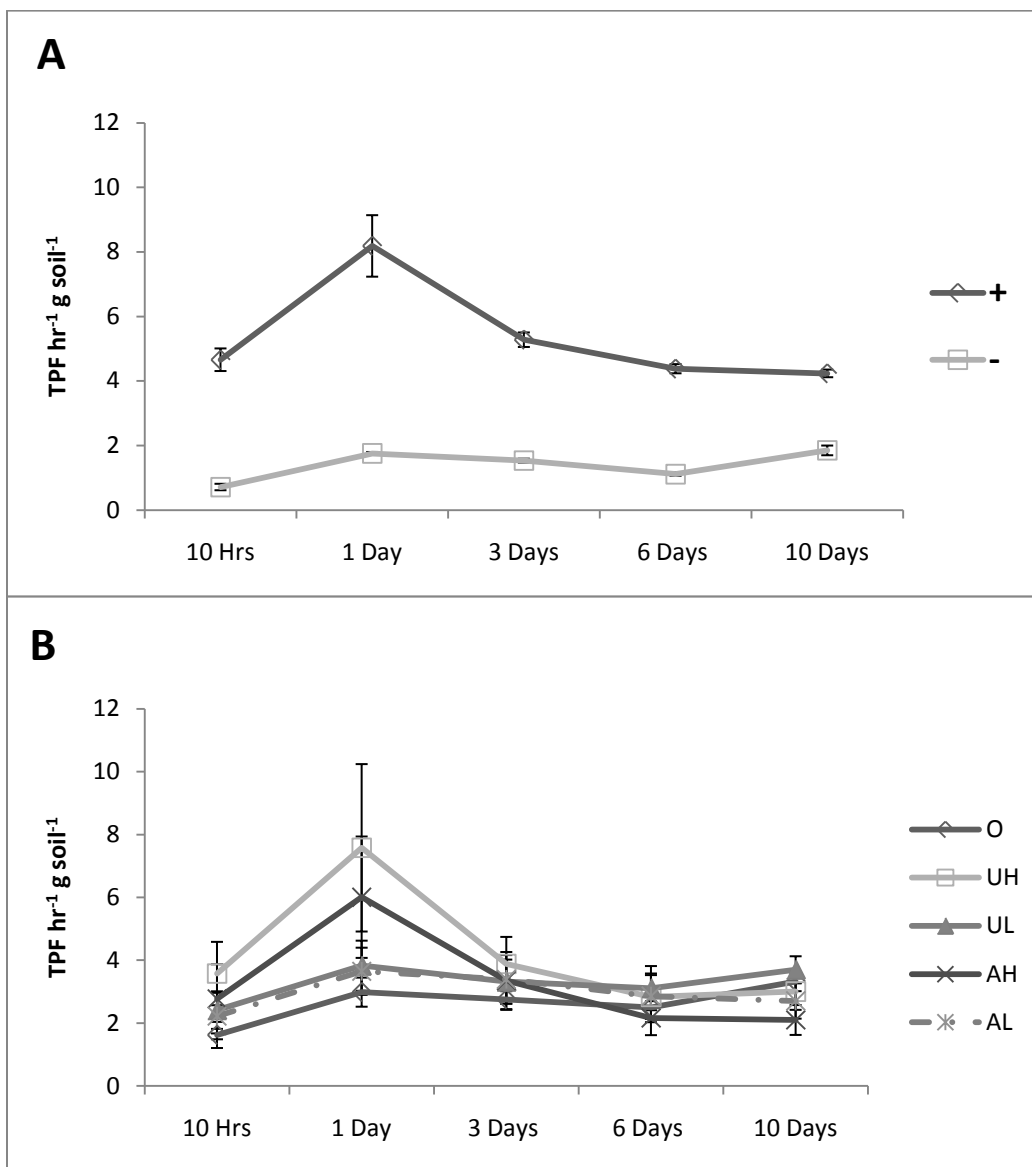


Figure 39. Effects of glucose addition (Panel A) and fertilizer treatment (Panel B) on dehydrogenase activity over 10 days. Treatment means (n=4) of glucose amended soils were significantly greater than non-glucose soil ($p < 0.0001$). +=with glucose amendment, -= control, O=control, UH=high UAN, UL=low UAN, AH=high ammonium sulphate, AL=low ammonium sulphate.

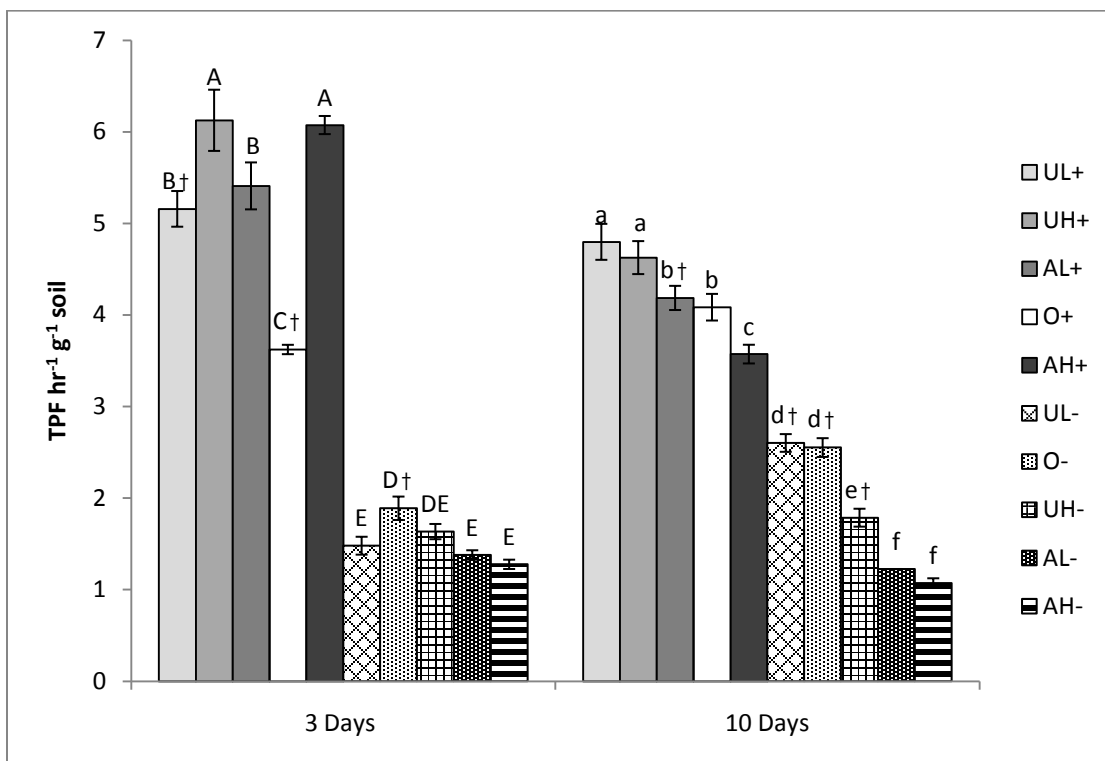


Figure 40. Interaction of glucose, fertilizer treatment and time as seen after three days and ten days incubation. Treatment means designated † are significant at $p < 0.001$. All others designated by different letters are significant at $p < 0.01$. (U=UAN, A=ammonium sulfate, +=glucose, -=no glucose, H=high rate, L=low rate, O=control)

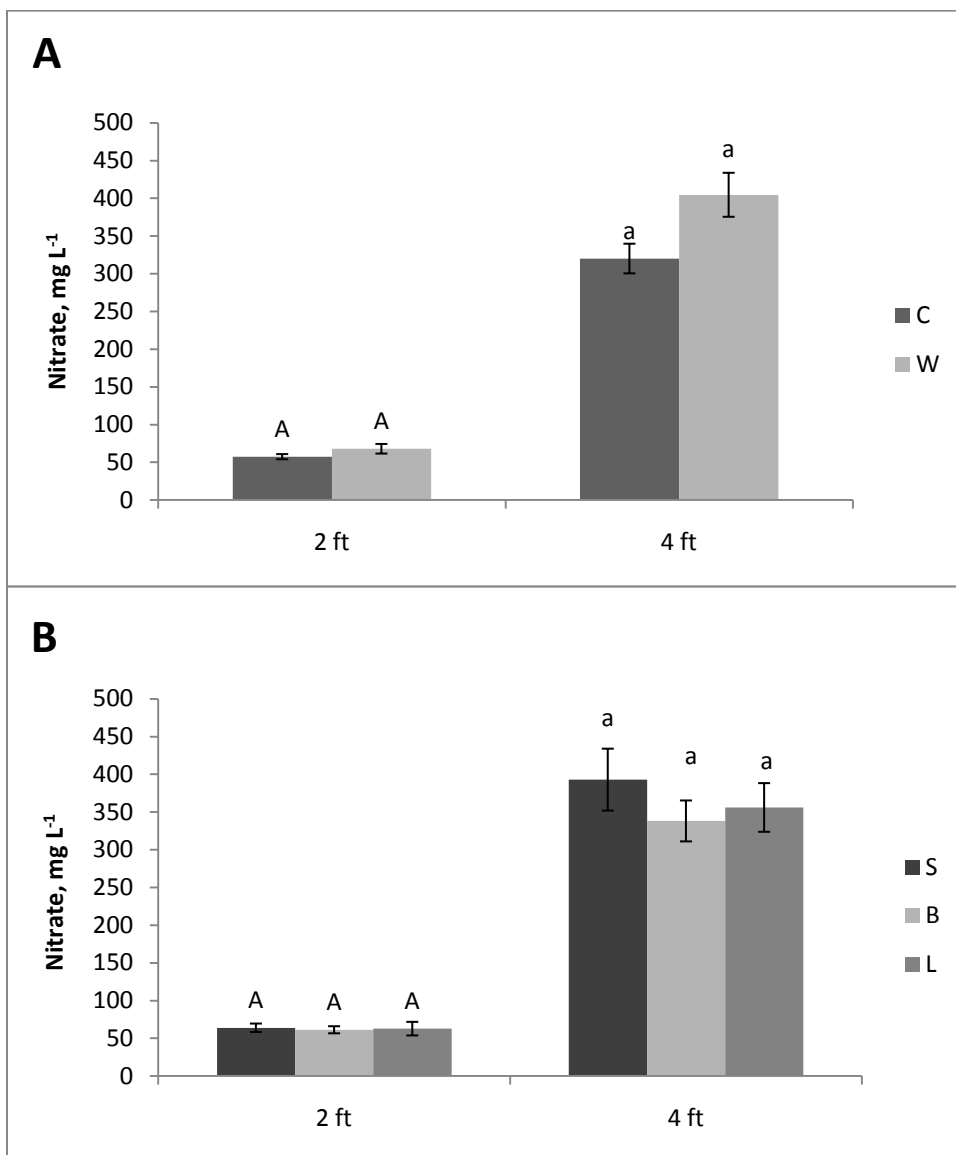


Figure 41. Effects of crop rotation (Panel A) and fertilizer treatment (Panel B) on cumulative nitrate in soil leachate collected at 2 and 4 ft depths in 2009. Treatment means (n=4) labeled with the same letters did not significantly differ within sample depth. C=corn, W=wheat, S=standard rate, B=biostimulant, L=low rate

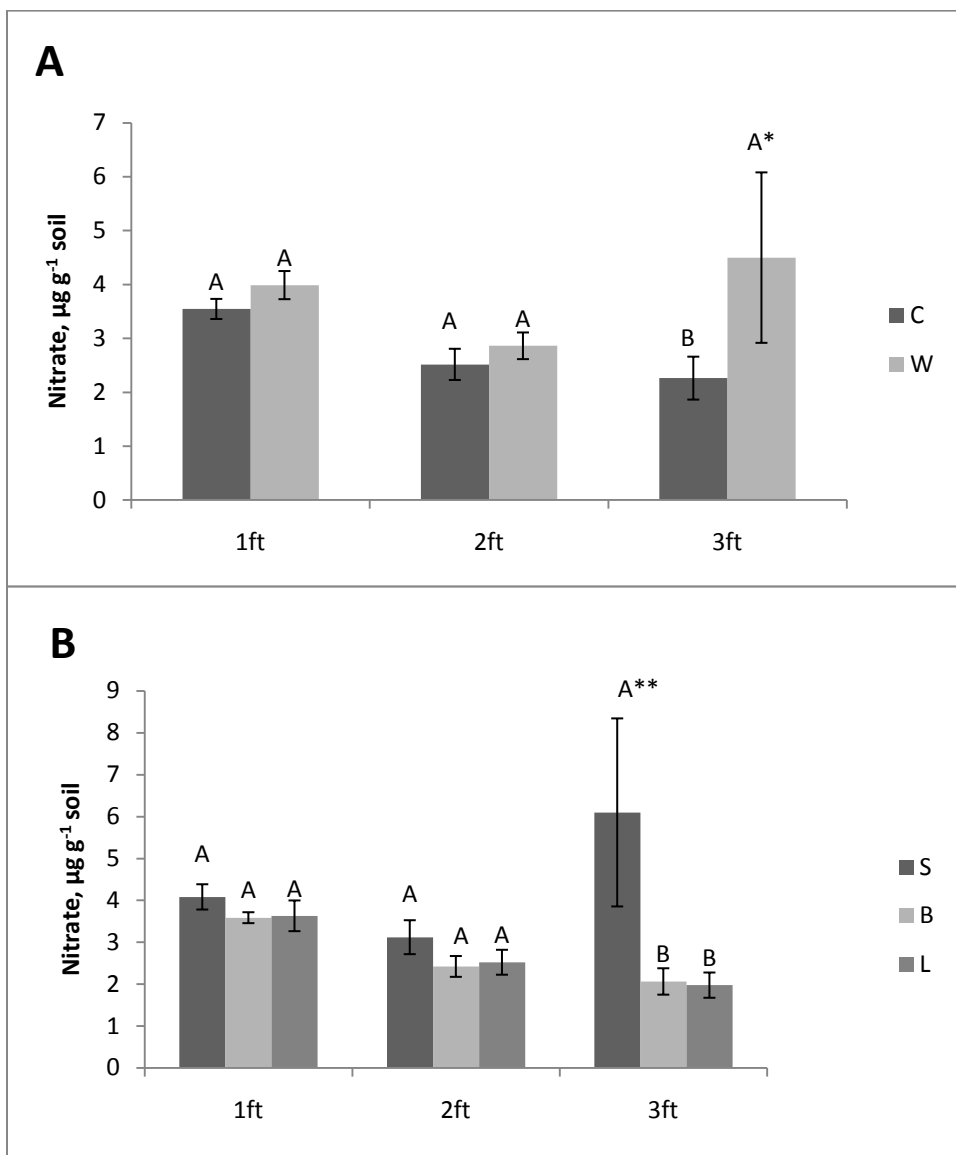


Figure 42. Effects of crop rotation (Panel A) and fertilizer treatment (Panel B) on extractable soil nitrate collected at 1, 2 and 3 ft depths after snow melt in March 2010. Treatment means (n=4) designated * and ** are significant within sample depth at $p=0.0016$ and $p<0.0001$, respectively. C=corn, W=wheat, S=standard rate, B=biostimulant, L=low rate

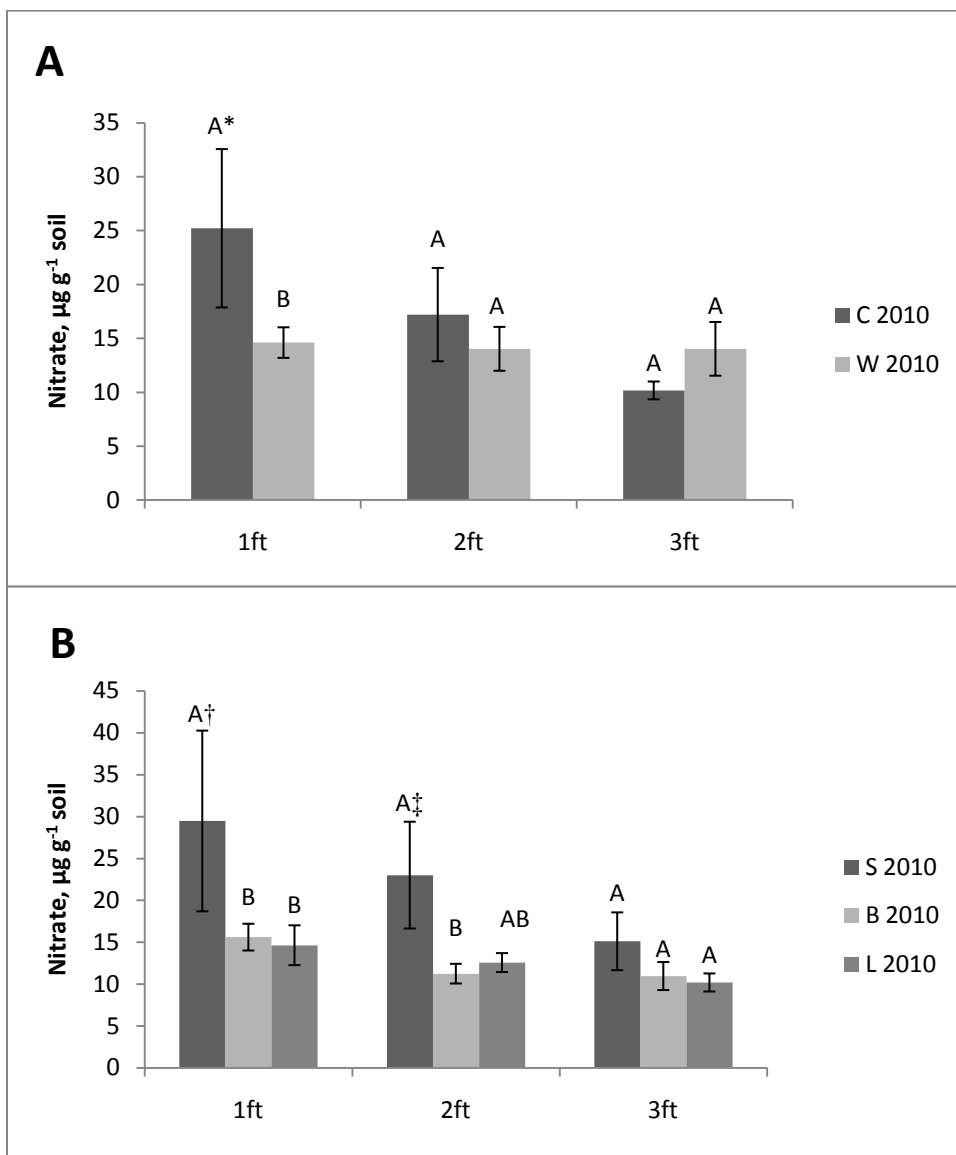


Figure 43. Effects of crop rotation (Panel A) and fertilizer treatment (Panel B) on extractable soil nitrate collected at 1, 2 and 3 ft depths after onion harvest in October, 2010. Treatment means ($n=4$) designated *, † are significant at $p=0.0447$, $p=0.0478$, respectively. Treatment means designated ‡ represent a significant difference between S and B treatments ($p=0.0283$) and a notable difference between S and L treatments ($p=0.065$). C=corn, W=wheat, S=standard rate, B=biostimulant, L=low rate

CHAPTER III

EVALUATING LACEY PHACELIA, CARROT, AND BUCKWHEAT AS TRAP CROPS IN ONION TO
REDUCE ONION THRIPS AND IYSV¹**Abstract**

The primary insect pest of onions in the western United States is *Thrips tabaci* Lindeman, onion thrips (OT). Besides reducing yields from feeding injury, OT transmit a devastating tospovirus, iris yellow spot virus (IYSV). Costly insecticide applications and increased insecticide resistance have prompted interest in alternative thrips and IYSV control options. The goal of this study was to evaluate three trap crops *Phacelia tanacetifolia* Benth. (lacey phacelia) *Fagopyrum esculentum* Moench. (buckwheat) and *Daucus carota* L. (carrot) for attraction of OT within a commercial onion field in two different years. Thrips adult, larva and egg populations were monitored on whole plant and leaf samples collected from the trap crops and onions and at distances of 0, 0.7, 6.1 and 12.2 m from the trap crop row. Aerial sticky traps in these same locations provided data on adult thrips and other flying insect populations. Both lacey phacelia and buckwheat were more attractive than onions to adult OT early in the season and during peak trap crop bloom and maturation. However, when stands of trap crops were sparse or onion plant size was large late in the season, trap crops were less effective in attracting thrips. Little difference in numbers of thrips was observed in onions outside of trap crop rows. There were no treatment effects on IYSV infection as measured by ELISA testing; however, overall IYSV incidence was low. The early season attractiveness of phacelia and buckwheat to onion thrips are promising. If early season reductions in thrips densities on onions is shown to reduce later

¹ Coauthored by K. Buckland, D. Alston, J.R. Reeve, C. Nischwitz, D. Drost.

season densities and/or incidence of IYSV in fields with attractive trap crops, then this strategy may prove economically viable.

1. Introduction

Thrips Tabaci Lindeman (*Thysanoptera*), onion thrips (OT), a polyphagous herbivorous pest, is a frequent problem in *Allium cepa* L., bulb onions. Feeding damage alone has been estimated to reduce yields, particularly during the bulbing stage of development which typically peaks during July in northern North America production regions (Kendall and Capinera, 1987). Recently, the tospovirus iris yellow spot virus (IYSV) has emerged as a world-wide problem in onion, and has the potential to decrease yields more than thrips feeding damage alone (Gent et al., 2006). Onion thrips are the only known insect vector for the disease (Jones, 2005).

Onion thrips has a wide host range including common weed species such as *Amaranthus retroflexus* L., which have also been shown to be alternate hosts of IYSV (Gent et al., 2006). Young, rapidly growing tissues are favorite food sources for onion thrips, particularly in confined spaces, such as the neck of developing onion plants. The unique life history of OT contributes to a complex pest management situation. While some OT populations reproduce sexually, in the western US, nearly all OT are female and reproduce through a specific type of parthenogenesis called thelotoky (Kendall and Capinera, 1990; Nault et al., 2006) Nault et al. (2006) report reproduction rates that average 11 offspring per adult female. Females oviposit unfertilized eggs within leaf tissue which shields them from topical insecticides and predaceous insects. Instars 1 and 2 are active feeders and are the only life stages where virus acquisition occurs (Jones, 2005). The quiescent instars 3 and 4 do not feed and remain protected in the soil, in bulb scales or on the lower plant (Alston and Drost, 2008). Viruliferous adults can transmit IYSV for the remainder of their life (Jones, 2005). A generation requires approximately 20-40 days

and several generations may occur each season (Jones, 2005). Onion thrips overwinter as adults, frequently in soil or bulb cull piles, serving as a inoculum source for subsequent crops (Larentzaki et al., 2007).

Management strategies for thrips frequently involve insecticide sprays, occurring as often as every 7-10 days, throughout the season. Carbamates and pyrethroids were most common until the recent advent of plant systemic compounds (Shelton et al., 2006). These non-selective applications severely impact other arthropod populations, also reducing natural predators of thrips as an additional means of control. Short generation time coupled with persistent exposure to closely related insecticides and parthenogenetic reproduction has resulted in dramatic levels of pesticide resistance in onion thrips populations over time (MacIntyre Allen et al., 2005; Shelton et al., 2006).

In an effort to enhance sustainability and a diverse insect population that contributes to biological control of onion thrips, management strategies that allow reduced insecticide applications while maintaining acceptable yields have been a focus of emerging research. One study investigated applications of entomopathic fungi which proved to be effective for thrips control while maintaining acceptable yields. This control method also showed no negative impacts on non-target insects (Maniania et al., 2003). Another study demonstrated reduced OT damage when leeks were sprayed with plant derived essential oils such as marjoram or lavender (Koschier et al., 2002).

Although research has focused on controlling the insect vector, the spread of OT and IYSV into and within a field is still not well understood. Based on a model of thrips invasions, Mo et al. (2009) explained thrips dispersion within a field as a result of an initial adult invasion and gradual population build-up. Schwartz et al. (2010) reported some degree of secondary

IYSV spread within onion crops in Colorado, while Hsu et al. (2010) observed very limited, if any, secondary spread. These studies suggest the initial introduction of IYSV into a field is the most critical action point. Decreasing crop apparancy may be the best management option.

Push-pull strategies used in insect management seek to modify the behavior of pest species in a manner that is advantageous to the grower (Cook et al., 2007). Intercropping and trap-cropping are types of push-pull strategies, where each strategy attempts to attract the pest to a crop species other than the economically important host. The practice of intercropping mostly exists today in organic or subsistence farming throughout the world (Cook et al., 2007). Traditionally a low cost alternative to prevent pest population explosions, intercrops serve to promote both insect and plant biodiversity which may be beneficial to insect control (Altieri and Letourneau, 1982). Intercropping is successful in some crops, however, onion production has had limited success due to the shallow-root system, narrow foliage canopy, and poor competitive abilities (Trdan et al., 2006).

The use of trap crops to aid in pest control is a promising management strategy. A trap system allows for limited competition between the trap crop and onion while still providing an attractive lure for the pest. Trap crops have been successful in greenhouse applications with other thrips species. *Frankliniella occidentalis* Pergande, western flower thrips, were drawn to attractive, flowering trap plants in a greenhouse study (Buitenhuis and Shipp, 2006). The same study identified the stage of trap crop development as a critical factor in effective control of the pest species (Buitenhuis and Shipp, 2006). Banks and Ekbom (1999) describe a general strategy to trap cropping where the critical impact of crop attractiveness and proportion in the field must be understood to produce effective results. To our knowledge, there have been no published reports of trap crops systems in onions. Trap crop efficacy involves complex interactions

between pest life history, trap crop development, and crop growth. The goal of this study was to investigate the potential for use of trap crops to aid in the control of OT in onion production. Specifically, the objective was to evaluate three trap crops, *Phacelia tanacetifolia* Benth. (lacey phacelia), *Fagopyrum esculentum* Moench. (buckwheat), and *Daucus carota* L. (carrot) for attraction to OT and beneficial predators in a commercial onion field.

2. Materials and Methods

2.1 Field Design

The trap crops, lacey phacelia (S&S Seeds, Albany, OR), buckwheat, and carrot (Anderson's Seed, Logan, UT) were planted in two separate commercial onion fields near Corrine, UT in the spring of 2009 and 2010. Four replicated blocks were established at each site containing one 4.6 m long section of each trap crop. Each trap crop was separated by 61.0 m from the next crop and each block was separated by at least 30.5 m from the next block and the field edges. Due to field size limitations, control samples were taken outside of treatment blocks in 2009.

2.2 Crop Establishment

In 2009, lacey phacelia and carrots were planted on April 24, 2009 and were reseeded on May 8, 2009 due to poor emergence as a result of soil crusting. Buckwheat was planted on June 4. The initial seed date was based on an ideal bloom time of late June thru early July to coincide with peak thrips densities and onion bulb sizing period. By June 30, the lacey phacelia was at full height, approximately 61 cm tall and in full bloom. The buckwheat reached full height, approximately 61 cm, and bloom by July 21. The carrots remained vegetative throughout the season with canopy height approximately 25 cm. The lacey phacelia completed

its lifecycle and senesced in early to mid July while the buckwheat and carrots retained suitable leaf tissue through the end of the season.

Due to the dramatic difference in trap crop development observed in 2009, the seeding dates were adjusted in 2010. In an attempt to provide attractive, young leaf tissue and alluring blooms over a longer time period, trap crops were successively seeded in 2010. Initially, all trap crops were seeded on May 17, 2010 and then re-seeded on 8 and 21 June. The spring of 2010 was unusually cold and wet which slowed overall growth. Buckwheat bloom was first observed on June 30 and carrot crops remained vegetative as in 2009. Field conditions in 2010 proved to be a significant obstacle as excessive moisture and possible herbicide residue affected establishment of lacey phacelia. In 2010, lacey phacelia crops never grew larger than approximately 15 cm nor produced flowers.

2.3 Grower Management

Each field site was fertilized with split applications of approximately 112 kg N/ha each season. Commercially available herbicides were applied to the fields following a typical grower management plan to include a pre-emergent and 2-4 post emergent sprays. Since the trap crops were not labeled for the herbicide rates used in onion production, the trap crops were covered with thick plastic sheeting immediately before field application of herbicides to prevent damage. However, in 2010, an early season field application of a pre-emergent herbicide was made without protecting the soil where trap crops were to be planted. This application may have resulted in a significant residual effect hindering trap crop establishment. No insecticides were applied to either study field. The fields were furrow irrigated approximately every 7-10 days between the months of June and September to provide approximately 2-3 inches of water per irrigation cycle.

2.4 Soil Sampling

Soils were sampled on a monthly basis from May to August. Six soil subsamples were collected at 0-30 cm and combined in the field. Soils were sieved through a 4 mm screen, stored in re-sealable plastic bags and refrigerated at 4° C until processed within 10 days of sampling. Nitrate and ammonium were extracted using 1M KCl, and analyzed by Lachat (Quickchem 8500, Hach Company, Loveland, CO). Total carbon and nitrogen levels were measured using a LECO TruSpec. Soil pH was measured in a 1:2 soil:water suspension. Soil P and K levels were measured using the Olsen method in July following final field applications of fertilizer.

2.5 Thrips Monitoring

Insect populations were assessed using several methods. Aerial insect traps were constructed from 15 cm long white PVC pipe painted with exterior flat white paint and mounted on a wooden stake. Clear fly paper was placed around the cylindrical traps with the sticky surface facing outward. Aerial traps were placed in the trap crop row and at approximately 0.7 m, 6.1 m and 12.2 m away from the trap crops. Sticky fly paper samples were removed and replaced approximately every 2 weeks from May through August, covered with clear plastic wrap and stored at 40° F. In the laboratory, sticky traps were examined using 20-30X magnification and insects counted.

At each location with an aerial trap, onions were sampled at approximately two week intervals for onion thrips from June through August in each 2009 and 2010. Two whole at each sample location were cut at ground level and immediately submerged in a glass jar containing soapy water. Jars were sealed and transported to the laboratory. In the lab, the onions and soapy water were washed over a 200-mesh sieve and all insects collected with 70% ethanol into

a glass vial for storage until counting. During the washing process, the third youngest leaf from each of the two plants was removed and placed into a nalgene bottle to stain thrips eggs for counting. The two leaves were stained with an acid fuchsin technique described by Bowling (1979). The leaves and stain were heated to first boil in a microwave oven to facilitate absorbance of the stain through the thick, waxy leaf cuticle. The stained leaves were then destained in a lactic acid solution to remove stain from leaves while leaving protein in the eggs a darker contrast. Leaves were then sectioned and placed between glass plates. Thrips adults, larvae, and other insects in ethanol and eggs in leaves were counted with the aid of a dissecting microscope at 20-30X magnification.

Thrips hatch from eggs within leaves was also measured. The third youngest leaf from each of two additional plants in each plot was collected, placed in a sealed plastic bag, and transported to the laboratory in a cooler with blue ice. Leaves were rinsed under running water to remove external insects, placed into a sealed plastic bag with a moist filter paper, and placed into an incubator at 25°C for 7 days. At the end of incubation, the two leaves and the inside of the bag were washed with water over a 200-mesh sieve to collect the hatched thrips larvae. The thrips were washed with 70% ethanol into a glass vial for storage until counting as described above.

2.6 Disease Intensity

The presence and severity of IYSV was measured at 0.7 m, 6.1 m and 12.2 m from each crop using a commercially available double antibody sandwich enzyme linked immunosorbent assay, DAS-ELISA (Agdia, US). Onions leaves were sampled monthly from June to August in 2009 and at two week intervals from August thru Sep 2010. One leaf from twenty plants per plot was selected at random, individually bagged and stored at -20°C until processing. Samples

were considered positive for IYSV presence if results were greater than 2 times the value of the average negative control plus 3 times the standard deviation of the negative control.

2.7 Onion Growth and Quality

Onion plant samples were collected monthly from May to August. Ten whole plants were selected randomly throughout the field, washed, and stored at 4°C. The total number of leaves per plant, total leaf area per plant (LI-3100, LI-COR Biosciences, Lincoln, NE), chlorophyll levels and total weight were measured. Tissues were dried at 60°C and processed for total carbon and nitrogen content using a LECO TruSpec. Onions were lifted, topped and bagged in two 3.1 m sections on Oct 2, 2009. Due to an oversight, onion yields were not collected in 2010 and approximate yield was obtained from the grower instead. Bulbs were sized, counted, weighed and re-bagged for storage under commercial conditions (Utah Onion, Brigham City, UT) until Feb 11, 2010. Stored onions were assessed for loss due to rot and weighed. Ten randomly selected samples were cut in half, measured for overall diameter, number of scales, number of centers and presence of rot or disease.

2.8 Statistical Methods

The effects of trap crop, distance and sample date on numbers of thrips and insect populations were assessed using an analysis of variance of a 3-way factorial in a random complete block mixed model design. Factors were trap crop species, distance from trap crop and time. Different fields and control plot designs were used in different years and therefore each year was analyzed separately. Since no spatial or temporal correlations were apparent between sample periods suggesting homogenous variances, the variance structure used was compound symmetry. Responses were square root or log transformed prior to analysis to

better meet assumptions of normality and homogeneity of variance. Statistical analyses were completed using PROC MIXED in the Statistical Analysis System (SAS), version 9.2.

3. Results

3.1 First Season

Onion growth and soil properties within the trap crop fields were monitored at monthly intervals throughout both seasons (Table 3). In 2009, the trap crop field was adjacent to both corn and wheat crops as well as a road and fallow field. In 2010, wheat and alfalfa were neighboring crops with roads on the other two sides. Fields were both located within the Salt Lake valley, Utah, approximately 15 km of each other. Soil types were sandy loam and silt loam in 2009 and 2010, respectively. Cumulative extractable soil nitrate levels were slightly lower than local averages in 2009 and much lower than averages in 2010. Onion growth data shown for July of each year was very different between years. Overall, the growing season in 2010 was much colder with more moisture early in the season. Onion growth was delayed when compared with 2009 growth data.

In 2009, relative seasonal thrips populations were monitored at four control points within the field (Figure 43, 44, and 45). Thrips numbers were low, with the highest adult populations observed on the July 14th sample date. With a few exceptions, most of the whole plant samples for adults, immatures and eggs were lower in the trap crop rows than at any sample distances from the traps. IYSV symptoms were also low throughout the season.

Buckwheat was attractive to adult OT on July 30th when the buckwheat was at full height and in bloom (Figure 46). Populations on onions within the buckwheat were greater than on onions at 3, 20 or 40 ft distances ($p=0.0005$, $p=0.0003$, $p=0.0003$). However, on June 29th before the buckwheat crop was well-established, there were fewer adult OT within the

buckwheat row than on onions at 3, 20 or 40 ft ($p=0.0051$, $p=0.0137$ and $p=0.0224$). The number of immature thrips (Figure 47) was lower ($p<0.0001$) within the buckwheat row than at any other distance. Egg counts (Figure 48) in the buckwheat plots suggested an increasing attraction as the season progressed. The number of eggs was notably lower in buckwheat rows on June 29th than at 20 and 40 ft ($p=0.0657$ and $p=0.0511$) and significantly lower on July 14th than 3, 20 and 40 ft ($p=0.0110$, $p<0.0001$, and $p=0.0174$). However, by July 30th, which had the highest egg counts of the season, eggs counts in the buckwheat rows were greatest over 3, 20 and 40 ft ($p=0.0110$, $p<0.0001$, and $p=0.0292$). There were also greater numbers of eggs at a distance of three feet than at 20 ft ($p=0.0305$). No other differences were observed in buckwheat.

Unlike buckwheat, there did not seem to be a noticeable effect of carrot on adult thrips populations. While the number of immature was negatively impacted by carrot, the number of eggs showed an early season increase. Adult OT populations (Figure 49) in carrot rows showed a consistent pattern with the lowest counts at zero feet at all the sample dates ($p<0.05$). There were no differences in number of immature thrips (Figure 50) in carrot until July 14th, where there were fewer thrips at 0 ft than at 3, 20 and 40 ft ($p<0.0001$). On July 30th, there were fewer immature thrips at zero than 3, 20 and 40 ft ($p=0.0002$, $p<0.0001$, $p<0.0001$). Egg number (Figure 51) was initially higher at zero feet than 3, 20 or 40 on 6 June ($p=0.0002$, $p<0.0001$, $p=0.0094$). However, on July 14th, there were fewer ($p<0.0001$) eggs at zero feet than at all other samples points. On July 30th, there were fewer eggs at zero feet than at 3 and 20 ft ($p=0.0680$, $p=0.0544$).

Phacelia showed the greatest influence on early season thrips, with increased adult OT, immature, and egg counts within the trap crop rows. On June 6th, adult OT populations (Figure

52) were greater at the zero feet than at 3, 20 and 40 ft ($p=0.0032$, $p=0.0049$, and $p=0.0016$). The June 29th samples also were greater at zero feet ($p=0.0999$ and $p=0.0079$ and $p=0.0600$). However, by July 14th, the attraction was no longer observed as phacelia rows had less adult OT than onion at 3, 20 and 40 ft ($p=0.0125$, $p=0.0313$, and 0.0450). Immature thrips counts (Figure 53) followed a similar trend where numbers at zero feet were greater than at 3, 20 and 40 ft on June 6th ($p<0.0001$, $p=0.0001$ and $p<0.0001$) and June 29th ($p=0.0175$, $p=0.0091$, $p=0.025$). Much like in the adult OT data, July 14th samples showed the same absence of attraction with immature thrips within phacelia row notably fewer than onions at 3, 20 and 40 ft ($p=0.0576$, $p=0.0844$, and $p=0.0625$). The only significant differences in egg counts (Figure 54) were observed on June 29th where there were more eggs at zero ft than at 3, 20 or 40 ft ($p=0.0012$, $p=0.0212$ and $p=0.0218$).

3.2 Second Season

While the second season had an overall higher thrips numbers than in 2009, trap crop growth was less successful and had less influence within the field. Buckwheat plots were somewhat attractive at close range, however, the effect of both carrots and phacelia were limited (Figure 55, 56). There were significantly greater adult OT in buckwheat (Figure 57) than the control plots at zero feet on both July 15th and August 4th ($p=0.0243$ and $p=0.0002$, respectively). The number of immature thrips (Figure 58) at zero feet was generally lower than in the control. There were fewer immature thrips with buckwheat on both July 15th and August 4th ($p<0.0001$) than in the control.

Carrot and phacelia were much less attractive to adult and immature thrips than buckwheat. There were fewer adult OT in carrots (Figure 59) than the control plots on June 24th ($p=0.00274$) and August 18th ($p=0.0307$). The only attraction observed was on August 18th when

adult OT were greater at distance 3ft ($p=0.0002$) than in the control. A similar pattern was seen in immature thrips populations (Figure 60) with fewer immature thrips at zero feet than the control on June 24th ($p<0.0001$), August 4th ($p=0.0146$) and August 18th ($p=0.0049$). Thrips were impacted least by phacelia in 2010. Adult OT populations (Figure 61) were greater ($p=0.0003$) at zero feet than control on June 24th. Conversely, there were fewer adult OT at zero feet ($p=0.0007$) than the controls on July 15th. Immature thrips (Figure 62) counts were not significantly different in any sample period.

Not only did the trap crops show a lack of influence on thrips populations, but there was also no impact on IYSV incidence (Figure 63). There was no influence on IYSV of any trap crop at any distance on July 26th. Overall, levels of virus ranged from 0-35% positive for the first sampling date, which is fairly low incidence rate.

4. Discussion

Both phacelia and buckwheat showed potential for use as trap crops for onion thrips. However, there was a clear preference by adult OT to onion throughout a significant portion of the season. The periods of increased thrips populations within a trap crop seem to be most greatly aligned with periods when trap crops were at full height and, in the case of buckwheat, in bloom. The larger plants may be more apparent to colonizing thrips.

Phacelia attracted the most thrips in 2009. Adult, immature and egg counts were highest within the trap crop row. The effect on thrips in 2010 was less but still significant on June 24th with increase adult OT presence within the phacelia crop rows. In 2010, the phacelia did not establish as well or grow as vigorously which likely explains the differences between seasons. By mid-July, most of the phacelia plants had senesced, just as the overall thrips pressure throughout the field was the greatest. Attempts to establish sequential plantings of

phacelia were unsuccessful due to hot dry weather and the long periods between flood irrigation cycles typically used by Utah growers. While thrips appeared to be less attracted to buckwheat than phacelia overall, there was a clear window of attraction during bloom in both seasons. The buckwheat bloomed towards the end of July and early August indicating a potential for use as an attractant just as thrips populations were peaking. Carrot, while providing continuing vegetative plants throughout the season, does not appear to hold any attractiveness to thrips over onion.

Host plant finding and colonization by onion thrips is not well understood. Research on other thrips species suggests a variety of factors may be involved, such as visual cues, plant volatiles and diversity of surrounding vegetation. *Frankliniella occidentalis* Pergande, western flower thrips (WFT), have been observed to fly towards yellow visual cues and decrease flight movement in the presence of odor cues (Teulon *et al.*, 1999). Plant induced responses from feeding damage have also been identified to function in host plant selection by WFT (Delphia *et al.*, 2007). A study conducted by den Belder *et al.* (2000) observed a decrease in adult OT populations in leeks that had been previously undersown with clover. After the clover was removed from the potted leeks and pots were placed in a monocropped field, the leeks retained an anti-attractant quality with adult OT populations 68% lower than the control. The authors suggest a persistent effect on the leek crop that changed the quality of host plant and continued to discourage colonization (den Belder *et al.*, 2000).

The cause of increased population counts on both buckwheat and phacelia cannot specifically identified from this study. However, the timing of trap crop planting and maturation appear to be the most critical factors affecting thrips attraction to phacelia and buckwheat. In response to these observations in the first season, we attempted to extend critical windows of

highly apparent crops using successive plantings in 2010. However, this was not effective due to unfavorable conditions for germination later in the season. The excessively cold and wet season in 2010 coupled with suspected persistent herbicide in the soil resulted in less biomass production that season. Further research in more favorable conditions should include a method of providing successive plantings. An alternate approach that could prove more effective would be to utilize a series of different trap crop species. Different traps timed to meet the changing field conditions could provide continuous attractive plants while increasing chances of achieving adequate stands.

While an ideal trap crop would provide a full season of potentially attractive plants to avert pests away from the cash crop, onion crops could be greatly impacted by early season escape from colonization. According to Mo et al. (2009), the timing and rate of early season invasions is the most predictive factor of late season OT populations. Delaying the invasion of thrips therefore seems of great advantage. Some areas of the country do not generally rotate other crops with onion and therefore build significant OT populations from overwintering sites (Larentzaki et al., 2007). This is not the case in most onion fields in Utah where onions are rotated with alfalfa, corn and wheat. Instead, onion fields are colonized in the beginning of the season and populations build within the field, as modeled by Mo et al. (2009). Since our study showed a very limited range of influence of the trap crops with most differences in populations less than 3 ft from the trap crop, the most effective use of a trap system may be as border rows, to intercept the colonizing thrips populations before entering the field. Buitenhuis and Shipp (2006) reported that colonizing thrips preferentially chose larger, flowering plants within a greenhouse and tended to have limited secondary movement.

Secondary movement within field is not well understood and is also the subject of much debate. While Schwartz et al. (2010) and Hsu et al. (2010) both noted limited secondary IYSV infection rates, Hsu et al. (2010) observed that late season population numbers were the most predictive of IYSV levels at harvest. Late season invasion from neighboring fields that had been harvested were the suspected cause of population increases and possibly IYSV transmissions (Hsu *et al.*, 2010). Again, an attractive, highly apparent trap crop placed between suspected sources of new infestations and the onion field may be an effective control method during this critical time period of crop development.

5. Conclusion

Onion thrips were attracted to phacelia and buckwheat trap crops in early season. Both numbers of adults and immature were higher in the trap crops than in control plots for portions of the growing season. Numbers of thrips eggs were also higher in phacelia plants than surrounding onions in early the season. Thrips were not attracted to carrot crops.

Phacelia and buckwheat crops show promise as trap crops for onion thrips. Although there were periods with no attraction noted, crop maturation, flowering, and overall canopy height may have been the biggest factor. Since the range of observed attraction was limited, targeting the invading thrips population with edge rows may be the most effective management strategy. Multispecies plantings designed for prolonged growth and flowering could provide the most effective way to extend the window of attractiveness to thrips. Research on secondary movement of onion thrips within the onion field could provide further information on the most effective layout of trap crops in and around the field to avoid crop loss due to feeding damage as well as IYSV infection.

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Table 3. Soil properties, onion growth and thrips data for trap crop fields as compared with average onion field in the local area. Average local conditions obtained in 2009 from survey data of 16 commercial onion fields located within the same area of the Salt Lake Valley, Utah (Reeve, unpublished).

	Trap Crop 2009	Trap Crop 2010	Average
Soil type	Sandy loam [†]	Silt Loam [†]	varied
pH	8.3	8.41	8.2
NO ₃ [‡]	967 µg g soil ⁻¹	229 µg g soil ⁻¹	1841 µg g soil ⁻¹
Tissue N*	4.14%	2.76%	3.79%
Onion Dry weight*	9.16 g	7.88 g	2.29 g
Number of Leaves*	5.2	9.7	6.07
Yield	15.77 kg ha ⁻¹	unavailable	45.95 kg ha ⁻¹
Adult OT [‡]	275	unavailable	480.19
Immature OT [‡]	1700	540	3672.44
Eggs [‡]	388	unavailable	1020.88
Adjacent fields	corn, wheat	wheat, alfalfa	wheat, alfalfa, corn

[†] USDA Web Soil Survey; *average per onion plant in July; [‡] cumulative numbers obtained from aerial sticky traps for adult counts and whole plant samples for immature and egg counts

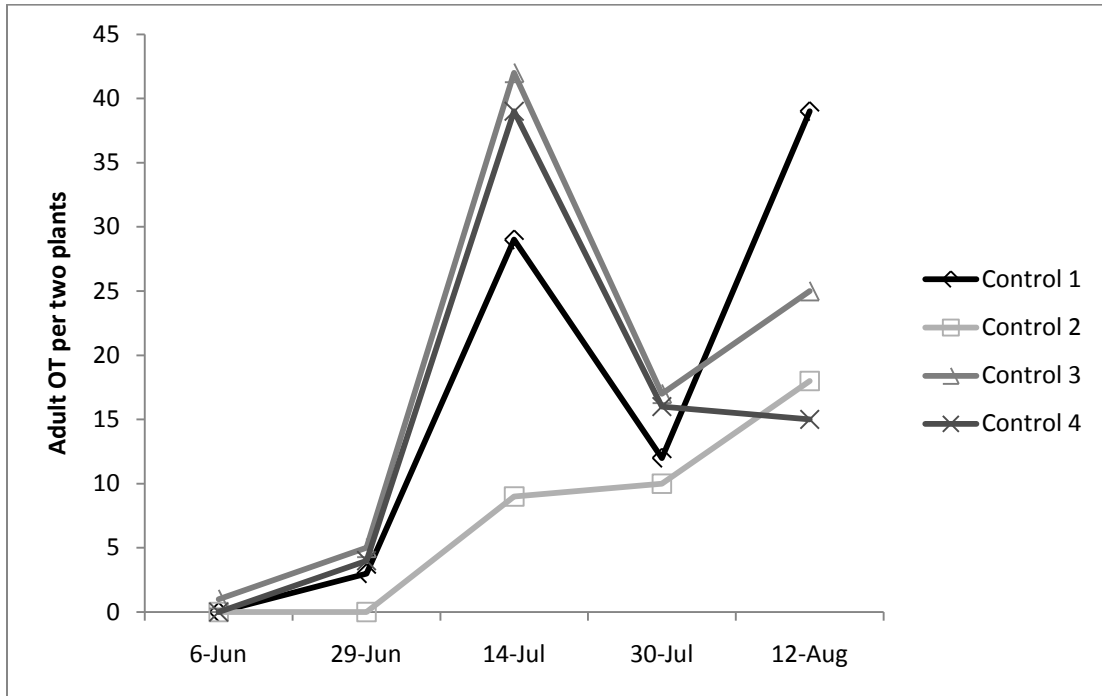


Figure 44. Number of adult OT per two plants for the control plots in 2009.

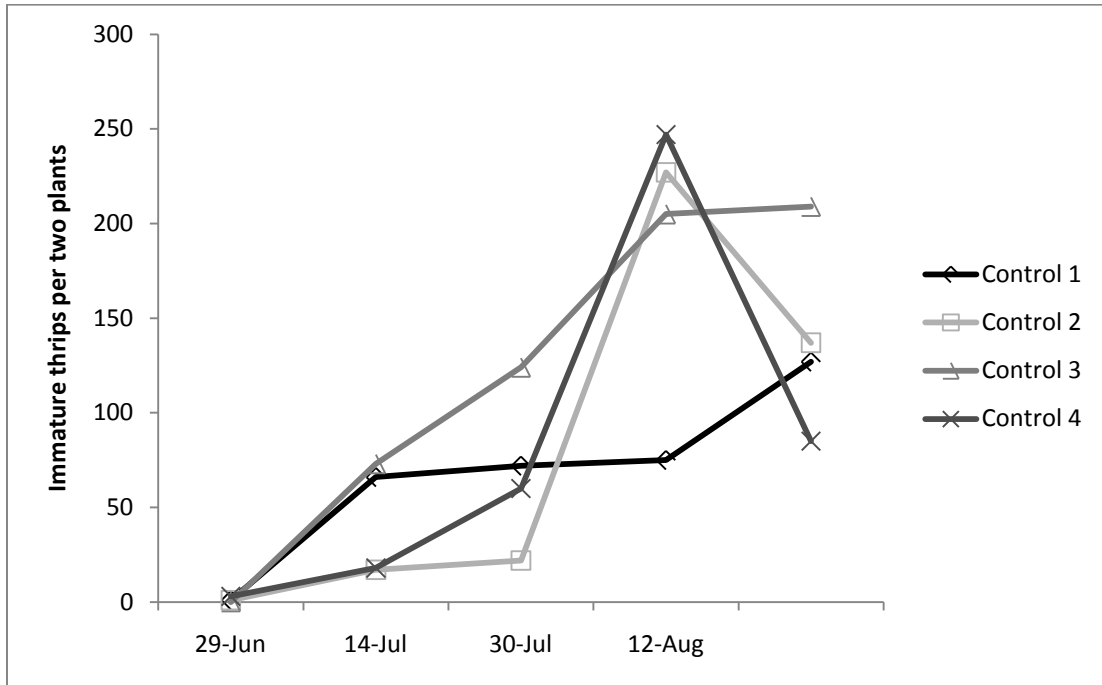


Figure 45. Number of immature OT per two plants for the control plots in 2009.

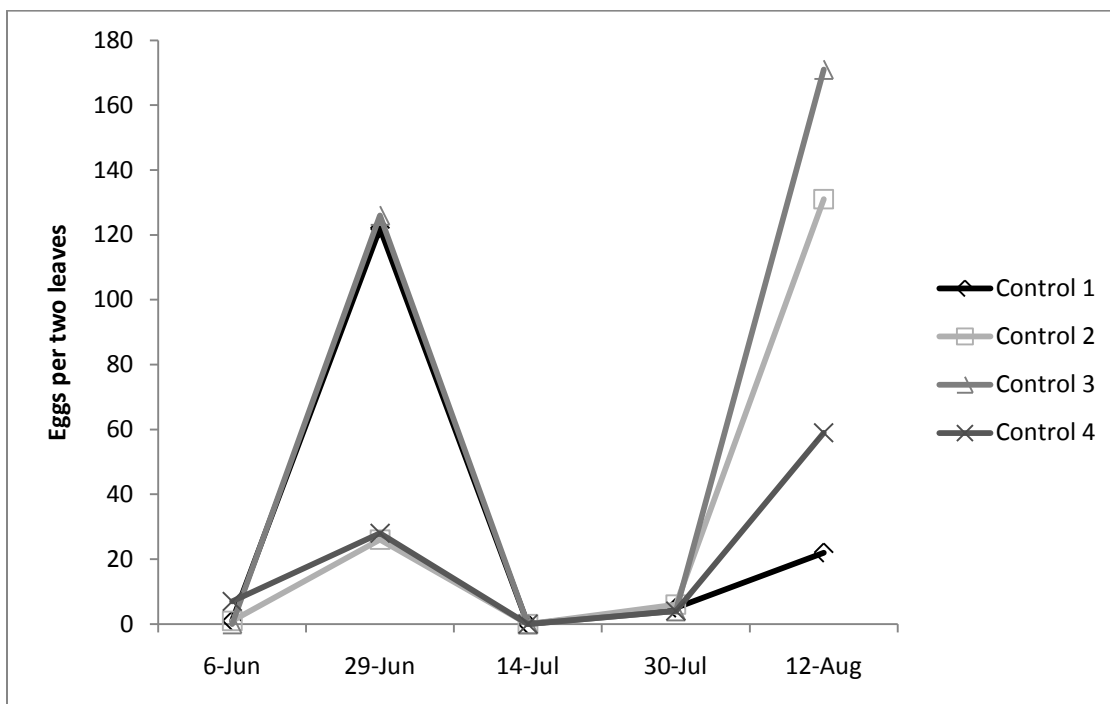


Figure 46. Number of thrips eggs per two plants for the control plots in 2009.

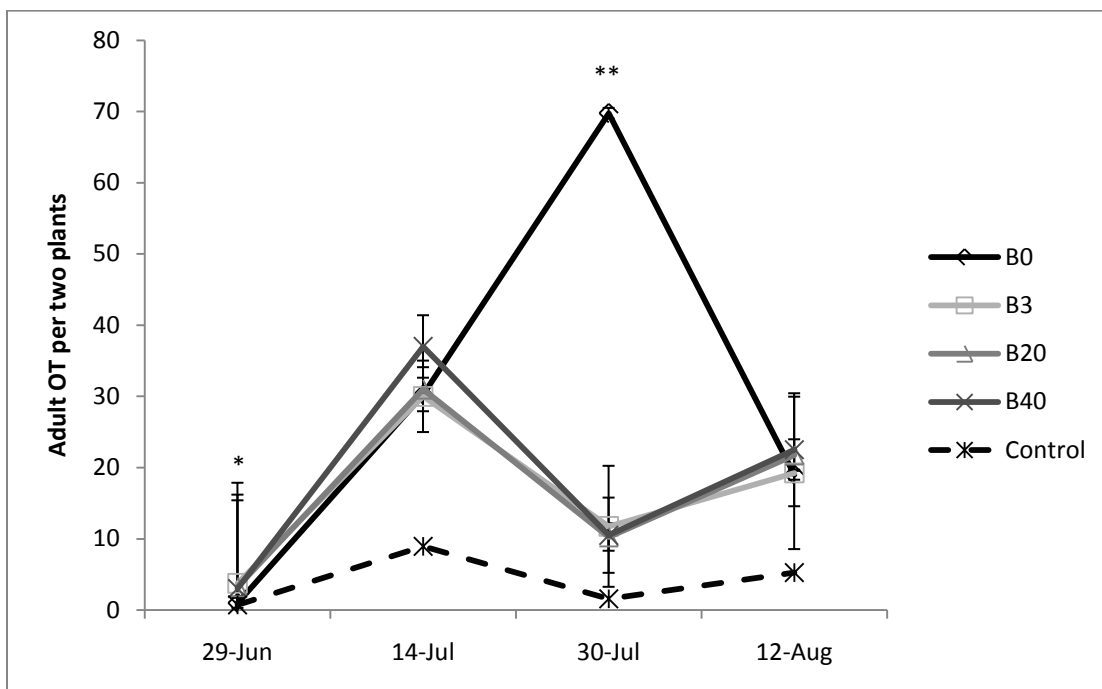


Figure 47. The influence of buckwheat on adult OT populations over distance and four sample dates in 2009. Treatment means ($n=4$) labeled * and ** are significant at $p<0.05$ and $p<0.01$, respectively.

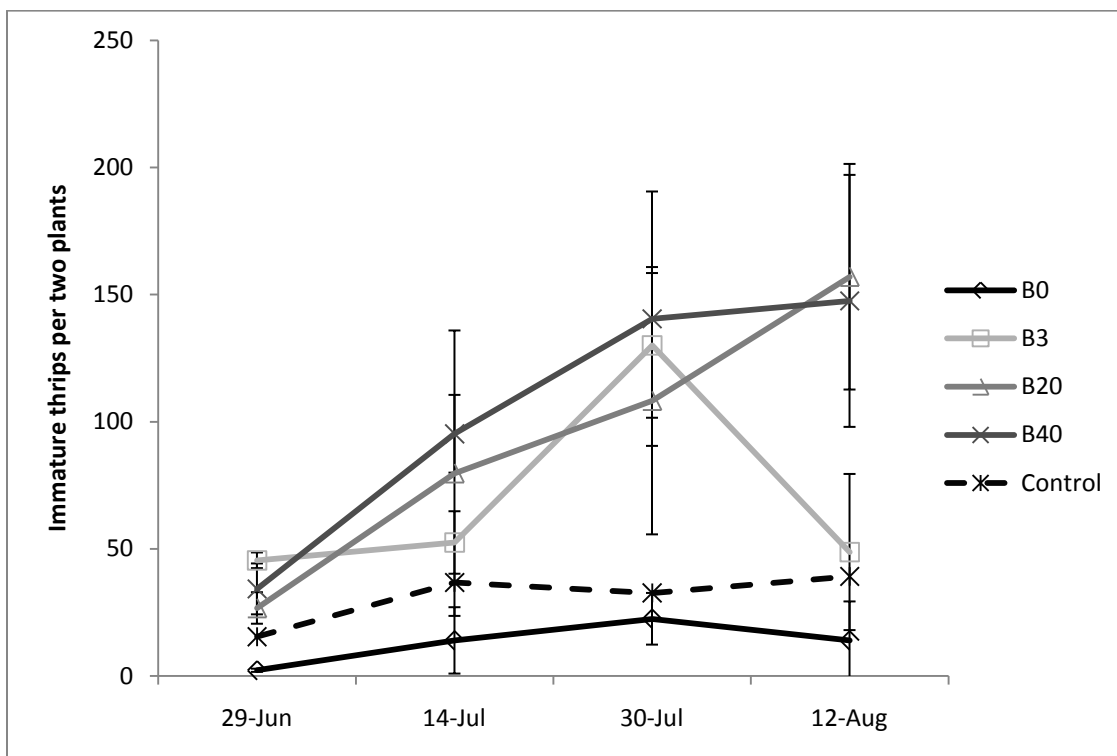


Figure 48. The influence of buckwheat on immature thrips populations over distance and four sample dates in 2009. The main effect treatment mean of distance (n=4) is significant at $p < 0.001$.

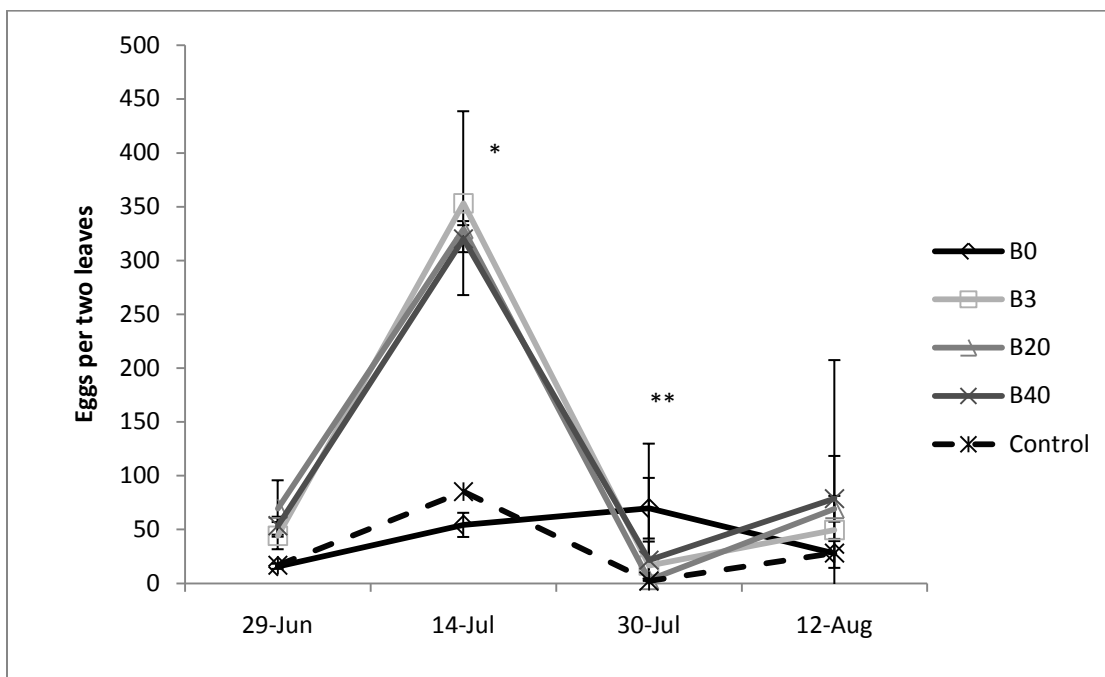


Figure 49. The influence of buckwheat on number of thrips eggs over distance and four sample dates in 2009. Treatment means ($n=4$) labeled * and ** represent the following notable or significant differences: eggs at distance zero were less than both the 20 and 40 distances ($p=0.0657$ and $p=0.0511$) on 29 June and 3, 20 and 40 distances ($p=0.0110$, $p<0.0001$, and $p=0.0174$) on 14 July; eggs counts at zero distance were greater than 3, 20 and 40 distances ($p=0.0110$, $p<0.0001$, and $p=0.0292$) on 30 July samples, respectively.

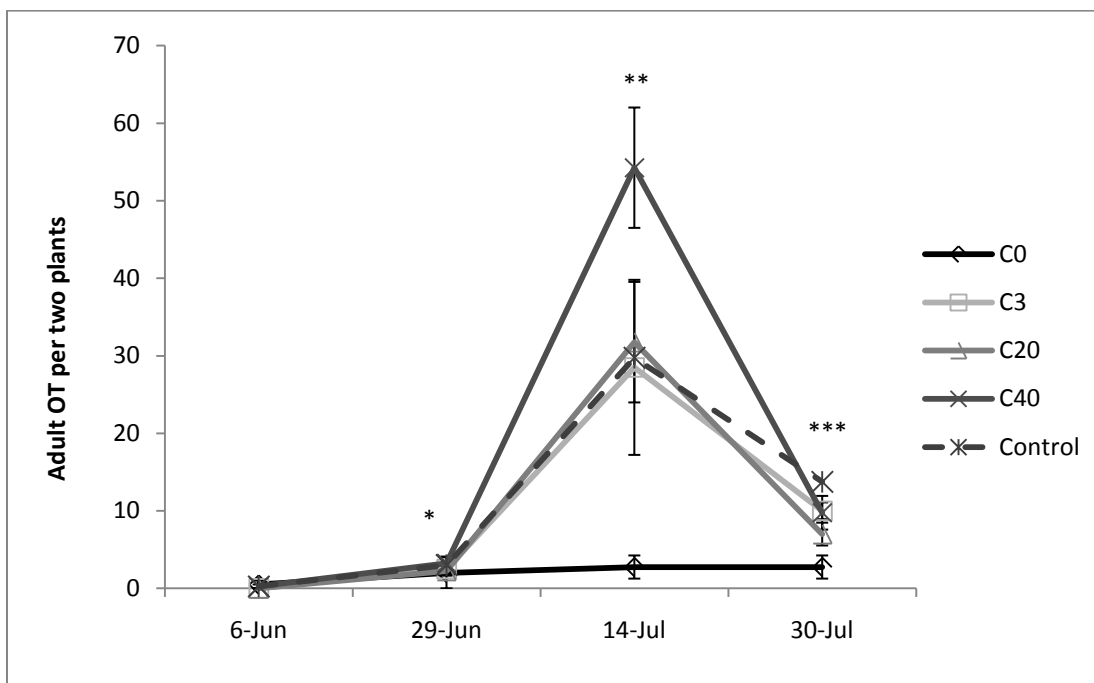


Figure 50. The influence of carrot on number of adult OT over distance and four sample dates in 2009. Treatment means (n=4) labeled *, ** and *** represent the following notable or significant differences: adult OT populations at zero distance were less than 3, 20 or 40 distances on 29 June ($p=0.0406$, $p=0.0466$, and $p=0.0125$), 14 July ($p<0.0001$), and 30 July ($p=0.0017$, $p=0.0148$, $p=0.0026$).

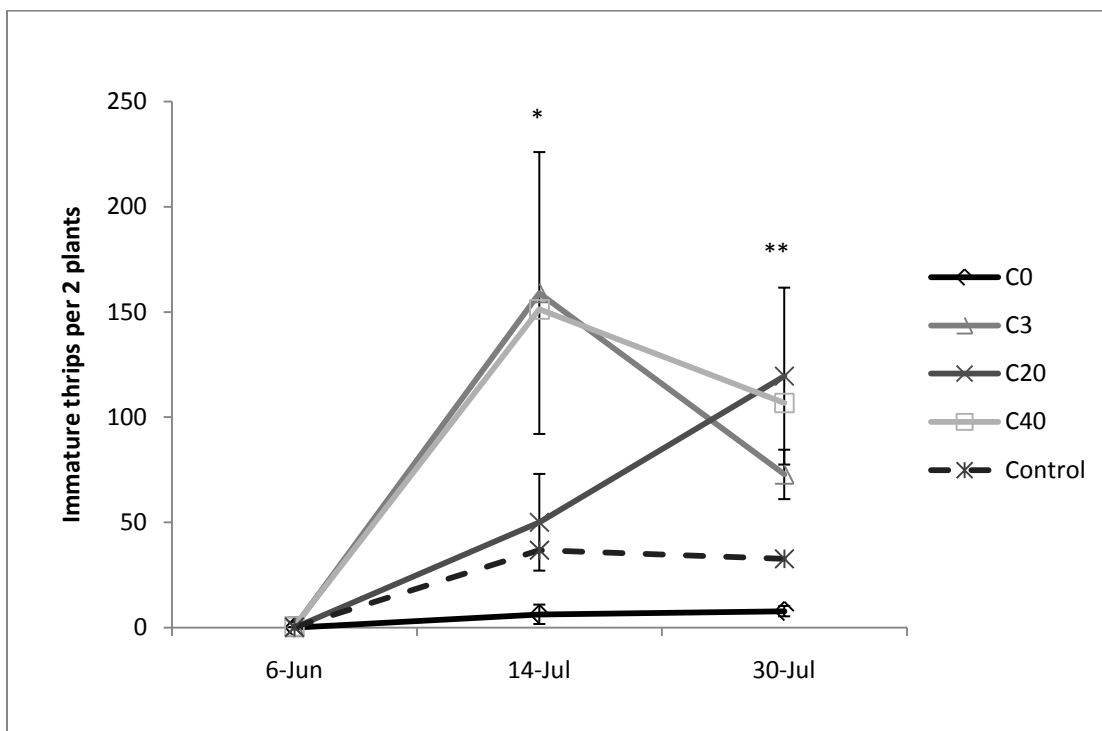


Figure 51. The influence of carrot on number of immature thrips over distance and three sample dates in 2009. Treatment means (n=4) labeled *and ** represent the following notable or significant differences: immature populations at zero distance were less than 3, 20 or 40 distances on 14 July ($p < 0.0001$) and 30 July ($p = 0.0002$, $p < 0.0001$, $p < 0.0001$).

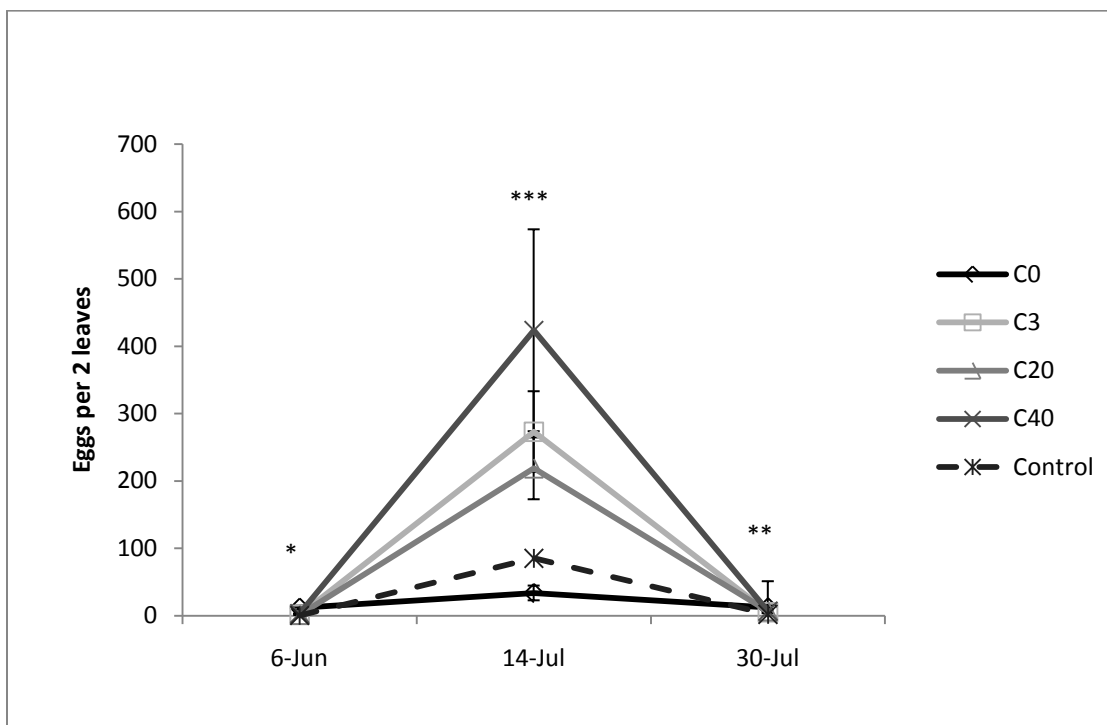


Figure 52. The influence of carrot on number of thrips eggs over distance and three sample dates in 2009. Treatment means ($n=4$) labeled *, **, *** represent the following significant differences: egg populations at zero distance were greater than 3, 20 or 40 distances on 6 June ($p=0.0002$, $p<0.0001$, $p=0.0094$) and greater than 3 and 20 distances on 30 July ($p=0.0680$, $p=0.0544$); zero distance was less than 3, 20 and 40 distances ($p<0.0001$) on 14 July.

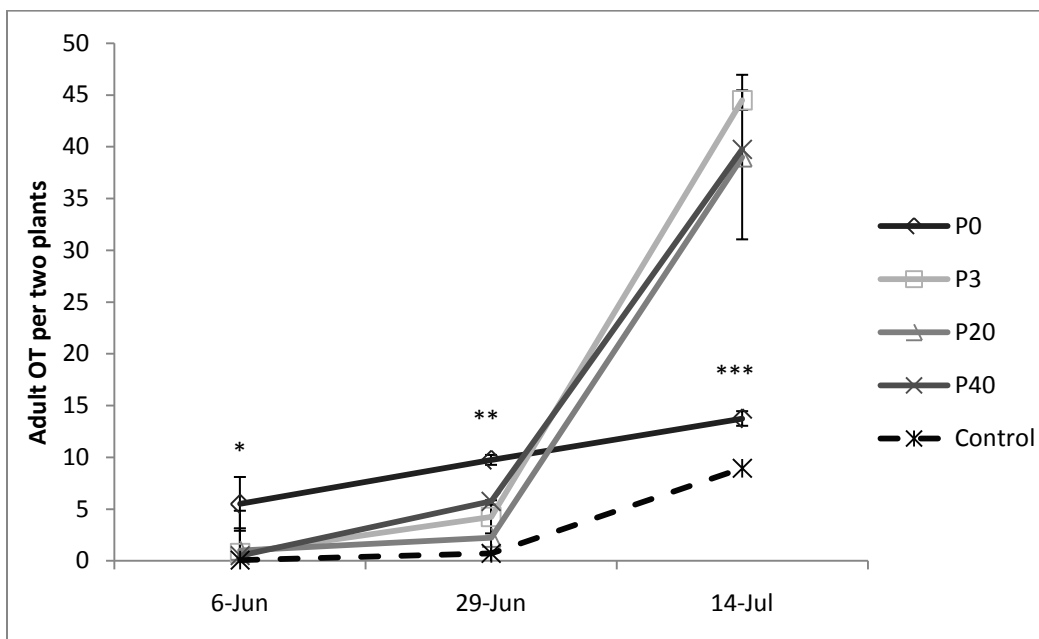


Figure 53. The influence of phacelia on number of thrips adult OT over distance and three sample dates in 2009. Treatment means (n=4) labeled *, **, *** represent the following significant or notable differences: egg populations at zero distance were greater than 3, 20 or 40 distances on 6 June ($p=0.0032$, $p=0.0049$, and $p=0.0016$), on 29 June ($p=0.0999$ and $p=0.0079$ and $p=0.0600$); egg counts at zero distance were less than 3, 20 and 40 ft samples on 14 July ($p=0.0125$, $p=0.0313$, and 0.0450).

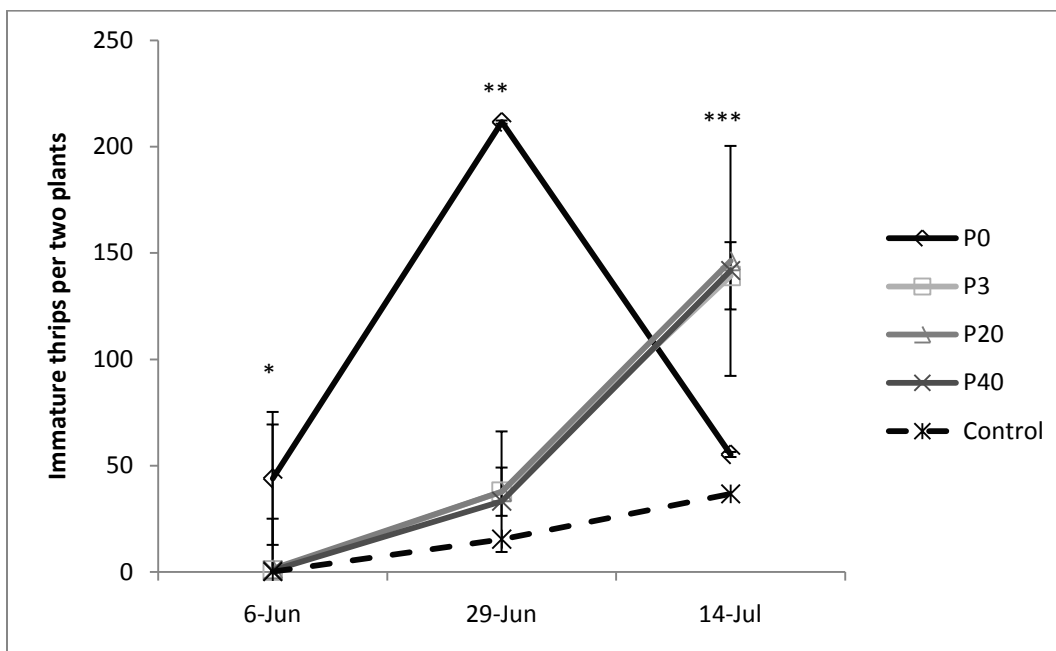


Figure 54. The influence of phacelia on number of immature thrips over distance and three sample dates in 2009. Treatment means (n=4) labeled *, **, *** represent the following significant or notable differences: egg populations at zero distance were greater than 3, 20 or 40 distances on 6 June ($p < 0.0001$, $p = 0.0001$ and $p < 0.0001$) and 29 June ($p = 0.0175$, $p = 0.0091$, $p = 0.025$); zero distance immature populations were notably smaller than the 3, 20 and 40 ft plots on 14 July ($p = 0.0576$, $p = 0.0844$, $p = 0.0625$).

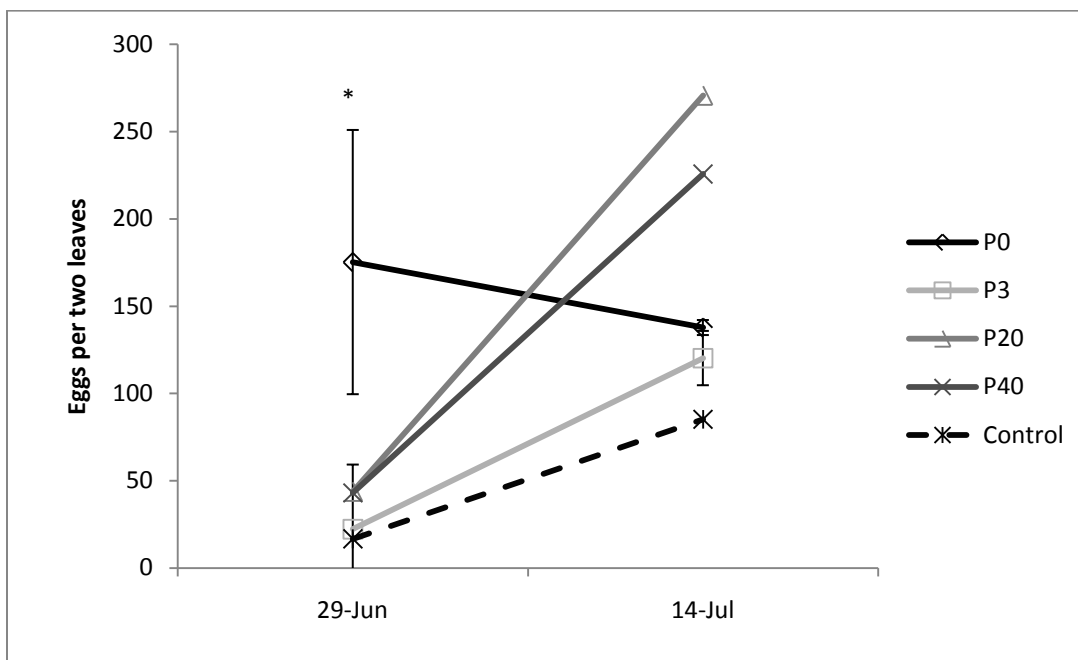


Figure 55. The influence of phacelia on number of thrips eggs over distance and two sample dates in 2009. Treatment means (n=4) labeled * represent the following significant or notable differences: egg populations at zero distance were greater than 3, 20 or 40 distances on 29 June ($p=0.0012$, $p=0.0212$ and $p=0.0218$).

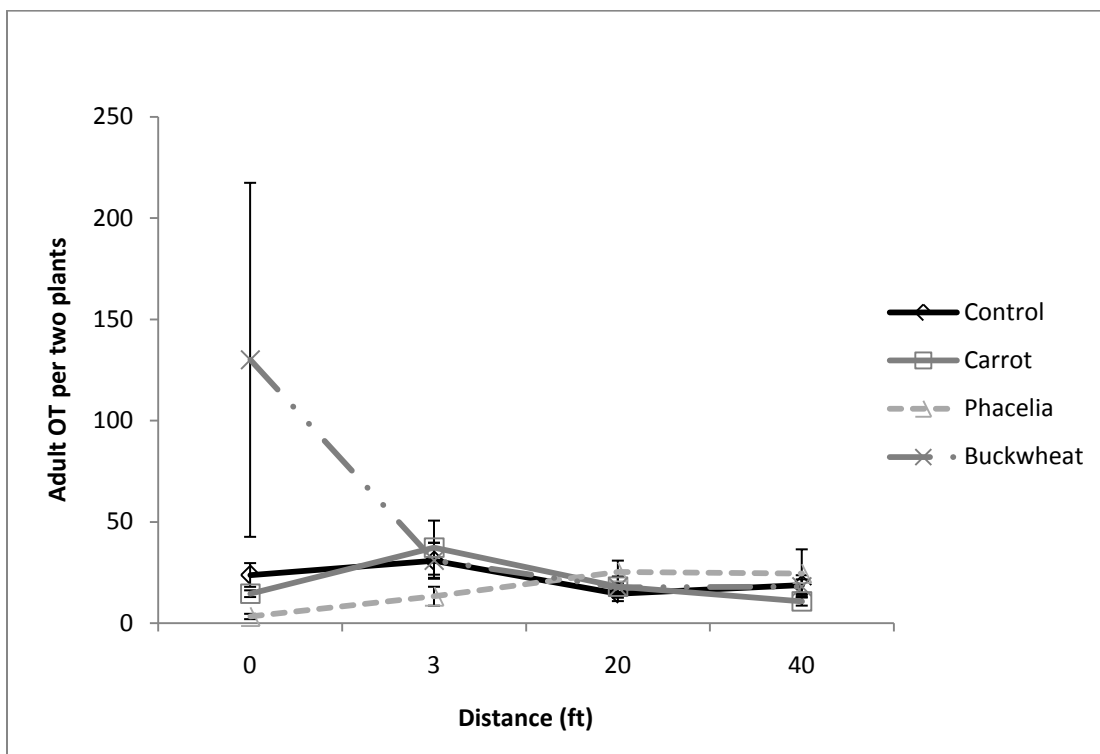


Figure 56. The number of adult OT per two plants as impacted by trap crop 15 July 2010. The main effect of trap crop and the interaction between trap crop and distance were significant at $p=0.0250$ and $p<0.0001$, respectively.

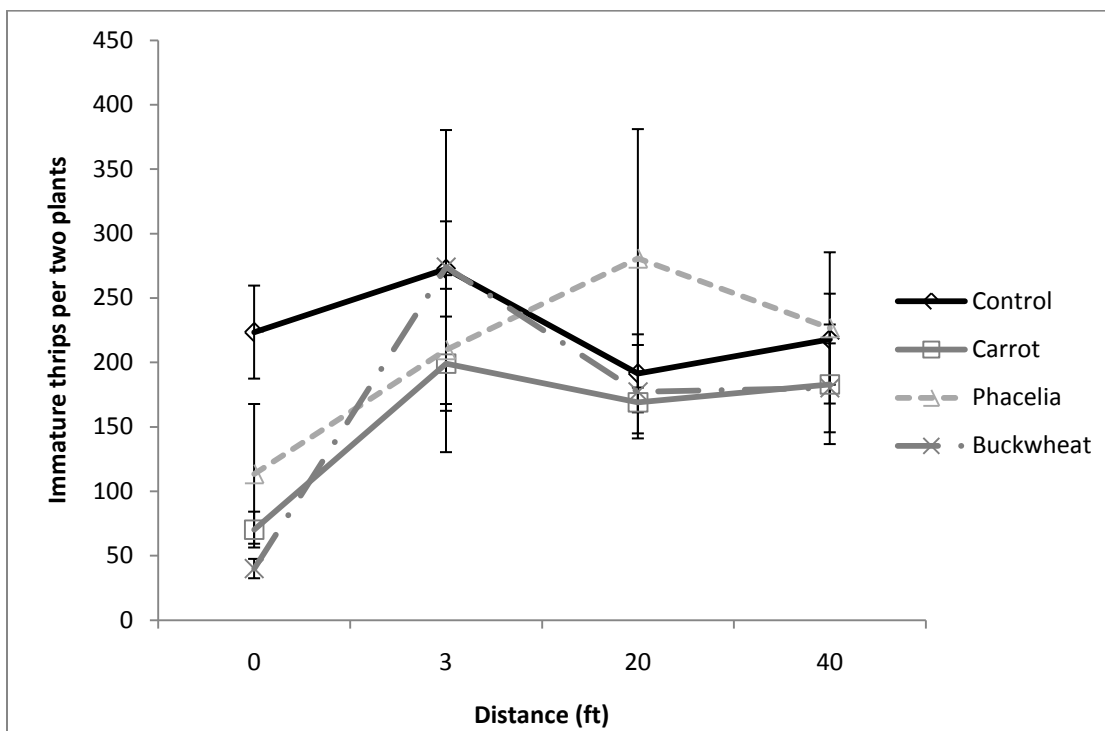


Figure 57. The number of immature thrips per two plants as impacted by trap crop 15 July 2010. Main effects of trap crop and distance were notable and significant at $p=0.0579$ and $p<0.0001$, respectively. The interaction between trap crop and distance was notable at $p=0.0599$.

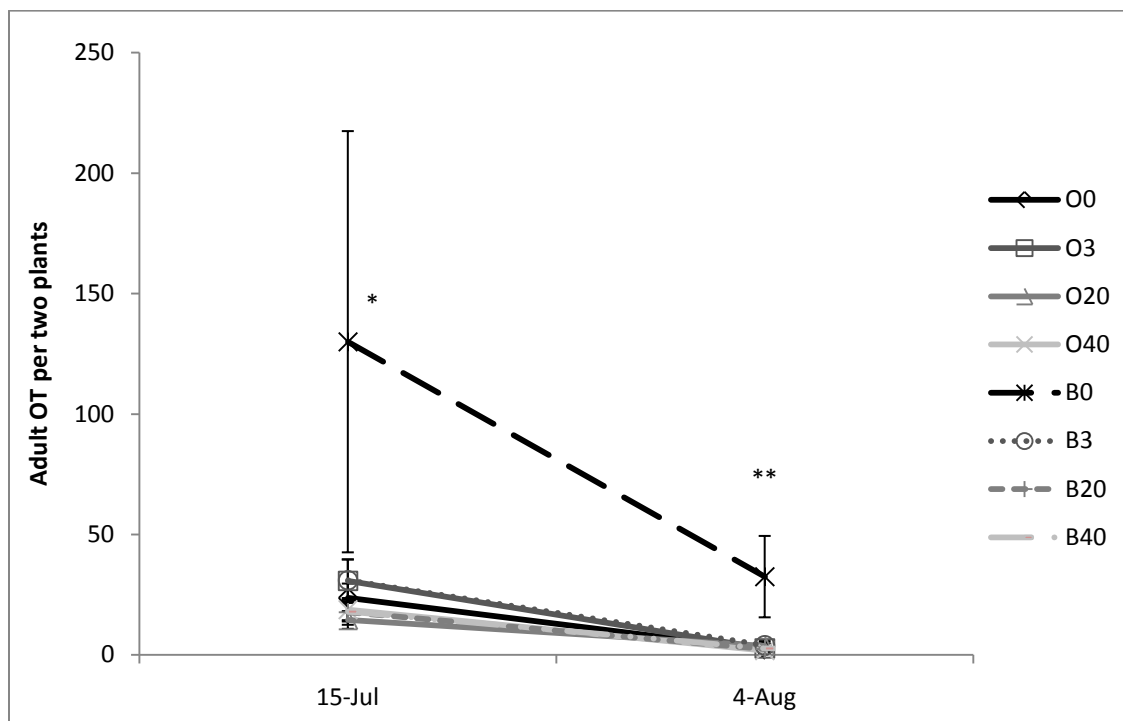


Figure 58. The influence of buckwheat on number of adult OT over distance and two sample dates in 2010. Treatment means ($n=4$) labeled * and ** represent the following significant or notable differences: adult OT populations at zero distance were greater than populations at zero distance in control plots on 15 July and 4 Aug sample periods ($p=0.0243$ and $p=0.0002$, respectively).

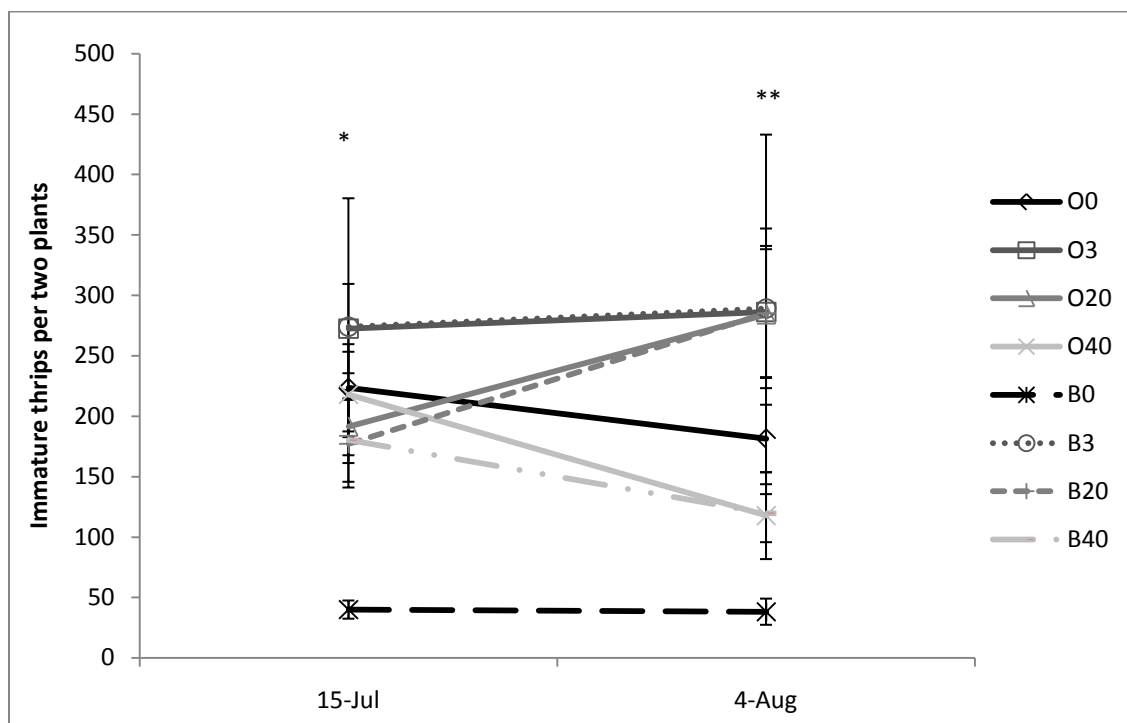


Figure 59. The influence of buckwheat on number of immature thrips over distance and two sample dates in 2010. Treatment means (n=4) labeled * and ** represent the following significant or notable differences: immature populations at zero distance were less than populations at zero distance in control plots on 15 July ($p < 0.0001$) and 4 August ($p < 0.0001$).

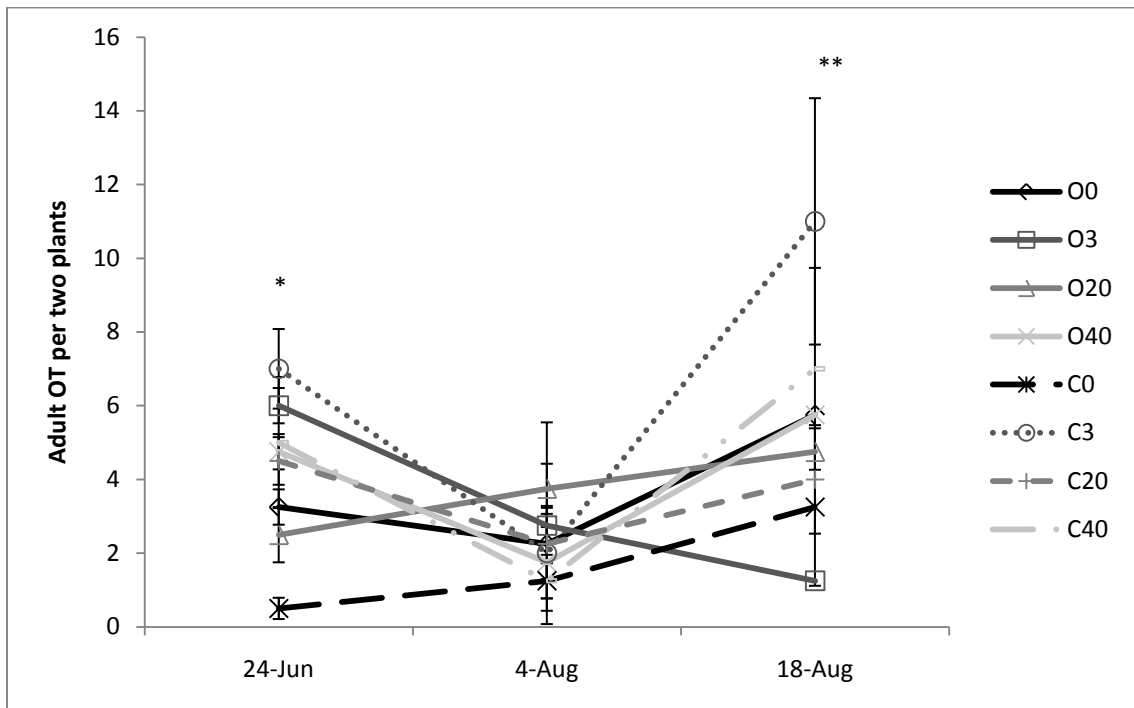


Figure 60. The influence of carrot on number of adult OT over distance and three sample dates in 2010. Treatment means (n=4) labeled * and ** represent the following significant or notable differences: adult OT populations at zero distance were less than populations at zero distance in control plots on 24 June ($p=0.00274$) and 18 Aug ($p=0.0307$).

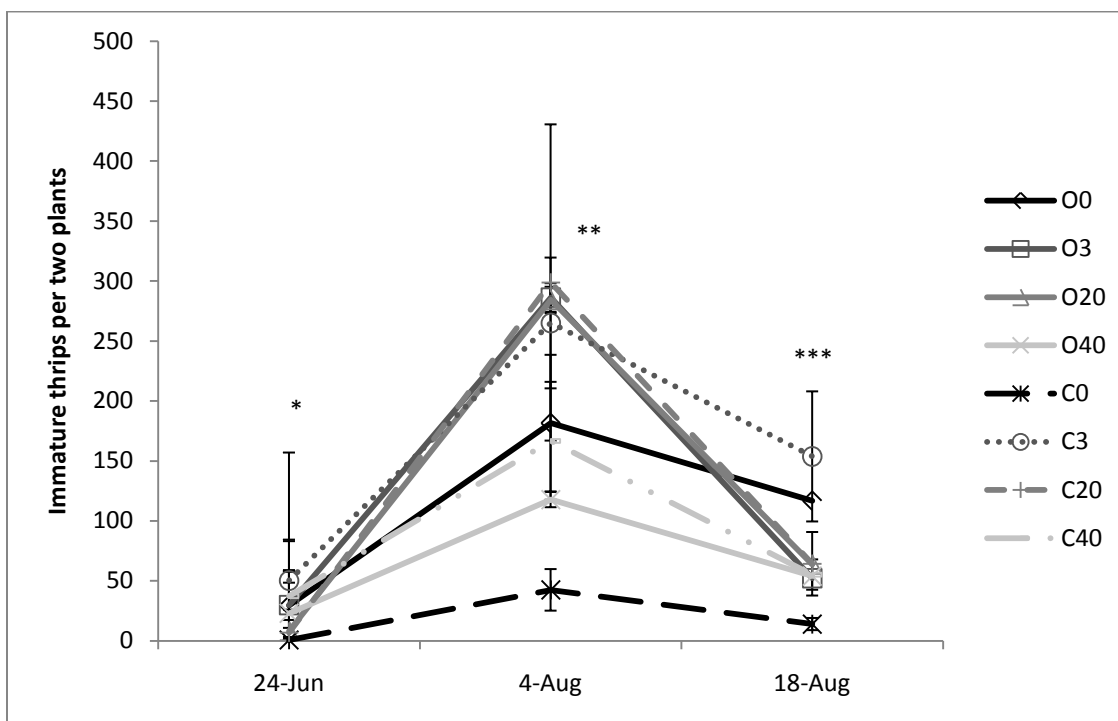


Figure 61. The influence of carrot on number of immature thrips over distance and two sample dates in 2010. Treatment means (n=4) labeled *, ** and *** represent the following significant differences: immature populations at zero distance were less than populations at zero distance in control plots on 24 June ($p < 0.0001$), 4 Aug ($p = 0.0146$) and 18 Aug ($p = 0.0049$).

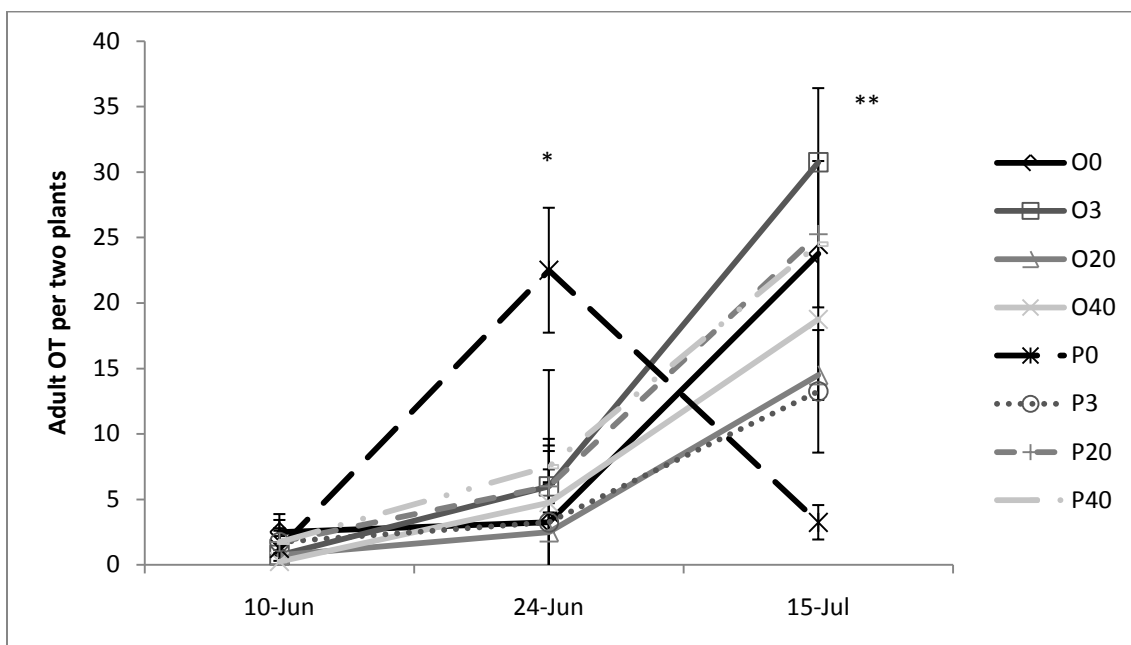


Figure 62. The influence of phacelia on number of adult OT over distance and three sample dates in 2010. Treatment means ($n=4$) labeled * and ** represent the following significant differences: adult OT populations at zero distance were greater than populations at zero distance in control plots on 24 June ($p=0.0003$) and less than populations at zero distance control plots on 15 July ($p=0.0007$).

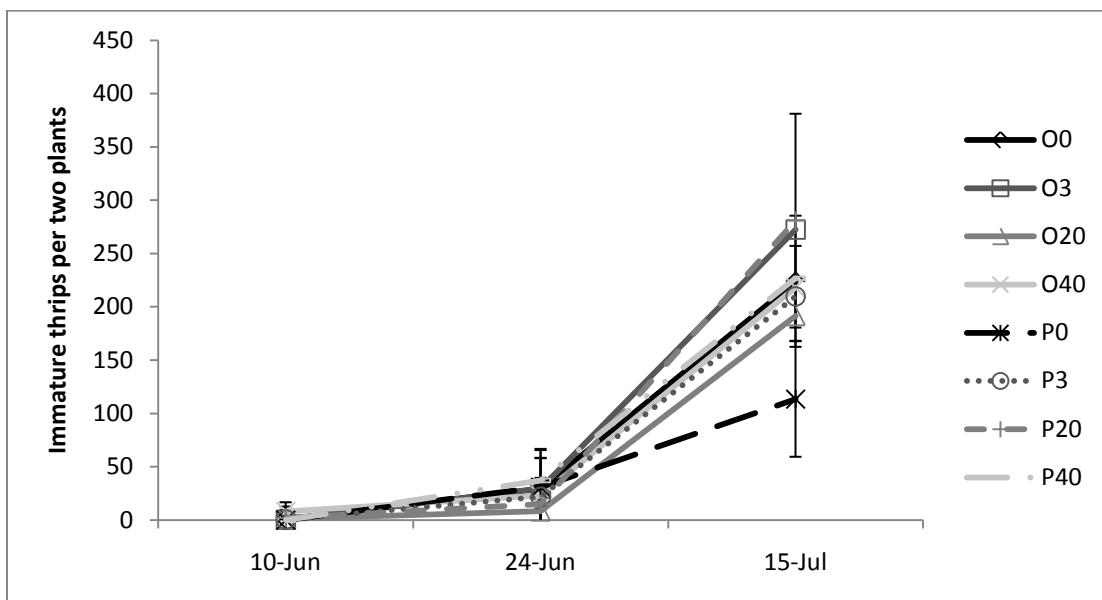


Figure 63. The influence of phacelia on number of immature thrips over distance and three sample dates in 2010. Treatment means (n=4) were not significantly different at any date.

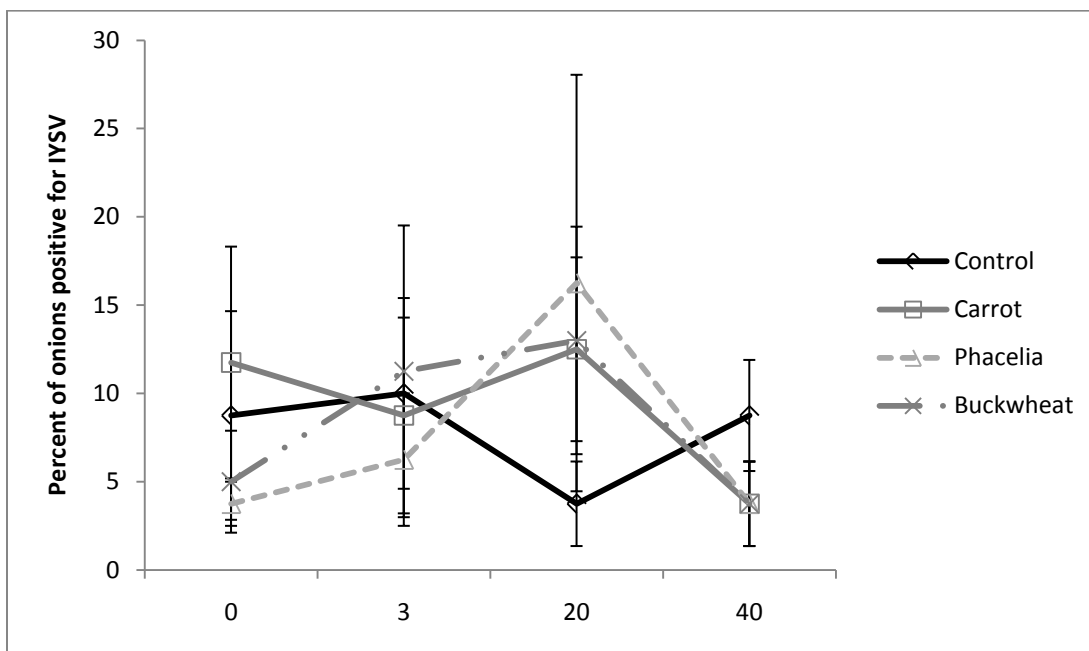


Figure 64. The influence of trap crops on the percent of onions plants that tested positive for IYSV infection over distance on 26 July 2010. Treatment means (n=4) were not significantly different at any date.

CHAPTER IV

GENERAL CONCLUSIONS

As new reports of IYSV infection continue throughout the world, onion production remains threatened. The number of plants known to have the ability to harbor the disease is also increasing. The current practices of frequent pesticide applications and high rates of fertilizer are not sustainable, and do not appear to be effectively controlling the disease. Alternative management strategies that involve a whole farm approach offer promising options to growers, and may provide a reduced environmental impact.

The benefits of reduced N fertilizer rates are clear. Decreased soil nitrate levels, increased soil microbial activity and decreased thrips populations with no reduction in onion yield in a normal growing season are strong indicators that a reduced N management strategy should be considered in commercial onion production. The use of trap crops such as buckwheat and phacelia offer attractive alternatives to colonizing thrips. A combined use of these management strategies could enhance onion production while reducing costs of fertilizer and pesticide applications.

The results of this study have wide application to decreasing thrips pressure by manipulating onion growth and apparancy. While reductions in overall thrips populations can reduce loss from feeding damage, the transmission of IYSV is not as clear. The interaction between timing of disease transmission, field conditions and crop loss is not well understood, still leaving growers to aggressively manage thrips infestations throughout the season. More research to understand disease expression in onions is needed. Providing growers with a critical window of control to minimize economic loss could help focus efforts of fertilizer timing and trap crop growth.