AN ABSTRACT OF THE THESIS OF

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Title: Cover Crop Effects on Root Rot of Sweet Corn and Soil Properties.

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Root rot of sweet corn in western Oregon and Washington is a significant disease that can reduce yield of intolerant cultivars of processed sweet corn by fifty percent. Root rot is caused by a complex of soilborne organisms, including *Drechslera sp.*, *Phoma terrestris*, and *Pythium arrhenomanes*. Processors have adopted tolerant cultivars but farmers continue to seek cultural management strategies that reduce inoculum potential. High rate manure and compost amendments (16.8 - 56.0 Mg ha^{-1}) suppress root rot of corn through general suppression but this practice is not agronomically viable. General suppression is typically associated with high rates of organic amendment and high microbial (FDA) activity. Processed vegetable farmers currently grow winter cover crops to improve soil and water quality and are interested in identifying cover crops that

suppress root rot of corn and increase yield. High biomass cover crops can yield up to 12 Mg ha^{-1} dry matter; this rate of organic amendment may or may not be sufficient to generate general suppression. However, specific cover crops, such as species and cultivars of crucifers and oats, have been shown to more suppressive than other cover crop species and cultivars against specific soilborne diseases. Oat is grown as a winter cover crop in the Willamette Valley and contains avenecin, a chemical that has been shown to have activity against pathogen propagules. In addition, in previous work in containers oat cover crops suppressed root rot of sweet corn. However, there is a concern that oat cover crops immobilize N and reduce corn yield.

The objectives of this research were to 1) identify high biomass cover crops with agronomic potential for western Oregon processed vegetable cropping systems, 2) evaluate the impact of high biomass cover crops on root rot severity and yield of sweet corn, 3) determine whether there is a correlation between dry matter, soil microbial activity and root rot severity and 4) determine whether cover crops immobilize nitrogen and reduce corn yield.

Research station field trials were conducted in 2003-04, 2004-05 and 2005-06 at the Oregon State University vegetable research farm in Corvallis, Oregon and an on-farm experiment was conducted in 2004-05 at Kenagy Family Farm in Albany, Oregon.

Oat 'Saia' winter-killed in 2005-06 and mustard mix 'Caliente' winter-killed every winter except 2004-05, when winter temperatures never dropped below -7 °C. Rape 'Dwarf Essex', mustard 'Braco', and arugula are reliably winter-hardy. All mustard cover crop species are susceptible to white mold caused by *Sclerotinia sclerotiorum*, causal agent of white mold of snap bean. Oat (*Avena sativa*) is susceptible to barley yellow

dwarf virus (BYDV), an important pathogen of grass seed crops. Mustard cover crops could contaminate cruciferous seed crops.

All of the cover crop species evaluated demonstrated some potential to suppress root rot of corn. Oat 'Saia' was the most consistently suppressive; it suppressed root rot in 4 of 6 experiments. Sudangrass was suppressive in the only year it was evaluated as well as in container experiments in previous work. In general, cover crops increased or had no impact on shoot and root dry matter in greenhouse bioassays. There was only one significant cover crop treatment effect on yield; in 2006, the oat treatment increased yield by 11.6% compared to the fallow.

Overall, cover crop aboveground dry matter (DM) ranged from 4.2 Mg ha^{-1} (summer R 2003) to 12.2 Mg ha^{-1} (winter O 2004). Overall, there was a significant relationship between cover crop DM and radicle rot severity in greenhouse bioassay but not in field experiment. Cover crop treatments consistently increased soil microbial activity. Overall, there was a significant negative correlation between microbial activity and root rot severity in greenhouse bioassays early after cover crop incorporation, but the correlation weakened over time and ultimately was lost by about 80 days after incorporation.

The C:N of oat and rape residues was 51 and 21, respectively. Soil nitrogen was immobilized by both the oat and rape cover crops, but oat immobilized more N than rape. Corn grown in the oat treatment soils had lower SPAD values, but it is not clear whether foliar N was sufficiently low to reduce yield potential. There was no consistent trend in above- or below-ground corn dry matter after oat incorporation over the three years. In 2006, the oat treatment had no significant effect on corn DM but increased yield by

11.1%. More work is required to better understand the impact of oat cover crop N immobilization on corn N status and yield.

Oat ‘Saia’ has the potential to suppress root rot of sweet corn and maintain or increase corn productivity. However, this oat cultivar is not reliably winter-hardy and is susceptible to BYDV. Future research should screen *Avena* species and/or cultivars for improved winter hardiness, BYDV resistance, and root rot suppressive potential.

Cover Crop Effects on Root Rot of Sweet Corn and Soil Properties

by
Mikio Miyazoe

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Mikio Miyazoe, Author

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CHAPTER 1

INTRODUCTION

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General introduction

Over the past 80 years, crop production technologies in the United States have improved, such as the development of superior lines from breeding program, improved fertilizers, herbicide and pesticides; improved irrigation systems, and larger farming equipment to ease and increase crop productivity (Wolf and Snyder, 2003). Monoculture has also been widely accepted in industrialized agriculture. However, these practices have negatively impacted the soil environment; heavy machinery use can result in soil compaction, waterlogging and plow pans, and intensified soil tillage can cause soil erosion and soil organic matter (SOM) loss. Industrialized agriculture in the U.S. has also in some cases intensified disease, weed, and pest pressures, and has resulted in the increased use of fungicide, herbicide, and pesticide inputs that may cause environmental and food contamination (Deluca, 1995; Pimentel et al. 2005; Herrick and Wander, 1997; Wolf and Snyder, 2003). More recently, scientists and agriculturalists have begun to focus on improving soil health to reduce disease, pest, and weed pressure and increase or sustain higher crop productivity (Wolf and Snyder, 2003).

Problem in Willamette Valley sweet corn production

Processed sweet corn growers in Willamette Valley of Oregon experienced yield reductions in the 1990's (Hoinacki, 2003). The economic loss from yield reduction was a significant concern to the Willamette Valley processed vegetable growers. Until recently, many processed vegetable farmers practiced two- or three-year crop rotations (sweet corn / snap beans) or (sweet corn / snap beans / wheat) resulting in increased root rot severity in sweet corn crops (Darby, 2004; Hoinacki, 2003). The causal agents of root rot of sweet corn are *Drechslera sp.*, *Phoma terrestris*, and *Pythium arrhenomanes* (Hoinacki et al., 2004). These pathogens cause necrosis of the radicle and nodal roots of sweet corn as early as 3-4 weeks after planting, and the severity of infection rate can reach 100 % necrosis within 6 weeks in

heavily infested fields (Hoinacki et al., 2004). The secondary symptoms are leaf chlorosis (known as 'firing'), small ears, poor tip-fill of ears, dimpled kernels, and an overall reduction in yield (Hoinacki, 2003; Hoinacki et al., 2004).

The disease cycle of these root rot pathogens generally has three stages: 1) overwintering of pathogen propagules, 2) infection of the roots, and 3) symptom development (Hoinacki et al., 2004). These root rot pathogens are classified as non-obligate parasites, which can persist in soil or plant debris (Agrios, 1997). Overwintering structures of oospores from *P. arrhenomanes*, mycelium from *Drechslera* sp., and microsclerotia from *P. terrestris* pathogens can persist in soil for 4 to 5 years (Hoinacki et al., 2004; Stone, personal communication). Soon after germination of corn seedlings, the leakage of nutrients from corn roots can activate germination of these pathogens; they then infect the roots (Hoinacki et al., 2004). The pathogens then quickly grow, colonize, and cause necrosis of the radicle and nodal roots (Hoinacki et al., 2004).

Fumigation with methyl bromide reduced root rot severity by 89 % resulting in a 50 % increased corn yield (Hoinacki, 2003). However, fumigation is not economically feasible and also has negative implications for the environment and human health (Darby, 2004). Therefore, corn growers are looking for alternative management strategies for this problem. Industry has identified and adopted tolerant cultivars and their widespread adoption has solved this problem in the short term. However, there is concern that cultivar tolerance could be lost over time, so growers are interested in cultural strategies for root rot management that could be used in conjunction with the tolerant cultivars.

Soil health

Although the definition of 'sustainability' in a farming system is difficult to define precisely, SOM has a significant role to play in the sustainability of farming systems (Swift and Woomer, 1993). Sustainable agriculture relies heavily on the quality and function of a healthy soil that can sustain the chemical, physical, and

biological functions of the soil environment (Wolf and Snyder, 2003). Soil health is defined as "the capacity of a soil to function as a vital living system… and to promote plant and animal health" (Doran and Zeiss, 2000). In other words, a healthy soil releases and retains water and nutrients (Stone et al. 2004), and promotes biological productivity, environmental quality, and the health of living organisms (Herrick and Wander, 1997; Pankhurst et al., 1997). An important constituent of a healthy soil is SOM, which is generated by inputs of organic matter (OM) from a wide variety of plants and animal tissues, manure and composted materials (Wolf and Snyder, 2003).

Increasing SOM contents and quality through organic amendment can substantially increase SOM content; this can provide nutrients and energy to the microbial community and plants and reduce inputs of synthetic fertilizer (Ochiai, 2004; Wolf and Snyder, 2003). Organic amendments can improve soil physical, biological, and chemical properties that can also suppress soil-borne pathogens in field agricultural systems (Darby et al., 2006; Stone et al., 2004); however, this area of study remains difficult to understand as a whole system because there is such complexity of biotic and abiotic factors involved (Ochiai, 2004; Stone et al, 2004). Although the relationship between SOM management and plant health and productivity in field agriculture is poorly understood, increasing SOM content and quality may have the potential to reduce disease pressure and enhance yield in some crop/disease systems.

Cover cropping and disease suppression

One way of increasing SOM is by soil amendment with manures, composts, or other organic residues. However, this is not practical for most processed vegetable growers. However, increasingly, many of these growers practice cover cropping to protect soils from erosion, reduce nutrient leaching, and improve overall soil quality and biological diversity. An overlooked potential benefit of cover cropping is disease suppression. The use of green manures to suppress corn root rot would be an ecological approach that could improve overall soil health while reducing root rot

severity and increasing yield of sweet corn at the same time. Certain high biomass cover crops such as the mustard mix "Caliente" are being marketed to farmers as biofumigants due to specific chemical constituents that under laboratory conditions have the potential to destroy pathogen propagules. However, while efficacy has been shown in laboratory experiments, there is little information on efficacy under field conditions. In addition, no work has been done to investigate efficacy of these cover crops for the management of root rot of sweet corn.

Research objectives

The objectives of this research were to:

1) identify high biomass cover crops with agronomic potential for western Oregon processed vegetable cropping systems.

2) evaluate the impact of high biomass cover crops on root rot severity and yield of sweet corn.

3) determine whether there is a correlation between dry matter, soil microbial activity and root rot severity.

4) determine whether oats immobilize nitrogen and reduces corn yield.

CHAPTER 2

LITERATURE REVIEW

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Benefits and drawbacks from use of cover crops

Use of legume cover crops as green manures to improve soil tilth and fertility occurred as early as fifth century B.C. in China, 287 B.C. in Greece, and 116 B.C. in Roman (Pieters, 1927). This old technique was revived in the late eighteenth century in the U.S., and leguminous green-manure crops, such as cowpea and clover, were used in Maryland and Virginia (Pieters, 1927). Since ancient times, use of cover crops seemingly enhanced yield of food crops, and farmers systematically developed this as an agricultural technique. Although increasing yield would be the reason why most farmers in the past used cover crops for their production system, they also understood that their cover crops improved overall soil health by improving soil physical, chemical, and biological properties.

Use of over-wintering cover crops can protect soil from erosion by wind and water (Hall et al., 1984; Malik et al., 2000) and from loss of available plant nutrients through leaching and runoff (Dabney et al., 2001). Green manuring soil can improve aggregation by soil microorganisms that reduces bulk density and increases porosity and water infiltration and retention (Aiguo et al., 2005; Dabney et al., 2001; Franzluebbers, 2002; Mendes et al., 1999; Schuttera and Dick, 2002); these factors create favorable conditions for plant root growth. Legume cover crops have symbiotic associations with N-fixing bacteria (Wagger, 1989b), increasing the amount of readily available nitrogen to plants (Dick, 1998). Amendment of cover crops to soils can increase mineral nitrogen contents. Conversely, the cover crops can scavenge available soil nutrients and store them in their tissues until they are released after the cover crop is incorporated (Dick, 1998). This process can reduce nitrate leaching to groundwater if over-wintering cover crops are planted after harvest (Dick, 1998). Some cover crops can also be used as a form of IPM to suppress diseases, weeds, and pests (Abdina et al., 2005; Peachey et al., 2002; Utkhede and Hogue, 1999).

However, cover cropping can have some drawbacks. Cover crop species, growth stage, management strategies, and environmental factors can all potentially impact the performance of cash crops after cover cropping. For example, while cover

crops can suppress germination and growth of weeds by allelopathic chemicals and/or toxins (Barnes and Putnam, 1986; Raimbault et al., 1990), they can be phytotoxic to the crop root system if cover crops do not have sufficient time to decompose before the crop is planted. Therefore, timing of seeding is critical, especially for annual crops.

Cover crop species and cultivars may perform differently in different microclimates. Creamer et al. (1997) evaluated the performance of 23 different cover crop species including legumes, winter hardy cereals, forage grasses and summer annuals in two different locations (Columbus and Fremont) in Ohio. According to this study, annual ryegrass was winterkilled in Fremont due to a colder winter than Columbus. The drier climate in Fremont also reduced establishment of cover crops at 1 and 2 months after planting. In contrast, cover crop establishment in Columbus was strong and uniform, due to different precipitation, soil temperature, and soil characteristics.

Cover crop incorporations can increase moisture retention and delay soil temperature increase in spring, which may delay tillage and planting (Dick 1998).

Cover crop residues with high C : N ratios, such as grasses and cereals, can immobilize soil nitrogen and limit its availability to cash crops (Wagger, 1989b ; Kuo and Sainju, 1998). In general, a C : N ratio below 15 to 20 is expected to result in net mineralization from cover crop amendments, whereas a C : N ratio above 15 to 20 favors N immobilization (Gale et al., 2007; Kusonwiriyawong, 2005; Kumar and Goh, 2003). Nitrogen immobilization occurs primarily through microbial assimilation (Bruun et al., 2006), and excess nitrogen as inorganic forms can be released into the soil solution (Brady C. N. and R. R. Weil, 2002). Different maturities and different parts of plants may have different C : N ratios, which generate different N immobilization rates. For instance, Quemada and Cabrera (1995) investigated net N mineralization in leaves and stems of oat. While the C : N ratio in leaves is about 13, the C : N ratio in stems is about 79. Shortly after incorporation, oat stems actually immobilized inorganic nitrogen, while at the same time, the leaves mineralized nitrogen.

Vigil and Kissel (1991) estimated N mineralization from sorghum plants. While young sorghum plants had a C : N ratio of less than 20, sorghum plants after harvest had a C : N of 44; mature sorghum plants immobilized nitrogen to a higher degree than immature sorghum plants. Nitrogen immobilization can also differ in different soil textural classes. Kumar and Goh (2003) investigated maximum N immobilization in various plant materials in sandy loam, silt loam, and clay soils. Nitrogen immobilization was higher in finer soil textured soils such as clays when compared to sandy soils. This different N release may be attributed to adsorption of organic N by the clay particles.

Kuo and Sainju (1998) illustrated that a mixture of annual ryegrass or cereal rye and vetch residues (60:40, wt:wt, grass and vetch) can reduce the C : N ratio by approximately 40 % compared to annual ryegrass or cereal rye alone; this would improve subsequent N availability to the crop. Late summer to fall cover crops can be used for weed suppression and erosion control, and for scavenging excess N from fertilizer (Stivers-Young, 1998). Some may winter-kill and remain a dead mulch on the surface of the soil. Unfortunately, in this case, most of the accumulated N from the above ground biomass is then lost by decomposition, and the mineralized nitrate may be leached (Stivers-Young, 1998).

Some cover crops can be alternative hosts for pathogens of cash crops. For example, Koike et al. (1996) reported that the cover crops *Phacelia*, Lana woolypod vetch, and Austrian winter pea were identified as hosts for *Sclerotinia minor*, the causal agent of lettuce drop disease. The cover crops 'Saia' oats (*Avena strigosa* Schreb.), 'Garry' oats (*Avena sativa* L), and 'Triple S' sorghum-sudangrass (*Sorghum bicolor* x *S. sudanense*) were alternative hosts of *Rhizoctonia fragariae* and *Pratylenchus penetrans*, the causal agents of strawberry black root rot (LaMondia, 1994). However, further investigation of strawberry black root rot with above mentioned cover crops from Elmer and LaMondia (1999) showed that the application of ammonium sulfate and calcium nitrate fertilizer impacted the severity of strawberry black root rot. When fertilized with calcium nitrate, severity was 50 to 60 % across the three cover crops; when fertilized with ammonium sulfate, severity was 30 %

lower. Elmer and LaMondia (1999) hypothesized that fertilization of oats with ammonium sulfate may increase the availability of manganese to strawberry roots due to soil acidification, and this resulted in an enhanced plant resistance to black root rot.

Oat is a host for barley yellow dwarf virus (BYDV), which can be transmitted by disease vectors, such as aphids, to wheat, barley, rice and maize (Miller and Rasochová, 1997). BYDV has been diagnosed in oat cover crops in the Willamette Valley (Putnam, Oregon state Univ. disease clinic). BYDV is also an important pathogen of grass seed crops grown in the valley (Melodie Putnam, personal communication).

Many cruciferous plants, including oilseed rape (*Brassica napus* L.) and other cover crops species, are susceptible to *Sclerotinia sclerotiorum*, the causal agent of white mold for snap bean (Zhao et al., 2004) and many other important diseases in many cropping systems.

Cover crops and disease suppression

A suppressive soil is defined as a soil in which "the pathogen does not establish or persist, establishes but causes little or no damage, or establishes and causes disease for a while but thereafter the disease is less important, although the pathogen may persist in the soil" (Baker and Cook, 1974). However, the suppressiveness to soil-borne diseases is still difficult to define due to the involvement of many complex biological and abiotic factors (Ochiai, 2004).

Historically, soil suppressiveness can be divided into general or specific suppression. General suppression can be defined as suppression generated by the soil microbiological activities as a whole (Cook and Baker, 1983). Specific suppression can be defined as suppression which is generated by one or several groups of microorganisms (Cook and Baker, 1983). Alternatively, non-suppressive soils are soils in which disease occurs and progresses (Stone et al., 2004).

Beside biological factors, the nature of physical and chemical properties of soil such as temperature, soil texture, soil structure, soil porosity, water holding capacity,

soil pH, electric conductivity, cation exchange capacity, and soil nutrients can relate to incidence and severity of soil-borne diseases (Ochiai, 2004). Both biotic and abiotic factors affect the soil microbial community in various ways, and disease suppression can result from conditions that are unfavorable to the pathogen and/or favorable to antagonists or competitors of pathogen.

Amendments of cover crops into soils can increase SOM and microbial activity and biomass (Bandick and Dick, 1999; Kuo et al. 1997) and increase the potential for general suppression to soil-borne pathogens (Davis et al., 1996; Workneh et al., 1993). However, general suppression via amendments of cover crops alone may take several years because cover crops have low biomass and are easily broken down compared to manure, peat, or compost amendments (Workneh et al., 1993). Microbial biomass and activity have been positively correlated to general suppression of soil borne diseases such as Pythium damping off and corn and bean root rots (Darby, 2003).

On the other hand, the growth of specific cover crop species and/or cultivars in soils can suppress specific soil-borne diseases (Stone et al., 2004). For instance, Alström (2000) identified several genera of root-colonizing fungi, including *Trichoderma, Gliocladium, Mortierella, Fusarium*, *and Alternaria*, from oilseed rape and also investigated bacterial colonization of *Serratia* spp., *Alcaligenes* sp., *Pseudomonas putida*, *P. acidovorans*, and *Stenotrophomonas* sp. in oilseed rape (Alström 2001). These fungal and bacterial communities delayed and reduced the symptoms of infection of oilseed rape by *Verticillium dahliae* Kleb. These fungal and bacterial antagonists are capable of competing for root colonization sites with the fungal and bacterial pathogens (Alström, 2000; 2001). Also, growth of specific wheat cultivars was suppressive to the growth and infection of *Rhizoctonia solani* (Mazzola and Gu, 2000). The suppressive wheat cultivars reduced populations of *Pseudomonas syringae* and *P. fluorescens* biotype C. and increased populations of *P. putida*, a known biocontrol agent (Mazzola and Gu, 2000). The growth of specific cultivars of wheat can alter the microbial community and suppress replant disease of apple (Mazzola et al., 2001; Mazzola and Gu, 2000). In the greenhouse experiment, soil

amendment with seed meals of *Brassica napus*, 'Dwarf Essex', and Canola can suppress apple replant disease, (causal agents *Rhizoconia solani.* and *Pratylenchus penetrans*), but the above ground biomass of apple seedlings was reduced with high amendment rates because of phytotoxicity (Mazzola et al., 2001). However, in field experiment, *Rhizoconia solani* was not suppressed by *B. napus,* 'Dwarf Essex' seed meal in two-year amendments. (Mazzola and Mullinix, 2005). The field application of cover crop and green manure application does not always cause the same result as in the laboratory or greenhouse experiments.

Specific cover crops or residue amendments from plants in the *Brassicaceae* suppress soil-borne diseases in container experiments by releasing toxic compounds during decomposition (Mayton et al., 1996; Brown and Morra, 1997). The plant tissues from *Brassica* species contain glucosinolates, and they can break down by several enzymatic processes to produce thiocyanates, isothiocyanates (ITC), nitriles, epinitriles, and glucose (Mayton et al., 1996; Vaughn et al. 1993). Some of these byproducts can be toxic to soil organisms, such as fungi (Mayton et al., 1996; Vaughn et al., 1993).

Oats contain antifungal saponin compounds, avenacin and avenocosides; these can suppress pathogens such as the root-infecting fungus *Gaeumannomyces graminis* var. *tritici*, the causal agent of take-all disease of wheat (Bowyer et al., 1995; Carter et al., 1999; Dixon, R.A., 2001; Osbourn, A.E. 1996; Osbourn et al., 1994; Papadopoulou et al., 1999).

Subbarao et al. (1999) showed that amending broccoli residues into the field suppressed Verticillium wilt of cauliflower. However, broccoli residues did not suppress Verticillium wilt in *in vitro* studies. Further research from Shetty et al. (2000) showed significant reduction of *Verticillium dahliae* microsclerotia in soil, and vascular discoloration of cauliflower was reduced by broccoli amendment. Shetty et al. (2000) also observed unknown fungal hyphae from broccoli-amended cauliflower root that compete at the infection site against the hyphae of *V. dahliae*. Shetty et al. (2000) hypothesized that broccoli residues contain lignin, and a temporal increase in lignin degrading enzymes can also degrade melanin, which is the protective layer for

V. dahliae microsclerotia, as lignin and melanin are chemically similar. Debode et al. (2005) investigated the relationship between *V. dahliae* density in soil and different plant materials with 1 % wt : wt lignin concentrations. According to their study, the population of microsclerotia in soil was significantly reduced in soils amended with broccoli, ryegrass, Indian mustard, and cauliflower residues compared to populations in control soils.

Hartz et al. (2005) evaluated mustard spp. cover crops for the suppression of wilts caused by *Verticillium dahliae* Kleb. and *Fusarium* spp. in processing tomato. Although mustard cover crops produced high dry biomass (approximately 5 to 10 Mg ha^{-1} in various study sites), no disease suppression was observed. Hartz et al. (2005) also evaluated how much ITC was produced from the incorporated mustards. Compared to metam sodium fumigation, ITC content was very low and unlikely to significantly reduce *V. dahliae* Kleb. and *Fusarium* spp. inoculum potential in soil.

Microbial biomass and activity are soil factors that have been shown to be related to general suppression of certain soilborne diseases (Boehm and Hoitink,1992; Chen et al., 1988; Darby et al., 2006; Hoitink and Boehm, 1999). The measure of microbial activity most predictive of general suppresssion is the rate of hydrolysis of fluorescein diacetate (FDA). Suppression of Pythium root rot, causal agent *Pythium ultimum*, of poinsettia can be predicted in dark and light peat-amended container media by measuring FDA activity (Boehm and Hoitink, 1992; Hoitink and Boehm, 1999). Pythium damping-off severity is predictively low when the rate of hydrolysis of FDA is sustained above a level of 3.2 μg min^{-1} g^{-1} dry weight potting mix (Boehm and Hoitink, 1992). Darby et al. (2006) showed similar results in manure-amended field soils. Severity of cucumber damping-off and root rot of sweet corn and bean was significantly reduced when the rate of hydrolysis of FDA was above a level of 2.9 μg min^{-1} g^{-1} dry weight. In Darby's related cover crop study (Darby, 2003), sudangrass (*Sorghum sudanense* cv. Piper) and oat (*Avena sativa* cv. Monida) were most suppressive to corn root rot compared to cereal rye (*Secale cereale* cv. Merced), annual ryegrass (*Lolium multiflorum* cv. Gulf), and the fallow control. Oat was also suppressive to snap bean root rot, and had higher FDA activity than any other

treatment (Darby, 2003). These data indicate that sweet corn root rot suppression may be correlated with FDA activity, and that some cover crop species may be more suppressive than others. However, the cover crop work was conducted in containers, not in the field.

Compared to amendment with composted bark or dairy manure, an increase in FDA activity after cover crop amendment is typically of much lower intensity and duration. This is due to the fact that cover crops are of lower dry matter and higher labile materials than manures or composts. Grünwald et al (2000) amended a soil with an oat-vetch cover crop; the rate of FDA hydrolysis increased by 7 days after amendment of oat-vetch to approximately 4.0 and 3.0 $\mu g\ min^{-1}\ g^{-1}$ dry weight, respectively, but the values then dropped 20 days after incorporation to 2.7 and 2.0 $\mu g\ min^{-1}\ g^{-1}$ dry weight, respectively.

Soilborne disease suppression with cover crop amendments is complex and likely involves multiple mechanisms, including chemical and biological factors. Some possible mechanisms include competitive colonization of roots by other microbes, release of compounds toxic to pathogen propagules, and suppression of propagule germination.

Amendment of cover crops and soil nitrogen mineralization

Use of over-wintering cover crops can reduce nitrate leaching (Kanwar et al., 2005; Nissen and Wander, 2003), and inputs of organic matter can increase nitrogen mineralization (Kuo and Jellum, 2002; Kuo and Sainju, 1998; Ranells and Wagger, 1996). Cover crop type will influence mineralizable nitrogen in soil due to differences in biochemical composition, such as high lignin and other recalcitrant carbon compounds, complexed cellulose structure and high C : N ratios, rendering the residue resistant to decomposition. For example, Ranelles and Wagger (1997) showed that cereal rye had approximately twice the C : N ratio of crimson clover; in addition, cereal rye contained more cellulose and hemicellulose but 50 % less lignin than crimson clover. As the result, mineralizable N contents for cereal rye and crimson

clover were 17 and 35 kg N ha^{-1}, respectively. Because of the high C : N ratio, high hemicellulose content and low lignin content in cereal rye, its residue resides longer in soil than does the residue of crimson clover because of its slower decomposition rate (Wagger et al., 1998).

Creamer and Baldwin (2000) reported high C : N ratios, ranging from 42 to 53, in five grasses, such as sorghum-sudangrass (*Sorghum bicolor* L. Moench x *Sorghum sudanense* L.), sudangrass (*Sorghum sudanense* L.), pearl millet (*Pennisetum glaucum* L.), German foxtail millet (*Setaria italica* L.), and Japanese millet (*Echinochloa frumentacea* Roxb.). Although sorghum-sudangrass produced the highest aboveground biomass during the summer, it also had the highest C : N ratio (53), resulting in immobilization of soil N and requiring additional N inputs to produce fall vegetable crops. However, a biculture of sorghum-sudangrass and cowpea (40 : 60 wt:wt) reduced the C : N ratio to 39. Kuo and Jellum (2002) showed that a biculture of over wintering cereal rye or ryegrass with vetch reduces the C : N ratio and increased mineralizable N compared to cereal rye or ryegrass alone. Therefore, if cover crops have high C : N ratios with higher contents of lignin and hemicellulose, they will immobilize N for a period of time after incorporation.

Malpassi et al. (2000) reported that oats and rye roots were amended into the soils in laboratory experiment, while plant roots were grown and incorporated without above ground biomass in an *in situ* experiment. They found that mineralized soil N content among oats, rye, and control was not significantly different at 14, 28, and 56 days after incubation, but cover crop amendments were significantly higher than control at 7, 84, and 112 days after incubation. Conversely, the control was significantly higher in N mineralization in soil than both cover crop treatments in an *in situ* experiment when samples were taken at 7, 14, 28, 56, and 84 days after incorporation. *In situ* experiment, oats and rye were no difference in mineralized soil N. Although Malpassi et al. did not incorporate above ground biomass into soil for incubation, lower mineralized soil N was observed both oat and rye roots, which may be influenced by nitrogen immobilization. Plant roots generally have higher C : N than leaves or stems, and the chemical composition, such as hemicelluloses, may resist

to biodegradation from various soil microbes. Poor source of nitrogen from roots may lead to nitrogen immobilization and slow release of inorganic N in soil.

In addition to soil nitrogen mineralization from cover crops, Andraski and Bundy (2005) reported the relationships between the management of nitrogen fertilizer with cover crop amendments, which were oat (Avena sativa L.), winter triticale (x *triticosecale*), and winter rye (*Secale cereale* L.) and field corn yield. According to their study, the corn yield from cover crops and ammonium nitrate fertilizer rates from 0 to 280 kg N ha^{-1} was significantly higher than the control during the second and third years in experiment, but there were no significant differences in yield in the first year. There were no differences in yield in the first year because there was a lower C : N ratio in the cover crops in the first than in the second and third years. In the first year, oat, winter triticale, and winter rye had C : N ratios of 15, 21, and 18, respectively. The extractable NO_3-N from first year ranged from 24 to 12 and was correlated with the C : N ratio. The C : N ratio in second and third year was between 22 to 38, and the extractable NO_3-N was between 1 to 10 kg ha^{-1}.

Environmental factors, such as weather and soil temperature, can affect microbial decomposition of cover crop residues; in addition, the chemical composition of cover crops can be impede microbial nitrogen assimilation. For example, Quemada and Cabrera (1997) applied crimson clover residues at four different air temperatures between 10 to 35 ºC and different soil moisture contents. Water potentials between -5.0 to -0.03 MPa with warmer air temperatures between 28 and 35 ºC increased soil inorganic N and net mineralized N.

Sweet corn leaf chlorophyll analysis by SPAD meter

Chlorophyll is a pigment that can efficiently absorb visible light. Chlorophyll selectively absorbs amounts of light in the red (600-700 nm) and blue (400-500 nm) wavelengths (Taiz and Zeiger, 2002). The SPAD-502 (Konica Minolta Inc., Osaka, Japan) can measure red and near infrared transmitted by a leaf and represent that as a relative SPAD value that is proportional to the amount of chlorophyll present in the

leaf. The chlorophyll concentration in corn leaves correlates with plant nitrogen concentration (Waskom et al., 1996; Wood et al., 1992). As nitrogen content declines in a corn leaf, the leaf chlorophyll concentration declines (Blackmar and Schepers, 1995; Blackmar et al., 1993; Varvel et al., 1997).

However, using a SPAD meter under different environmental conditions, such as soil types and soil moisture contents, or measuring SPAD on different crop cultivars, can impact the result. As the result, SPAD readings may not be comparable between two different sampling locations or cultivars (Bullock and Anderson, 1998). Numerous measurements would increase the accuracy of measurement to represent corn leaf N status, but this is labor intensive. Nitrogen deficiency in early season corn (V6-V7) based upon SPAD values poorly correlates with the grain yield, because additional N mineralization from organic matter and nitrate reaching from irrigation may yet occur; however, the leaf nitrogen status from the SPAD readings from later growth stages (R1-R4) of corn significantly correlates with the grain yields (Bullock and Anderson, 1998).

Although correlation between leaf N status and SPAD readings is not perfectly accurate, Varvel et al. (1997) suggest using reference plots to calculate a sufficiency index; the ratio between treatments received low and high N fertilizer (Shapiro and Francis, 2006; Peterson et al., 1993). Based on their study, sufficient N must be available for early season corn growth to promote the maximum grain yield. In other words, sufficient N from starter fertilizer would reduce the potential yield loss. The sufficiency index below 0.90 in early season (V8) corn did not recover the maximum grain yield from additional N application between 60 to 120 kg ha^{-1}. The sufficiency index above 0.91 to 0.95 maintained the higher grain yield with additional N application between 60 to 120 kg ha^{-1}.

CHAPTER 3

RESEARCH STATION EXPERIMENT (2003-2004)

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MATERIALS AND METHODS

Research Station Experiment (2003-2004)

Site description

Field trials were conducted at the Oregon State University Vegetable Research Farm east of Corvallis, Oregon. The soil at the study field is classified as a Chehalis silt clay loam. The general climatic condition in the Willamette Valley is similar to a Mediterranean climate, which is dry and warm in the summer and cool and moist in the winter. The annual precipitation is 111 cm, and average temperature in July is 18.9 °C and average temperature in January is 3.3 °C. The study field has been in continuous corn for several years and is known to have high root rot potential for sweet corn production. The cropping history for this site was buckwheat in 2003. Sweet corn (*Zea mays* L.) 'Sweet Jubilee' was planted in 2002, 2001, 2000, 1999, and 1998.

Experimental design

The experimental field was 89.9 m by 22.9 m and divided into two sections (late summer and winter cover crop experiments). The late summer experiment was approximately 54.9 m by 23.0 m, which was divided into three blocks of 18.3 m by 18.3 m. Each block contained 9 treatments listed in Table 3.1. All treatments were assigned in a randomized complete block design with 3 replications.

The winter cover crop experiment section was 18.3 m by 18.3 m in size. It was divided into three blocks of 18.3 m by 6.1 m, each containing 4 plots of approximately 6.1 m by 4.6 m (Fig. 3.1). Treatments are listed in Table 3.1. All treatments were assigned in a randomized complete block design with 3 replications (Fig. 3.1).

Table 3.1. List of cover crop treatments, sources, and seeding rates.

Abbreviation	Description	Source	Seeding rate
	-----Summer-----		----- kg ha^{-1} -----
Mb	Mustard 'Braco': *Sinapis alba*	Bailey Seed Inc., Salem, OR	16.8
Mc	Mustard mix 'Caliente': *Brassica juncea* and *Sinapis alba* mixture	High Performance Seeds Inc., Moses Lake, WA	16.8
R	Rape 'Dwarf Essex': *B. napus*	Bailey Seed Inc., Salem, OR	16.8
SS	Sorghum-sudangrass hybrid 'Cadan 99B': *Sorghum bicolor*	Kenagy Family Farm	44.8
O	Oat 'Saia': *Avena sativa*	Bailey Seed Inc., Salem, OR	123.2
Mc-SS	Mustard 'Caliente' and sorghum-sudangrass 'Cadan 99B' mix (50:50 w/w)	Same location as above mentioned	8.4 / 8.4
Mc-O	Mustard 'Caliente' and oat 'Saia' mix (14: 86 w/w)	Same location as above mentioned	8.4 / 61.6
SS-O	Sorghum-sudangrass 'Cadan 99B' and oat 'Saia' mix (14: 86 w/w)	Same location as above mentioned	8.4 / 61.6
F	Fallow	--------	-----
	-----Winter-----		
Mc	[§]Mustard mix 'Caliente': *Brassica juncea* and *Sinapis alba* mixture	Same location as above mentioned	16.8
Mb	Mustard 'Braco': *Sinapis alba*	Same location as above mentioned	16.8
O	Oat 'Saia': *Avena sativa*	Same location as above mentioned	123.2
F	Fallow	--------	-----

[§]Mustard mix ‘Caliente’ was winter-killed.

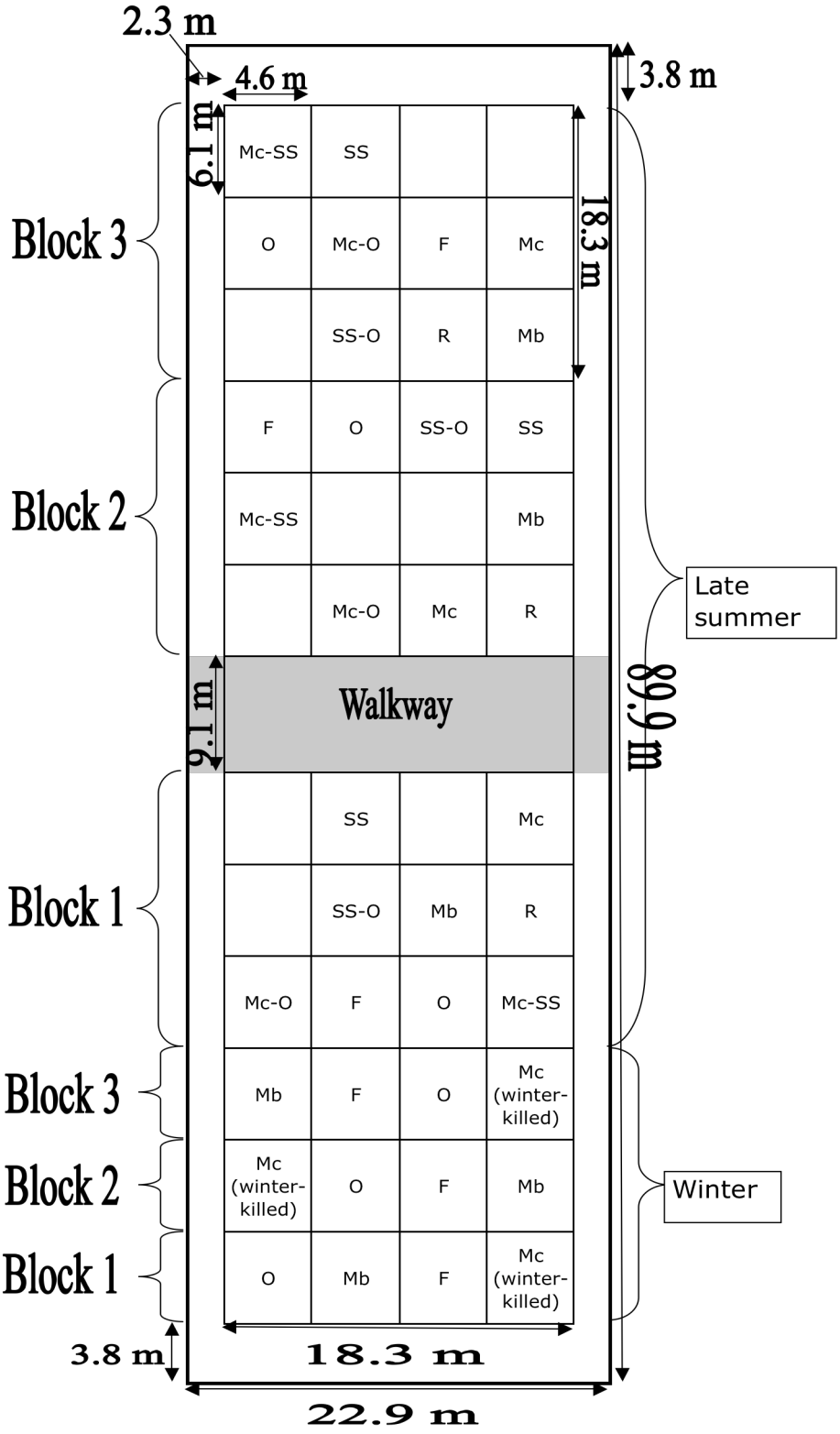

Fig. 3.1. Schematic of the experimental design for the field trial.

Source of seeds

The seeds for mustard 'Braco', rape 'Dwarf Essex', and oat 'Saia' came from the seed company Bailey Seed Inc., in Salem, OR, in summer 2003. Mustard 'Caliente', a mixture of two mustard species, was obtained from High Performance Seeds Inc. in Moses Lake, WA. Sorghum-sudangrass hybrid 'Cadan 99B' was obtained from the vegetable grower, Peter Kenagy, from Albany, OR.

Treatments

Summer cover crop experiment:

Treatments are listed in Table 3.1. All cover crop seeds were directly seeded in the prepared seeding bed on August 12, 2003. Seeds were incorporated with a walk –behind rototiller to approximately 5 cm depth. The field was irrigated immediately after sowing. On October 21, 2003, aboveground dry matter was measured. Two randomly selected quadrats (50.8 cm by 50.8 cm) were sampled in each plot. An approximately 600 g subsample was taken and dried at 38 °C for 48 hr to determine moisture content. On October 25 and 26, 2003, all cover crops were flail-chopped with a walk-behind flail chopper. The chopped crop residues were manually spread across the plot and immediately incorporated into the soil with a rotovator to a depth of 12 cm.

Winter cover crop experiment:

Treatments are listed in Table 3.1. Cover crops were seeded by hand on September 18, 2003, and incorporated with a walk-behind rototiller to approximately 5 cm depth and irrigated. The mustard mix was winter-killed so no data was taken on this treatment. On April 25, 2004, aboveground dry matter was measured from two randomly selected quadrats (50.8 cm by 50.8 cm) per plot. A subsample (approximately 600 g fresh residues) was taken and dried at 38 °C for 48 hr. On the same day, all cover crops were flail-chopped, manually spread across the plots with rakes, and immediately incorporated into the soil with a rotovator to a depth of 12 cm.

Sweet corn crop management:

Sweet corn 'Reward' (Rogers Seeds: Syngenta Seed Inc., Boise, ID) was planted on May 23, 2004. Starter fertilizer was applied at the rate of 60, 146, and 50 kg ha^{-1} of N, P_2O_5, and K_2O, respectively. Approximately 8 seeds m^{-1} were planted and the stand was thinned to 6 plants m^{-1} when seedlings emerged after two weeks. When sweet corn 'Reward' reached the 6-leaf stage, approximately 46 days after planting, urea (113 kg ha^{-1} of N) was side-dressed manually. On July 6, 2004, aboveground dry matter was measured. Ten corn plants per plot were randomly sampled from one row (4.6 m) in between 6.1 m row, and dried at 38 °C for 48 hr.

Soil sampling

Greenhouse cone-tube bioassay:

For the baseline cone-tube bioassay, three adjacent plots (6.1 m by 4.6 m each) were sampled as a unit (18.3 m by 4.6 m). Eight soil wedges were taken from each 18.3 m by 4.6 m area and composited. For cone-tube bioassays conducted on treatment samples, eight soil wedges were taken from each plot (6.1 m by 4.6 m) at approximately three and seven months after incorporation of summer cover crops (January 19 and May 22, 2004) and at approximately four weeks after incorporation of winter cover crops (May 22, 2004). Each soil wedge (approximately 13 cm x 5 cm x 15 cm) was sampled with an AMS Soil Sampling Sharpshooter Shovel (AMS Inc., American Falls, ID). The wedges were composited, air-dried, passed through a 2.54 cm screen, and mixed thoroughly.

Microbial activity:

At 31 days after planting sweet corn, soil was sampled for fluorescein diacetate (FDA) analysis. Ten soil cores (approximately 15 cm x 2.5 cm) were sampled from each plot. Each soil core was sieved first through an 8 mm sieve and then through a 2 mm sieve, mixed thoroughly, and stored in a Ziploc bag at 4 ºC.

Greenhouse root rot bioassay

Cone-tube bioassays were conducted in a greenhouse maintained at approximately 24 ºC day and 18 ºC night with continuous 16 hour photoperiod during the winter and natural sunlight during the summer. Soil samples passed through a 2.54 cm screen were potted into 8 - 550 mL cone-shaped tubes (Stuewe & Sons Inc., Corvallis, OR) per plot. Since the field soil physical properties are very different than potting mix, the cone-tubes were gently tapped to settle the soil.

Sweet corn seeds, (*Zea mays* L.) cv Golden Jubilee, treated with Captan, were treated with 10 % sodium hypochlorite solution for 5 minutes and rinsed thoroughly with diH_2O before planting into the cone tubes. Two sweet corn seeds were planted in each cone tube at a depth of 2.5 cm.

When the seedlings emerged, they were thinned to one corn plant per container. Cone tubes were irrigated daily to maintain soil moisture near field capacity, and were fertilized every week with liquid fertilizer (0.058 g N, 0.038 g P, and 0.049 g K cone tube $^{-1}$ week^{-1}; Schultz Co., St. Louis, MO).

When the corn plants reached the six-leaf stage, plants were harvested. Roots were washed and evaluated by visual assessment for percent necrosis of radicle and nodal roots. Severity of necrosis was assessed on eight-point scale: 0 = healthy, 1 = 1 to 10 % necrotic, 2 = 11 to 20 % necrotic, 3 = 21 to 40 % necrotic, 4 = 41 to 60 % necrotic, 5 = 61 to 80 % necrotic, 6 = 81 to 90 % necrotic, 7 = 91 to 99 % necrotic, and 8 = 100 % necrotic root. For the baseline trial, disease severity rating was based on a 0 to 4 scale (0 = healthy, 1 = 10 % necrotic, 2 = 11 to 50 % necrotic, 3 = 51 to 99 % necrotic, and 4 = 100 % necrosis). Above- and below-ground dry matter was dried at 37.7 °C for 48 hr and weighed.

In-field bioassays

Ten corn plants per plot were randomly sampled from the row adjacent to the two center rows (4.5 m per row) for evaluating root rot severity and aboveground dry matter at the 6-leaf stage (approximately 46 days after planting). At harvest, 86 days after planting, ten plants per plot were randomly sampled from two 4.6 m center rows. The sampled roots were washed, and percent necrosis of radicle and nodal roots was

evaluated by visual assessment using the scale described previously for the greenhouse cone-tube bioassay. Aboveground dry matter was dried at 37.7 ºC for 48 hr and weighed.

Sweet corn yield

Corn ears from two center rows per plot (approximately 4.5 m per row) were harvested by hand at maturity to assess corn yield. Marketable yield of corn was determined by weighing the corn ears without husks. All ears of less than approximately 15 cm of edible corn kernels were discarded.

Measurement of soil microbial activity

The rate of hydrolysis of fluorescein diacetate (FDA) was measured 48 h after each soil sampling by modifying the procedure used by Zelles et al. (1991). One gram of field-moist soil from stored subsamples sieved through a 2 mm sieve was placed in a 125 ml Erlenmeyer flask with four replications. Twenty mL of buffer (60 mM sodium phosphate at pH 7.6) was added to each flask. After 15 minutes shaking at 178 rev min^{-1}, 100 μL of 4.8 mM fluorescein diacetate solution (3', 6' diacetylfluorescein) was added to three of the four flasks. The remaining flask (control) received 100 μL of fluorescein diacetate solution only after the addition of acetone. Flasks were shaken at 178 rev min^{-1} for 2 h at 25 °C on an Innova 2003 platform shaker (New Brunswick Scientific Co., Inc., Edison, NJ). At the end of 2 hours, 20 mL acetone was added to each flask to stop the hydrolysis reaction, and the samples were centrifuged for 5 min at 4960 times *g* (Model J2-HS, Beckman Coulter, Inc., Fullerton, CA) to separate the soil from the liquid. The separated samples were filtered (Whatman No 4), and the absorbance of the filtrate was measured at 490 nm with a spectrophotometer (Model DU 800, Beckman Coulter, Inc., Fullerton, CA). FDA activity was expressed as μg FDA hydrolyzed hr^{-1} g^{-1} dry wt soil and was compared to a standard curve. Background absorbance of the sample solutions was corrected by subtraction of the control absorbance.

Statistical analysis

Statistical analysis was performed with SAS (SAS system for Windows 9, SAS Inst., 1999). Treatment effects on disease severity, dry matter, microbial activity, and yield for each sampling date was computed using analysis of variance (ANOVA) from the PROC GLM procedure. Treatment means were separated when F-test was significant ($P \leq 0.05$). Mean separation was performed by the LSD procedure using MEANS statement if sampling data was balanced. Treatment means were separated by the student's *t* test using LSMEANS statement when the sampling data was unbalanced. Linear regression analysis using PROC REG was computed in SAS to describe the relationship between root rot severity and microbial activity.

RESULTS

Cover crop dry matter

In the summer cover crop experiment, there was a significant difference amongst cover crop dry matter contents ($P \leq 0.05$). The SS treatment generated the highest dry matter at approximately 6.9 Mg ha^{-1}, which was approximately 28 % and 39 % higher than R and O, respectively (Table 3.2). However, the biomass of SS-O was 23 % lower than SS alone (Table 3.2). There were no significant differences between SS and Mc-SS, Mb, Mc-O, Mc, or SS-O (Table 3.2).

In the winter cover crop experiment, mustard mix 'Caliente' was winter-killed. There was no significant difference between dry matter contents of Mb and O ($P = 0.13$), which produced approximately 12.2 and 10.5 Mg ha^{-1} dry matter, respectively, (Table3.2).

Table 3.2. Cover crop dry matter: summer and winter cover crop experiments.

Treatment	Mean dry matter
---------- Summer ----------	----- Mg ha^{-1} -----
SS	6.9 (0.99) A[†]
Mc-SS	6.6 (0.37) AB
Mb	6.4 (0.12) AB
Mc-O	6.3 (0.43) AB
Mc	6.0 (0.60) AB
SS-O	5.3 (0.21) ABC
O	5.0 (0.62) BC
R	4.2 (0.29) C
---------- Winter ----------	
O	12.2 (0.55) A[†]
Mb	10.5 (0.56) A
Mc	NA[§] (winter-killed)

[†]Means followed by the same letter are not significantly different based on least significance test (P = 0.05). Number between parentheses indicates standard error. [§]No data on Mc due to winter-killed.

Greenhouse bioassay

Baseline disease severity:

Root rot severity was high and there was little variability in the field as determined by the baseline cone-tube bioassay. Mean radicle and nodal root rot severity were 78 and 22 %, respectively, with no significant differences among sampled plots (data not shown).

Disease severity (summer cover crop experiment):

At three months after cover crop incorporation (January), radicle rot severity was significantly different amongst treatments ($P \leq 0.001$). The fallow treatment had the highest radicle rot severity (approximately 98 %). The SS, Mc-O, O, SS-O, and

Mc-SS treatments generated 7.9, 10.2, 11.8, 13.5, and 15.4 %, respectively, lower severity ratings (Table 3.3). Nodal root rot severity was 38.3, 41.4, and 47.6 % lower, respectively, in the O, Mc-O, and Mc-SS treatments than in the F treatments ($P \leq 0.001$) (Table 3.3).

At seven months after incorporation, radicle rot severity in Mc, SS-O, O, and Mc-SS treatments were approximately 9 to 15 % lower than in the F treatment (Table 3.5). The Mb treatment had 46 % higher nodal root rot severity than the fallow treatment and was significantly higher than all other treatments ($P \leq 0.001$). The Mc treatment nodal root rot severity was suggestively lower than the fallow treatment ($P = 0.07$) (Table 3.4).

Table 3.3. Disease severity: summer cover crop experiment. Greenhouse cone-tube bioassay at 3 months after incorporation.

Treatment	Mean radicle necrosis	Mean nodal root necrosis
	---------- % ----------	
F	97.7 (3.32)	22.7 (0.09)
R	96.5 (2.60)	23.1 (0.03)
Mc	93.2 (2.27)	18.1 (0.06)
Mb	90.4 (2.91) *	21.7 (0.08)
SS	90.0 (1.84) **	19.4 (0.14)
Mc-O	87.7 (2.03) ***	13.3 (0.02) ***
O	86.2 (1.95) ***	14.0 (0.06) ***
SS-O	84.5 (1.84) ****	19.4 (0.13)
Mc-SS	82.7 (1.72) ****	11.9 (0.04) ***

Number between parentheses indicates standard error. *$p \leq 0.10$, **$p \leq 0.05$, ***$p \leq 0.01$, ****$p \leq 0.001$ from pairwise comparison against fallow using LSD test.

Table 3.4. Disease severity: summer cover crop experiment. Greenhouse cone-tube bioassay at 7 months after incorporation.

Treatment	Mean radicle necrosis	Mean nodal root necrosis
	---------- % ----------	
Mb	98.1 (0.73)	35.4 (3.69) ****
F	94.0 (1.73)	19.2 (3.50)
R	91.6 (1.49)	21.7 (2.08)
SS	89.6 (2.09)	21.3 (2.86)
Mc-O	88.6 (1.86) *	18.8 (0.36)
Mc-SS	85.2 (3.49) ***	24.8 (5.51) **
O	84.6 (2.67) ***	15.2 (2.18)
SS-O	82.5 (3.54) ****	17.5 (2.95)
Mc	79.8 (3.53) ****	14.0 (1.16) *

Number between parentheses indicates standard error. *$p \leq 0.10$, ***$p \leq 0.01$, ****$p \leq 0.001$ from pairwise comparison against fallow using LSD test.

Disease severity (winter cover crop experiment):

At five weeks after incorporation, there was a significant difference between the F and O treatments in both radicle and nodal root rot severity of ($P \leq 0.001$ and $P \leq 0.05$, respectively); the O treatment generated 26.1 and 54.5 % lower radical and nodal root rot severity, respectively, than the F treatment (Table 3.5).

Table 3.5. Disease severity: winter cover crop experiment. Greenhouse cone-tube bioassay at 1 month after incorporation.

Treatment	Mean radicle necrosis	Mean nodal root necrosis
	---------- % ----------	
Mb	80.7 (8.77)	23.3 (8.80)
F	78.3 (9.00)	17.9 (2.40)
O	59.6 (7.65)****	10.6 (3.13)**

Number between parentheses indicates standard error. **$p \leq 0.05$, ****$p \leq 0.001$ from pairwise comparison against fallow using LSD test.

Crop dry matter (summer cover crop experiment):

Mean aboveground dry matter at approximately 3 months after incorporation was significantly different amongst treatments ($P \leq 0.001$). The fallow treatment had the lowest aboveground dry matter; all other treatments generated from 15 (SS-O treatment) to 29 (Mc treatment) % higher dry matter (Table 3.6). There were suggestive differences between mean belowground dry matter of the fallow and the treatments Mc-O and R ($P = 0.11$), which were approximately 23 and 29 %, respectively, higher dry matter than the fallow (Table 3.6). There were no significant differences amongst treatments in above- and below-ground dry matter at 7 months after incorporation ($P \geq 0.20$) (Table 3.7).

Table 3.6. Above- and below-ground dry matter: summer cover crop experiment. Greenhouse cone-tube bioassay at 3 months after incorporation.

Treatment	Mean aboveground dry matter	Mean belowground dry matter
	---------- g plant^{-1} ----------	
Mc	5.63 (0.03) ****	1.20 (0.05) *
R	5.59 (0.03) ****	1.30 (0.03) **
Mc-O	5.55 (0.18) ****	1.24 (0.02) **
O	5.35 (0.20) ****	1.09 (0.06) *
Mc-SS	5.29 (0.13) ****	1.17 (0.04)
Mb	5.13 (0.24) ***	1.16 (0.08)
SS	5.04 (0.50) **	1.17 (0.14)
SS-O	5.02 (0.43) **	1.19 (0.13)
F	4.36 (0.54)	1.01 (0.09)

Number between parentheses indicates standard error. *$p \leq 0.10$, **$p \leq 0.05$, ***$p \leq 0.01$, ****$p \leq 0.001$ from pairwise comparison against fallow using LSD test.

Table 3.7. Above- and below-ground dry matter: summer cover crop experiment. Greenhouse cone-tube bioassay at 7 months after incorporation.

Treatment	Mean aboveground dry matter	Mean belowground dry matter
	---------- g plant^{-1} ----------	
SS-O	5.88 (0.03)	1.44(0.02)
Mc-SS	5.75 (0.36)	1.27(0.08)
R	5.74 (0.23)	1.31(0.01)
SS	5.71 (0.26)	1.44(0.11)
Mb	5.65 (0.18)	1.33(0.03)
Mc	5.59 (0.25)	1.27(0.06)
F	5.52 (0.45)	1.31(0.09)
O	5.51 (0.25)	1.05(0.13)
Mc-O	5.13 (0.60)	1.13(0.13)
	NS‡	NS

Number between parentheses indicates standard error. ‡NS indicates there are no significant differences between treatments based on LSD test ($P = 0.05$).

Crop dry matter (winter cover crop experiment):

There were no significant treatment effects on corn above- ($P = 0.73$) and below-ground dry matter ($P = 0.75$) at approximately 5 weeks after incorporation (Table 3.8). The O treatment consistently generated the lowest root rot severity (Table 3.5) and highest corn biomass of the three treatments.

Table 3.8. Above- and below-ground dry matter: winter cover crop experiment. Greenhouse cone-tube bioassay at 1 month after incorporation.

Treatment	Mean aboveground dry matter	Mean belowground dry matter
	---------- g plant^{-1} ----------	
O	4.0 (0.40)	0.81 (0.08)
F	3.7 (0.37)	0.71 (0.11)
Mb	3.6 (0.42)	0.74 (0.09)
	NS‡	NS

Number between parentheses indicates standard error. ‡NS indicates no significant differences between treatments ($P = 0.05$) according to LSD test.

Field-grown corn

Disease severity (summer cover crop experiment):

At 46 days after planting, radicle rot severity among treatments was significantly different ($P \leq 0.001$). The Mc, R, and Mb treatments generated slightly higher radicle rot severity than the F treatment. Radicle rot severity was significantly lower than the F treatment in the O, SS-O, Mc-O, and SS treatments (Table 3.9). Nodal root rot severity was significantly lower in the R than in the F treatment ($P \leq 0.001$) (Table 3.9).

Table 3.9. Disease severity: summer cover crop experiment. Field grown corn bioassay at 46 days after planting.

Treatment	Mean radicle necrosis	Mean nodal root necrosis
	---------- % ----------	
Mc	94.5 (0.29)	19.8 (4.60)
R	93.8 (2.03)	11.5 (0.76) ****
Mb	93.7 (3.83)	20.5 (3.91)
F	92.2 (1.67)	18.3 (2.13)
Mc-SS	88.7 (1.92)	18.8 (4.64)
SS	86.0 (4.70) **	15.5 (2.29)
Mc-O	85.9 (3.46) **	16.2 (2.83)
O	82.3 (4.44) ****	16.0 (2.50)
SS-O	81.1 (2.90) ****	17.2 (0.44)

Number between parentheses indicates standard error. $^{**}p \leq 0.05$, $^{****}p \leq 0.001$ from pairwise comparison against fallow using LSD test.

At maturity, 86 days after planting, radicle necrosis was not significantly different amongst treatments ($P = 0.70$) (Table 3.10). However, there were significant differences among treatments for nodal root necrosis ($P \leq 0.001$). The Mc-O, Mc-SS, SS, Mc, and Mb treatments generated significantly lower nodal root necrosis than the

F treatment ($P \leq 0.05$) (Table 3.10). The O treatment and the F treatment were suggestively lower ($P = 0.07$) (Table 3.10).

Table 3.10. Disease severity: summer cover crop experiment. Field grown corn bioassay at 86 days after planting.

Treatment	Mean radicle necrosis	Mean nodal root necrosis
		---------- % ----------
F	97.3 (0.86)	61.3 (1.84)
R	94.7 (2.43)	60.4 (2.17)
SS-O	94.7 (1.31)	60.0 (2.30)
O	96.7 (1.13)	56.0 (2.38)*
Mc-O	97.2 (0.75)	55.2 (2.80)**
Mc-SS	94.0 (3.18)	53.3 (2.16)***
SS	97.3 (0.86)	49.3 (2.25)****
Mc	96.7 (0.84)	46.7 (2.73)****
Mb	96.8 (1.20)	43.0 (2.67)****
	NS‡	

Number between parentheses indicates standard error. *$p \leq 0.10$, **$p \leq 0.05$, ***$p \leq 0.01$, ****$p \leq 0.001$ from pairwise comparison against fallow using LSD test. ‡NS indicates no significant differences between treatments ($P = 0.05$) according to LSD test.

Disease severity (winter cover crop experiment):

In the winter cover crop experiment at 46 days after planting, the O treatment generated higher radicle rot severity than the F treatment ($P \leq 0.05$) (Table 3.11). In contrast, the O treatment generated approximately half the nodal root rot severity of the F and Mb treatments ($P \leq 0.001$) (Table 3.11).

Table 3.11. Disease severity: winter cover crop experiment. Field grown corn bioassay at 46 days after planting.

Treatment	Mean radicle necrosis	Mean nodal root necrosis
	---------- % ----------	
O	96.2 (0.73)**	11.0 (1.30)****
Mb	91.5 (1.29)	22.5 (2.17)
F	90.8 (1.88)	20.2 (1.85)

Number between parentheses indicates standard error. $^{**}p \leq 0.05$, $^{****}p \leq 0.001$ from pairwise comparison against fallow using LSD test.

At maturity, 86 days after planting, radicle rot severity was not significantly different among treatments ($P = 0.12$) (Table 3.12). However, nodal root severity in the O treatment was approximately 14 and 6 % lower than in the Mb and F treatments, respectively ($P \leq 0.05$) (Table 3.12).

Table 3.12. Disease severity: winter cover crop experiment. Field grown corn bioassay at 86 days after planting.

Treatment	Mean radicle necrosis	Mean nodal root necrosis
	---------- % ----------	
Mb	95.7 (1.19)	53.7 (3.04)**
F	97.8 (0.65)	46.3 (3.76)
O	98.4 (0.60)	39.9 (4.06)**
	NS‡	

Number between parentheses indicates standard error. $^{**}p \leq 0.05$ from pairwise comparison against fallow using LSD test. ‡NS indicates no significant differences between treatments ($P = 0.05$) according to LSD test.

Crop dry matter (summer cover crop experiment):

At 46 days after planting, the O, F, and Mc treatments generated higher corn aboveground dry matter than all other treatments ($P \leq 0.001$). There were significant differences between aboveground dry matter of the fallow and the Mc-O, Mb, R, and

SS treatments ($P \leq 0.05$) (Table 3.13). The aboveground dry matter of the Mc-O, Mb, R, and SS treatments generated 15.2, 23.3, 28.3, and 30.2 %, respectively, lower than the F treatment (Table 3.13).

Table 3.13. Aboveground dry matter: summer cover crop experiment. Field grown sweet corn at 46 days after planting.

Treatment	Mean aboveground dry matter	*P*-value compared to fallow
	---------- g plant^{-1} ----------	
O	54.2 (4.92)	
F	54.0 (0.85)	---
Mc	52.7 (3.44)	
Mc-SS	48.3 (1.53)	
SS-O	46.3 (4.17)	**
Mc-O	45.8 (2.58)	***
Mb	41.4 (5.70)	****
R	38.7 (2.03)	****
SS	37.7 (2.21)	****

Number between parentheses indicates standard error. $^{**}p \leq 0.05$, $^{***}p \leq 0.01$, $^{****}p \leq 0.001$ from pairwise comparison against fallow using LSD test.

Crop dry matter (winter cover crop experiment):

At 46 days after planting, there were significant differences in aboveground biomass between the F treatment and the O ($P \leq 0.001$) and Mb ($P \leq 0.01$) treatments (Table 3.14). The Mb treatment generated approximately 12 % more dry matter than the F treatment, and the O treatment generated approximately 17 % less dry matter than the F treatment.

Table 3.14. Aboveground dry matter: winter cover crop experiment. Field grown sweet corn at 46 days after planting.

Treatment	Mean aboveground dry matter	*P*-value compared to fallow
	----- g plant^{-1} -----	
Mb	39.4 (1.54)	***
F	35.2 (2.92)	---
O	29.1 (3.12)	****

Number between parentheses indicates standard error. ***$p \leq 0.01$, ****$p \leq 0.001$ from pairwise comparison against fallow using LSD test.

Sweet corn yield

Summer cover crop experiment:

There was no treatment effect on yield in either the summer or winter cover crop experiments. In the summer cover crop experiment, the Mc-O, SS and Mc treatment yields were numerically 14, 18 and 22 % higher than the F treatment yield (Table 3.15).

Winter cover crop experiment:

In the winter cover crop experiment, the Mb and O treatments had numerically 9 and 22% lower yield, respectively, than the F treatment (Table 3.16).

Table 3.15. Sweet corn yield (Mg ha^{-1}): summer cover crop experiment.

Treatment	Mean sweet corn yield	Yield compared to fallow
	----- Mg ha^{-1} ------	----- % -----
Mc	23.0 (0.67)	22
SS-O	22.1 (1.66)	18
Mc-O	21.4 (0.88)	14
R	20.4 (0.74)	9
Mc-SS	19.2 (1.01)	2
F	18.8 (0.41)	---
Mb	18.6 (1.95)	-1
O	18.6 (1.98)	-1
SS	18.5 (0.49)	-2
	NS‡	

Number between parentheses indicates standard error. ‡NS indicates no significant differences between treatments (P = 0.05) according to LSD test.

Table 3.16. Sweet corn yield (Mg ha^{-1}): winter cover crop experiment.

Treatment	Mean sweet corn yield	Yield compared to fallow
	----- Mg ha^{-1} ------	----- % -----
F	23.2 (1.76)	---
Mb	21.1 (2.70)	-9
O	18.1 (1.61)	-22
	NS‡	

Number between parentheses indicates standard error. †NS indicates no significant differences between treatments (P = 0.05) according to LSD test.

Correlation between cover crop aboveground dry matter and radicle rot severity

In summer experiment, there was correlation between cover crop aboveground dry matter and radicle rot severity from greenhouse experiment at approximately 3 month after incorporation ($R^2 = 0.17$, -b = 2.66, P = 0.047) (Fig. 3.2). However, there was no correlation between cover crop aboveground dry matter and radicle rot severity in any other sampling dates.

In winter experiment, there was no correlation between cover crop aboveground dry matter and radicle rot severity at any sampling dates from greenhouse and in-field experiments.

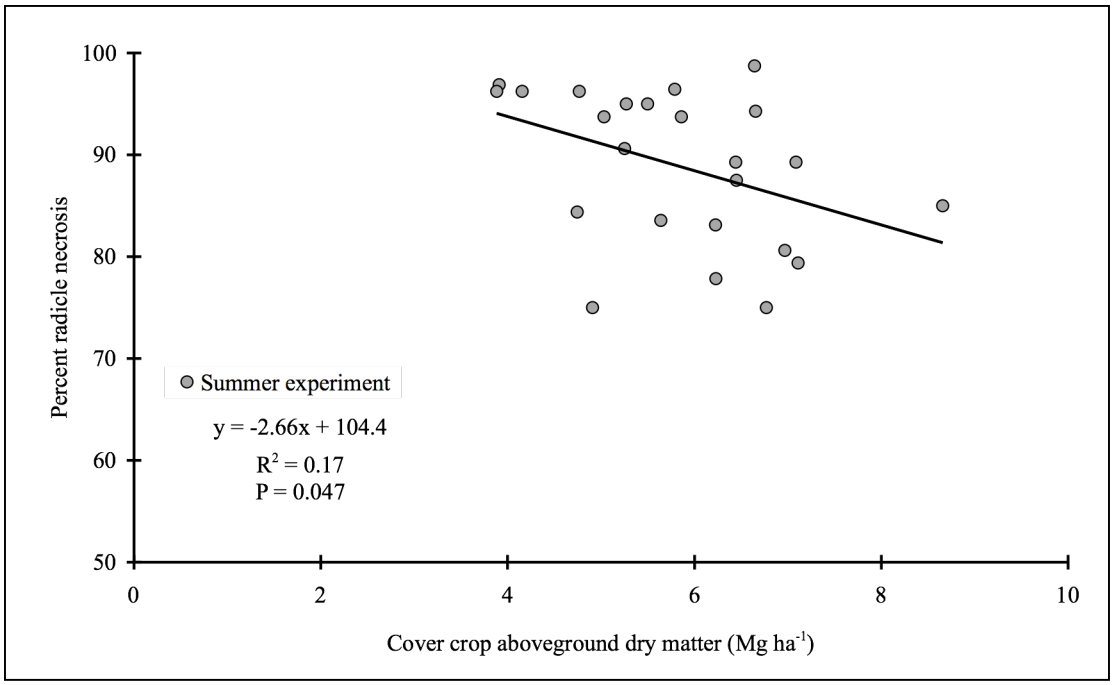

Fig. 3.2. Correlation between cover crop aboveground dry matter and radicle rot severity in greenhouse grown corn.

Soil microbial activity

Summer cover crop experiment:

In the summer cover crop experiment, the SS-O treatment generated 21.5 % higher microbial activity (approximately 33.9 µg FDA hydrolyzed hr^{-1} g^{-1} dry soil wt),

than the F treatment. However, the Mc-O, Mc-SS, and Mc treatments were not significantly different than the F treatment ($P \geq 0.05$) (Table 3.17).

Winter cover crop experiment:

In the winter cover crop experiment, the O treatment generated 61.6% higher microbial activity than the F treatment ($P \leq 0.001$); the Mb treatment was only slightly higher than the F treatment ($P \leq 0.01$) (Table 3.18).

Correlation between soil microbial activity and radicle necrosis

Summer and winter cover crop experiments:

The rate of hydrolysis of FDA and percent radicle necrosis at the 6-leaf stage in field grown corn were not correlated in the summer cover crop experiment (R^2 =0.02, b = 0.18, P = 0.51) (Fig. 3.3). However, the rate of hydrolysis of FDA and percent radicle necrosis at the 6-leaf stage were correlated in the winter cover crop experiment (R^2 =0.51, b = 0.42, P = 0.03). As microbial activity increased, percent radicle necrosis increased (Fig. 3.3).

Table 3.17. Microbial activity: summer cover crop experiment. Soil sampled at 8 months after incorporation.

Treatment	Microbial activity	*P*-value compared to fallow
	--- µg hydrolyzed FDA hr^{-1} g^{-1} dry wt ---	
SS-O	33.9 (2.05)	****
R	33.3 (1.23)	***
SS	32.9 (2.78)	***
O	32.1 (2.34)	**
Mb	32.0 (3.75)	**
Mc	28.5 (4.06)	**
Mc-SS	28.3 (2.18)	
F	27.9 (2.88)	---
Mc-O	26.0 (3.46)	

Number between parentheses indicates standard error. ** $p \leq 0.05$, ***$p \leq 0.01$, ****$p \leq 0.001$ from pairwise comparison against fallow using LSD test.

Table 3.18. Microbial activity: winter cover crop experiment. Soil sampled at 2 months after incorporation.

Treatment	Microbial activity	*P*-value compared to fallow
	--- μg hydrolyzed FDA hr^{-1} g^{-1} dry wt ---	
O	31.2 (1.19)	****
Mb	23.1 (2.12)	***
F	19.3 (0.58)	---

Number between parentheses indicates standard error. ***$p \leq 0.01$, **** $p \leq 0.001$ from pairwise comparison against fallow using LSD test.

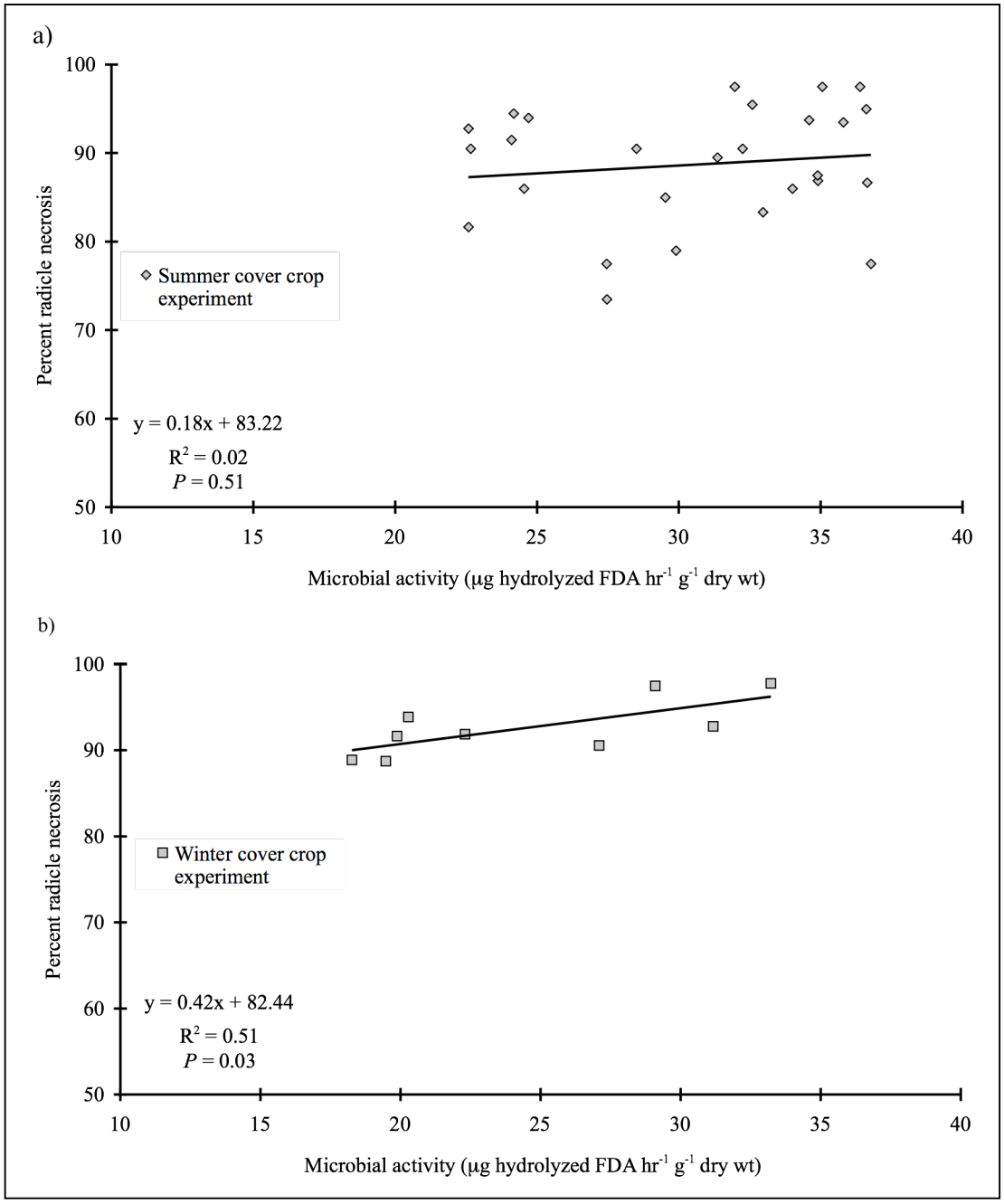

Fig. 3.3. Correlation between microbial activity and radicle rot severity in field grown corn. a) summer and b) winter cover crop experiments.

Summary: 2004 research station summer and winter cover crop experiments

Cover crop dry matter and winter hardiness

August 12-seeded (October 25-flailed) summer cover crop aboveground dry matter (DM) ranged from 4.2 (R) to 6.9 (SS) Mg ha^{-1}. The treatment O generated 5.0, R generated 4.2, Mc generated 6.0, and Mb generated 6.4 Mg ha^{-1}. The September 18-seeded Mc winter-killed, so no DM data was collected. September 18-seeded and April 25-flailed O and Mb generated 12.2 and 10.5 Mg ha^{-1}, respectively.

Effect of cover crop treatments on root rot severity

All cover crop treatments suppressed either radicle or nodal root rot on at least one sampling date in either greenhouse bioassays or in corn grown in the field. Mixtures were highly variable so will not be discussed further in this summary. Overall, the oat treatment was most suppressive and rape was least (not) suppressive to root rot in 2004. Listed in order of decreasing suppressiveness, the treatments were oat ‘Saia’, mustard mix ‘Caliente’, sorghum-sudangrass hybrid 'Cadan 99B', mustard ‘Braco’, and rape ‘Dwarf Essex’.

Corn productivity

No treatments significantly impacted yield in either the summer or the winter experiment. All summer cover crop treatments significantly increased aboveground dry matter (DM) and most increased belowground DM at 3 months after incorporation in greenhouse bioassays. Effects of cover crops on DM of field grown corn was highly variable. In the winter experiment, the oat treatment decreased aboveground DM at 46 days and numerically reduced yield by 22% in field grown corn.

Microbial activity

All summer cover crop treatments except Mc-O and Mc-SS increased FDA activity relative to the fallow at 8 months after incorporation. Both winter cover crop

treatments (Mb and O) increased FDA activity relative to the fallow at 2 months after incorporation.

Relationship between microbial activity and root rot severity

There was a significant positive correlation between microbial activity and root rot severity at 2 months, but there was no correlation at 8 months after incorporation.

CHAPTER 4

RESEARCH STATION AND ON-FARM EXPERIMENTS (2004-2005)

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MATERIALS AND METHODS

Research Station Experiment (2005)

Site description

Field trials were conducted at the Oregon State University Vegetable Research Farm east of Corvallis, Oregon. The soil at the study field is classified as a Chehalis silt clay loam. The general climatic condition in the Willamette Valley is similar to a Mediterranean climate, which is dry and warm in the summer and cool and moist in the winter. The annual precipitation is 111 cm. Average temperature in July is 18.9 °C and average temperature in January is 3.3 °C.

Cropping history

The cropping history for the study field was fallow in 2004, sweet corn (*Zea mays* L.) in 2003 and 2000, squash (*Cucumis pepo* L.) and cucumber (*Cucumis sativus* L.) in 2001, and a cover crop trial during the winter of 2002-03 (oat 'Saia', triticale 'Trios 102', common vetch, woolypod vetch, chickling vetch, Persian clover 'Lightning', phacelia, crimson clover, berseem clover, rape 'Dwarf Essex', canola, mustard mix 'Caliente', white mustard 'Braco', and mustard 'NemFix')

Experimental design

The field was approximately 73.2 m by 29.9 m, which was divided in half into summer and winter cover crop experiments. Both the summer and winter cover crop fields were 48.8 m by 36.5 m; each plot was 12.2 m by 6.1 m. The trial design was a randomized complete block design with 6 replications (Fig. 4.1).

Table 4.1. List of cover crop treatments, sources, and seeding rates.

Abbreviation	Description	Source	Seeding rate
	----- Summer and winter -----		kg ha^{-1}
Mc	Mustard mix 'Caliente': *Brassica juncea* and *Sinapis alba* mixture	High Performance Seeds Inc., Moses Lake, WA	16.8 (S)[§] 13.5 (W)
R	Rape 'Dwarf Essex': *B. napus*	Bailey Seed Inc., Salem, OR	16.8 (S) 13.5 (W)
O	Oat 'Saia': *Avena sativa* L.	Kenagy Family Farm	123.2 (S) 89.7 (W)
F	Fallow	-----	-----

[§](S) and (W) indicate summer and winter treatments, respectively.

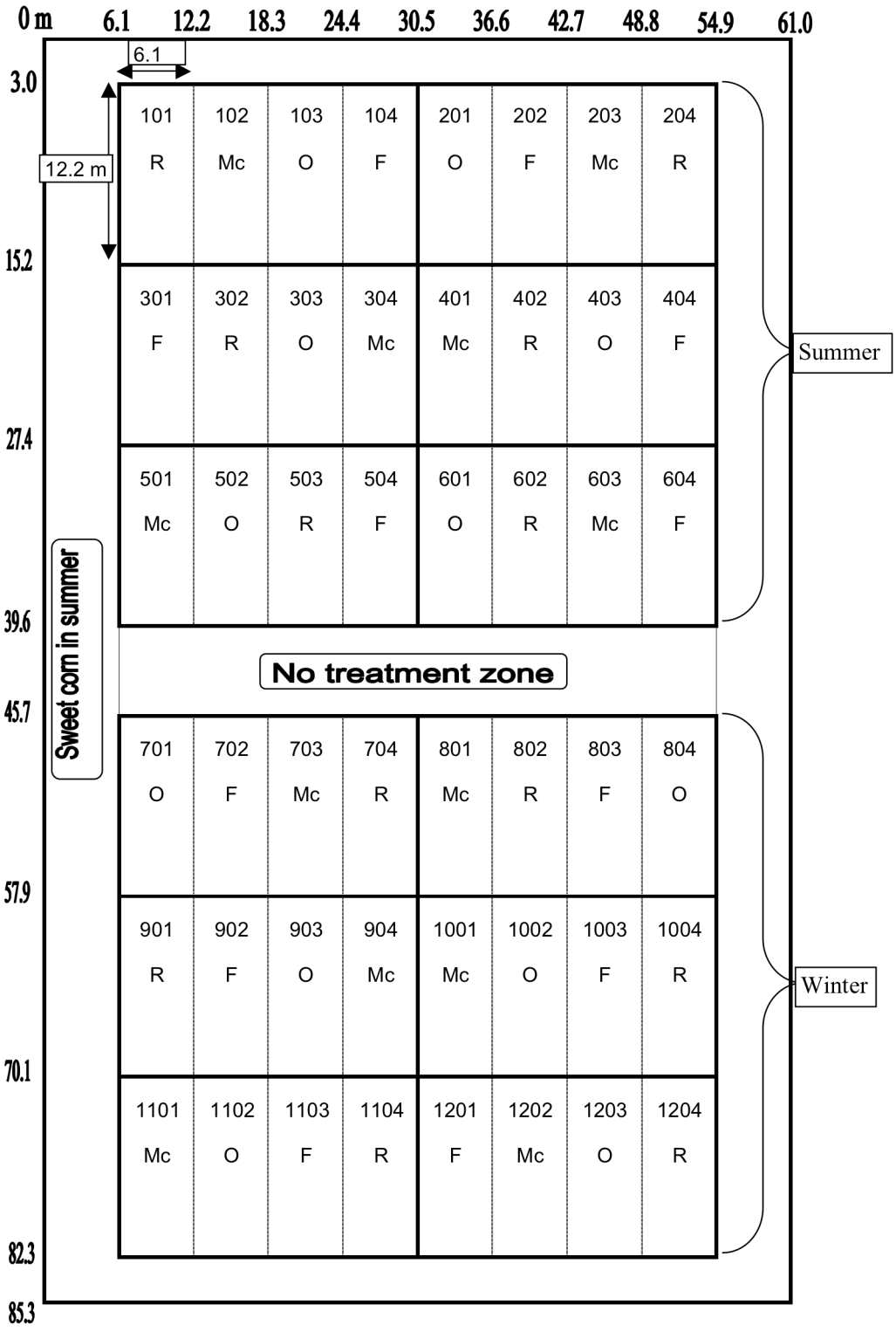

Fig. 4.1. Schematic of the experimental design for the field trial.

Treatments

Summer and winter cover crop experiments:

The cover crop treatments, seeding rates, and source of seeds are listed in Table 4.1. Cover crops were hand-seeded and tilled into the soil to 5.1 cm with a walk-behind rototiller on August 19, 2004 and September 24, 2004 for summer and winter cover crops, respectively. Cover crop dry matter was evaluated immediately before incorporation. Aboveground dry matter was collected from three randomly selected quadrats (50.8 cm by 50.8 cm) in each plot. An approximately 600 g subsample was taken and dried at 38 °C for 48 hr to determine moisture content and cover crop dry matter. All cover crops were flail-chopped, manually spread across the plot, and immediately incorporated into the soil with a rotovator to a depth of 12 cm. The summer treatment was flailed and incorporated on October 14, 2004, and the winter treatment was flailed and incorporated on April 6, 2005. Herbicides were applied to the fallow plots to control weeds.

Sweet corn crop management:

Captan treated seed of sweet corn 'Reward' (Rogers Seeds: Boise ID), was planted in both summer and winter experiments on May 24, 2006 at approximately 3.8 cm deep and 20 cm apart in rows on 0.76 m center. This cultivar was selected as it is early maturing and root rot intolerant. The seeding rate of corn was approximately 8 seeds m^{-1}; plants were thinned to 5 plants m^{-1} after emergence. Starter fertilizer (N-P-K: 12-29-10) was applied at a rate of 60 kg N ha^{-1}. Urea fertilizer, approximately 113 kg N ha^{-1}, was side-dressed on each row in the plot manually when sweet corn reached the 6-leaf growth stage.

Soil sampling

Soils were sampled throughout the year from 2004 to 2005. A baseline sample was taken one day before seeding the cover crops. After the cover crops were incorporated, soils were sampled for greenhouse bioassays and microbial activity at days 26, 51, and 84 (summer cover crop experiment) and at days 27, 55, and 80

(winter cover crop experiment). Soils were sampled for microbial activity after planting corn at days 37 and 92 for both the summer and winter experiments.

Greenhouse cone-tube bioassay:

For sweet corn greenhouse bioassays, ten soil wedges were randomly sampled from each treatment plot. Each soil wedge (approximately 13 cm x 5 cm x 15 cm) was sampled with a sharpshooter shovel (AMS Inc., American Falls, ID). Ten sampled soil wedges were passed through a 2.54 cm screen and mixed thoroughly before potting in cone-tubes.

Microbial activity:

For fluorescein diacetate (FDA) analysis, ten soil cores (approximately 15 cm depth, 2.5 cm diameter) were sampled from each plot. Soils were sampled at above-mentioned days after incorporation of summer and winter cover crops and at 37 and 92 days after corn planting. The cores were sieved through an 8 mm screen and then sieved through a 2 mm screen, and mixed thoroughly, and stored in a Ziploc bag at 4 ºC.

Nitrogen mineralization incubation:

For NO_3-N mineralization analysis, ten soil cores (approximately 15 cm depth, 2.5 cm diameter) were sampled from each plot with cover crop treatments on June 2, 2005. The cores were sieved through a 4.75 mm screen, mixed thoroughly, and stored in a Ziploc bag at 22 ºC.

Greenhouse root rot bioassays

Processed soil samples were potted into ten 550 mL cone-shaped tubes (Stuewe & Sons Inc., Corvallis, OR) per plot. Since the field soil has a very different structure than a potting mix, the cone-tubes were gently tapped to settle the soil.

Two seeds of sweet corn ‘Golden Jubilee’ treated with Captan were planted about 2.54 cm deep in each cone-tube and thinned to one plant after emergence. Cone

tubes were irrigated daily to maintain soil moisture near field capacity. Bioassays were grown in a greenhouse at approximately 24 ºC day and 18 ºC night with continuous 16 hour photoperiod during the winter and natural sunlight during the summer. Cone tubes were fertilized weekly with liquid fertilizer (0.058 g N, 0.038 g P, and 0.049 g K cone-tube^{-1} week^{-1}, Schultz Co., St. Louis, MO). When the corn plants reached the six-leaf stage, plants were harvested. Roots were washed and evaluated by visual assessment for percent necrosis of radicle and nodal roots. Root rot severity was assessed on an eight-point scale: 0 = healthy, 1 = 1 to 10 % necrotic, 2 = 11 to 20 % necrotic, 3 = 21 to 40 % necrotic, 4 = 41 to 60 % necrotic, 5 = 61 to 80 % necrotic, 6 = 81 to 90 % necrotic, 7 = 91 to 99 % necrotic, and 8 = 100 % necrotic root. Above- and below-ground dry matters were dried at 37.7 °C for 48 hr and weighed.

In-field bioassays

Three plants per plot were randomly sampled for evaluating root rot severity and shoot biomass at approximately 37, 51, 65, and 92 days after planting, which approximated the three-leaf (June 29, 2005), six-leaf (July 13, 2005), tasseling (July 27, 2005), and maturity (harvest) (August 23, 2005) developmental stages. The sampled roots were washed, and disease severity of the radicle and nodal roots was evaluated by visual assessment using the eight-point scale described above. Aboveground dry matter was dried at 37.7 ºC for 48 hr and weighed.

Corn yield

Corn ears from two center rows per plot (approximately 3 m per row) were harvested by hand to assess corn yield. Ears were husked and ears with less than 15 cm of edible corn kernels were discarded.

Soil microbial activity

The rate of hydrolysis of fluorescein diacetate (FDA) was measured 48 h after each soil sampling by modifying the procedure used by Zelles et al. (1991). Soils

sampled for the greenhouse bioassays were sieved through a 2 mm sieve. Approximately one gram wet weight soil (subsample of the soil stored at 4 ºC in a Ziploc bag) was placed in each of four 125 ml Erlenmeyer flasks per plot. Twenty mL of pH buffer (60 mM sodium phosphate at pH 7.6) was added to each flask. After 15 minutes shaking at 178 rev min^{-1}, 100 μL of 4.8 mM fluorescein diacetate solution (3', 6' diacetylfluorescein) was added to three of the four flasks. The remaining flask (control) received 100 μL of fluorescein diacetate solution only after the addition of acetone. Flasks were shaken at 178 rev min^{-1} for 2 h at 25 °C on an Innova 2003 platform shaker (New Brunswick Scientific Co., Inc., Edison, NJ). The addition of 20 mL acetone to each flask instantly stopped the hydrolysis reaction, and then the samples were centrifuged for 5 min at 4960 times *g* (Model J2-HS, Beckman Coulter, Inc., Fullerton, CA) to separate the soil from the liquid. The separated samples were filtered (Whatman No 4), and the absorbance of the filtrate was measured at 490 nm with a spectrophotometer (Model DU 800, Beckman Coulter, Inc., Fullerton, CA). FDA activity was expressed as μg FDA hydrolyzed hr^{-1} g^{-1} dry wt soil and was compared to a standard curve. Background absorbance of the sample solutions was corrected by subtraction of the control absorbance.

Soil NO_3-N measurement from mineralization

An irrigation was scheduled for approximately 36 hrs before sampling to raise soil moisture contents to near field capacity. Soils, sampled a week before planting sweet corn, were sieved through a 4.75 mm sieve. The stored subsamples from the summer (230 days after incorporation of cover crops) and winter (50 days after incorporation of cover crops) treatments were moistened to approximately 25 % gravimetric moisture by adding distilled water with a spray bottle. Approximately 625 g of moist soil was mixed and stored in a 1 L Ziploc bag (SC Johnson & Son. Inc.). A straw was inserted into the opening of each bag so it remained slightly open to allow air circulation. The bags were placed into a 30 L plastic tub. A moistened foam pad (approximately 2.5 cm depth) was placed at the bottom of the incubation tub and was

re-moistened at 7 days intervals to maintain soil moisture contents. The bags were incubated at 22 °C for approximately 70 days.

After the incubation period, a 15 g soil sample was taken from each Ziploc bag and placed into a 125 mL Erlenmeyer flask. Fifty ml of 2 M KCl was added to each flask, and the flasks were shaken at 178 rev min^{-1} for 1 hr. Colloids of soil and 2 M KCl were filtered by Whatman No. 42 filter paper and analyzed for inorganic N by colorimetric analysis using the cadmium reduction method (Keeney and Nelson, 1982). Gravimetric soil moisture content was determined for each sample by oven-drying approximately 10 g of soil at 105 °C for 24 hr, and the obtained values were used to calculate soil N concentration on a dry soil basis.

Calculations

Net available N ($N_{available}$) for cover crop incorporated soil was calculated and expressed as mg kg^{-1}:

$$N_{available}\,(\text{mg } NO_3\text{-N kg}^{-1}\text{ dry wt}) = (NO_3\text{-N})_{\text{cover crop}} - (NO_3\text{-N})_{\text{fallow}} \quad [1]$$

where NO_3-$N_{cover\ crop}$ is the amount of NO_3-N extracted from a incorporated cover crop treatments (mg kg^{-1}), NO_3-N_{fallow} is the amount of NO_3-N extracted from fallow treatment (mg kg^{-1}).

Amount of N in cover crop residue was calculated and expressed as N content ($N_{crop\ residue}$) in cover crop residue (mg kg^{-1}):

$$N_{\text{crop residue}}\,(\text{mg kg}^{-1}) = \text{Total N (\%)} \times DM_{\text{cover crop}}\,(\text{mg kg}^{-1}) \quad [2]$$

where Total N is percent of N in cover crop residue, $DM_{cover\ crop}$ is cover crop aboveground dry matter.

Statistical analysis

Statistical analysis was performed with SAS (SAS system for Windows 9, SAS Inst., 1999). Treatment effects on disease severity, dry matter, microbial activity, and yield for each sampling date was computed using analysis of variance (ANOVA) from the PROC GLM procedure. Treatment means were separated when F-test was significant ($P \leq 0.05$). Mean separation was performed by the LSD procedure using MEANS statement if sampling data was balanced. Treatment means were separated by the student's *t* test using LSMEANS statement when the sampling data was unbalanced. Linear regression analysis using PROC REG was computed in SAS to describe the relationship between root rot severity and microbial activity.

RESULTS

Cover crop dry matter

The air-dried cover crop dry matter for the summer and winter experiments is reported in Table 3.2. Dry matter was lower in the winter O treatment than in the summer O treatment, due to cold injury and barley yellow dwarf virus (BYDV) infection as diagnosed by Melodie Putnam, OSU Plant Clinic. Dry matter in the summer Mc and O treatments was significantly higher, approximately 18 and 24 %, respectively, than in the R treatment (F statistic $P = 0.07$; LSD $P = 0.02$). Dry matter in the winter Mc was approximately 17 and 43 % higher ($P = 0.0003$) than in the R and O treatments, respectively. The R treatment generated approximately 31 % more dry matter than in the O treatment (Table 4.2).

Table 4.2. Cover crop dry matter: summer and winter cover crop experiments.

Treatment	Mean dry matter
----- Summer -----	----- Mg ha^{-1} -----
O	11.0 (0.6) A[†]
Mc	10.2 (0.4) A
R	8.4 (0.3) B
----- Winter -----	
Mc	10.3 (0.6) X
R	8.5 (0.4) Y
O	5.9 (0.4) Z

Number between parentheses indicates standard error. [†]Mean separation followed by different letters was significantly different based on LSD test at $P = 0.05$.

Greenhouse bioassays

Baseline disease severity:

There was no treatment difference in radicle or nodal root rot severity in the summer and winter baseline disease severity assessments (Fig. 4.2). Mean radicle rot severity across all cover crop treatments was 80.5 %, and mean nodal root severity across all cover crop treatments was 20.8 % (Fig. 4.2).

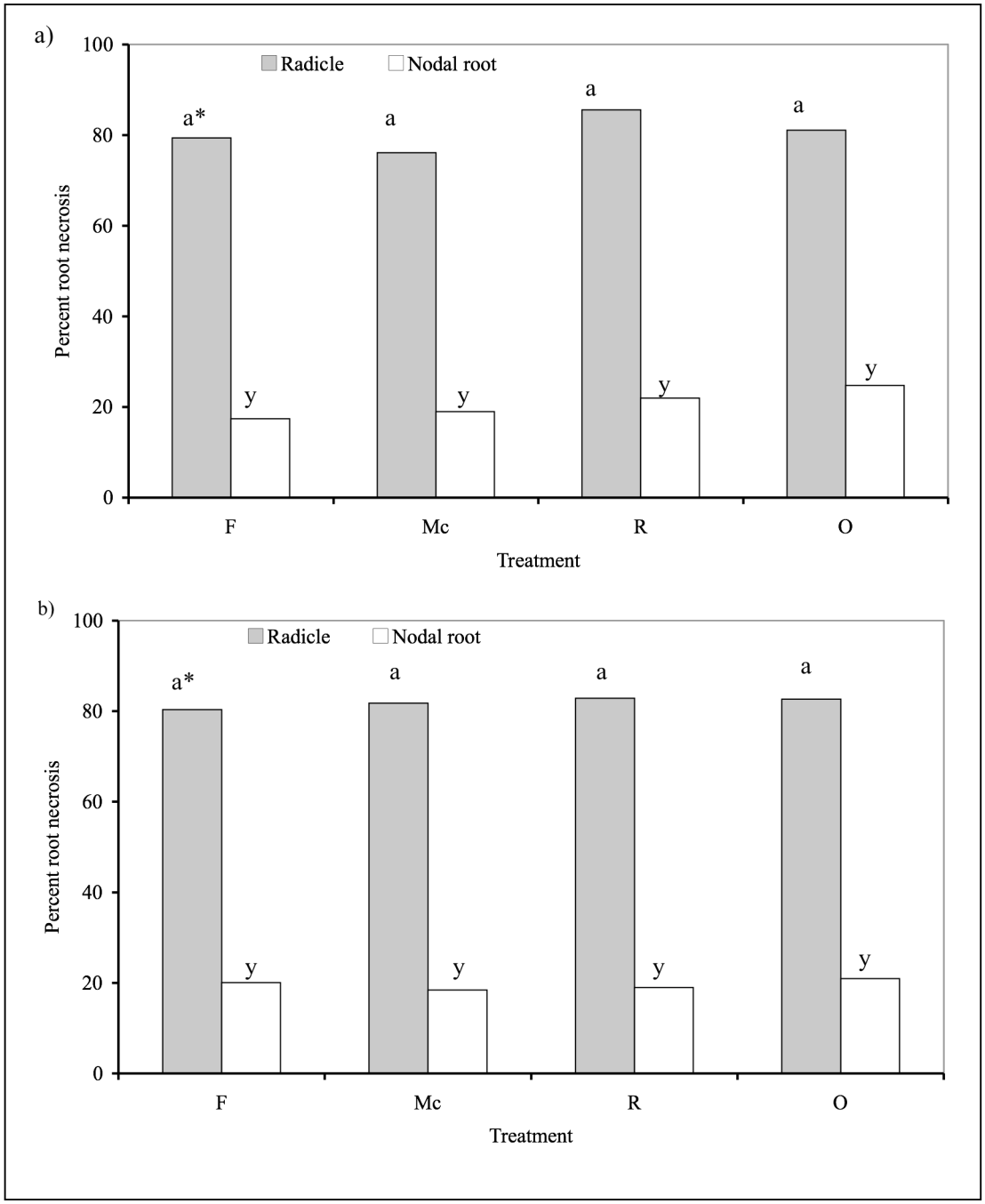

Fig. 4.2. Baseline disease severity. Baseline assessment from a) summer and b) winter cover crop experiments. *Treatment bars followed by same letters indicate no significant difference at $P = 0.05$ based on LSD test.

Disease severity (summer cover crop experiment):

At 26 days after incorporation of the summer cover crops, mean radicle rot severity was reduced by approximately 17 % by all cover crop treatments ($P \leq 0.01$). Mean radicle rot severity across all cover crop was 65.9 %, and mean radicle rot severity in the F treatment was 79.4 % (Fig. 4.3). The O and Mc treatments reduced radicle rot severity by approximately 13 and 18 %, respectively, compared to the F treatment ($P = 0.06$) at 51 days after incorporation (Fig. 4.3). Radicle rot severity in the Mc treatment was reduced by approximately 18 % compared to the F treatment at day 84 ($P \leq 0.05$). The Mc treatment was the only treatment that suppressed radicle rot through day 84 (Fig. 4.3). There was no treatment difference for nodal root rot severity, but disease severity was numerically lower than the F treatment for all cover crop treatments at 26 and 51 days after incorporation. On average, at 26 and 51 days after incorporation, nodal root rot severity was numerically 16 and 17 % lower, respectively, in the cover crop treatments than in the F treatment. Mean nodal root rot severity for the F, Mc, R, and O at 26 days after incorporation was 27, 23, 24, and 21 %, respectively. Mean nodal root rot severity for the F, Mc, R, and O at 51 days after incorporation was 35, 28, 33, and 27 %, respectively (Fig. 4.3).

Disease severity (winter cover crop experiment):

Radicle and nodal root rot severity was significantly lower in at least two of three cover crop treatments at 28 and 50 days after incorporation of the winter cover crops. Radicle and nodal root severity in the Mc treatment was numerically, but not significantly, lower than in the F treatment at 77 days after incorporation (Fig. 4.4). On average, winter cover crop treatments reduced radicle and nodal root rot severity by approximately 30 and 27 %, respectively, across all sampling dates (Fig. 4.4).

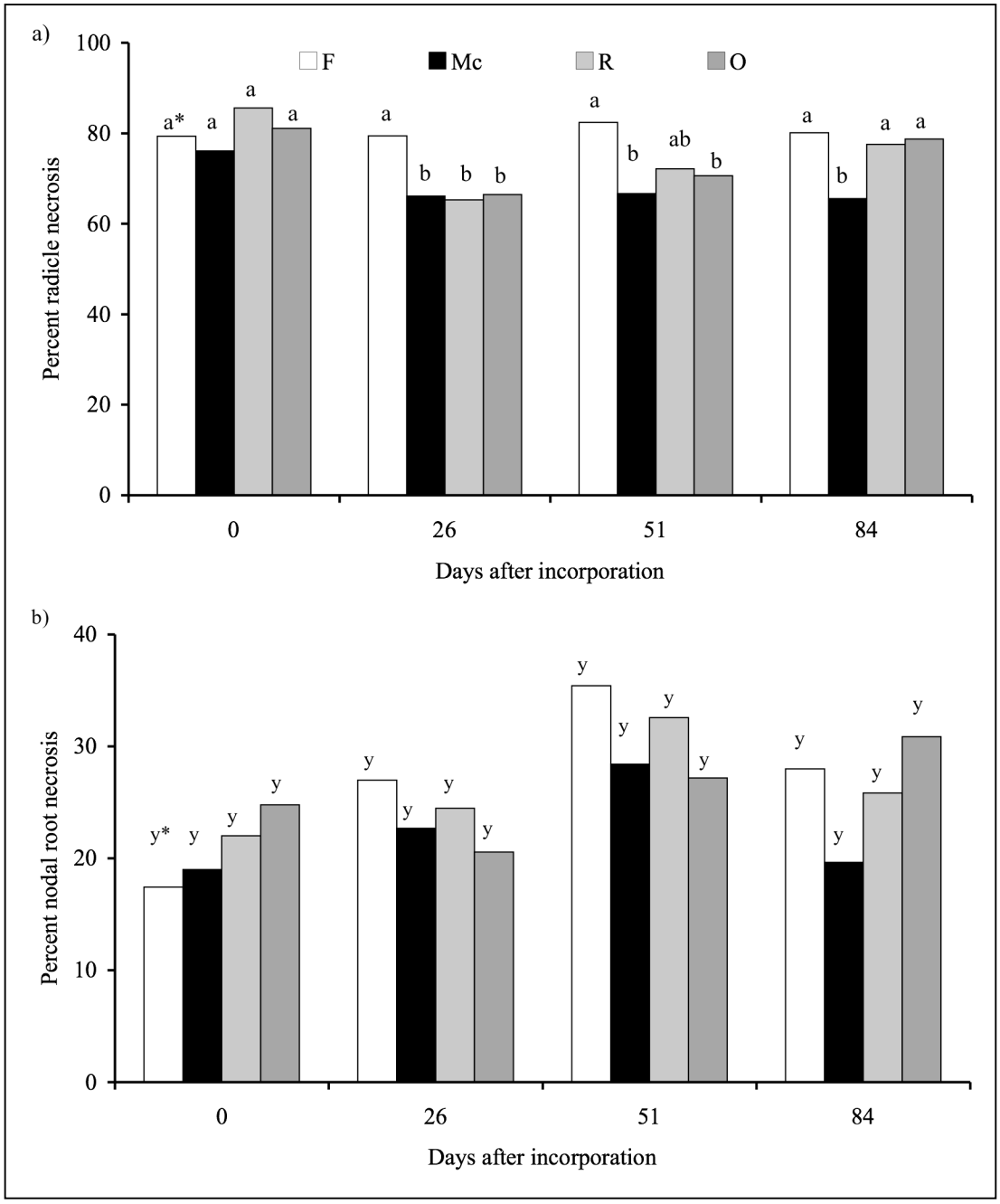

Fig. 4.3. Disease severity: greenhouse-grown corn from summer cover crop experiment. a) Radicle and b) nodal root rot severity. *Treatment bars followed by same letters indicate no significant difference at $P = 0.05$ based on LSD test.

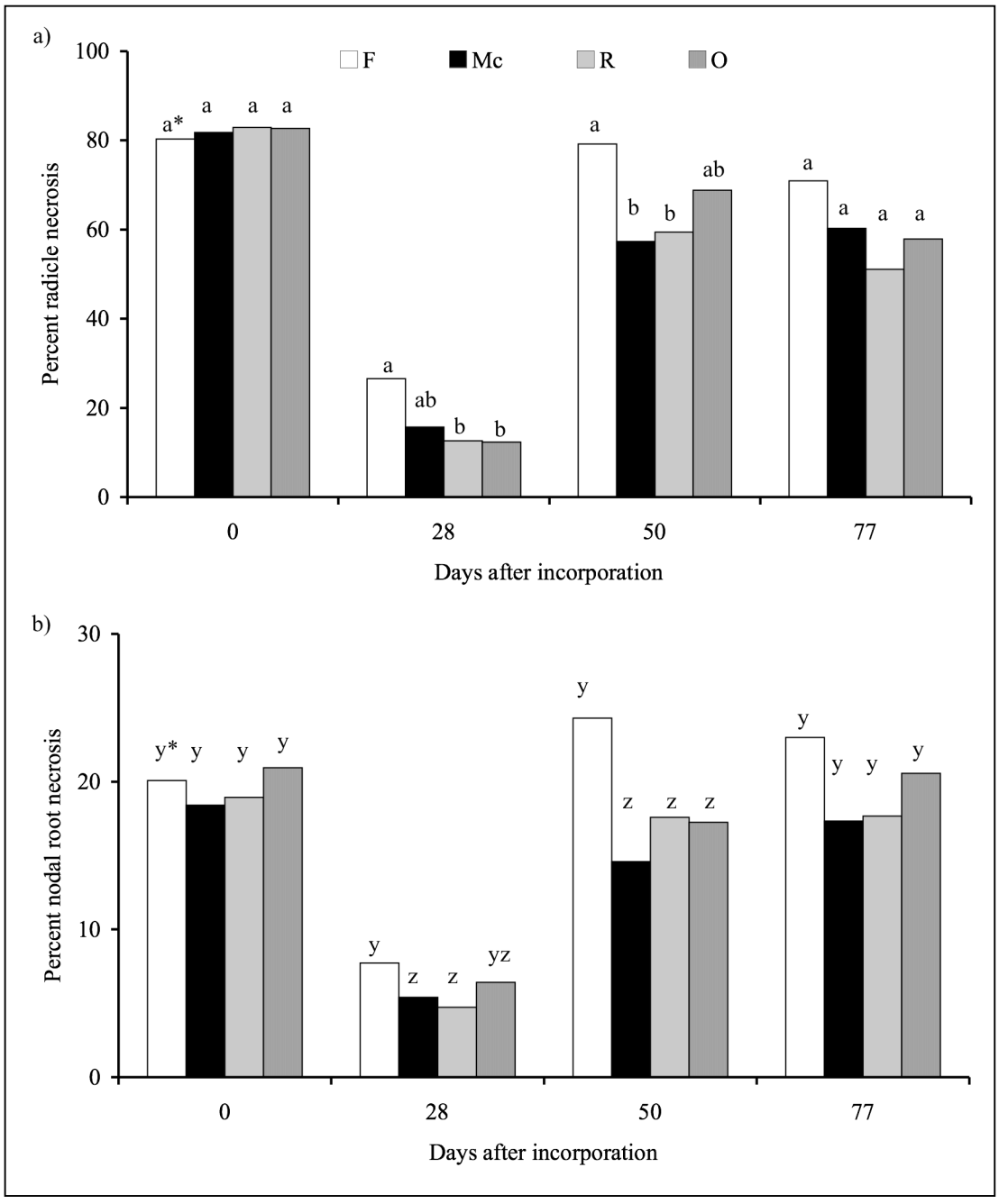

Fig. 4.4. Disease severity: greenhouse-grown corn from winter cover crop experiment. a) Radicle and b) nodal root rot severity. *Treatment bars followed by same letters indicate no significant difference at $P = 0.05$ based on LSD test.

Crop dry matter (summer cover crop experiment):

At 51 days after incorporation of the summer cover crops, the Mc and R treatments generated 18 and 23 %, respectively, more mean aboveground dry matter than the F treatment ($P \leq 0.01$). Although there was no treatment difference for aboveground dry matter at 26 days after incorporation, the aboveground dry matter for Mc and R treatments generated almost the same percentage increase relative to the F treatment as at 51 days. There was no difference between the O and F treatments on any sampling dates (Fig. 4.5).

On day 26, there was no difference between belowground dry matter in any of the cover cropped treatments and the F treatments, but there was 21 % higher belowground dry matter in the R than in the O treatments. On day 51, the Mc treatment increased belowground dry matter and at day 84, the Mc and R treatments increased belowground dry matter compared to the F treatment ($P \leq 0.05$). On average, the R treatment generated approximately 21 % more belowground dry matter than the F treatment across the three sampling dates. There was a trend toward higher belowground dry matter in the Mc and R treatments than in the F treatment, but not in the O treatment (Fig. 4.5).

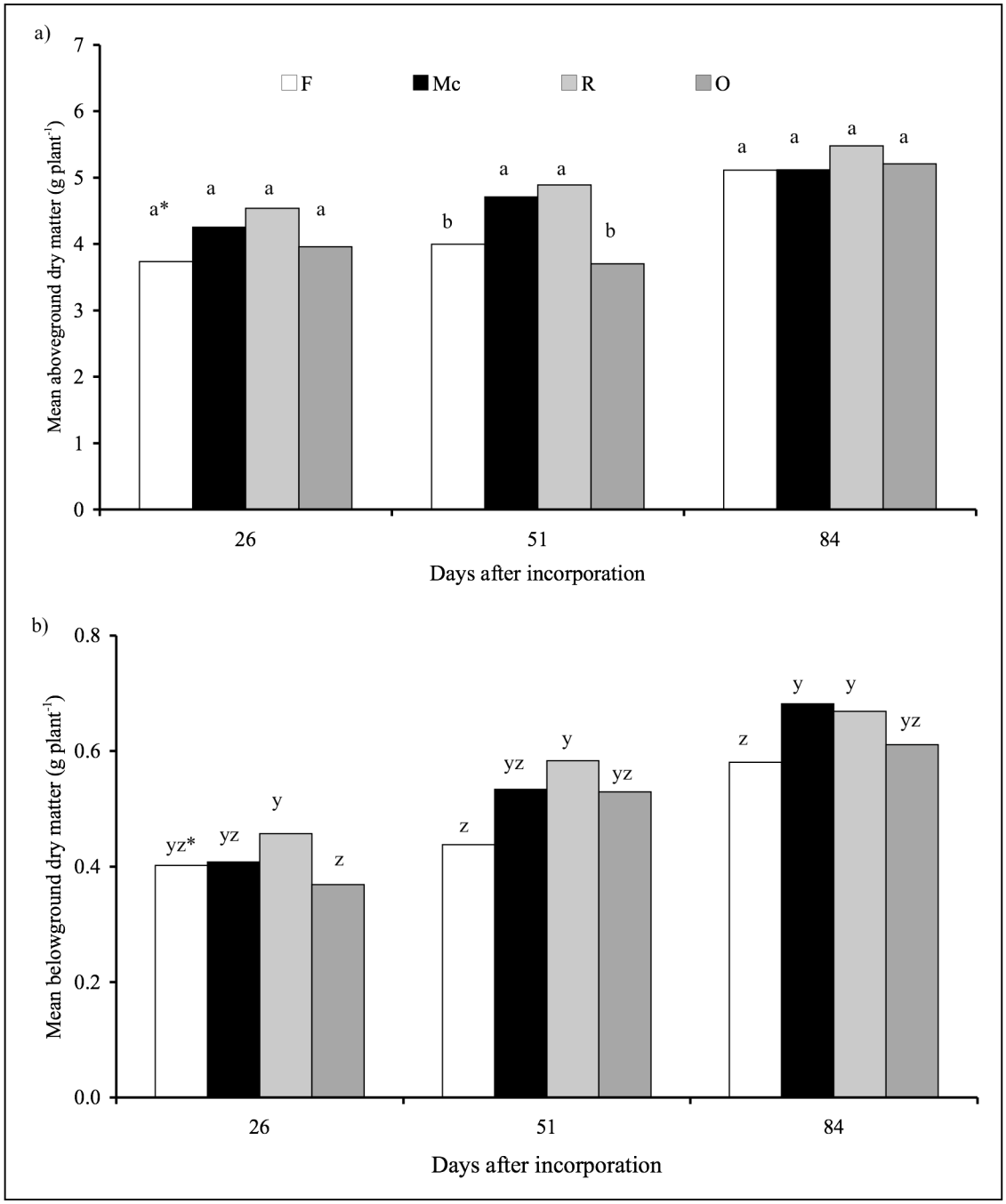

Fig. 4.5. Corn dry matter: greenhouse-grown corn from summer cover crop experiment. Mean a) aboveground and b) belowground dry matter. *Treatment bars followed by same letters indicate no significant difference at $P = 0.05$ based on LSD test.

Crop dry matter (winter):

Mean aboveground dry matter in all cover crop treatments at 28 days after incorporation was 8 to 13 % greater than in the F treatment ($P \leq 0.05$). The R treatment generated approximately 25 % greater dry matter than the F treatment at 50 days after incorporation ($P \leq 0.05$). There was no treatment difference for aboveground dry matter at 77 days after incorporation (Fig. 4.6).

Mean belowground dry matter at 28 days after incorporation was significantly different amongst treatments ($P \leq 0.001$). The R treatment generated approximately 36 %, and the Mc and O treatments approximately 25 %, more belowground dry matter than the F treatment. At 50 days after incorporation, the R treatment generated approximately 29 % more belowground dry matter than the F treatment. There was no treatment difference for mean belowground dry matter at 77 days after incorporation. Overall, the R treatments generated higher aboveground and belowground dry matter than the Mc, O, and F treatments. The Mc and O generated almost the same quantity of aboveground and belowground dry matter (Fig. 4.6).

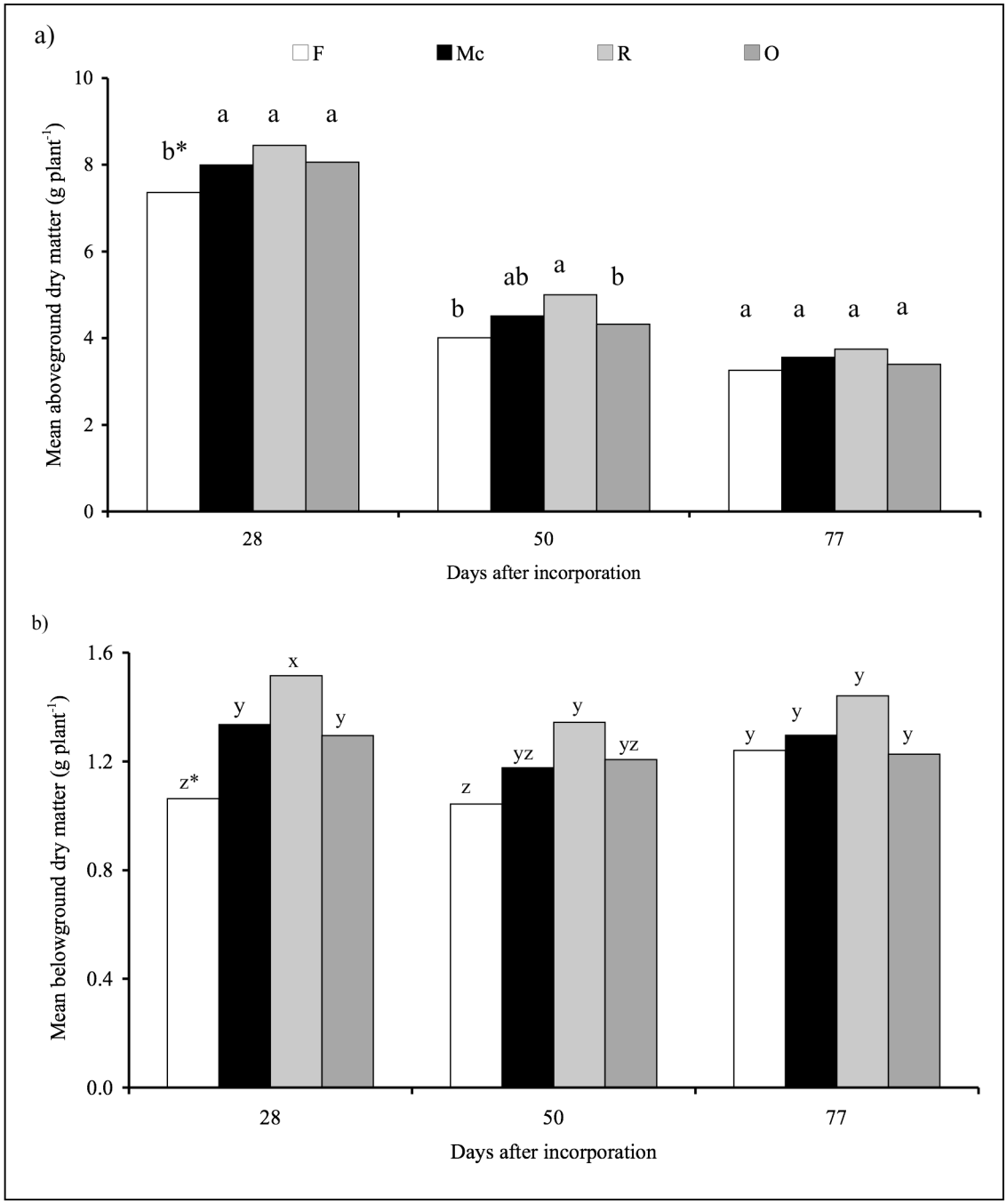

Fig. 4.6. Corn dry matter: greenhouse-grown corn from winter cover crop experiment. Mean a) aboveground and b) belowground dry matter. *Treatment bars followed by same letters indicate no significant difference at $P = 0.05$ based on LSD test.

Field-grown corn

Disease severity (summer cover crop experiment):

Root rot severity increased over time in all treatments. Mean radicle rot severity at 37 and 51 days after planting corn was not different amongst treatments ($P \geq 0.05$). Mean radicle and nodal root severity were significantly different at 65 and 92 days after planting corn ($P \leq 0.05$). Radicle rot severity in the O treatment was approximately 33 % lower than the Mc treatment at 65 days after planting ($P \leq 0.01$). Radicle rot severity from the Mc treatment was approximately 21 % lower than the F treatment at 92 days after planting corn ($P \leq 0.05$) (Fig. 4.7).

Mean nodal root rot severity in the Mc treatment was approximately 76 % lower than in the O treatment at 51days after planting corn ($P \leq 0.01$). Nodal root rot severity in the O treatment was approximately 30 % lower than in the R treatment at 65 days after planting corn ($P = 0.07$). Nodal root rot severity in the Mc treatment was approximately 22 % lower than in the F treatment at 92 days after planting corn ($P \leq 0.001$) (Fig. 4.7).

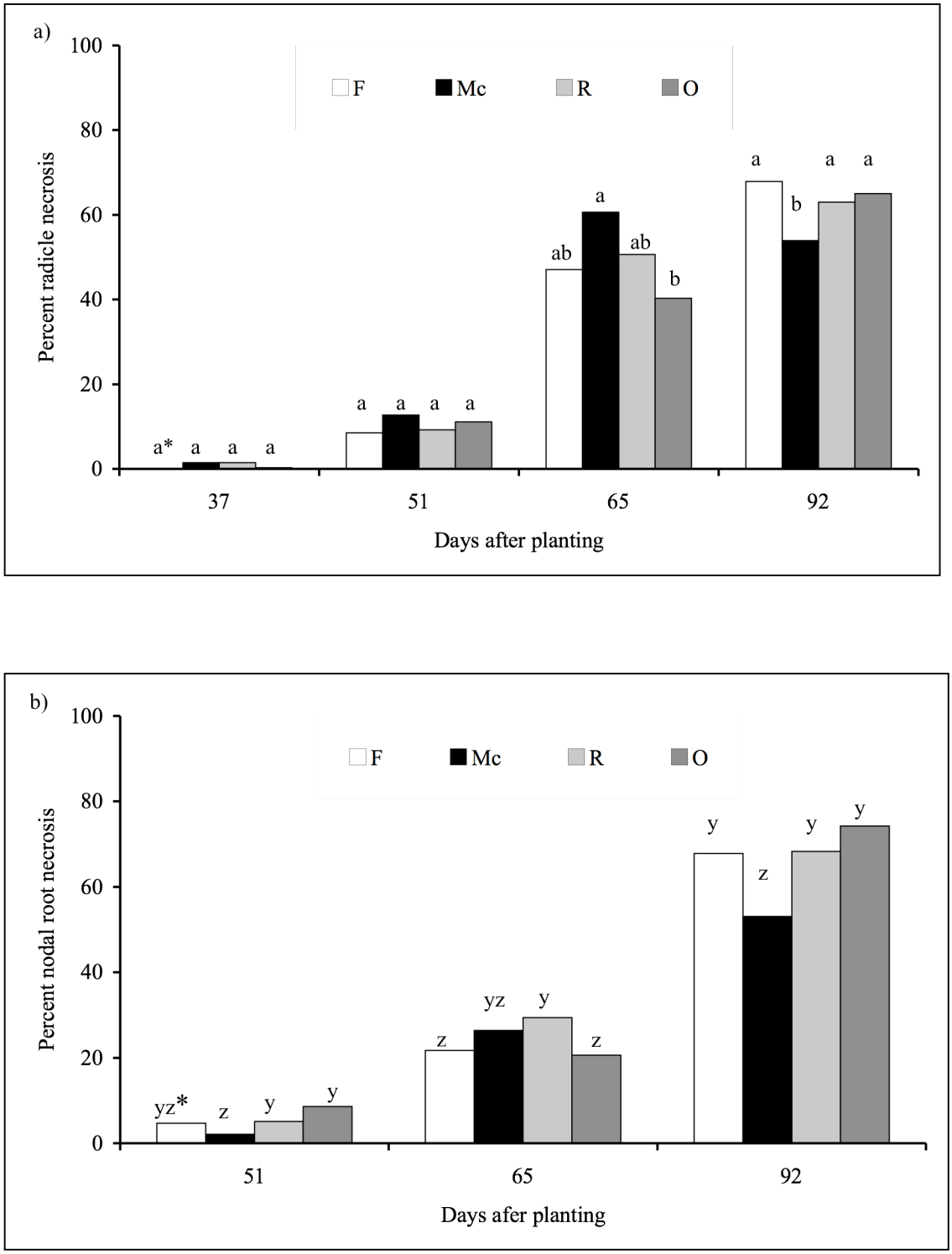

Fig. 4.7. Disease severity: field grown corn. Mean percent a) radicle and b) nodal root necrosis in summer cover crop experiment. *Treatment bars followed by same letters indicate no significant difference at $P = 0.05$ based on LSD test.

Disease severity (winter cover crop experiment):

Root rot severity increased over time in all treatments. Mean radicle rot severity at 37 days after planting corn was not different amongst treatments ($P \geq 0.05$). Radicle rot severity in the F treatment was numerically, but not necessarily significantly, higher than all other treatments at 51, 65, and 92 days after planting. The R treatment at 51 days after planting corn had 70 % lower radicle rot severity than the F treatment ($P \leq 0.01$). The O treatment at 65 days after planting corn had 30 % lower radicle rot severity than the F treatment ($P \leq 0.05$). The O and R treatments at 92 days after planting corn had approximately 23 and 34 % lower radicle rot necrosis, respectively, than the F treatment (O treatment: $P \leq 0.05$; R treatment: $P \leq 0.01$) (Fig. 4.8).

Mean nodal root rot severity in the F treatment was consistently higher than all other treatments across sampling dates, except at 65 days after planting corn. All cover crop treatments at 51 days after planting corn had approximately 77 % lower nodal root rot severity than the F treatment ($P \leq 0.001$). The R and O treatments at 65 days after planting corn had 28 and 32 %, respectively, lower nodal root rot severity than the F treatment ($P \leq 0.05$). At 92 days after planting corn, the Mc, O, and R treatments had approximately 15, 19, and 27 % lower nodal root rot severity than the F treatment (Mc treatment: $P \leq 0.01$; O and R treatments: $P \leq 0.001$) (Fig. 4.8).

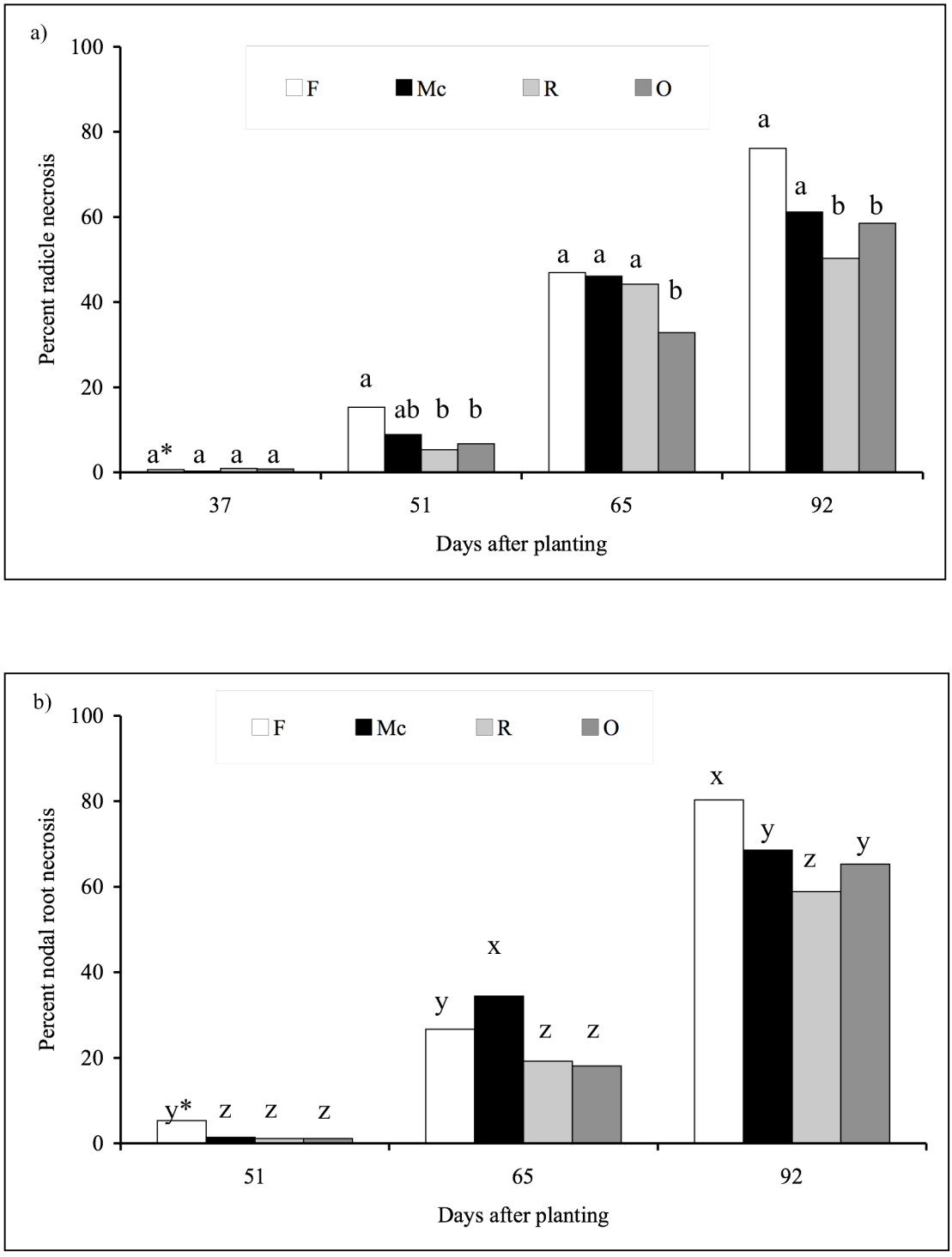

Fig. 4.8. Disease severity: field grown corn. Mean percent a) radicle and b) nodal root necrosis in winter cover crop experiments. *Treatment bars followed by same letters indicate no significant difference at $P = 0.05$ based on LSD test.

Crop dry matter (summer and winter cover crop experiments):

There were no significant differences in aboveground dry matter at any sampling date in the summer and winter field experiments (Table 4.3).

Table 4.3. Aboveground dry matter: summer and winter experiment. Field grown sweet corn at 37, 51, 65, and 92 days after planting. Parentheses indicate standard error.

Days after planting sweet corn	Treatment	Mean aboveground dry matter	
		---------- dry g plant^{-1} ----------	
		----- Summer -----	----- Winter -----
37	F	1.8 (0.2)	1.2 (0.1)
37	Mc	1.9 (0.2)	1.8 (0.2)
37	R	1.9 (0.2)	2.1 (0.4)
37	O	1.6 (0.2)	1.9 (0.3)
		NS‡	NS
51	F	39.1 (1.4)	32.2 (1.7)
51	Mc	41.9 (2.3)	38.6 (2.6)
51	R	37.3 (2.3)	40.5 (2.0)
51	O	37.8 (1.4)	37.2 (2.4)
		NS	NS
65	F	84.2 (4.0)	72.1 (9.2)
65	Mc	74.6 (8.4)	87.2 (8.6)
65	R	67.6 (4.3)	79.8 (7.1)
65	O	74.7 (4.3)	79.9 (7.6)
		NS	NS
92	F	117.4 (18.9)	127.5 (18.2)
92	Mc	130.9 (28.4)	138.4 (18.6)
92	R	124.0 (14.4)	133.8 (16.8)
92	O	104.5 (13.4)	95.5 (9.2)
		NS	NS

Number between parentheses indicates standard error. ‡NS indicates there are no significant differences between treatments based on LSD test ($P = 0.05$).

Sweet corn yield

Summer cover crop experiment:

There was no significant difference in mean yield among treatments. Mean yield across treatments was 21.2 Mg ha^{-1} (9.5 ton $acre^{-1}$) (Table 4.4).

Winter cover crop experiment:

Twelve spot beetle larvae (Coleoptera: Chrysomelidae: *Diabrotica undecimpunctata undecimpunctata*) severely damaged the corn seedlings only in the fallow treatment; as the result, yield data could not be taken for this treatment. There were no significant differences in yield amongst the cover crop treatments ($P \geq 0.05$) Mean yield across the cover crop treatments was 20.9 Mg ha^{-1} (9.3 ton $acre^{-1}$) (Table 4.4).

Table 4.4. Yield of sweet corn.

Treatment	Mean yield
----- Summer -----	----- Mg ha^{-1} -----
F	21.3 (1.2)
Mc	21.6 (0.9)
R	20.8 (0.8)
O	20.9 (0.7)
	NS‡
----- Winter -----	----- Mg ha^{-1} -----
F	NA§
Mc	20.4 (0.9)
R	21.5 (0.8)
O	20.9 (1.0)
	NS

Number between parentheses indicates standard error. §NA indicate no yield data due to twelve spot beetle larvae infestation. ‡NS indicates there are no significant differences between treatments based on LSD test ($P = 0.05$).

Correlation between cover crop aboveground dry matter and radicle rot severity

There were no correlations between cover crop aboveground dry matter and radicle rot severity at any sampling dates in both summer and winter experiments (data not shown).

Soil microbial activity:

Summer cover crop experiment:

Microbial activity (rate of hydrolysis of FDA) for all cover crop treatments on all three sampling dates was higher than microbial activity in the F treatment. At 26 days after incorporation, microbial activity ranged from 13.9 % higher in the Mc treatment to 18.7 % higher in the R treatment than in the F treatment ($P \leq 0.01$). At 51 days after incorporation, microbial activity ranged from 14.2 % higher in the O treatment to 23.2 % higher in the R treatment than the F treatment ($P \leq 0.001$). At 84 days after incorporation, on average microbial activity across all cover crop treatments was 21.2 % higher than the F treatment ($P \leq 0.01$) (Fig. 4.9). In general, microbial activity from cover crops was approximately 18 % higher than the F treatment at all sampling date.

Winter cover crop experiment:

Microbial activity was always higher in the cover crop treatments than in the F treatment. Overall, the R treatment had the highest microbial activity, and the F had the lowest. Microbial activity for the O treatment was consistently the lowest amongst cover crop treatments, and there were no significant differences between the O and the F treatment at any sampling dates ($P \geq 0.05$) (Fig. 4.9). At 28 days after incorporation, microbial activity for the Mc and R treatments was approximately 16 and 24 %, respectively, higher than the F treatment (Mc treatment: $P \leq 0.05$; R treatment: $P \leq 0.01$). At 50 days after incorporation, microbial activity for the Mc and R treatments was approximately 16 and 26 %, respectively, higher than the F treatment (Mc treatment: $P \leq 0.01$; R treatment: $P \leq 0.001$). At 77 days after

incorporation, the overall hydrolysis of FDA decreased 21.1 % amongst treatments compared to 50 days after incorporation. On average, microbial activity for the Mc and R treatments was approximately 15 and 23 %, respectively, higher than the F treatment at all sampling dates (Fig. 4.9). Microbial activity slightly decreased at approximately 84 and 77 days after incorporation in all treatments in both the summer and winter cover crop experiments.

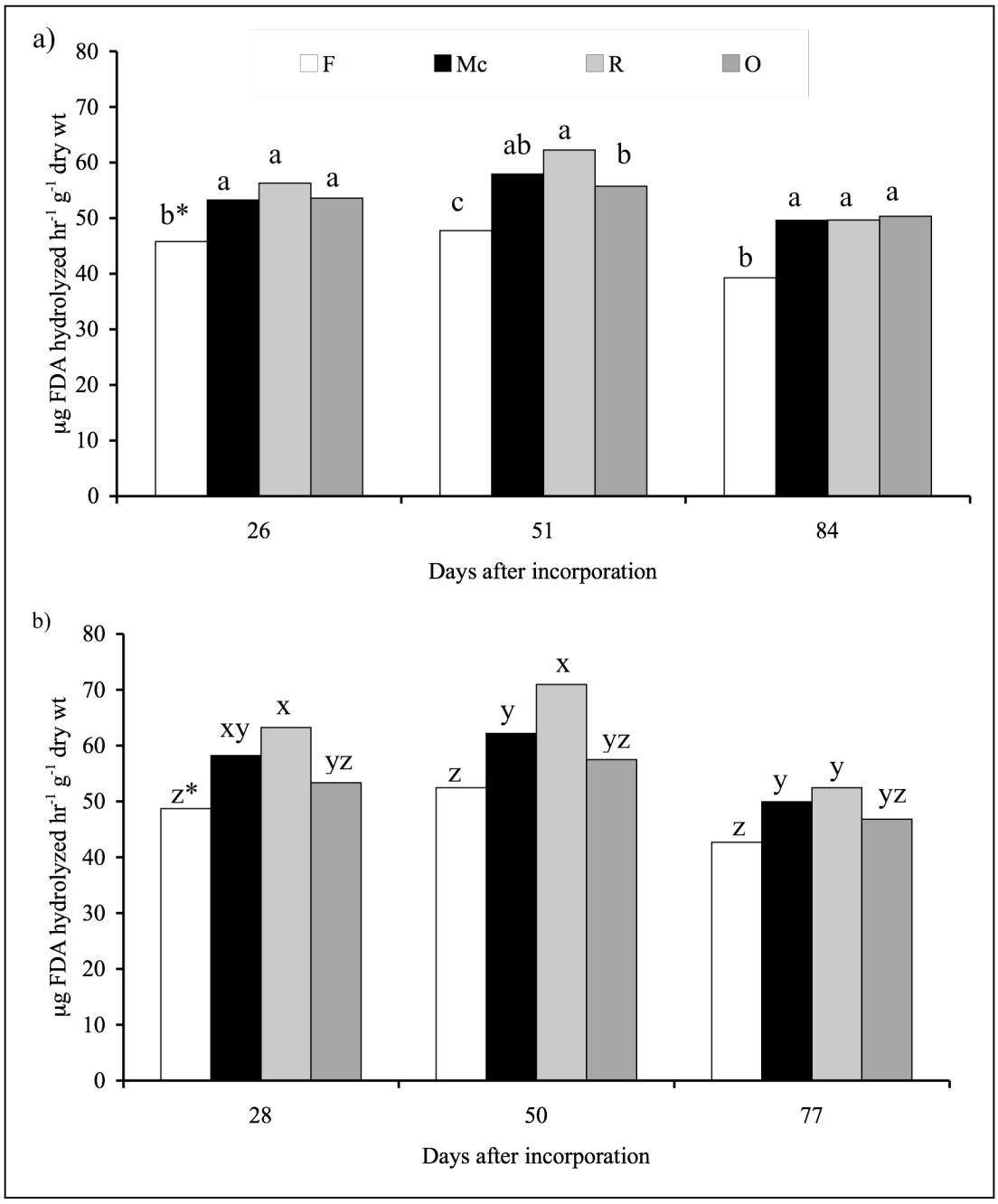

Fig. 4.9. Microbial activity. Rate of hydrolysis of FDA in a) summer and b) winter cover crop experiments at three different sampling dates. *Treatment bars followed by same letters indicate no significant difference at $P = 0.05$ based on LSD test.

Microbial activity at 37 and 92 days after planting

Microbial activity was measured at 37 and 92 days after planting corn in both the summer and winter cover crop experiments. There was no difference amongst treatments at 37 and 92 days after planting in either experiment ($P \geq 0.05$). Interestingly, the values of FDA hydrolysis were almost the same in the summer and winter treatments, even though cover crop incorporation occurred at 260 / 315 days and 85 / 140 days earlier, respectively (Table 4.5).

Table 4.5. Microbial activity in soils at 37 and 92 days after planting. Parentheses indicate standard error.

Days after planting	Days after incorporation	Treatment	µg FDA hydrolyzed hr^{-1} g^{-1} dry wt
	---------- Summer ----------		
37	260	F	40.1 (1.9)
37	260	Mc	42.5 (1.9)
37	260	R	38.8 (1.3)
37	260	O	38.8 (1.8)
			NS‡
92	315	F	46.4 (2.2)
92	315	Mc	48.2 (1.6)
92	315	R	47.5 (1.5)
92	315	O	45.9 (2.1)
			NS
	---------- Winter ----------		
37	85	F	40.8 (2.3)
37	85	Mc	40.6 (3.8)
37	85	R	36.5 (2.5)
37	85	O	41.9 (2.0)
			NS
92	140	F	39.8 (1.0)
92	140	Mc	43.8 (1.0)
92	140	R	44.2 (1.2)
92	140	O	42.2 (2.3)
			NS

Number between parentheses indicates standard error. ‡NS indicates there are no significant differences between treatments based on LSD test ($P = 0.05$).

Microbial activity over time

All cover crop treatments generated higher microbial activity than the F treatment through days 84 and 77 in both summer and winter cover crop experiments, respectively. Microbial activity in all treatments decreased in both summer and winter experiments after days 260 and 85, respectively, and remained low at days 315 and 140 in both summer and winter cover crop experiment treatments (Fig. 4.10).

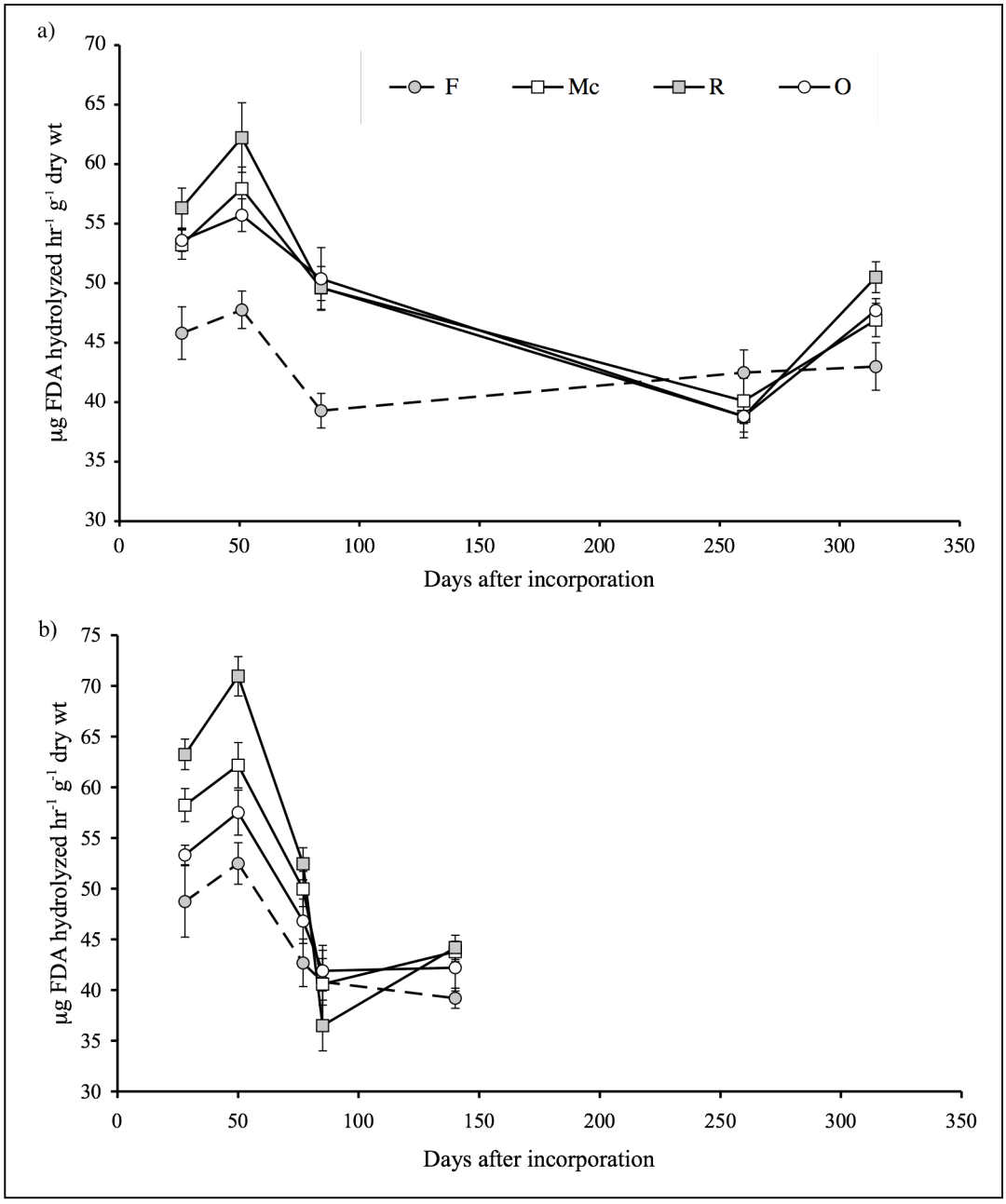

Fig. 4.10. Microbial activity. Rate of hydrolysis of FDA in a) summer and b) winter cover crop experiments at five different sampling dates. [§]Error bars indicate standard error (n = 6).

Correlation between soil microbial activity and root rot severity (greenhouse bioassays)

Summer cover crop experiment:

Radicle rot severity and the rate of hydrolysis of FDA across the three sampling dates in the summer and winter cover crop experiments were significantly negatively correlated (R^2 =0.40, -b = 0.69, P = 0.03). As microbial activity increased, root rot severity declined (Fig. 4.11). The relationship was strongest and the slope steepest at 26 days (R^2 =0.94, b = -1.45, *P* = 0.01), intermediate at 51 days (R^2 = 0.60, b = -0.85, *P* = 0.08), and weakest and not significant at 84 days (R^2 = 0.18, b = -0.54, *P* = 0.46) (Fig. 4.12).

Winter cover crop experiment:

There was no overall relationship between the rate of FDA hydrolysis and mean radicle rot severity across the three sampling dates (R^2 = 0.04, -b = 0.60, *P* = 0.54) (Fig. 4.11). This was due largely to the very low root rot severity ratings at day 28. However, in addition, there was only a significant negative correlation between FDA activity and radicle rot severity at 55 days after incorporation and not significant at the other two sampling dates (Fig. 4.12).

Correlation between soil microbial activity and root rot severity (harvest)

Since radicle rot severity was very low in the summer and winter cover crop experiments at 37 days after planting, the correlation between microbial activity and radicle rot severity was determined only at harvest. There was no correlation between microbial activity and radicle rot severity in the summer (R^2 = 0.1, -b = 1.89, *P* = 0.15) and winter (R^2 = 0.08, -b = 1.86, *P* = 0.17) cover crop experiments. There was a negative correlation between microbial activity and radicle rot severity in both summer and winter treatments, but it was not significant (Fig 4.13).

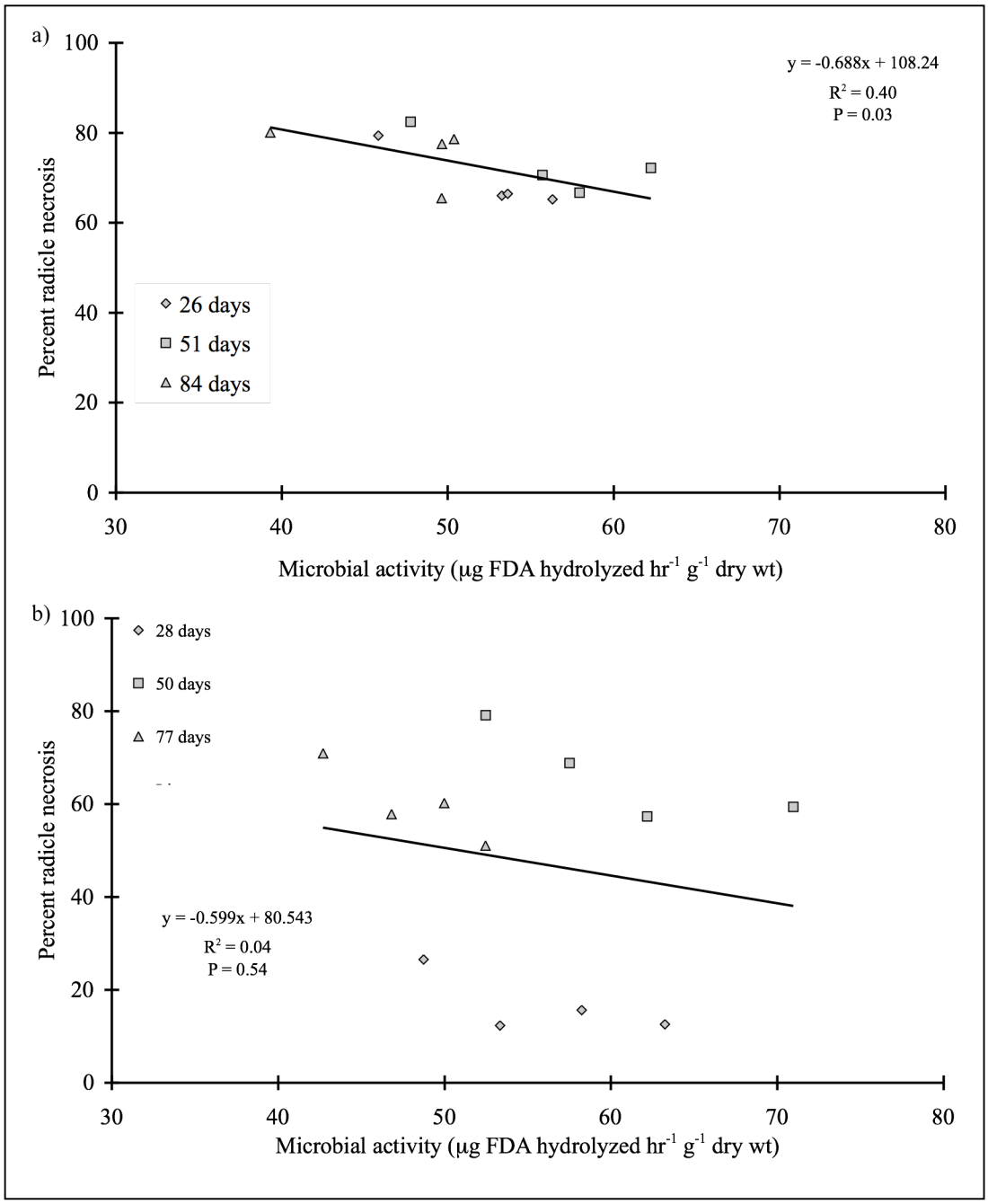

Fig. 4.11. Correlation between microbial activity and radicle necrosis: greenhouse bioassays. a) summer and b) winter cover crop experiments at three different sampling dates.

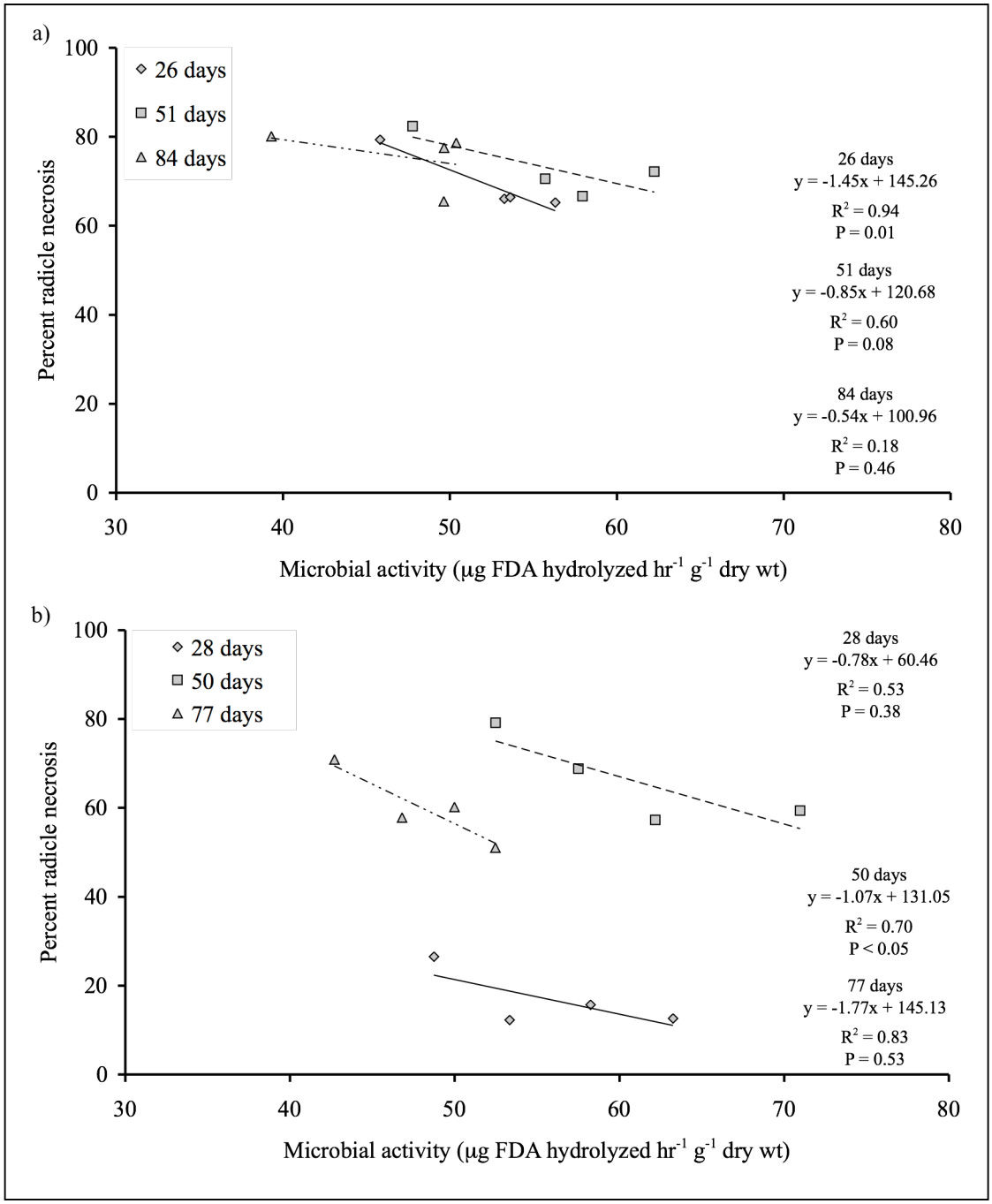

Fig. 4.12. Correlation between microbial activity and radicle necrosis: greenhouse bioassays. a) summer and b) winter cover crop experiments at three different sampling dates.

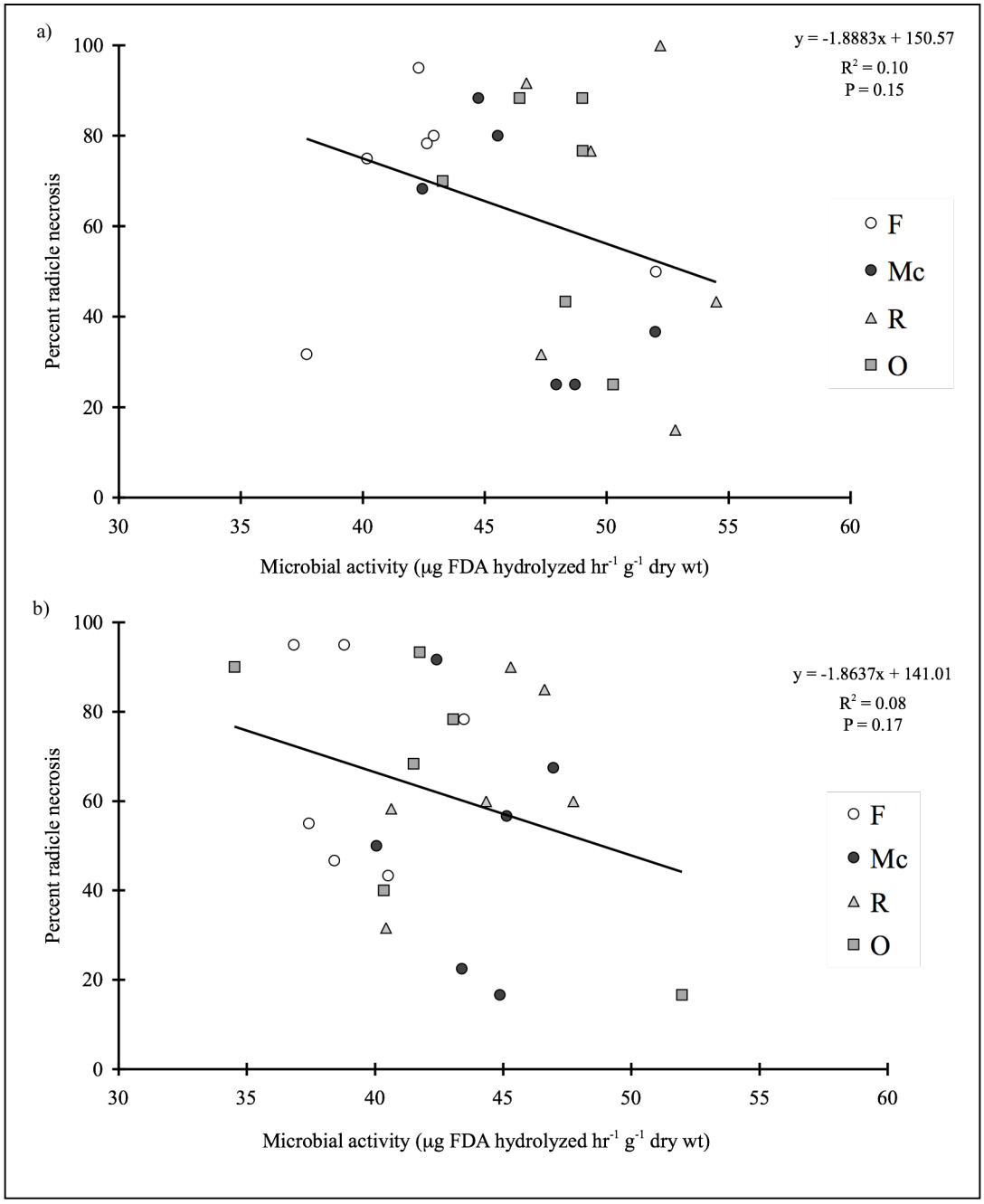

Fig. 4.13. Correlation between microbial activity and radicle necrosis: a) summer and b) winter cover crop experiments at harvest.

Soil NO_3-N Mineralization

Summer cover crop experiment:

Extractable soil NO_3-N at 70 days after incubation (302 days after incorporation) was significantly higher in all cover crop treatments than in the F treatment ($P \leq 0.01$). The net increase in soil NO_3-N from the Mc, O and R treatments was 5.4, 7.1, and 7.8 mg N kg^{-1} dry wt, respectively (Table 4.6).

C : N ratio in Mc, R, and O treatments was approximately 26, 9, and 17, respectively. Nitrogen content in the Mc, R, and O residues was approximately 162, 376, and 270 kg ha^{-1}, respectively (Table 4.7).

Winter cover crop experiment:

Extractable NO_3-N from soil at 70 days after incubation (127 days after incorporation) was significantly higher in all cover crop amended treatments than the F treatment ($P \leq 0.0001$). The net increase of soil NO_3-N from the O, Mc, and R treatments was 8.5, 14.3, and 28 mg N kg^{-1} dry wt, respectively (Table 4.6). Overall, net NO_3-N mineralization from the winter cover crop treatments was higher than from the summer cover crop treatments.

C : N ratio in Mc, R, and O treatments was approximately 18, 11, and 16, respectively. Nitrogen content in the Mc, R, and O residues was approximately 246, 332, and 160 kg ha^{-1}, respectively (Table 4.7).

Table 4.6. Extractable NO_3-N: laboratory incubation. Soils were sampled at 232 and 57 days after incorporation of summer and winter cover crops, respectively, and incubated for 70 days.

Treatment	Extractable NO_3-N	Net available NO_3-N
----- Summer -----	---------- mg N kg^{-1} dry wt ----------	
R	37.2 (1.0) A[†]	7.8
O	36.5 (1.5) A	7.1
Mc	34.8 (0.9) A	5.4
F	29.4 (1.6) B	----
----- Winter -----		
R	68.0 (3.2) X	28.0
Mc	54.3 (2.0) Y	14.3
O	48.5 (1.6) Y	8.5
F	40.0 (1.9) Z	----

[†]Different letters indicate significant difference between treatments ($P = 0.05$) according to least significant difference test. Number between parentheses indicates standard error.

Table 4.7. Soil NO_3-N mineralization and N content in cover crop residue in summer and winter experiment.

Treatment	Dry matter	Total C	Total N	C/N ratio	Net available NO_3-N	N content in cover crop residue
---------- Summer ----------	--- Mg ha^{-1} ---	---------- % ---------			----- mg kg^{-1} -----	------- kg ha^{-1} -------
Mc	10.2	42.9	1.59	27.0	5.4	162.2
R	8.4	41.2	4.47	9.2	7.8	375.5
O	11	41.5	2.45	16.9	7.1	269.5
--------- Winter ---------	--- Mg ha^{-1} ---	---------- % ---------			----- mg kg^{-1} -----	------- kg ha^{-1} -------
Mc	10.3	42.1	2.39	17.6	14.3	246.2
R	8.5	41.5	3.90	10.6	28.0	331.5
O	5.9	41.9	2.71	15.5	8.5	159.9

§Soil cores (15 cm depth, 2.5 cm diameter) were sampled from each plot at 232 and 58 days after cover crop incorporation in summer and winter experiment, respectively. Collected soils with incorporated cover crop residues were incubated for 70 days at 22 °C. Mean soil moisture was 24.8 and 24.5 % in summer and winter experiment, respectively.

MATERIALS AND METHODS

On-farm field experiment at Kenagy Family Farm (2005)

Site description

An on-farm trial was conducted at the Kenagy Family Farm in west Albany, Oregon. The soil at the study field is classified as a Chapman loam, which consists of very deep and well-drained soils that formed in mixed alluvium. The general climatic condition in the Willamette Valley is similar to a Mediterranean climate, which is dry and warm in the summer and cool and moist in the winter. The annual precipitation is 111 cm, and average temperature in July is 18.9 °C and average temperature in January is 3.3 °C.

Cropping history

The cropping history for the study field was sweet corn (*Zea mays* L.) in 2005, 2003, and 2001 and snap beans (*Phaseolus vulgaris* L.) in 2004, 2002 and 2000.

Table 4.8. List of cover crop treatments, sources, and seeding rates.

Abbreviation	Description	Source	Seeding rate
	--- winter experiment ---		kg ha^{-1}
Mc	Mustard mix 'Caliente': *Brassica juncea* and *Sinapis alba* mixture	High Performance Seeds Inc., Moses Lake, WA	6.6
A	Arugula: *Eruca sativa* L.	High Performance Seeds Inc., Moses Lake, WA	4.0
O	Oat 'Saia': *Avena sativa* L.	Kenagy Family Farm	56.0
F	Fallow	----------	------

Experimental design

Fall cover crop treatments were assigned in a pseudo-replicated strip design across a circular pivot. The field experiment was laid out in a long strip across the

entire pivot in the direction of crop rows; it ran the length of the field and was 73 m in width. Eighteen meter wide strips that ran the length of the field were each divided into three sections to create three ‘pseudoreplicate’ plots within the strip. Each plot was 80 m by 18 m (Fig. 4.14).

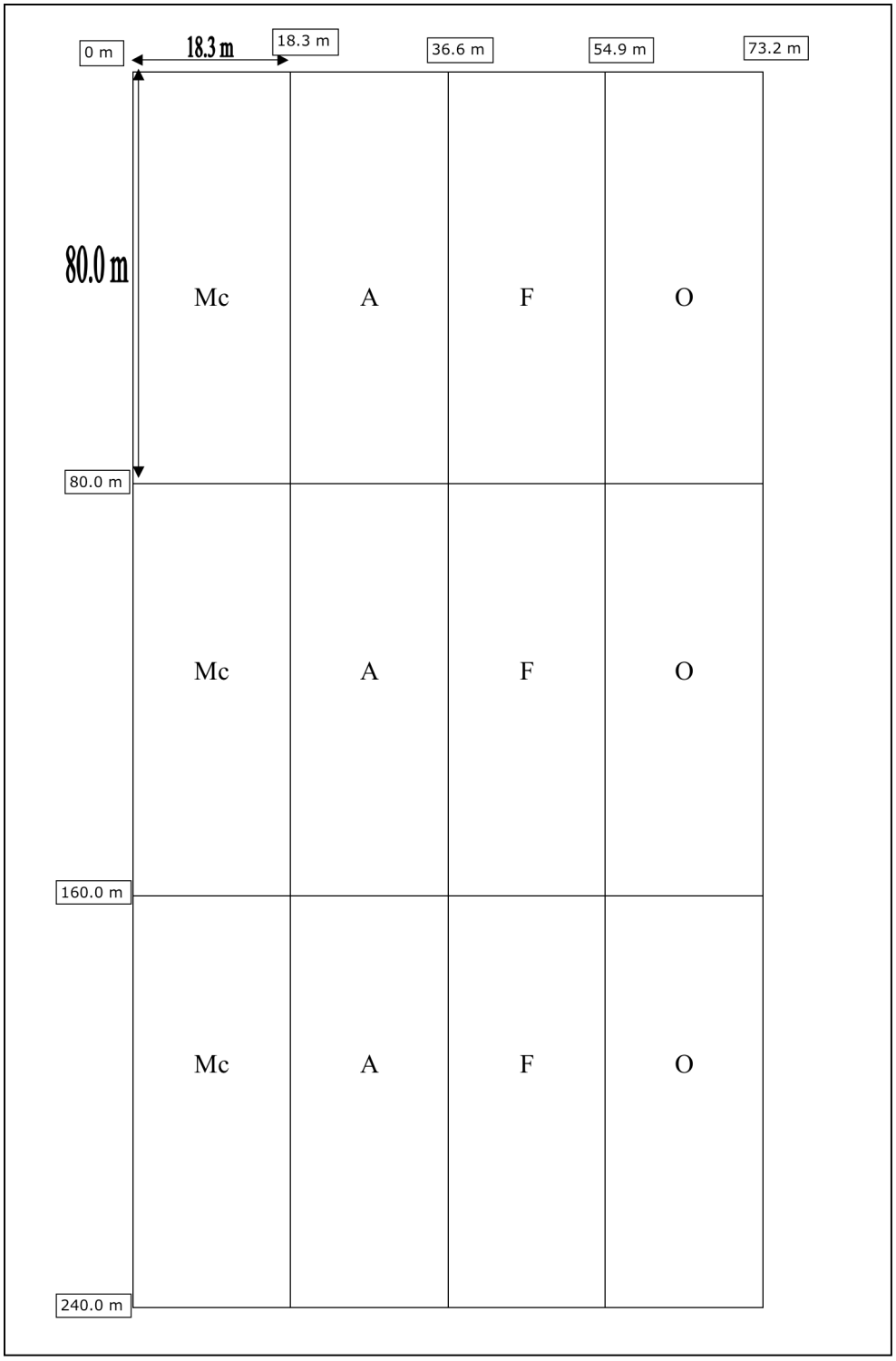

Fig. 4.14. Schematic of the experimental design for on-farm experiment at Kenagy Family Farm.

Treatments

Cover crop management:

Treatments are listed in Table 4.8. The O treatment was planted August 17th, 2004. The Mc treatment was planted September 16th, 2004, and the A treatment was planted September 15th, 2004. All treatments were drilled to approximately 5.1 cm depth.

Aboveground biomass was collected from three randomly selected quadrats (50.8 cm by 50.8 cm) in each plot. The Mc and A treatments were sampled on March 16th, 2005, and the O treatment was sampled on March 29th, 2005. An approximately 600 g subsample was taken and dried at 38 °C for 48 hr to determine moisture content and cover crop dry matter. All cover crops were flailed and incorporated into the soil with a rotovator to a depth of approximately 12 cm on March 23rd, 2005.

Sweet corn crop management:

Sweet corn 'Super Sweet Jubilee' was planted on June 14th 2005 at approximately 3.8 cm deep and 20 cm apart in rows on 0.76 m center. The crop received starter fertilizer at a rate of 56, 67, and 28 kg ha^{-1} of N, P_2O_5, and K_2O, respectively. Owner of Kenagy Family Farm sampled leaves (approximately 3 leaf stage) from the experimental field for tissue analysis. Based on the tissue analysis, the F, Mc, and A treatments were side-dressed with 45 kg N ha^{-1} at the 6 leaf stage. The O treatment received 67 kg N ha^{-1} at the 6 leaf stage.

Soil sampling

Soils were sampled for the greenhouse root rot bioassay on May 12th, 2005, approximately 49 days after cover crop incorporation. Ten soil wedges were randomly sampled from each treatment plot. Each soil wedge (approximately 13 cm x 5 cm x 15 cm) was sampled with a sharpshooter shovel (AMS Inc., American Falls, ID). Ten sampled soil wedges were passed through a 2.54 cm screen and mixed thoroughly before potting in cone-tubes.

Greenhouse root rot bioassay

Processed soil samples were potted into ten 550 mL cone-shaped tubes (Stuewe & Sons Inc., Corvallis, OR) per plot. Cone-tubes were gently tapped to settle the soil.

Two seeds of sweet corn 'Golden Jubilee' treated with Captan were planted about 2.54 cm deep in each cone-tube and thinned to one plant after emergence. Cone tubes were irrigated daily to maintain soil moisture near field capacity. Bioassays were grown in a greenhouse at approximately 24 ºC day and 18 ºC night with photoperiod under natural sunlight. Cone tubes were fertilized weekly with liquid fertilizer (0.058 g N, 0.038 g P, and 0.049 g K cone-tube^{-1} week^{-1}, Schultz Co., St. Louis, MO). When the corn plants reached the six-leaf stage, plants were harvested. Roots were washed and evaluated by visual assessment for percent necrosis of radicle and nodal roots. Root rot severity was assessed on an eight-point scale: 0 = healthy, 1 = 1 to 10 % necrotic, 2 = 11 to 20 % necrotic, 3 = 21 to 40 % necrotic, 4 = 41 to 60 % necrotic, 5 = 61 to 80 % necrotic, 6 = 81 to 90 % necrotic, 7 = 91 to 99 % necrotic, and 8 = 100 % necrotic root.

In-field bioassays

Fifteen plants from 12 rows per plot were randomly sampled for evaluating root rot severity and shoot biomass at approximately 30, 42, 64, and 102 days after planting, which approximated the three-leaf (July 13, 2005), six-leaf (July 25, 2005), tasseling (August 16, 2005), and maturity (harvest) (September 23, 2005) developmental stages. The sampled roots were washed, and disease severity of the radicle and nodal roots was evaluated by visual assessment using the eight-point scale described above. Shoots were dried at 37.7 ºC for 48 hrs and weighed to determine aboveground dry matter.

Sweet corn yield

Corn ears from fifteen randomly chosen plants per plot were harvested by hand at maturity to assess corn yield. Marketable yield of corn was determined by weighing

the corn ears without husks. All ears of less than approximately 15 cm of edible corn kernels were discarded.

RESULTS

Cover crop dry matter

There were no significant treatments differences in aboveground dry matter ($P > 0.05$) (Table 4.9).

Table 4.9. Cover crop dry matter: Kenagy Family Farm.

Treatment	Aboveground dry matter
	----- Mg ha^{-1} -----
Mc	7.9 (0.3)
A	9.0 (0.4)
O	8.5 (0.4)
	NS‡

Number between parentheses indicates standard error. ‡NS indicates there are no significant differences between treatments based on LSD test ($P = 0.05$).

Root rot severity in greenhouse bioassays

There was no treatment difference in radicle or nodal root rot severity in the greenhouse bioassays ($P \geq 0.05$) (Table 4.10). However, radicle and nodal root rot severity in the A treatment was numerically 14.3 ($P = 0.12$) and 6.9 % ($P > 0.5$) lower, respectively, than in the F treatment (Table 4.10).

Table. 4.10. Disease severity: greenhouse grown corn from Kenagy Family Farm. 49 days after incorporation.

Treatment	Percent radicle necrosis	Percent nodal root necrosis
F	81.3 (4.0)	36.2 (3.2)
A	69.3 (4.7)	33.8 (2.8)
Mc	82.0 (3.6)	38.1 (2.5)
O	77.7 (4.4)	37.2 (2.4)
	NS‡	NS

Number between parentheses indicates standard error. ‡NS indicates there are no significant differences between treatments based on LSD test ($P = 0.05$).

Root rot severity in field grown corn

On average, radicle rot severity in all cover crop treatments was 64.4 % lower than the F treatment at 113 days after incorporation ($P \leq 0.0001$) (Fig.4.15). There were no significant differences among cover crop treatments in radicle rot severity at 125 days after incorporation ($P = 0.20$), but nodal root rot severity in the O treatment was approximately 48 % higher than in all other treatments ($P = 0.08$) (Fig.4.15). There were no significant differences among cover crop treatments in radicle rot severity at 139 days after incorporation ($P = 0.16$) (Fig.4.15). On average, nodal root rot severity in the A, Mc, and O treatments was 31.9 % lower than the F treatments at 147 days after incorporation ($P \leq 0.0001$) (Fig.4.15). On average, radicle and nodal root rot severity in the A, Mc, and O treatments were 22.7 and 32.6 %, respectively, lower than in the F treatment at 185 days after incorporation (Fig.4.15).

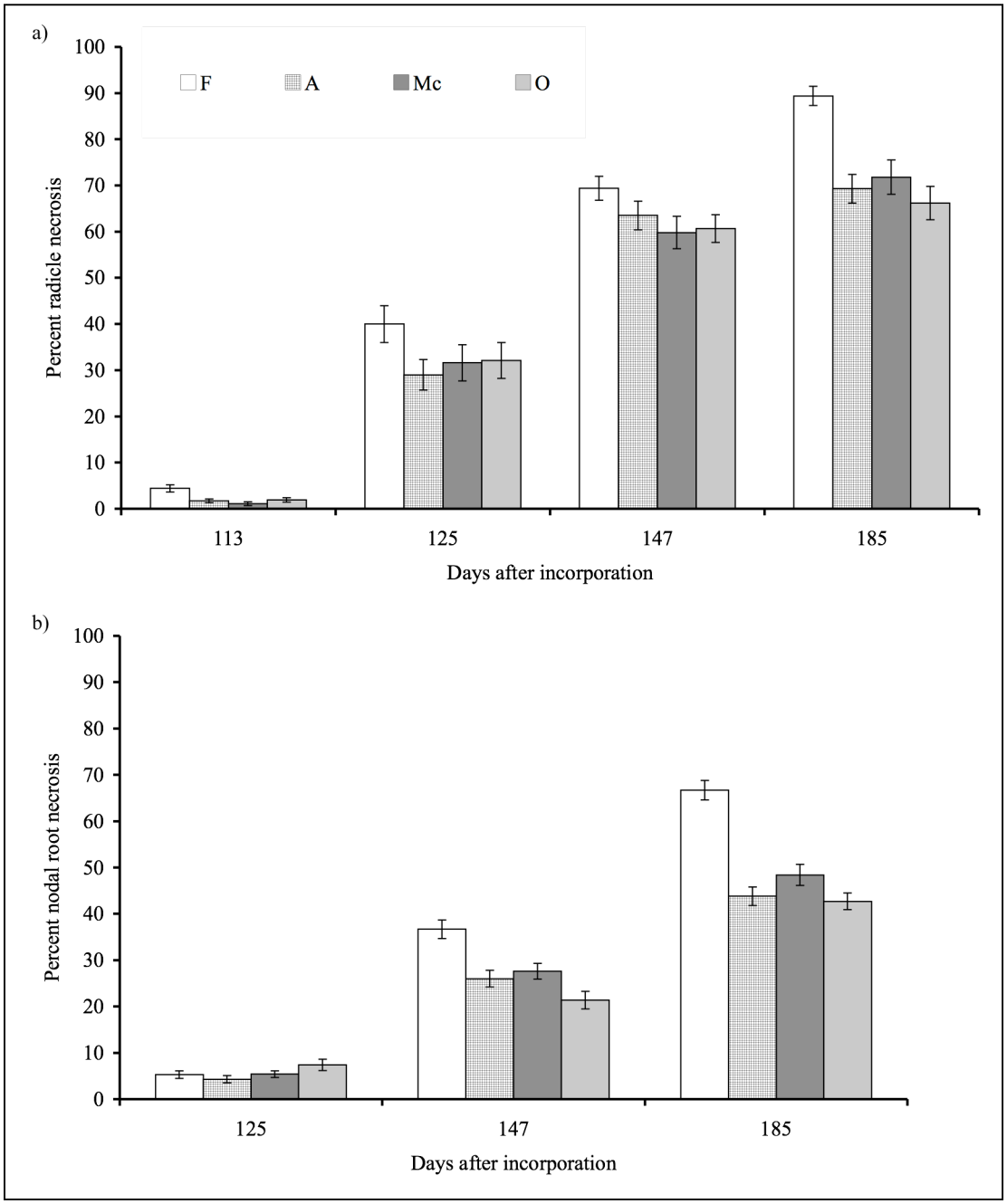

Fig. 4.15. Disease severity at 113, 125, 147, and 185 days after incorporation: field-grown corn at Kenagy Family Farm. Mean percent a) radicle and b) nodal root necrosis. †Error bars indicate standard error.

Sweet corn dry matter

There were no significant differences among treatments at 113, 125, and 147 days after incorporation ($P \geq 0.05$). The mean aboveground dry matter from the O treatments was numerically lower than all other treatments at 147 days after incorporation. The dry matter of the O treatment was 27.6 % lower than in the F at 147 days after incorporation (Table 4.11).

Table 4.11. Aboveground dry matter at 113, 125, and 147 days after incorporation: Field-grown corn. Kenagy Family Farm.

Treatment	Days after incorporation	Mean aboveground dry matter
		---------- g plant^{-1} ----------
F	113	7.1 (0.7)
A	113	6.6 (0.8)
Mc	113	7.5 (0.6)
O	113	7.2 (0.5)
		NS‡
F	125	13.7 (0.6)
A	125	12.0 (1.2)
Mc	125	13.2 (1.1)
O	125	15.1 (1.5
		NS
F	147	114.2 (18.2)
A	147	110.7 (11.8)
Mc	147	101.8 (15.5)
O	147	82.7 (14.5)
		NS

Number between parentheses indicates standard error. ‡NS indicates there are no significant differences between treatments based on LSD test ($P = 0.05$).

Sweet corn yield

There were no significant differences in mean yield or mean ear weight among treatments ($P = 0.66$). The mean ear weight in the O treatment was numerically 7.5 %

lower than in the F treatment (Table 4.12). The mean yield of the O treatment was numerically 7.7 % lower than the F treatment (Table 4.12).

Table 4.12. Sweet corn yield (Mg ha^{-1}): Kenagy Family Farm.

Treatment	Mean ear weight	Mean yield
	---------- g plant^{-1} ----------	---------- Mg ha^{-1} ----------
F	325.2 (6.4)	19.3 (0.4)
A	316.5 (28.6)	18.7 (1.7)
Mc	349.0 (15.2)	20.7 (0.9)
O	300.8 (15.4)	17.8 (0.9)
	NS‡	NS

Number between parentheses indicates standard error. ‡NS indicates there are no significant differences between treatments based on LSD test (P = 0.05).

Summary: Research station experiment (summer and winter, 2005)

Cover crop dry matter and winter hardiness

August 19-seeded (October 14-flailed) summer cover crop dry matter was 8.4, 10.2 and 11.0 Mg ha^{-1} in the R, Mc, and O treatments, respectively. September 24-seeded (April 6-flailed) winter cover crop dry matter was 5.9, 8.5 and 10.3 in the O, R, and Mc treatments, respectively. No cover crops were completely winter-killed, but the winter oat DM was 50% of that of the summer O treatment due to winter injury and BYDV infection.

Root rot severity

All cover crops were suppressive to root rot in greenhouse root rot bioassays conducted on winter and summer experiment soils and in field grown corn in the winter experiment. Overall, there was not much difference in suppressiveness amongst the cover crop treatments in greenhouse experiments. The Mc and O treatments were more suppressive than the R treatment in summer greenhouse experiments. The R treatment was more suppressive in winter than in summer greenhouse experiments, and slightly more suppressive than the Mc and O treatments in winter greenhouse experiments.

In the field, there was little suppressiveness generated by the summer cover crop treatments. All cover crop treatments were suppressive in the winter field experiment, but the R and O treatments were more suppressive than the Mc treatment.

Corn productivity

No cover crop treatments reduced above- or below-ground DM in any greenhouse bioassays. All cover crop treatments except the O treatment significantly increased above- and below-ground DM on at least one sampling date in bioassays conducted on summer experiment soils; the O treatment had no effect on above- and below-ground DM at any sampling date. All cover crop treatments increased above- and below-ground DM in greenhouse bioassays conducted on winter experiment soils.

There were no differences in DM or yield in field experiments; twelve-spot beetle larvae damaged the fallow treatment corn seedlings in the winter experiment, so yield could not be taken for that treatment.

Microbial activity

Microbial activity was higher in all cover crop treatments in the summer experiment except at day 250 after incorporation. Microbial activity was higher at all sampling dates except day 85 for both the Mc and R treatments in the winter experiment.

Relationship between microbial activity and root rot severity

Radicle rot severity and the rate of hydrolysis of FDA were significantly negatively correlated when data from all summer experiment greenhouse bioassay sampling dates were combined. As microbial activity increased, root rot severity declined. For individual sampling dates, the correlation was strongest and the slope most negative at 26 days, intermediate at 51 days, and weakest (and no longer significant) at 84 days after incorporation.

There was no overall correlation between the rate of FDA hydrolysis and mean radicle rot severity across the three sampling dates in the winter experiment greenhouse bioassays ($P \geq 0.05$, $R^2 = 0.04$) (Fig. 4.11). This was due largely to the very low root rot severity ratings at day 28. However, in addition, there was only a significant negative correlation between FDA activity and radicle rot severity at 55 days after incorporation and not at the other two sampling dates.

Nitrogen mineralization

There was little net N mineralization in the summer experiment in all cover crop treatments (5 to 8 mg N kg^{-1} dry wt). The net available N in the winter experiment was higher than in the summer experiment, and the Mc and R treatments mineralized 40.6 and 69.4 % more than the O treatment. The net available N in the O treatment was almost the same value in both summer and winter experiments.

Summary: On-farm experiment (Kenagy Family Farm, 2005)

Cover crop dry matter and winter hardiness

The O treatment was planted August 17, The Mc treatment was planted September 16, and the A treatment was planted September 15, 2004. All cover crop treatments were flailed on March 23, 2005. All cover crops survived the winter. Cover crop aboveground dry matter averaged 8.5 Mg ha^{-1} across all cover crop treatments, and there was no DM treatment effect.

Root rot severity:

There was no treatment effect on root rot severity in the one greenhouse bioassay conducted at 47 days after cover crop incorporation. However, all cover crop treatments suppressed root rot in field-grown corn, and there was no difference in the degree of suppressiveness of the cover crop treatments. On average, radicle rot severity in all cover crop treatments was 64.4 % lower than the F treatment at 113 days; nodal root rot severity was 31.9 % lower than the F treatments at 147 days after incorporation; and radicle and nodal root rot severity were on average 22.7 and 32.6 %, respectively, lower than in the F treatment at 185 days after incorporation.

Corn productivity:

Aboveground corn dry matter was lower in all cover treatments at all sampling dates. There were no significant differences in yield. The oat treatment generated numerically, but not significantly, lower DM at 147 days and yield than all other treatments.

Microbial activity

No soil measurements were taken.

Relationships between microbial activity and root rot severity.

No soil measurements were taken.

CHAPTER 5

RESEARCH STATION EXPERIMENT (2005-2006)

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MATERIALS AND METHODS

Rape 'Dwarf Essex' Experiment (2006)

Site description

The field experiment was located at the Oregon State University Vegetable Research Farm east of Corvallis, Oregon. The soil at the study field is classified as a Chehalis silt clay loam. The general climatic condition in the Willamette Valley is similar to a Mediterranean climate, which is dry and warm in the summer and cool and moist in the winter. The annual precipitation is 111 cm, and average temperature in July is 18.9 °C and average temperature in January is 3.3 °C.

Cropping history

The cropping history for the study field was sweet corn (*Zea mays* L.) in 2005, 2003 and 2000. Squash (*Cucumis pepo* L.) and cucumber (*Cucumis sativus* L.) were planted in 2001. The field was fallow in early 2004 and 2002. Cover crops were planted in fall of 2004, including Oats 'Saia' (*Avena sativa*), mustard mix 'Caliente' (*Brassica juncea* L. and *Sinapis alba* L.), and rape 'Dwarf Essex' (*Brassica napus*).

Experimental design

The field is approximately 73.2 m by 29.9 m. Each testing plot was 12.2 m by 6.1 m. The trial was a laid at in a randomized complete block design with 12 replications (Fig. 5.1). Source of seed and abbreviation were illustrated on Table 5.1.

Table 5.1. List of cover crop treatments, sources, and seeding rates.

Abbreviation	Description	Source of seeds	Seeding rate
	----- winter -----		--- kg ha^{-1} ---
R	Rape 'Dwarf Essex': *B. napus* with 113 kg N ha^{-1} urea application at 6 leaf stage	Bailey Seed Inc., Salem, OR	13.5
F	Fallow with 113 kg N ha^{-1} urea application at 6 leaf stage	------	------

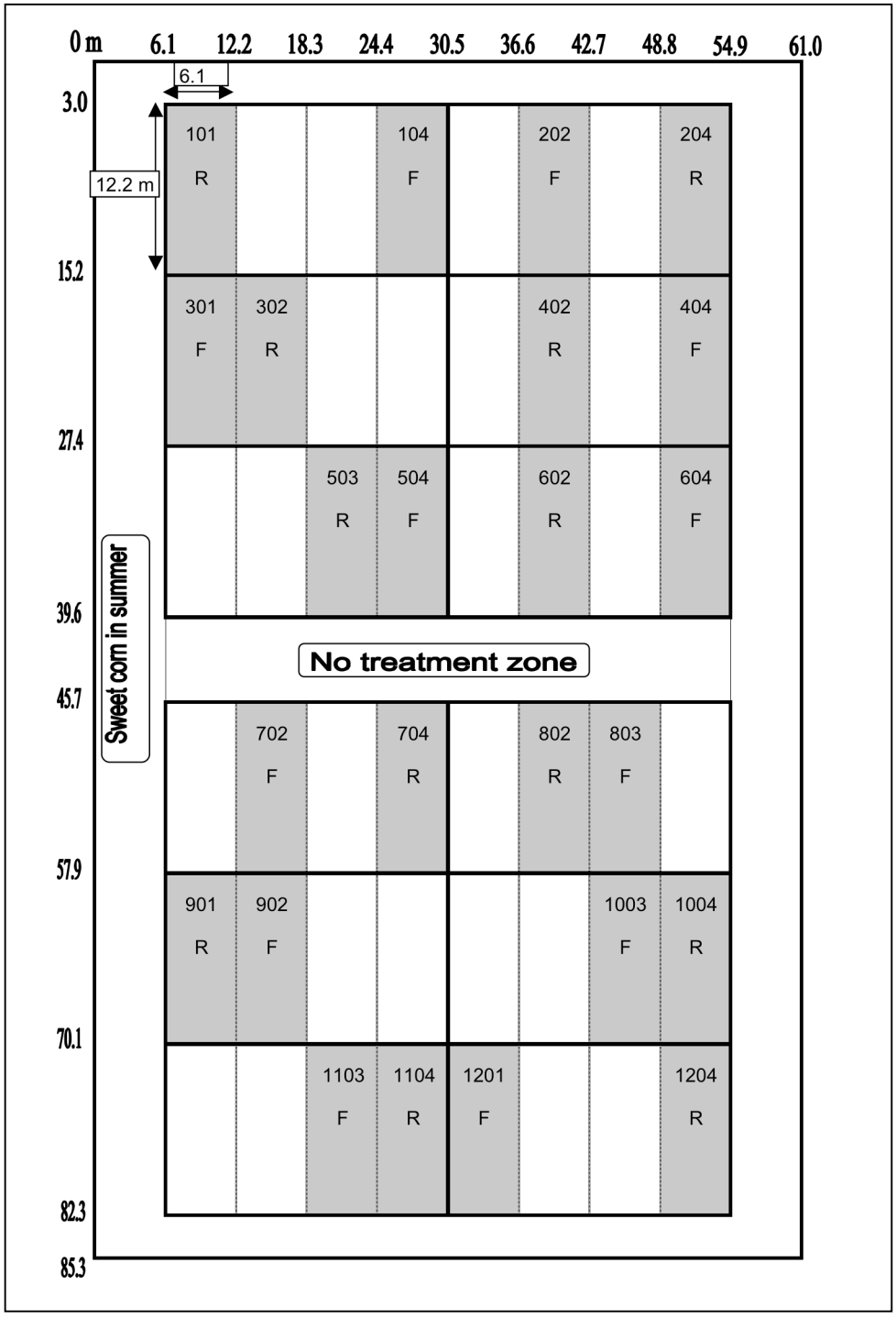

Fig. 5.1. Schematic of the experimental design for the field trial: rape cover crop experiment.

Treatment

Cover crop management:

Cover crops (O, Mc and R) were seeded into the summer cover crop experiment (in exactly the same plots as in the previous year's research station experiment) on September 9, 2005, approximately two weeks after harvesting sweet corn. Cover crop seedlings emerged but grew slowly due to stunting by the decomposing corn residues. Consequently, the cover crops in the summer experiment did not put on enough growth in the late summer to incorporate before the fall rains began, and they were allowed to grow through the winter along with the cover crops in the winter experiment. Subsequently, the O and Mc treatments were winter-killed in both the summer and winter experiments. As the result, there was no summer experiment, and the winter experiment included only the treatments R and F.

The treatments and seeding rate is listed in Table 5.1. Treatment R was seeded and all plots were tilled to a depth of 5.1 cm by rotovator on September 20, 2005.

Cover crop aboveground dry matter was collected on April 27, 2006 before incorporation. Three aboveground dry matter quadrats, approximately 50.8 cm by 50.8 cm, were randomly taken from each plot. Samples were air dried for 40 days at 32.7 ºC. Cover crop treatment plots were flailed on May 2, 2006; residues were manually spread over the plots, and immediately rotovated to a 12 cm depth.

Sweet corn crop management:

Captan treated seed of sweet corn 'Reward' (Rogers Seeds: Syngenta Seed Inc., Boise ID), was planted across the entire field on June 9, 2006 at approximately 3.8 cm deep and 20 cm apart in rows on 0.76 m center. This cultivar is early maturing and root rot intolerant. The seeding rate of corn was approximately 7 seeds m^{-1} and the stand was thinned to 5 plants m^{-1} when seedlings emerged. Starter fertilizer (N-P-K: 12-29-10) was applied at a rate of 60 kg N ha^{-1}. At 47 days after planting, urea was applied as a side-dress at 113 kg N ha^{-1} of N

Soil sampling

Greenhouse cone-tube bioassay:

At approximately 50 and 84 days after cover crop incorporation, soils were sampled for the greenhouse root rot bioassay and in-field nitrate-N extraction. For greenhouse root rot bioassays, ten soil wedges were randomly sampled from each treatment plot. Each soil wedge (approximately 13 cm x 5 cm x 15 cm) was sampled with a sharpshooter shovel (AMS Inc., American Falls, ID). Ten sampled soil wedges were passed through a 2.54 cm screen and mixed thoroughly before potting in cone-tubes.

Microbial activity:

At 84 days after incorporation, soils were sampled for analysis of the rate of hydrolysis of fluorescein diacetate (FDA). Ten soil cores (approximately 15 cm depth by 2.5 cm diameter) were removed from each plot. Each soil core was sieved through an 8 mm sieve and a 2 mm sieve, mixed thoroughly, and stored at 4 ºC in a Ziploc bag.

Soil nitrogen assessment:

For in-field nitrate-N extraction, ten soil cores (approximately 15 cm depth by 2.5 cm diameter) were taken from each plot at 19 and 84 days after rape incorporation. Each soil core was sieved through a 4.75 mm sieve and mixes thoroughly and stored at 22 ºC in Ziploc bag.

For the laboratory mineralization incubation, soil was collected from a fallow field at the OSU vegetable farm. Forty soil wedges (approximately 13 cm x 5 cm x 15 cm each) were randomly sampled from field with a sharpshooter shovel (AMS Inc., American Falls, ID). All soil wedges were sieved through a 4.75 mm sieve, mixed thoroughly, and stored at 22 ºC in a Ziploc bag.

Greenhouse root rot bioassays

Field soils were sampled and processed as described above and potted into ten 550 mL cone-shaped tubes (Stuewe & Sons Inc., Corvallis, OR) per plot (n = 10). Cone-tubes were gently tapped to settle the soil.

Two seeds of sweet corn 'Golden Jubilee' treated with Captan were planted in each tube at 2.54 cm depth and thinned to one plant after emergence. Bioassays were grown in a greenhouse at approximately 24 ºC day and 18 ºC night with photoperiod under natural sunlight. Cone tubes were irrigated daily to maintain soil moisture near field capacity and were fertilized weekly with liquid fertilizer (0.058 g N, 0.038 g P, and 0.049 g K cone tube $^{-1}$ week^{-1}, Schultz Co., St. Louis, MO). Corn plants were harvested when they reached the six-leaf stage. Roots were washed and evaluated by visual assessment for percent necrosis of the radicle and nodal roots. Percent necrosis was evaluated on an eight-point scale: 0 = Healthy, 1 = 1 to 10 % necrotic, 2 = 11 to 20 % necrotic, 3 = 21 to 40 % necrotic, 4 = 41 to 60 % necrotic, 5 = 61 to 80 % necrotic, 6 = 81 to 90 % necrotic, 7 = 91 to 99 % necrotic, and 8 = 100 % necrotic root. Shoots and roots were then dried and weighed to assess above- and below-ground dry matter.

In-field bioassays

For field grown sweet corn, three plants per plot were randomly sampled for evaluating root rot severity and aboveground dry matter at approximately 55 days (6 leaf stage) and 84 days (harvest) after planting. The sampled roots were washed, and disease severity of the radicle and nodal roots was assessed by visual assessment using the eight-point scale as described above. Aboveground dry matter was dried at 37.7 ºC for 48 hr and weighed.

Corn yield

Corn ears from two center rows per plot (approximately 3 m per row) were harvested by hand to assess corn yield. Ears were husked and ears with less than 15 cm of edible corn kernels were discarded.

Soil nitrogen analysis

Laboratory method for aerobic incubation:

Soils sampled as described above were brought to approximately 25 % gravimetric moisture by adding distilled water with a spray bottle, and approximately 625 g of moist soil was mixed and stored in an incubation bag (Ziploc, Johnson & Son. Inc.). The rape treatment received approximately 0.44 g kg^{-1} (dry wt basis) of rape residue; the fallow treatment soils were not amended with plant residues. A straw was inserted into each bag to allow air circulation. Each bag was placed into a 30 L plastic tub. A moistened foam pad (approximately 2.5 cm depth) was placed at the bottom of the incubation tub and was re-moistened approximately every 7 days to maintain humidity. The bags were incubated at 22 °C for 63 days.

At days 0, 21, 42, and 63, incubated soils were sampled and mineralized nitrate and ammonium contents were measured. A 15 g soil sample removed from each incubation bag and placed into a 125 mL Erlenmeyer flask. Fifty ml of 2 M KCl was added to each flask, and the flasks were shaken at 178 rev min^{-1} for 1 hr. Colloids of soil and 2 M KCl were filtered by Whatman No. 42 filter paper and analyzed for inorganic N by colorimetric analysis using the cadmium reduction method (Keeney and Nelson, 1982). Gravimetric soil moisture content was determined for each sample by oven-drying approximately 10 g of soil at 105 °C for 24 hr, and the obtained values were used to calculate soil N concentration on a dry soil basis.

Field soil NO_3-N extraction:

Field soils were sampled for N availability as described above. An irrigation was scheduled for approximately 36 hrs before sampling to raise soil moisture contents to near field capacity. A 15 g moist sample was removed from each aggregated sample and placed into a 125 mL Erlenmeyer flask. Fifty ml of 2 M KCl was added to each flask. Flasks were shaken at 178 rev min^{-1} for 1 hr, and the resulting solution was filtered with Whatman No. 42 filter paper. The filtrate was refrigerated at 4 ºC in capped plastic cuvettes until analyzed. Inorganic N was analyzed by colorimetric analysis by the cadmium reduction method (Keeney and Nelson, 1982) by the OSU Central Analytical Laboratory. Gravimetric soil moisture content was determined for each sample by oven-drying approximately 10 g of soil at

105 °C for 24 hr, and the obtained values were used to calculate soil N concentration on a dry soil basis.

Microbial activity

Microbial activity was evaluated as the rate of hydrolysis of fluorescein diacetate at 48 h after each soil sampling by modifying the procedure used by Zelles et al. (1991). Approximately one gram wet basis soils (subsample of the soil stored at 4 ºC in Ziploc bag) were placed in a 125 ml Erlenmeyer flask (n = 4). Twenty mL of pH buffer (60 mM sodium phosphate at pH 7.6) was added to each flask. After 15 minutes shaking at 178 rpm, 100 μL of 4.8 mM fluorescein diacetate solution (3', 6' diacetylfluorescein) was added to three of the four flasks. The remaining flask (control) received 100 μL of fluorescein diacetate solution only after the addition of acetone. Flasks were shaken at 178 rev min^{-1} for 2 h at 25 °C on an Innova 2003 platform shaker (New Brunswick Scientific Co., Inc., Edison, NJ). The addition of 20 mL acetone to each flask instantly stopped the hydrolysis reaction, and then the samples were centrifuged for 5 min at 4960 times *g* (Model J2-HS, Beckman Coulter, Inc., Fullerton, CA) to separate the soil from the liquid. The separated samples were filtered (Whatman No 4), and the absorbance at the filtrate was measured at 490 nm with a spectrophotometer (Model DU 800, Beckman Coulter, Inc., Fullerton, CA). FDA activity was expressed as μg FDA hydrolyzed hr^{-1} g^{-1} dry wt soil and was compared to a standard curve. Background absorbance of the sample solutions was corrected by subtraction of the control absorbance.

Calculations

Net available N ($N_{available}$) for cover crop incorporated soil was calculated and expressed as mg kg^{-1}:

$$N_{available}\,(\text{mg N kg}^{-1}\text{ dry wt}) = (NO_3\text{-N})_{\text{cover crop}} - (NO_3\text{-N})_{\text{fallow}} \quad [1]$$

where NO_3-$N_{cover\ crop}$ is the amount of NO_3-N extracted from a incorporated cover crop treatments (mg kg^{-1}), NO_3-N_{fallow} is the amount of NO_3-N extracted from fallow treatment (mg kg^{-1}).

Amount of N in cover crop residue was calculated and expressed as N content ($N_{crop\ residue}$) in cover crop residue (mg kg^{-1}):

$$N_{crop\ residue}\ (mg\ kg^{-1}) = Total\ N\ (\%) \times DM_{cover\ crop}\ (mg\ kg^{-1}) \quad [2]$$

where Total N is percent of N in cover crop residue, $DM_{cover\ crop}$ is cover crop aboveground dry matter.

Statistical analysis

Statistical analysis was performed with SAS (SAS system for Windows 9, SAS Inst., 1999). Treatment effects on disease severity, dry matter, microbial activity, and yield for each sampling date was computed using analysis of variance (ANOVA) from the PROC GLM procedure. Treatment means were separated when F-test was significant ($P \leq 0.05$). Mean separation was performed by the LSD procedure using MEANS statement if sampling data was balanced. Treatment means were separated by the student's *t* test using LSMEANS statement when the sampling data was unbalanced. Linear regression analysis using PROC REG was computed in SAS to describe the relationship between root rot severity and microbial activity.

RESULTS

Cover crop biomass

Mean aboveground dry matter for rape "Dwarf Essex" (R) was 10.74 ± 0.32 dry Mg ha^{-1} (Table 5.3).

Greenhouse bioassays

Root rot severity:

Radicle rot severity was 15 % lower ($P = 0.02$) at 50 days after incorporation in the R treatment than in the F treatment at the 6-leaf stage. There was no significant difference in nodal root rot severity ($P = 0.11$) (Fig. 5.2). At 84 days after incorporation, radicle and nodal root rot severity were lower in the F treatment than in the R treatment by 22 and 34 %, respectively ($P \leq 0.01$) (Fig. 5.2).

Mean above- and below-ground dry matter:

Mean corn aboveground dry matter was 11.1 % higher in the R treatment than in the F treatment at 50 days after incorporation ($P = 0.01$) (Fig. 5.3). There was no treatment effect on corn belowground dry matter at 50 days. Mean above- and below-ground dry matters were 21.6 and 24.0 %, respectively, higher in the R treatment than in the F treatment at 84 days after incorporation ($P \leq 0.01$) (Fig. 5.3).

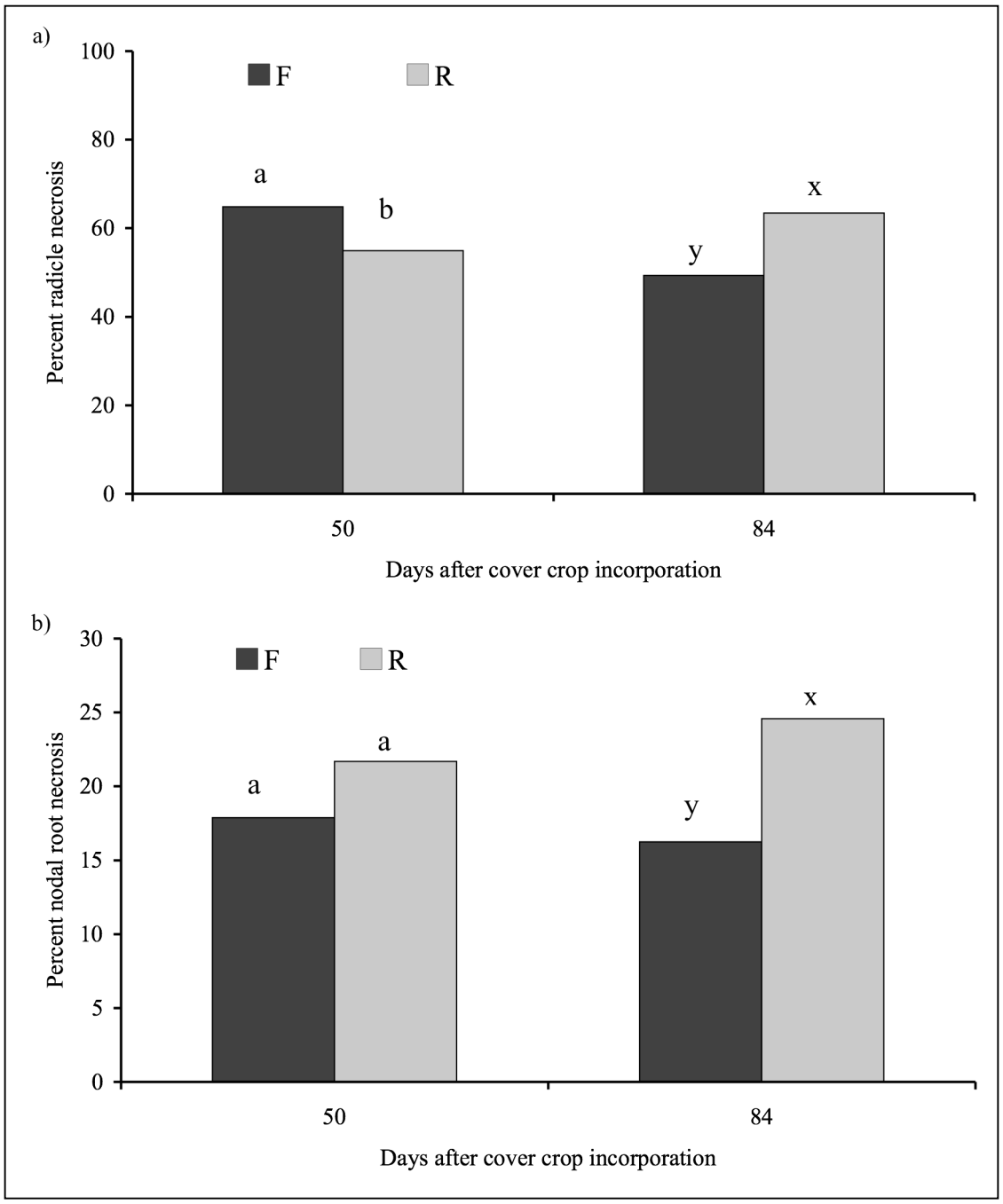

Fig. 5.2. Disease severity: a) radicle and b) nodal root rot severity. Greenhouse cone-tube bioassay at 50 and 84 days after incorporation. ‡Treatment bars followed by the same letter indicate not significantly different at P = 0.05 based on LSD test.

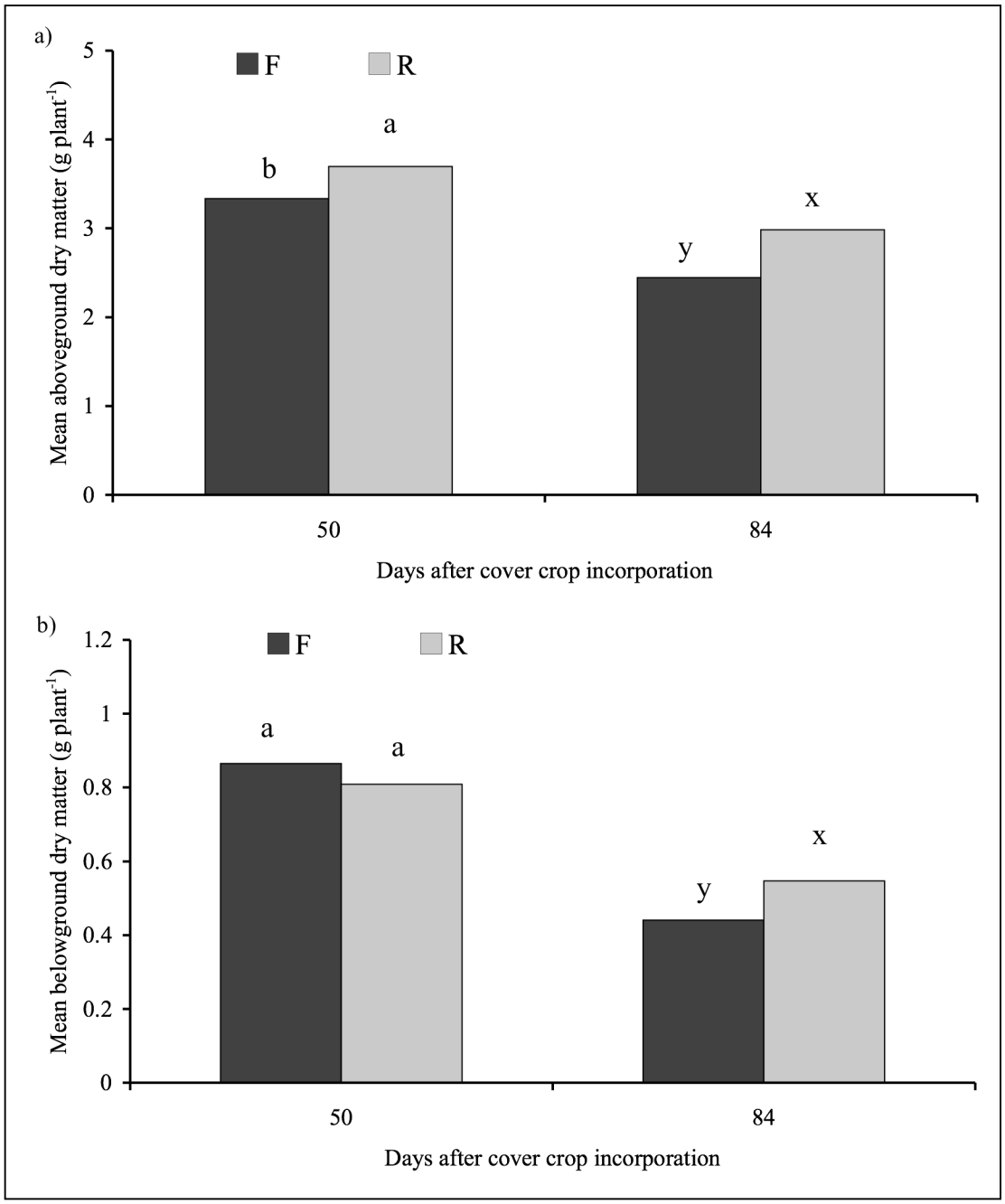

Fig. 5.3. Mean a) above- and b) below-ground dry matter: greenhouse cone-tube bioassay at 50 and 84 days after incorporation. ‡Treatment bars followed by the same letter indicate not significantly different at P = 0.05 based on LSD test.

Field-grown corn bioassay

Root rot severity:

There was no treatment effect on radicle rot severity at 92 and 120 days after incorporation. However, mean nodal root rot severity was 25 % lower ($P = 0.004$) in the F treatment than in the R treatment at 120 days after incorporation (Table 5.2).

Aboveground dry matter:

There was no treatment effect on mean aboveground dry mass at 92 and 120 days after incorporation (Table 5.2).

Corn Yield

There was no treatment effect on corn yield at harvest (Table 5.2).

Table 5.2. Disease severity, aboveground dry matter, and yield: field-grown corn.

Days after incorporation	Variable	Cover crop treatment		Significance
		F	R	
92	Radicle rot severity (%)	57.2 (7.2)	67.6 (8.8)	NS‡
	Nodal root rot severity (%)	27.1 (1.6)	27.1 (1.4)	NS
	Aboveground dry matter (g plant^{-1})	74.1 (3.0)	75.9 (3.2)	NS
120	Radicle rot severity (%)	78.7 (4.5)	86.9 (5.0)	NS
	Nodal root rot severity (%)	40.0 (1.9)	53.3 (2.7)	**
	Aboveground dry matter (g plant^{-1})	105.3 (5.2)	104.6 (7.2)	NS
	Yield of corn (Mg ha^{-1})	23.2 (0.3)	23.2 (0.4)	NS

** Indicates significance at $P \leq 0.01$ from pairwise comparison against fallow using LSD test. Number between parentheses indicates standard error. ‡NS indicates there are no significant differences between treatments based on LSD test ($P = 0.05$).

Correlation between cover crop aboveground dry matter and radicle rot severity

There was no correlation between rape aboveground dry matter and radicle rot severity at any sampling date (data not shown).

Soil nitrogen status

C : N ratio of rape:

Percent total C and N were 42.8 and 2.04, respectively (Central Analytical Laboratory, Oregon State Univ.). The C : N ratio of rape was 21.0 (Table 5.3).

Extractable soil NO_3-N:

There was no treatment difference in extractable soil NO_3-N at 19 days after incorporation ($P = 0.13$). Extractable soil NO_3-N content was 44.5 % higher in the R treatment (12.0 ± 0.6 mg kg^{-1} dry wt) than in the F treatment (8.3 ± 0.7 mg kg^{-1} dry wt) at 84 days after incorporation ($P = 0.007$) (Fig. 5.4). The net available NO_3-N for the R treatment at 19 and 84 days was -1.0 and 3.7 mg kg^{-1}, respectively (Table 5.3).

Cumulative extractable NO_3-N:

Cumulative extractable NO_3-N was significantly lower at days 21 and 42 (33.0 % and 21.6 %, respectively) in the R than in the F treatment (Fig. 5.5). There was no treatment effect on cumulative extractable NO_3-N at 63 days after incubation. Cumulative extractable NO_3-N increased in all treatments until day 63. The net available NO_3-N for the R treatment at days 0, 21, 42, and 63 was -0.3, -4.5, -4.9, and -2.1 mg kg^{-1}, respectively (Fig. 5.6).

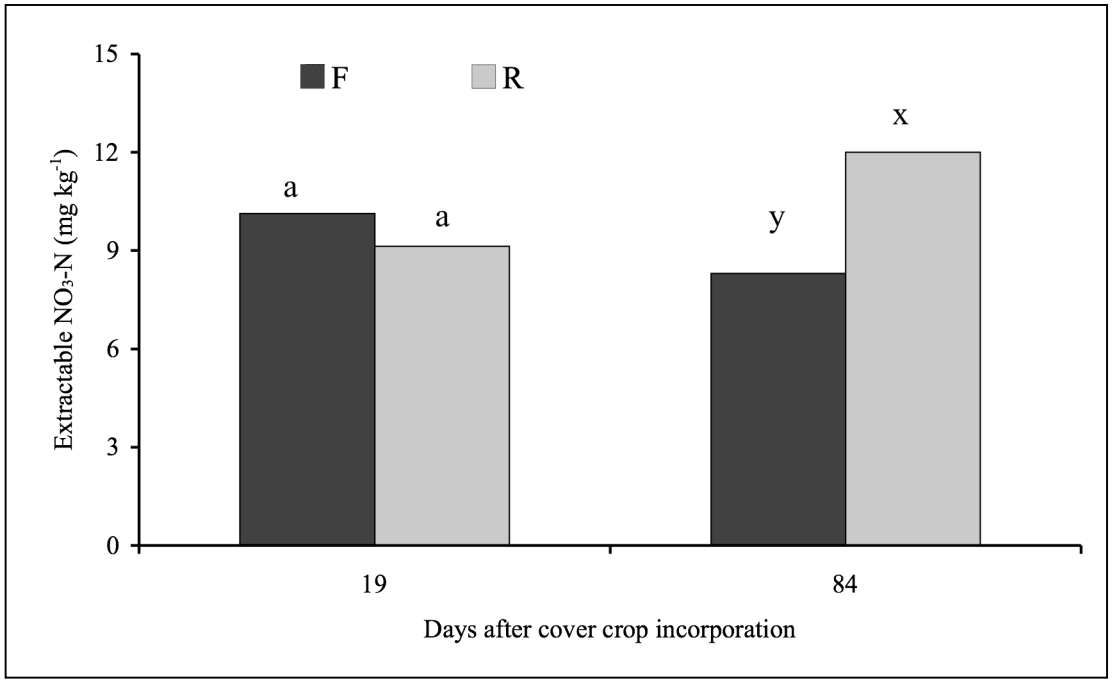

Fig. 5.4. Extractable NO_3-N in field soil at 19 and 84 days after incorporation. ‡Treatment bars followed by the same letter indicate not significantly different at P = 0.05 based on LSD test.

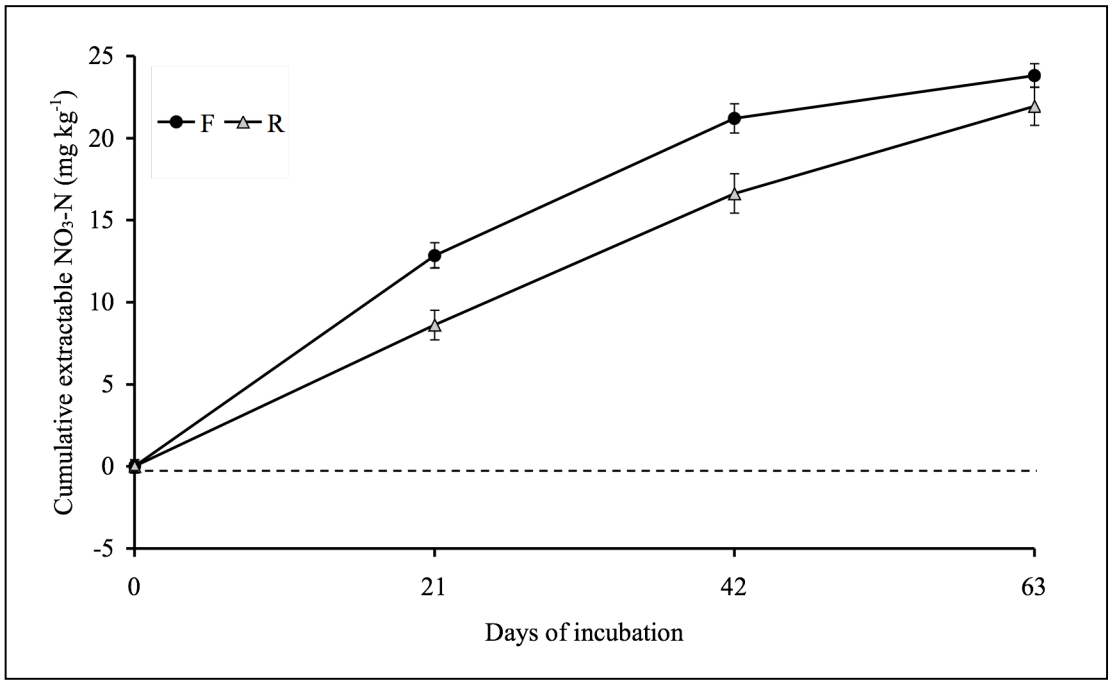

Fig. 5.5. Cumulative extractable soil NO_3-N: laboratory incubation. †Error bars indicate standard error.

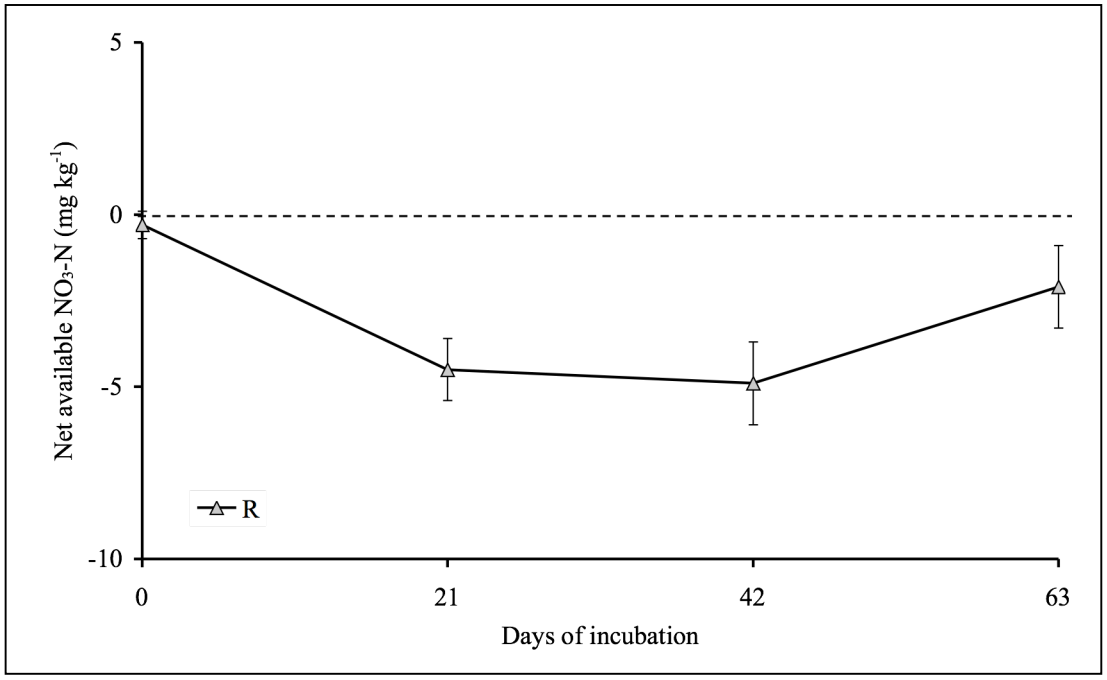

Fig. 5.6. Net available NO_3-N: laboratory incubation. †Error bars indicate standard error.

Nitrogen content in rape dry matter from field and laboratory experiments:

The values of N content in rape dry matter from laboratory and in-field experiments were 9.0 mg kg^{-1} and 219.1 kg ha^{-1}, respectively (Table 5.3).

Table 5.3. Soil NO_3-N mineralization and N content in cover crop residue: rape 'Dwarf Essex' experiment.

Treatment	Days after incorporation	Dry matter	Total C	Total N	C / N ratio	Net available NO_3-N	N content in rape residue
Rape	--Laboratory experiment--	--- mg kg^{-1} ---	---------- % ----------			-- mg kg^{-1}--	--- mg kg^{-1} ---
	0	440	42.8	2.04	21.0	-0.3	9.0
	21	440	42.8	2.04	21.0	-4.5	9.0
	63	440	42.8	2.04	21.0	-2.1	9.0
Rape	---In field experiment---	--- Mg ha^{-1} ---	---------- % ----------			-- mg kg^{-1} --	--- kg ha^{-1} ---
	19	10.7	42.8	2.04	21.0	-1.0	219.1
	84	10.7	42.8	2.04	21.0	3.7	219.1

Soil microbial activity

Microbial activity was 31.7 % higher in the R treatment than in F treatment (*P* = 0.0001) at 84 days after incorporation (Fig. 5.7).

Correlation between microbial activity and radicle rot severity

There was no correlation between microbial activity and radicle rot severity at 84 days after incorporation (R^2 = 0.009, P = 0.67) (Fig. 5.8).

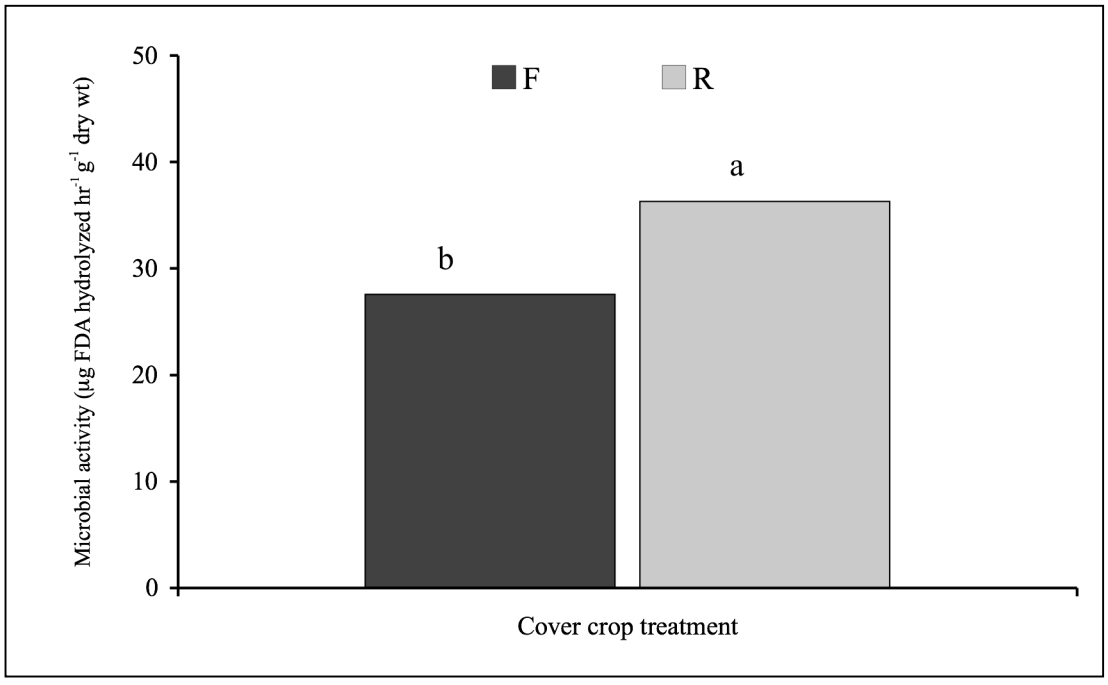

Fig. 5.7. Microbial activity. Rate of hydrolysis of FDA in cover crop experiment at 84 days after incorporation. ‡Treatment bars followed by the same letter indicate not significantly different at P = 0.05 based on LSD test.

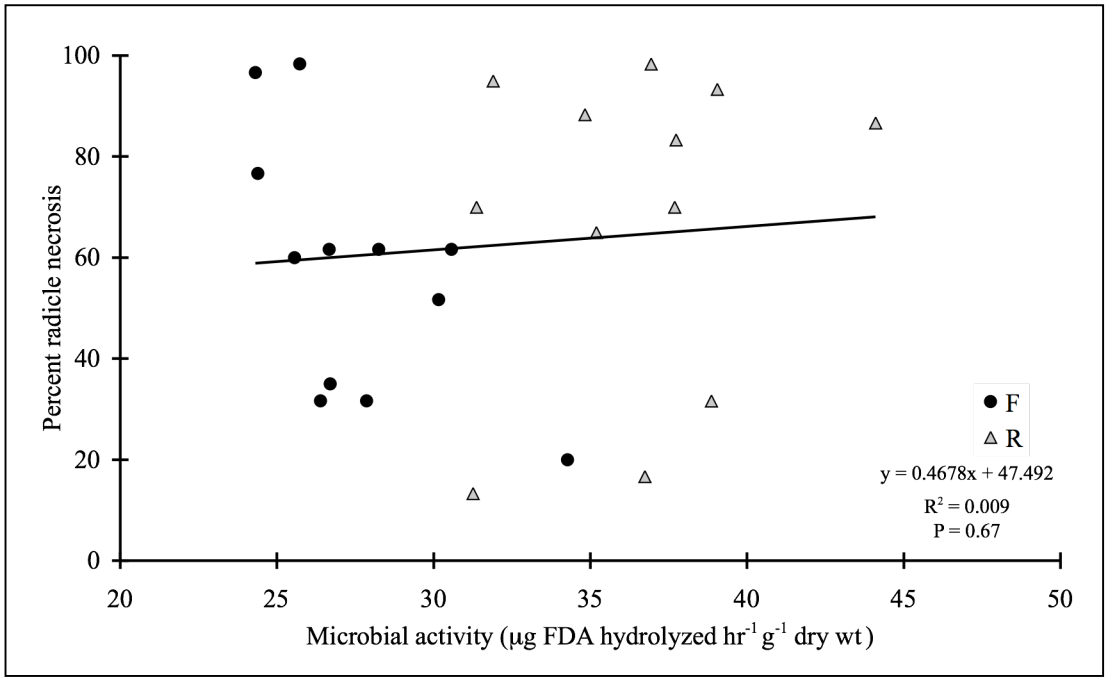

Fig. 5.8. Correlation between microbial activity and radicle rot severity.

MATERIALS AND METHODS

Oat 'Saia' Experiment (2006)

Site description

The oat field trial was conducted at the Oregon State University Vegetable Research Farm east of Corvallis, Oregon. The soil at the study field is classified as a Chehalis silt clay loam. The general climatic condition in the Willamette Valley is similar to a Mediterranean climate, which is dry and warm in the summer and cool and moist in the winter. The annual precipitation is 111 cm, and average temperature in July is 18.9 °C and average temperature in January is 3.3 °C. The study field has been in continuous corn for over 10 years and is known to have high root rot potential for sweet corn production.

Cropping history

The previous cropping history for the study field was fallow in 2005 with a cereal rye and common vetch cover crop mixture grown during the winter of 2004-2005. In summer 2004, sweet corn (*Zea mays* L.) 'Reward' was grown. A cover crop trial was grown in this field during the fall and winter of 2003-2004. Treatments included: mustard 'Braco', Mustard mix mix'Caliente', rape 'Dwarf Essex', Sorghum-sudangrass 'Piper', sorghum-sudangrass 'Cadan 99B', oat 'Saia', mixture of mustard mix 'Caliente' and sorghum-sudangrass 'Cadan99B', mixture of mustard mix 'Caliente' and *Crotolaria*, mixture of sorghum-sudangrass 'Cadan99B' and oat 'Saia', and mixture of sorghum-sudangrass 'Cadan99B' and *Crototolaria*. Buckwheat was grown in the field in early 2003 and sweet corn was grown in 2002.

Experimental design

The size of the experimental field was 73.2 m by 15.2 m, which was divided into four blocks 18.3 m by 15.2 m in size. Each of the 12 plots per block was 6.1 m by 3.8 m (Fig. 5.9). Each block contained eight O and four F plots. One of two urea applications (26 and 77 kg N ha^{-1}) was applied to each of 4 of the O and 2 of the F plots per block. O and F treatments were assigned in an incomplete randomized block

design with 4 replications. The two urea fertilizer application rates were assigned in a randomized split plot design (Table 5.4).

Table 5.4. List of cover crop treatments, sources, and seeding rates.

Abbreviation	Description	Source of seeds	Seeding rate
	----- winter -----		--- kg ha^{-1} ---
O-26	Oat 'Saia': *Avena sativa* L. with 26 kg N ha^{-1} urea application at 6 leaf stage corn	Kenagy Family Farm: grown by Peter Kenagy	51.6
O-77	Oat 'Saia': *Avena sativa* L. with 77 kg N ha^{-1} urea application at 6 leaf stage corn	Kenagy Family Farm: grown by Peter Kenagy	51.6
F-26	Fallow with 26 kg N ha^{-1} urea application at 6 leaf stage corn	-----	-----
F-77	Fallow with 77 kg N ha^{-1} urea application at 6 leaf stage corn	-----	-----

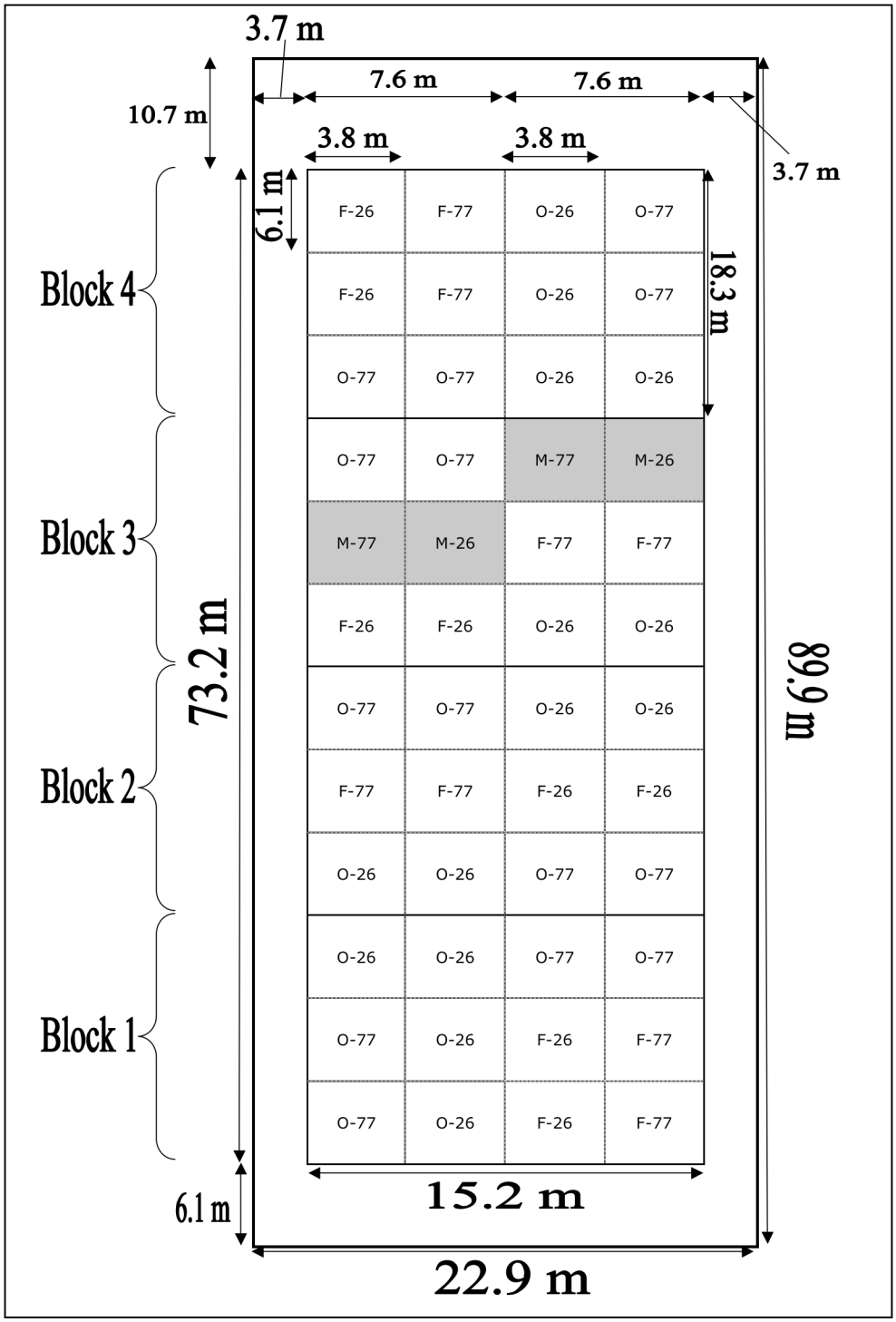

Fig. 5.9. Schematic of the experimental design for the field trial: oat cover crop experiment. Note: plots M-26 and M-77 in block 3 were originally designated as oat plots but the oats were mistakenly killed with herbicides.

Treatments

Cover crop management:

Oat 'Saia' (*Avena sativa*) was planted with a drill over the entire field on October 6, 2005. The F treatments were sprayed out with Round-up (Monsanto Co., St. Louis, MI) with a walk-behind boom sprayer (spray volume, 151.9 L ha^{-1}) on March 27, 2006 to create four fallow plots per block.

O treatment aboveground dry matter was collected on May 15, 2006 before incorporation. One aboveground dry matter quadrat, approximately 50.8 cm by 50.8 cm, was randomly taken from each plot. Samples were air dried for 40 days at 32.7 ºC. O plots were flailed on May 18, 2006 and the residues were manually spread evenly over the plots. Residues were immediately rotovated to a 12 cm depth.

Sweet corn crop management:

Captan treated seed of sweet corn 'Reward' (Rogers Seeds: Syngenta Seed Inc., Boise ID) was planted across the entire field on June 20, 2006 at approximately 3.8 cm deep and 20 cm apart in rows on 0.76 m center. This cultivar is early maturing and root rot intolerant. The seeding rate of corn was approximately 7 seeds m^{-1} and the stand was thinned to 5 plants m^{-1} after emergence. Starter fertilizer (N-P-K: 12-29-10) was applied at a rate of 60 kg N ha^{-1}. At 47 days after planting, urea was side-dressed at either 26 or 77 kg N ha^{-1} of N. Treatments are designated as oat 'Saia' (O) with one of two urea application rates (O-26 and O-77), and fallow (F) with one of two urea application rates (F-26 and F-77).

Soil sampling

Greenhouse cone-tube bioassay:

At approximately 35 and 80 days after cover crop incorporation, soils were sampled for the greenhouse root rot bioassay and in-field nitrate-N extraction. For greenhouse root rot bioassays, ten soil wedges were randomly sampled from each treatment plot. Each soil wedge (approximately 13 cm x 5 cm x 15 cm) was sampled with a sharpshooter shovel (AMS Inc., American Falls, ID). Ten sampled soil wedges

were passed through a 2.54 cm screen and mixed thoroughly before potting in cone-tubes.

Microbial activity:

At 80 days after incorporation, soils were sampled for analysis of the rate of hydrolysis of fluorescein diacetate (FDA). Ten soil cores (approximately 15 cm depth by 2.5 cm diameter) were removed from each plot. Each soil core was sieved through an 8 mm sieve and a 2 mm sieve, mixed thoroughly, and stored at 4 ºC in a Ziploc bag.

Soil nitrogen assessment:

For in-field nitrate-N extraction, ten soil cores (approximately 15 cm depth by 2.5 cm diameter) were taken from each plot at 35 and 80 days after oat incorporation. Each soil core was sieved through a 4.75 mm sieve and mixes thoroughly and stored at 22 ºC in Ziploc bag.

For the laboratory mineralization incubation, soil was collected from a fallow field at the OSU vegetable farm. Forty soil wedges (approximately 13 cm x 5 cm x 15 cm each) were randomly sampled from field with a sharpshooter shovel (AMS Inc., American Falls, ID). All soil wedges was sieved through a 4.75 mm sieve, mixed thoroughly, and stored at 22 ºC in Ziploc bag.

Greenhouse root rot bioassays

Field soils were sampled and processed as described above and potted into 550 mL cone-shaped tubes (Stuewe & Sons Inc., Corvallis, OR) per plot (n = 5). Cone-tubes were gently tapped to settle the soil.

Two seeds of sweet corn 'Golden Jubilee' treated with Captan were planted in each tube at 2.54 cm depth and thinned to one plant after emergence. Bioassays were grown in a greenhouse at approximately 24 ºC day and 18 ºC night with photoperiod under natural sunlight. Cone tubes were irrigated daily to maintain soil moisture near field capacity and were fertilized weekly with liquid fertilizer (0.058 g N, 0.038 g P, and 0.049 g K cone tube $^{-1}$ week^{-1}, Schultz Co., St. Louis, MO). Corn plants were harvested when they reached the six-leaf stage. Roots were washed and evaluated by

visual assessment for percent necrosis of the radicle and nodal roots. Percent necrosis was evaluated on an eight-point scale: 0 = Healthy, 1 = 1 to 10 % necrotic, 2 = 11 to 20 % necrotic, 3 = 21 to 40 % necrotic, 4 = 41 to 60 % necrotic, 5 = 61 to 80 % necrotic, 6 = 81 to 90 % necrotic, 7 = 91 to 99 % necrotic, and 8 = 100 % necrotic root. Shoots and roots were then dried and weighed to assess above- and below-ground dry matter.

In-field bioassays

On September 14, 2006, root rot severity was evaluated in field grown corn. Three plants were randomly sampled from each plot. Radicle and nodal root rot were evaluated using the eight-point scale as described above. Aboveground dry matter was dried at 37.7 ºC for 48 hr and weighed. The number of fired leaves was assessed on ten plants per 4.5 m of row in each plot.

Corn yield

Corn ears from two center rows per plot (approximately 3 m per row) were harvested by hand to assess corn yield. Ears were husked and ears with less than 15 cm of edible corn kernels were discarded.

Soil nitrogen analysis

Laboratory method for aerobic incubation:

Soils sampled as described above were brought to approximately 25 % gravimetric moisture by adding distilled water with a spray bottle, and approximately 625 g of moist soil was mixed and stored in an incubation bag (Ziploc, Johnson & Son. Inc.). The oat treatment received approximately 0.82 g kg^{-1} (dry wt basis) of oat residue; the fallow treatment soils were not amended with plant residues. A straw was inserted into each bag to allow air circulation. Each incubation bag was placed into a 30 L plastic tub. A moistened foam pad (approximately 2.5 cm depth) was placed at the bottom of the incubation tub and was re-moistened approximately every 7 days to maintain humidity. The bags were incubated at 22 °C for 63 days.

At days 0, 21, 42, and 63 incubated soils were sampled, and mineralized nitrate and ammonium were evaluated. A 15 g soil sample removed from each incubation bag and placed into a 125 mL Erlenmeyer flask. Fifty ml of 2 M KCl was added to each flask, and the flasks were shaken at 178 rev min^{-1} for 1 hr. Colloids of soil and 2 M KCl were filtered by Whatman no. 42 filter paper and analyzed for inorganic N by colorimetric analysis using the cadmium reduction method (Keeney and Nelson, 1982). Gravimetric soil moisture content was determined for each sample by oven-drying approximately 10 g of soil at 105 °C for 24 hr, and the obtained values were used to calculate soil N concentration on a dry soil basis.

Field soil NO_3-N extraction:

Field soils were sampled for N availability as described above. An irrigation was scheduled for approximately 36 hrs before sampling soil to raise soil moisture contents to near field capacity. A 15 g moist sample was removed from each aggregated sample and placed into a 125 mL Erlenmeyer flask. Fifty ml of 2 M KCl was added to each flask. Flasks were shaken at 178 rev min^{-1} for 1 hr, and the resulting solution was filtered with Whatman No. 42 filter paper. The filtrate was refrigerated at 4 ºC in capped plastic cuvettes until analyzed. Inorganic N was analyzed by colorimetric analysis by the cadmium reduction method (Keeney and Nelson, 1982) by the OSU Central Analytical Laboratory. Gravimetric soil moisture content was determined for each sample by oven-drying approximately 10 g of soil at 105 °C for 24 hr, and the obtained values were used to calculate soil N concentration on a dry soil basis.

Leaf chlorophyll content

A chlorophyll meter (Minolta SPAD-502, Minolta Camera Co., Osaka, Japan) was used to determine the concentration of leaf chlorophyll, which strongly correlates with leaf N content SPAD readings were taken before the urea side-dressing and also at one, two, three, and four weeks after the urea application. SPAD readings were taken on ten randomly chosen plants from 3 rows in the interior of each plot and averaged. Readings were taken on the newest fully expanded leaf with leaf collar

exposed. The height of all sampled corn plants at the newest fully expanded leaf was approximately the same to maintain consistency of the readings (± 2.5 cm). The reading was taken between the leaf margin and midrib of the lamina that was located at midway between the base and tip of the leaf.

Microbial activity

Microbial activity was evaluated as the rate of hydrolysis of fluorescein diacetate at 48 h after each soil sampling by modifying the procedure used by Zelles et al. (1991). Approximately one gram wet basis soils (subsample of the soil stored at 4 ºC in Ziploc bag) were placed in a 125 ml Erlenmeyer flask (n = 4). Twenty mL of pH buffer (60 mM sodium phosphate at pH 7.6) was added to each flask. After 15 minutes shaking at 178 rpm, 100 μL of 4.8 mM fluorescein diacetate solution (3', 6' diacetylfluorescein) was added to three of the four flasks. The remaining flask (control) received 100 μL of fluorescein diacetate solution only after the addition of acetone. Flasks were shaken at 178 rev min^{-1} for 2 h at 25 °C on an Innova 2003 platform shaker (New Brunswick Scientific Co., Inc., Edison, NJ). The addition of 20 mL acetone to each flask instantly stopped the hydrolysis reaction, and then the samples were centrifuged for 5 min at 4960 times *g* (Model J2-HS, Beckman Coulter, Inc., Fullerton, CA) to separate the soil from the liquid. The separated samples were filtered (Whatman No 4), and the absorbance at the filtrate was measured at 490 nm with a spectrophotometer (Model DU 800, Beckman Coulter, Inc., Fullerton, CA). FDA activity was expressed as μg FDA hydrolyzed hr^{-1} g^{-1} dry wt soil and was compared to a standard curve. Background absorbance of the sample solutions was corrected by subtraction of the control absorbance.

Calculations

Net available N ($N_{available}$) for cover crop incorporated soil was calculated and expressed as mg kg^{-1}:

$$N_{available}\,(\text{mg N kg}^{-1}\text{ dry wt}) = (NO_3\text{-N})_{\text{cover crop}} - (NO_3\text{-N})_{\text{fallow}} \quad [1]$$

where NO_3-$N_{cover\ crop}$ is the amount of NO_3-N extracted from a incorporated cover crop treatments (mg kg^{-1}), NO_3-N_{fallow} is the amount of NO_3-N extracted from fallow treatment (mg kg^{-1}).

Amount of N in cover crop residue was calculated and expressed as N content ($N_{crop\ residue}$) in cover crop residue (mg kg^{-1}):

$$N_{crop\ residue}\ (mg\ kg^{-1}) = Total\ N\ (\%) \times DM_{cover\ crop}\ (mg\ kg^{-1}) \quad [2]$$

where Total N is percent of N in cover crop residue, $DM_{cover\ crop}$ is cover crop aboveground dry matter.

Statistical analysis

Statistical analysis was performed with SAS (SAS system for Windows 9, SAS Inst., 1999). Treatment effects on each individual sample date were computed using analysis of variance (ANOVA) from the PROC GLM procedure. Mixed-model analysis using the PROC MIXED procedure (SAS Inst., 1999) was used when the fixed effect of side-dressing was taking account of each treatment effect. Treatment means were separated when F-test was significant ($P < 0.05$). Mean separation was performed by the LSD procedure using MEANS statement if sampling data was balanced. Treatment means were separated by the student's *t* test using LSMEANS statement when the sampling data was unbalanced. Linear regression analysis using PROC REG was computed in SAS to describe the relationship between root rot severity and microbial activity and the relationship between sweet corn yield and radicle rot severity.

RESULTS

Cover crop biomass

Mean aboveground dry matter of the O treatment was 11.48 ± 0.43 dry Mg ha^{-1} (Table 5.7).

Greenhouse bioassays

Root rot severity:

Radicle and nodal root rot severity were significantly lower (24 and 21 %, respectively) at 35 days after incorporation ($P < 0.0001$ and $P = 0.0008$, respectively) in corn plants grown to the 6 leaf stage in the O treatment when compared to the F treatment (Fig. 5.10). In contrast, there was no treatment effect on radicle and nodal root severity at 80 days after incorporation in corn plants grown to the 6 leaf stage (Fig. 5.10).

Mean above- and below-ground dry matter:

Mean above- and below-ground dry matter was significantly lower in the O treatment than the F treatment at 35 days after incorporation (16 % / $P = 0.03$ and 24 % / $P = 0.0005$, respectively) (Fig. 5.11). At 80 days after incorporation, there were no significant treatment differences (Fig. 5.11).

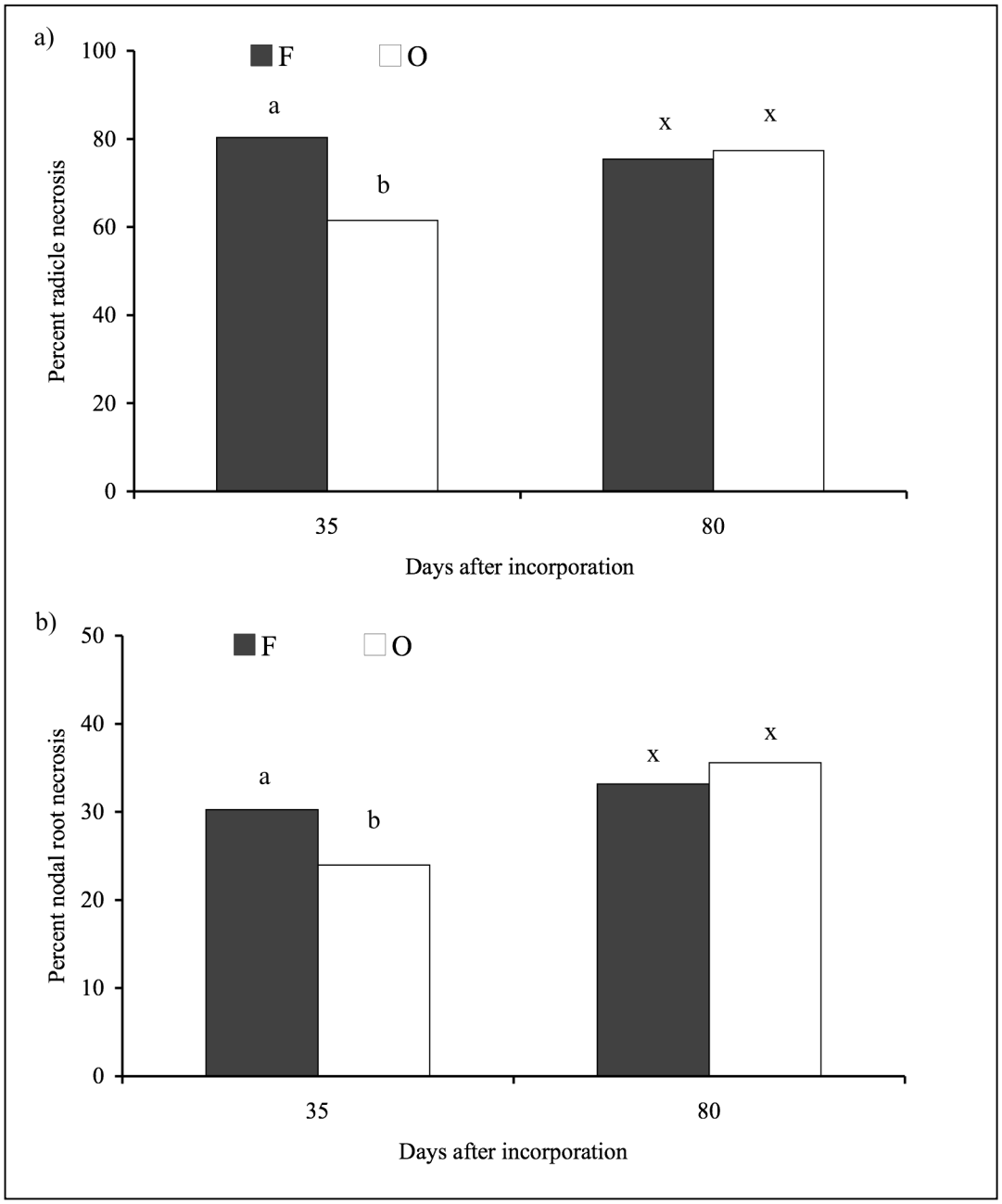

Fig. 5.10. Disease severity: a) radicle and b) nodal root rot severity. Greenhouse bioassay at 35 and 80 days after incorporation. ‡Treatment bars followed by the same letter indicate not significantly different at P = 0.05 based on LSD test.

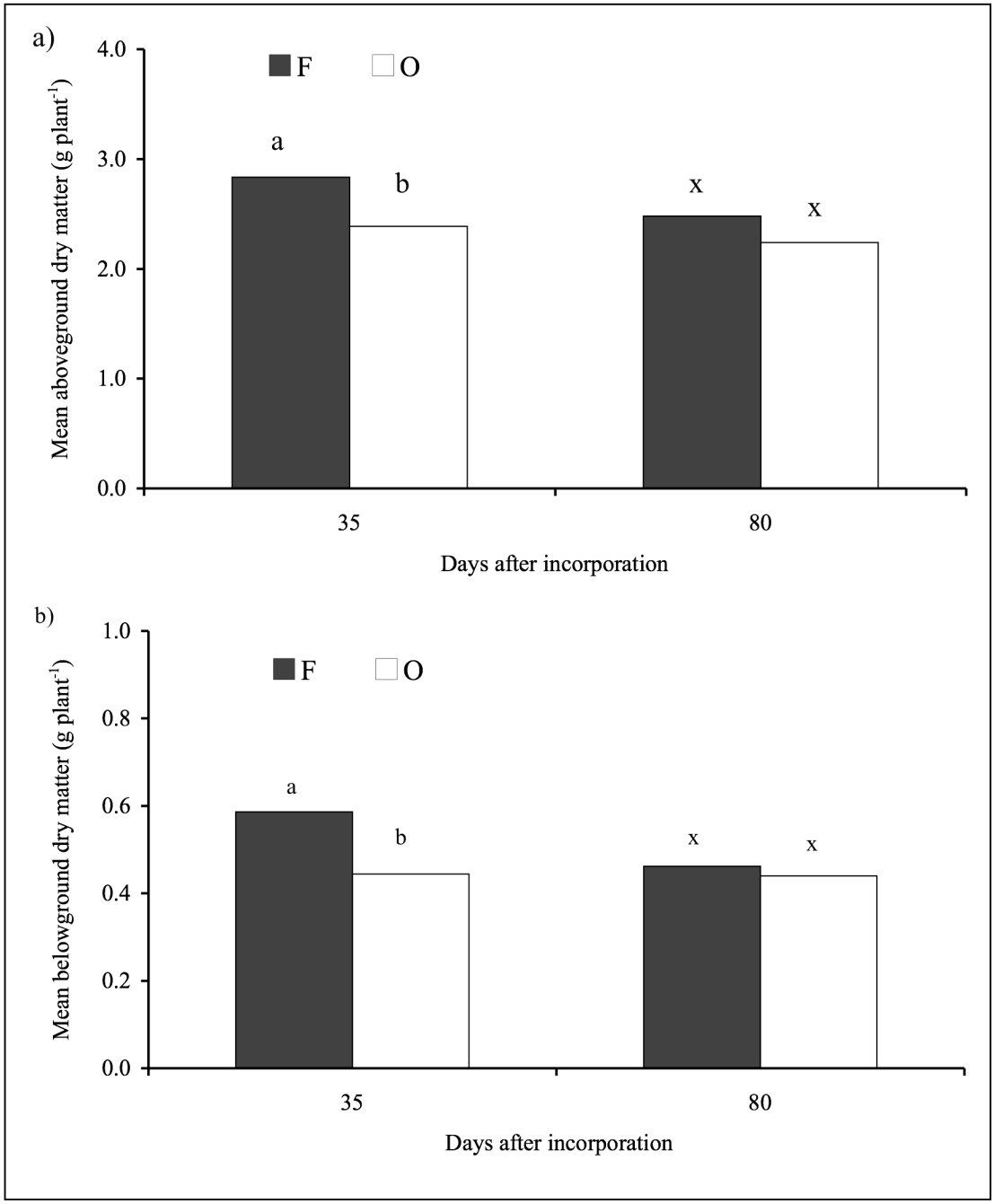

Fig. 5.11. Mean a) above- and b) below-ground dry matter: greenhouse bioassay at 35 and 80 days after incorporation. ‡Treatment bars followed by the same letter indicate not significantly different at P = 0.05 based on LSD test.

Field-grown corn

Root rot severity:

At harvest, radicle and nodal root rot severity were lower in the O treatment than in the F treatment by 25 % ($P = 0.07$) and 21 % ($P \leq 0.05$), respectively (Fig. 5.12).

There was no interaction between cover crop treatment and urea application ($P = 0.70$); however, there was an effect of block ($P = 0.06$). There was no interaction between block and treatment ($P = 0.11$) (Table 5.5). The median radicle root rot severity in the O treatment was generally lower than in the F treatment within blocks, but radicle rot severity was only significantly different in the O treatment in blocks 3 and 4 (Fig.5.13). Similarly, the median of nodal root rot severity in the O treatment within blocks was approximately 25 % lower than the median nodal root severity of the F treatment within blocks ($P = 0.0008$) (Fig. 5.13).

Number of corn leaves firied:

The number of leaves fired was 19.6 % lower in the O treatment (2.58 ± 0.12 leaves fired plant^{-1}) than in the F treatment (3.21 ± 0.19 leaves fired plant^{-1}) at harvest ($P = 0.004$) (Fig. 5.14).

Aboveground dry matter:

There was no treatment effect on mean aboveground dry matter in field-grown corn at harvest ($P = 0.60$). The aboveground dry matter in the high urea application was received numerically higher than the dry matter in the lower urea application in both the F and O treatments (Table 5.6).

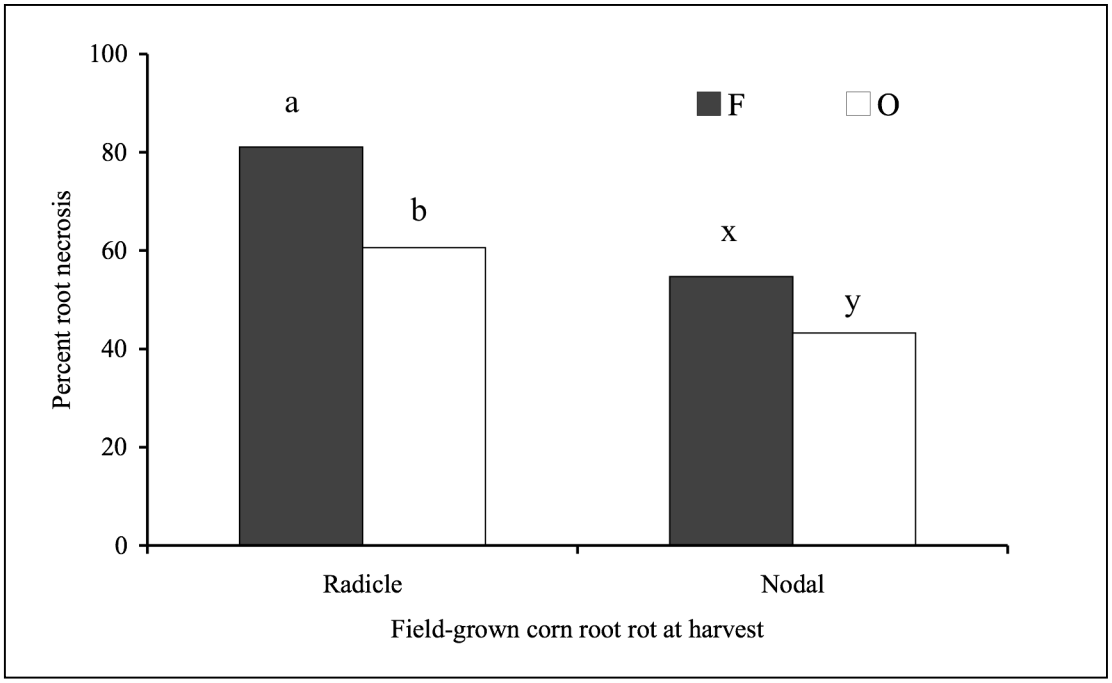

Fig. 5.12. Root rot severity: in field-grown corn at harvest. ‡Treatment bars followed by the different letter are significantly different at P = 0.05 based on LSD test.

Table 5.5. Analysis of variance of radicle and nodal root rot severity: field-grown corn at harvest.

Source of variation	Df	Radicle severity	Nodal severity
Block	3	*	NS
Cover crop	1	***	***
Urea application	1	NS‡	NS
Block x cover crop	3	NS	NS
Cover crop x urea	1	NS	NS
Block x urea	3	NS	NS
Block x cover crop x urea	3	NS	NS
Model	15		
Pooled Error	33		

*, *** Indicate significance at P ≤ 0.05 and P ≤ 0.001, respectively, from pairwise comparison against fallow using LSD test. ‡NS indicates there are no significant differences between treatments based on LSD test (*P* = 0.05).

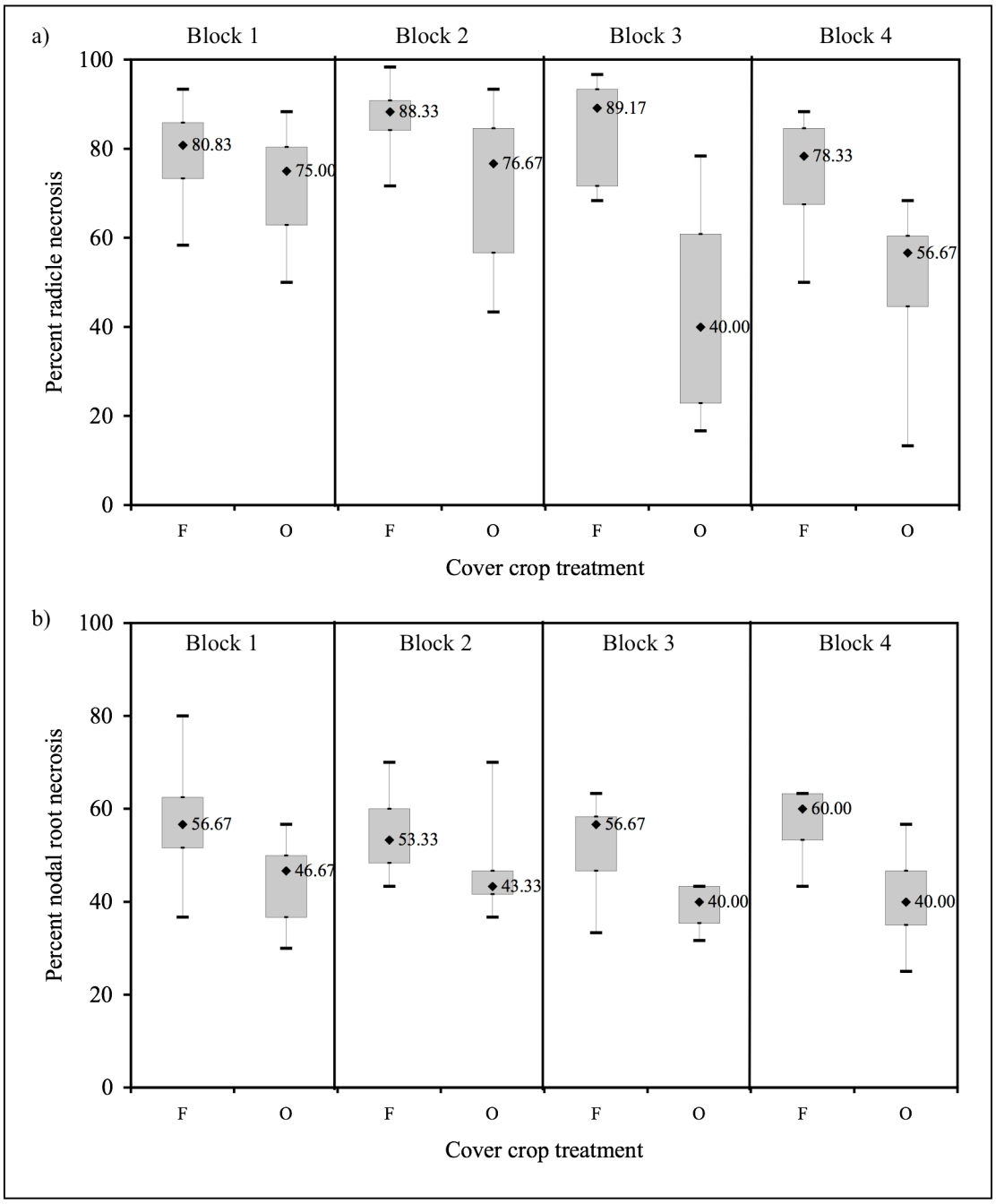

Fig. 5.13. Disease severity: in field-grown corn. Median of percent a) radicle and b) nodal root rot necrosis in blocks. Box plots represent lower and upper 95 % confidence interval of median, and bar represents minimum and maximum values observed within blocks.

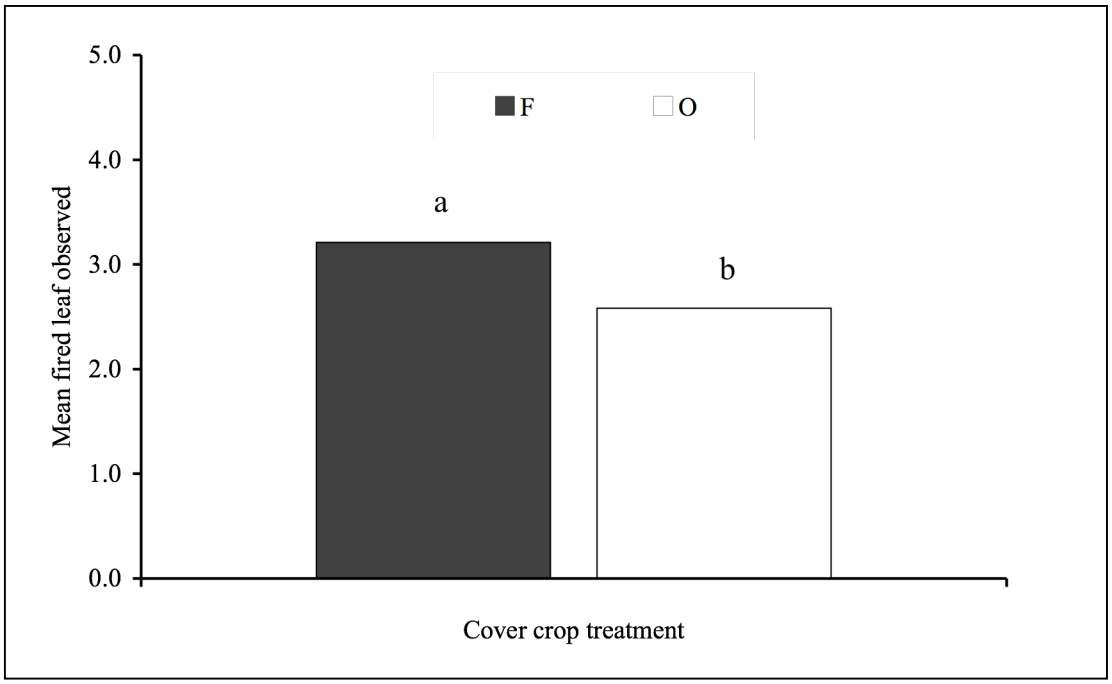

Fig. 5.14. Mean number of leaves fired in field-grown corn at harvest. ‡Treatment bars followed by different letters are significantly different at $P = 0.05$ based on LSD test.

Table 5.6. Mean aboveground dry matter at harvest.

Treatment	Urea application rate	Mean aboveground dry matter
	----- kg ha^{-1} -----	----- g plant^{-1} -----
F	26	95.3 (8.6)
F	77	105.7 (32.7)
O	26	100.8 (27.2)
O	77	103.1 (28.0)
		NS‡

Number between parentheses indicates standard error. ‡NS indicates there are no significant differences between treatments based on LSD test ($P = 0.05$).

Sweet corn yield

Yield was 11.6 % higher ($P = 0.01$) in the O treatment than in F treatment (Fig. 5.15 a). There were no interactions among block, cover crop treatment, and urea application rates ($P > 0.1$). There was no interaction between cover crop treatment and urea application ($P = 0.12$) (Fig. 5.15 b.)

Correlation between cover crop aboveground dry matter and radicle rot severity

There was no correlation between oat aboveground dry matter and radicle rot severity at any sampling dates (data not shown).

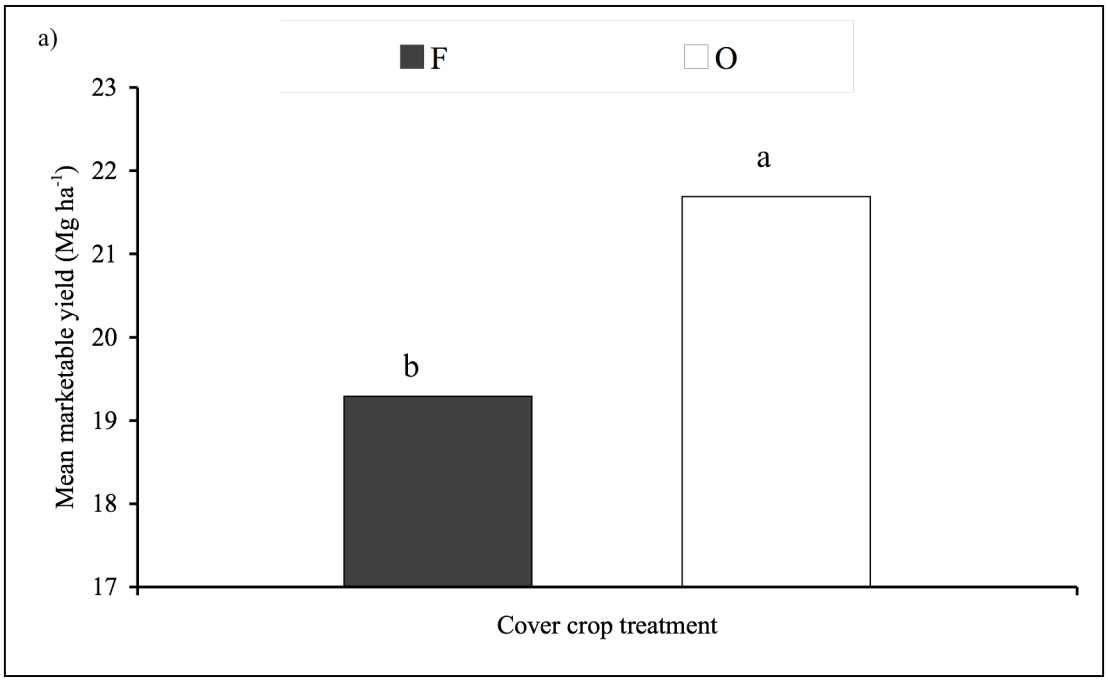

Fig. 5.15 a. Mean sweet corn yield: cover crop treatments. ‡Treatment bars followed by the different letter are significantly different at P = 0.05 based on LSD test.

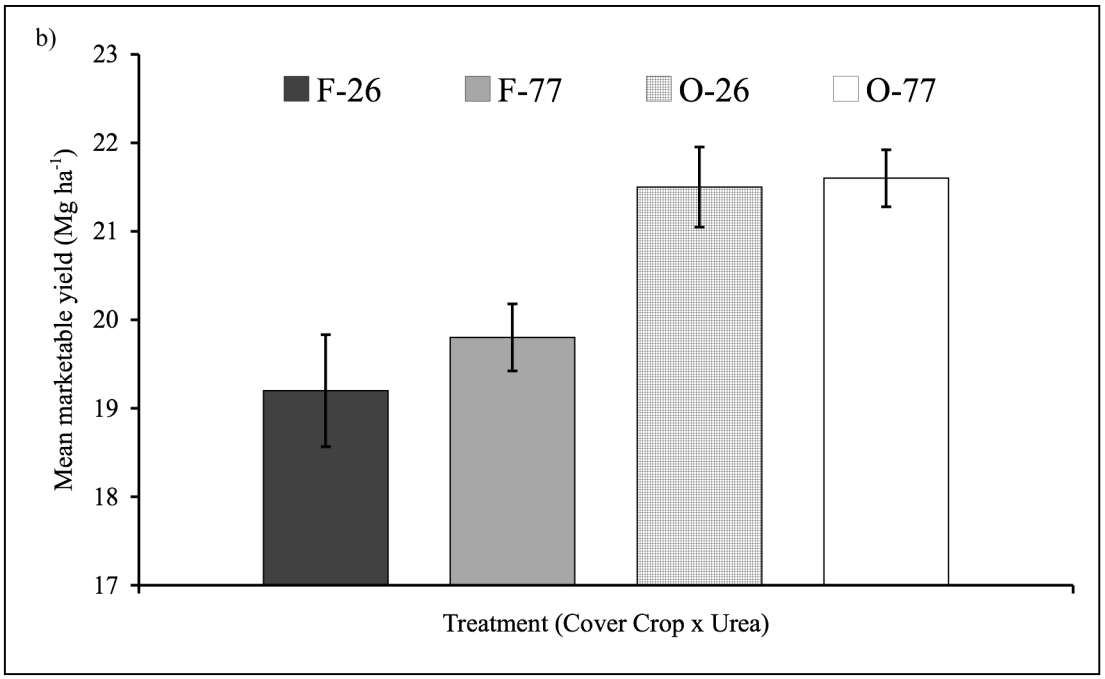

Fig. 5.15 b. Mean sweet corn yield: cover crop treatments and urea applications. †Error bars indicate standard error.

Correlation between disease severity and yield

There was a correlation between yield and percent radicle necrosis at harvest (R^2 = 0.18, -b = 0.04, *P* = 0.003). Based on the linear relationship, yield was lost 17.1 % at 100 % radicle rot severity compared to at 0 % (Fig. 5.16).

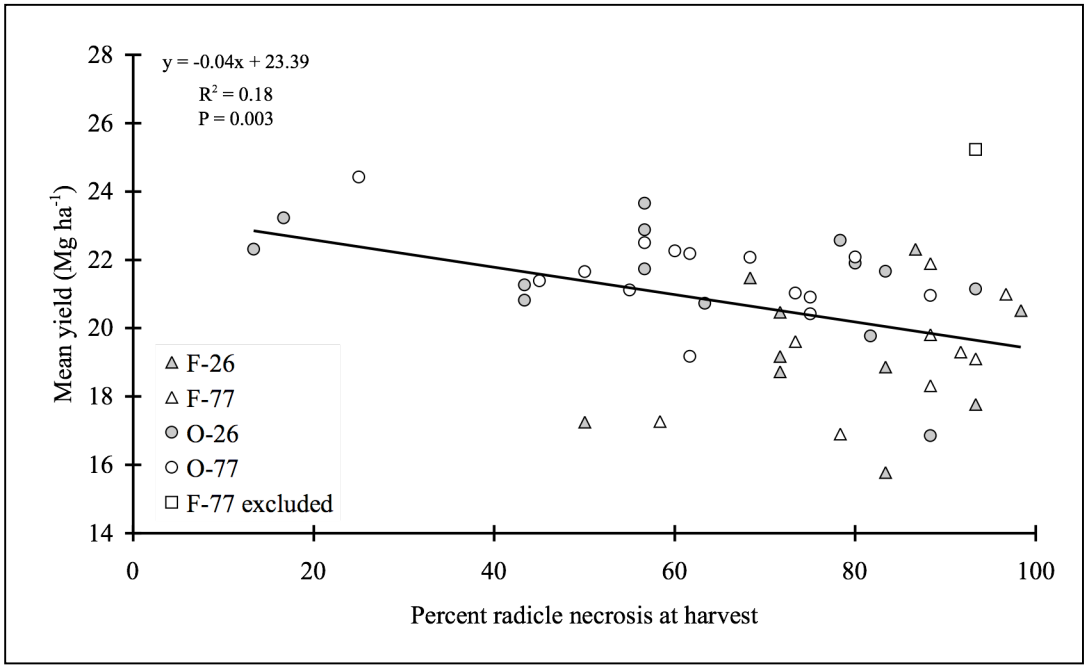

Fig. 5.16. Correlation between radicle rot severity and yield (Mg ha^{-1}).

Soil and corn foliar nitrogen status

C : N ratio of oat:

Percent total C and N were 43.8 and 0.86, respectively (Central Analytical Laboratory, Oregon State Univ.). The C : N ratio of oat was 50.9 (Table 5.7).

Extractable soil NO_3-N:

Extractable soil NO_3-N content was 75.1 % lower in the O treatment (6.6 ± 0.9 mg kg^{-1} dry wt) than in the F treatment (27.3 ± 1.35 mg kg^{-1} dry wt) soils at 35 days after incorporation ($P < 0.0001$) (Fig. 5.15). There was no significant difference between the O and F treatment in extractable soil NO_3-N at day 80 ($P = 0.11$) (Fig. 5.17). The net available NO_3-N for the O treatment at 35 and 80 days was -20.7 and -0.9 mg kg^{-1}, respectively (Table 5.7).

Cumulative extractable NO_3-N:

Cumulative extractable NO_3-N was significantly lower at days 21, 42, and 63 in the O treatment than in the F treatment (Fig. 5.18). Cumulative extractable NO_3-N in the O treatment at 21 days was not higher than at day 0, but it then slowly increased by 42 and 63 days to approximately 5.5 and 11.4 mg kg^{-1} extractable soil NO_3-N, respectively (Fig. 5.18). Soil NO_3-N also increased over time in the F treatment to 13.6, 17.8, and 22.9 mg kg^{-1}, respectively (Fig. 5.18). The net available NO_3-N in the O treatment at days 0, 21, 42, and 63 was -0.3, -13.9, -12.6, and -11.8 mg kg^{-1}, respectively (Fig. 5.19).

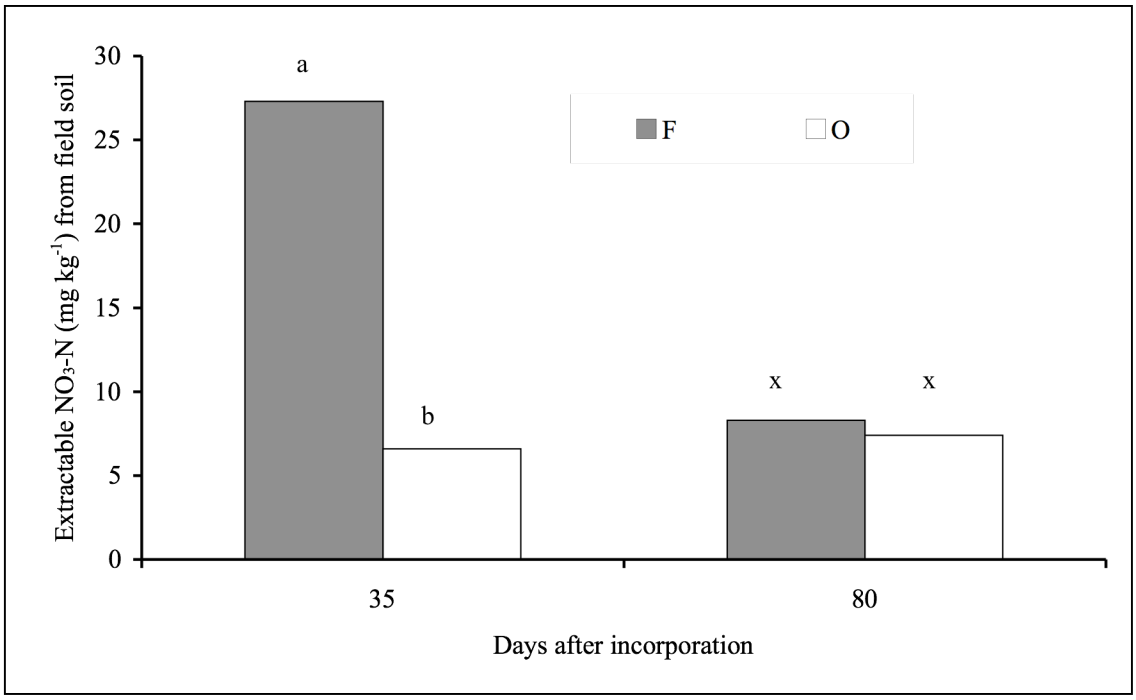

Fig. 5.17. Extractable NO_3-N in field soil at 35 and 80 days after incorporation. ‡Treatment bars followed by the same letter are not significantly different at P = 0.05 based on LSD test.

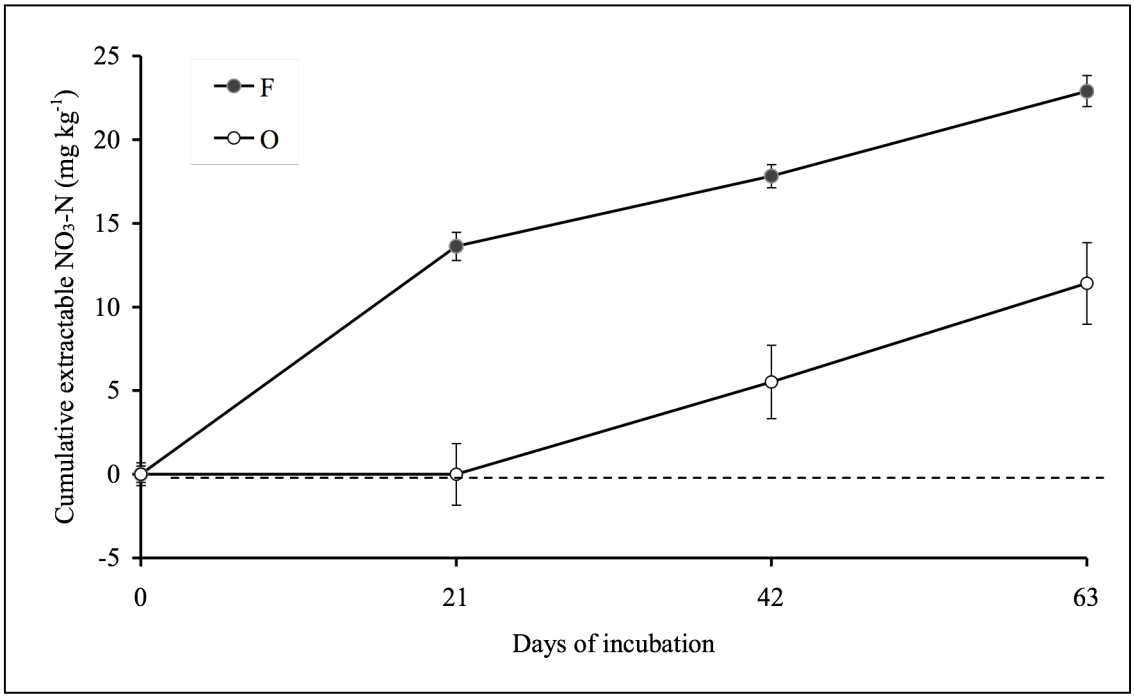

Fig. 5.18. Cumulative extractable soil NO_3-N: laboratory incubation. †Error bars indicate standard error.

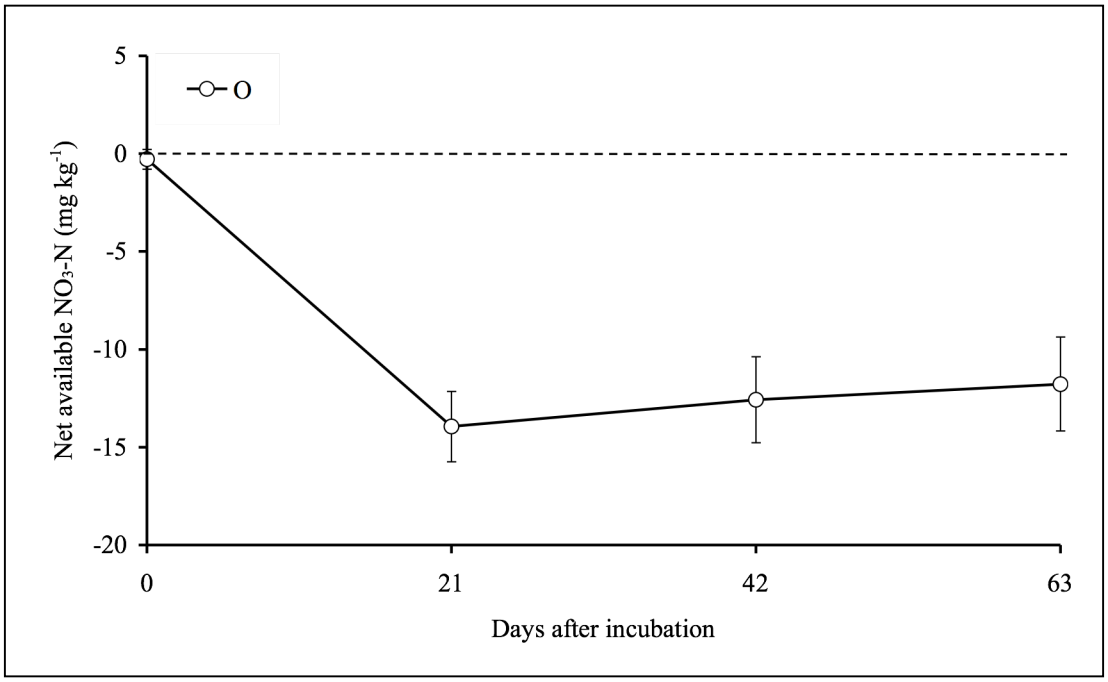

Fig. 5.19. Net available NO_3-N: laboratory incubation. †Error bars indicate standard error.

Nitrogen content in rape dry matter from field and laboratory experiments:

The values of N content in oat dry matter from laboratory and in-field experiments were 7.2 mg kg^{-1} and 98.9 kg ha^{-1}, respectively (Table 5.7).

Table 5.7. Soil NO_3-N mineralization and N content in cover crop residue: oat 'Saia' experiment.

Treatment	Days after incorporation	Dry matter	Total C	Total N	C / N ratio	Net available NO_3-N	N content in oat residue
Oat	--Laboratory experiment--	--- mg kg^{-1} ---	---------- % ----------			----- mg kg^{-1} ----	---- mg kg^{-1} ----
	0	838	43.8	0.86	50.9	-0.3	7.2
	21	838	43.8	0.86	50.9	-13.9	7.2
	63	838	43.8	0.86	50.9	-11.8	7.2
Oat	--- In field experiment---	Mg ha^{-1} dry wt	---------- % ----------			----- mg kg^{-1} -----	---- kg ha^{-1} ----
	35	11.5	43.8	0.86	50.9	-20.7	98.9
	80	11.5	43.8	0.86	50.9	-0.87	98.9

Foliar SPAD measurements:

There was no significance of any interaction among block, treatment, and urea application (Table 5.8). There were significant differences between the 26 and 77 kg ha^{-1} urea applications at 21 days after side-dressing ($P = 0.004$), at which time the 77 kg ha^{-1} treatment generated a 4.4 % higher SPAD reading than the 26 kg ha^{-1} treatment (Fig.5.20 a; Fig. 5.20 c).

Field-grown corn planted in the O treatment had lower SPAD readings than in the F treatment on all assessment dates. SPAD readings in both treatments immediately increased 7 days after side-dressing and remained high through day 21. SPAD readings decreased from days 21 to 28 after side dressing (Fig. 5. 20 b; Fig. 5.20 c.).

There were no correlation between cover crop treatments and urea applications of SPAD reading across all sampling dates ($P < 0.20$) (Table 5.8; Fig. 5. 20 c).

Table 5.8. Analysis of variance of Minolta-502 SPAD readings before and after side dressed urea.

		Days after side dressing				
Source of variation	Df	0	7	14	21	28
Block	3	NS‡	*	NS	NS	*
Cover crop	1	***	***	NS	*	*
Urea application	1		NS	NS	**	NS†
Block x cover crop	3	NS	NS	NS	NS	NS
Block x urea	3		NS	NS	NS	NS
Treatment x urea	1		NS	NS	NS	NS
Block x cover crop x urea	3		NS	NS	NS	NS
Model	15					
Pooled Error	33					

*, **, *** Indicate significant at P ≤ 0.05, P ≤ 0.01 and P ≤ 0.001, respectively, based on pairwise comparison against fallow / urea application using LSD test. †Indicates there is suggestively significant at P = 0.07. ‡NS indicates there are no significant differences at P = 0.05 based on LSD test.

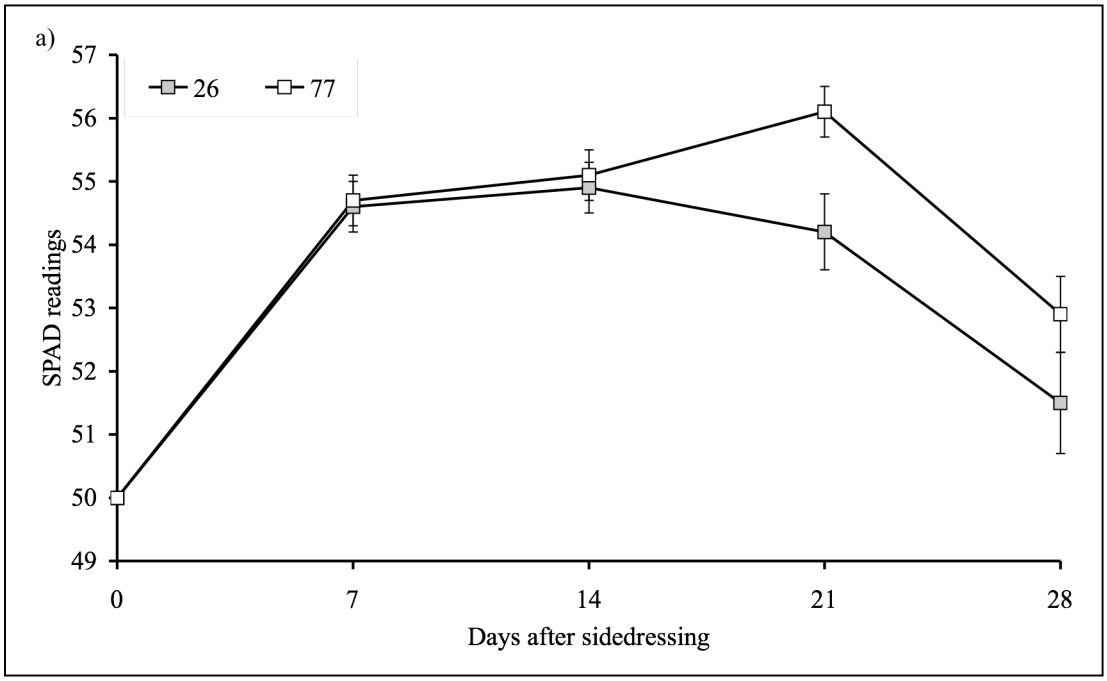

Fig. 5.20 a. Corn tissue nitrogen status from foliar SPAD measurements over time: difference between 26 kg ha^{-1} and 77 kg ha^{-1} urea treatments. †Error bars indicate standard error.

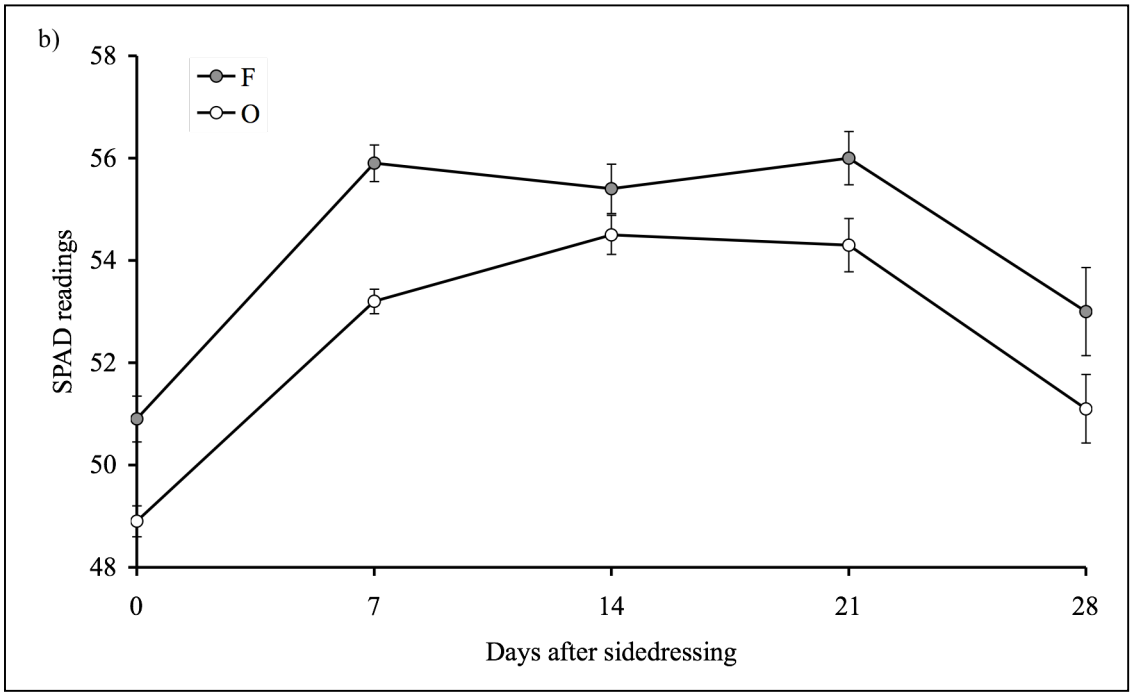

Fig. 5.20 b. Corn tissue nitrogen status from foliar SPAD measurements over time: difference between oat and fallow treatments. †Error bars indicate standard error.

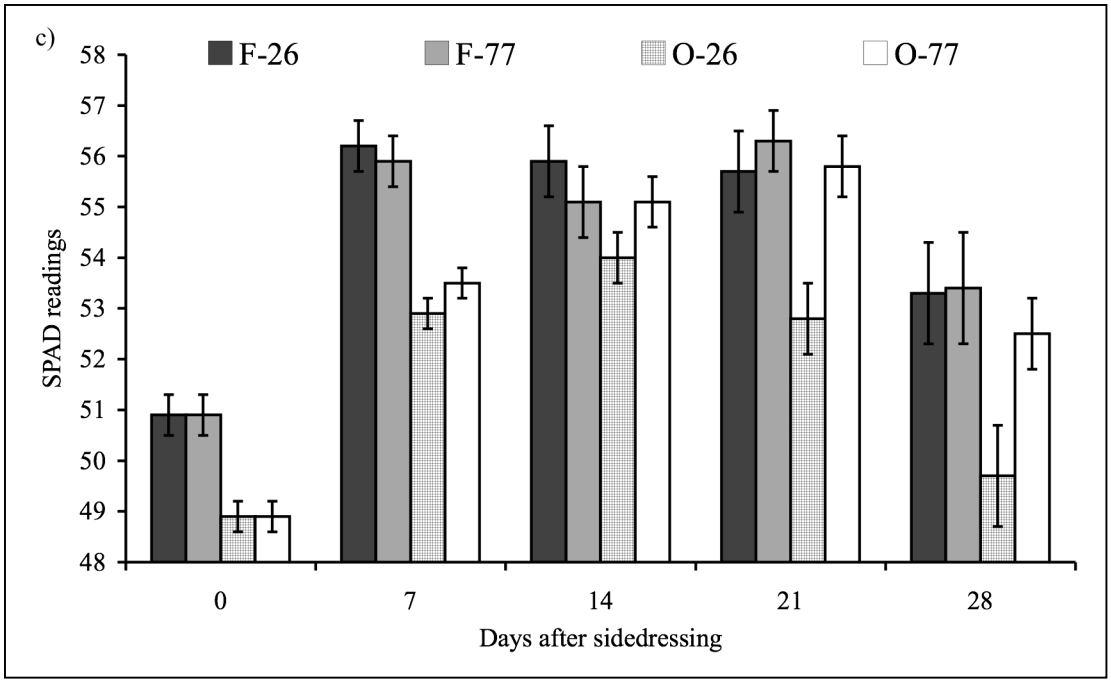

Fig. 5.20 c. Corn tissue nitrogen status from foliar SPAD measurements over time: difference between with two cover crop and urea treatments. †Error bars indicate standard error.

Soil microbial activity

Microbial activity in the O treatment (71.1 ± 1.2 ug FDA hydrolyzed g^{-1} soil hr^{-1} dry wt) was 43.2 % higher ($P < 0.0001$) than in the F treatment (49.6 ± 1.3 ug FDA hydrolyzed g^{-1} soil hr^{-1} dry wt) at 80 days after cover crop incorporation (Fig. 5.21).

Correlation between microbial activity and radicle rot severity

There was no correlation between microbial activity and radicle rot severity at 80 days after incorporation ($R^2 = 0.002$, $P = 0.76$) (Fig. 5.22).

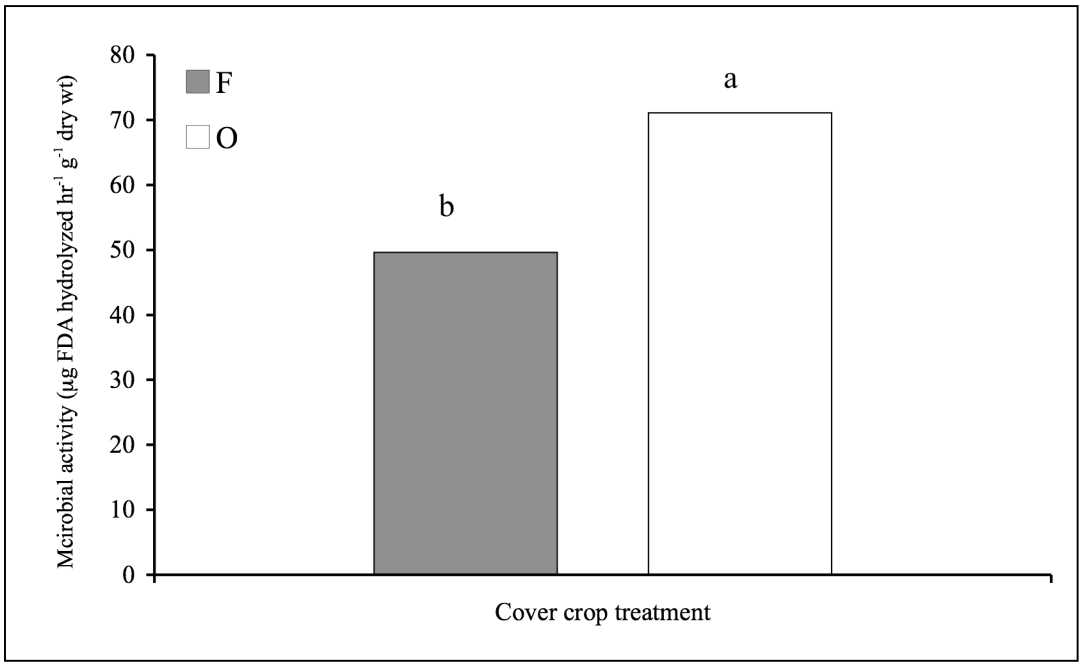

Fig. 5.21. Microbial activity (rate of hydrolysis of FDA). ‡Treatment bars followed by different letter indicate significantly different at P = 0.05 based on LSD test.

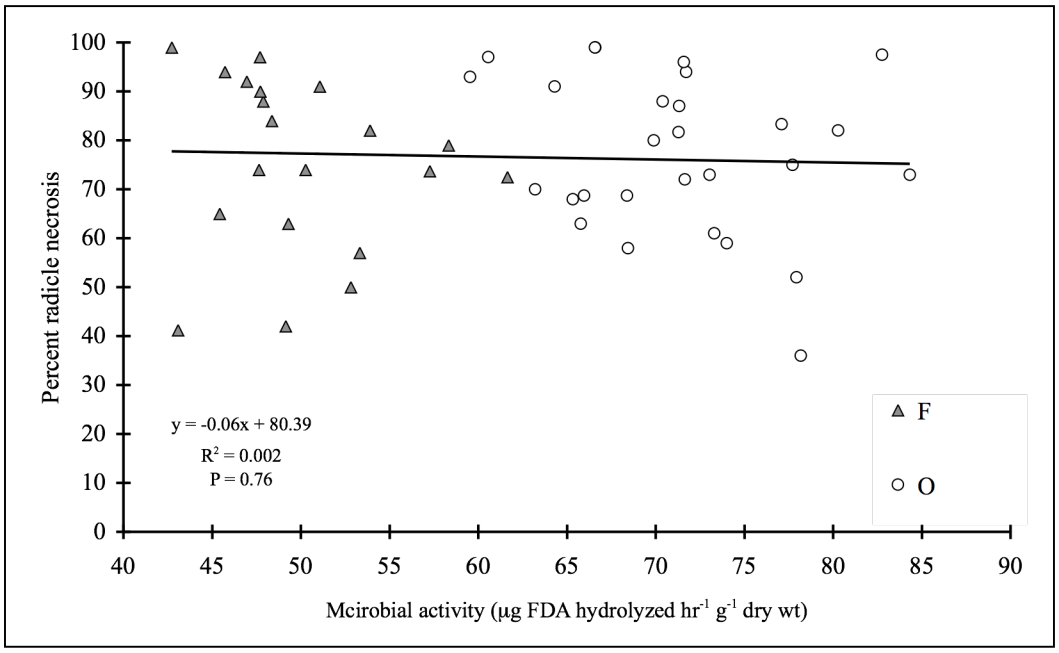

Fig. 5.22. Correlation between microbial activity and radicle rot severity.

Summary: Research station experiment (rape and oat, 2006)

Cover crop dry matter and winter hardiness

September 9-seeded summer O, Mc and R treatments were stunted and grew slowly due to the decomposing residues of the previous corn crop incorporated two weeks previously. The summer treatments as well as the September 20-seeded winter treatments went into the winter with very high biomass. The summer and winter Mc and O treatments were completely winter-killed; the R treatment (flailed May 2) was not affected. Oat 'Saia' seeded October 6 (flailed May 15) did not winter-kill. Aboveground DM for winter R and O was 10.7 and 11.5 Mg ha, respectively.

Root rot severity:

Overall, the R treatment increased root rot severity. The R treatment was suppressive to radicle rot at 50 days but increased radical and nodal root rot severity at 84 days in greenhouse bioassays. In field-grown corn, R had no effect on radicle rot at any date but increased nodal root rot severity at 120 days. Overall, the O treatment reduced root rot severity. The O treatment was suppressive to radicle and nodal root rot at 35 days but not at 80 days in greenhouse bioassays. In field grown corn, O suppressed radicle and nodal root rot at harvest (the only sampling date) and reduced the number of leaves fired.

Corn productivity:

In greenhouse bioassays, the R treatment increased aboveground DM at 50 days and above- and below-ground DM at 84 days. In field-grown corn, there was no effect on aboveground DM or yield.

The O treatment suppressed above- and below-ground DM at 35 days but had no effect at 80 days in greenhouse bioassays. In the field, there was no difference in aboveground DM at harvest, but nonetheless, the O treatment significantly increased yield by 11.6% compared to the F treatment.

Microbial activity

The R treatment increased microbial activity by 32 % at 84 days and the O treatment increased microbial activity by 43.2 % at 80 days, compared to their respective F treatments.

Extractable N, N mineralization potential, and foliar N status

The C:N of the rape was approximately 21. In the rape experiment, there was no difference in extractable NO_3-N at 19 days but extractable NO_3-N was 44.5% higher in the R than in the F treatment at 84 days. Cumulative extractable NO_3-N was lower in the R than in the F treatment at 21 and 42 days but there was no difference at 63 days. The R treatment slightly immobilized NO_3-N throughout the 63 days incubation.

The C:N of the oat cover crop was approximately 51. The O treatment immobilized more NO_3-N than R throughout the 63 day incubation. Extractable soil NO_3-N content was 75.1 % lower in the O than in the F treatment at 35 days after incorporation, but there was no significant difference at day 80. The net available NO_3-N for the O treatment at 35 and 80 days was -20.7 and -0.9 mg kg^{-1}, respectively.

The cover crop amendment rate was 2 g wet basis per 1 kg dry soil, and this was smaller than the recommended amendment rate (Gale, et al. 2007; Gale 2004; Kusonwiriyawong, 2005). The small amendment rate in the laboratory incubations reduced the sensitivity of the experiment. The net available NO_3-N value in Table 5.3 and 5.7 would likely be different if the oat and rape residues were amended on a 1 % dry wt basis.

Corn grown in the oat treatment soils had lower SPAD values than corn grown in the fallow soils. There was no significant interaction between cover crop and urea treatments. In addition, corn grown in the O-77 treatment generated higher SPAD values than corn grown in the O-26 treatment.

The sufficiency index number [(26 kg ha^{-1} side-dressing in oat treatment / 77 kg ha^{-1} side-dressing in fallow) * 100] (Shapiro and Francis, 2006, Peterson et al., 1993) at 0, 7, 14, 21, and 28 days after side-dressing was 96.1, 94.6, 98.0, 93.8, and 93.1%, respectively. According to Peterson et al. (1993), the sufficiency index

number below 95 % at V8 to V 10 stage corn generally requires an additional fertilizer. The sufficiency index number at 7 days after side-dressing (V10) was slightly lower than the recommendation from Shapiro and Francis (2006), but the value at 14 days after side-dressing was higher than the recommendation. The sufficiency index number at 21 and 28 day was lower than the recommendation, but physiological growth stage of corn was already at approximately silk (R1) to milk (R3). Thus, the corn was already in the reproductive stage and therefore past the point where additional fertilizer applications could have an impact on leaf chlorophyll status.

SPAD measurements were not collected in the rape experiment.

CHAPTER 6

DISCUSSION

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Objectives

The objectives of this research were to:

1) identify high biomass cover crops with agronomic potential for western Oregon processed vegetable cropping systems

2) evaluate the impact of high biomass cover crops on root rot severity and yield of sweet corn

3) determine whether there is a correlation between dry matter, soil microbial activity and root rot severity

4) determine whether cover crops immobilize nitrogen and reduce corn yield

Agronomic considerations:

Winter-hardiness

This project evaluated cover crops for utility as both late summer and winter cover crops. An important quality in winter cover crops is reliable winter-hardiness. Sorghum sudangrass is killed at 0°C, so cannot be grown over the winter in Oregon; as this is well-known, SS was only grown as a summer cover crop in this project.

Oats are considered to '…winterkill in zone 6 and colder and much of zone 7" (Managing Cover Crops Profitably, 2002). Mustard mix 'Caliente' is grown as a late summer cover crop in eastern Washington as it reliably winter-kills in that area. In this project, neither oat 'Saia' nor mustard mix 'Caliente' were reliably winter-hardy. Oat 'Saia' was only winter-killed in 2005-06; August- and September-planted oat 'Saia' in 2005-06 were completely winter-killed by sub-freezing temperatures for 3 weeks in November and 2 weeks in December, with 4 days below -7°C in December. Interestingly, the October 6-seeded winter oat in a separate experiment was not winter-killed and produced 11.5 Mg ha^{-1}.

Mustard mix 'Caliente' appears to be less winter-hardy than oat 'Saia'. It winter-killed every winter except 2004-05, when winter temperatures never dropped below -7°C. Because of the unreliable winter-hardiness of 'Caliente', a reliably winter-hardy mustard was sought to replace 'Caliente'. Rape 'Dwarf Essex', mustard

'Braco', and arugula are three reliably winter-hardy mustard cover crops in western Oregon that were evaluated in at least one experiment in this project.

Dry matter

Cover crop dry matter potential is an important factor to consider when selecting a cover crop as it is a measure of its overall potential to contribute organic matter and nutrients to the soil system; it may also drive some mechanisms involved in soilborne disease suppression (Ochiai et al, 2007; Sattell et al, 1999; Stone et al, 2004).

Dry matter ranged widely from species to species in the same experiment as well as from season to season for the same species. These differences were likely primarily related to the environmental conditions during the growth of the cover crops, including temperature, rainfall, day length, and days of sunshine, as well as the dates they were planted and harvested.

Overall, cover crop aboveground dry matter ranged from 4.2 Mg ha^{-1} (summer R 2003) to 12.2 Mg ha^{-1} (winter O 2004). This range is similar to the range (5-10 Mg ha^{-1}) reported by Hartz et al (2005) for high biomass cover crops grown in California. The higher end of the range is considerably higher than the typical cover crop dry matter in most western Oregon vegetable cropping systems. Because of the difficulties in managing large volume residues, farmers typically spray out cover crops during dry spells in February in March to permit cover crop decomposition before vegetable crop planting and to maintain cover crop dry matter to below 2 or 3 T/A (4.5 – 6.7 Mg ha^{-1})(Sattell et al, 1999).

Most processed vegetable growers spray out their cover crops in March and this typically maintains DM production below 7.0 Mg ha^{-1} (Sattell et al, 1999). However, in the Kenagy Family Farm trial, the arugula, Mc and O cover crops were flailed in March and all yielded approximately 8.5 Mg ha^{-1} DM; this was likely due to both the high DM potential of these species as well as the growing conditions in that mild winter.

In some years, late summer cover crop dry matter, across species, was lower than winter dry matter. For example, the summer O treatment in 2003-04 yielded 5.0 Mg ha^{-1} while the winter O yielded 12.2 (and increase of 144%). This is commonly true, as over-wintered cover crops grown to maturity have a very long growth period (Sattell et al, 1999). In other years this was reversed; for example in 2005, when conditions for growth were very good in the fall, and the late summer cover crop dry matter averaged 9.9 and the winter DM averaged 8.2 Mg ha^{-1} (due to very low dry matter in the O treatment from winter and disease injury).

Marginally winter-hardy cover crops such as oats generated higher biomass in summer compared to winter when the winter crops were damaged by low winter temperatures and/or BYDV. This was true in 2005 when the fall oats produced a mean DM of 11.0 Mg ha^{-1} but the winter oats yielded 5.9 Mg ha^{-1}.

Disease hosts:

All mustard cover crop species are susceptible to white mold caused by *Sclerotinia sclerotiorum*, which causes white mold of snap bean, the other main processed vegetable grown in western Oregon. This would be a major constraint to widespread adoption of mustard cover crops in western Oregon.

Oat (*Avena sativa*) is highly susceptible to barley yellow dwarf virus (BYDV) and oats grown in project experiments and at Kenagy Family Farm were diagnosed with BYDV. BYDV is an important pathogen of many grass family plants, and has been diagnosed in many grass seed crops by the OSU Plant Clinic (Melodie Putnam, personal communication).

Contamination of seed crops and rapeseed control areas

Mustard cover crops will often begin flowering before incorporation. There are many high value cruciferous seed crops grown in western Oregon that could be contaminated by the pollen from cruciferous cover crops. There is increasing concern about this issue due to the growing interest in canola as a rotation crop in grass seed production systems; this concern led to ODA regulation of cruciferous crop

production. Oregon farmers growing cruciferous cover crops that flower before incorporation must follow the ODA rapeseed control regulations (applicable to any cruciferous crop that flowers) (http://egov.oregon.gov/ODA/PLANT/canola_rapeseed.shtml) as well as regional pinning maps for cruciferous seed crops.

Severity of root rot of sweet corn

Impact of cover cropping and cover crop species on root rot severity

All cover crops evaluated in this project suppressed root rot of corn on at least one sampling date in at least one greenhouse bioassay or field-grown corn crop, but overall, suppressiveness was highly variable.

In 2003-04, there was a gradient in overall suppressiveness in the five cover crop species evaluated singly. Oat was most suppressive and rape was least (not) suppressive to root rot. Listed in order of decreasing suppressiveness, the cover crops were oat ‘Saia’, mustard mix ‘Caliente’, sorghum-sudangrass hybrid 'Cadan 99B', mustard ‘Braco’, and rape ‘Dwarf Essex’.

In 2005 in the research station trial, the cover crops were more equally suppressive. All cover crops were similarly suppressive to root rot in root rot bioassays conducted on summer and winter experiment soils. In the field, there was no treatment difference for suppressiveness in the summer experiment, but all treatments were suppressive in the winter experiment, and rape and oat were more suppressive than mustard mix ‘Caliente’.

In the 2005 on-farm trial, there was no treatment effect on root rot severity in the one greenhouse bioassay conducted at 47 days after cover crop incorporation. However, all cover crop treatments (oat, mustard mix ‘Caliente’, and arugula) similarly suppressed root rot in field-grown corn.

Overall in 2006, rape increased and oat decreased root rot severity. Rape was suppressive to radicle rot at 50 days but increased radical and nodal root rot severity at 84 days in greenhouse bioassays. In field-grown corn, rape had no effect on radicle rot at any date but increased nodal root rot severity at 120 days. Oat was suppressive

to radicle and nodal root rot at 35 days but not at 80 days in greenhouse bioassays. In field grown corn, oat suppressed radicle and nodal root rot at harvest. Oat also reduced the number of leaves fired at harvest. Leaf firing is an aboveground symptom of root rot of corn; corn leaves 'fire', or become chlorotic/necrotic starting from the base of the plant, when root rot is severe in intolerant corn cultivars (Hoinacki, 2003).

In conclusion, all of the cover crop species evaluated demonstrated some potential to suppress root rot of corn. Oat 'Saia' was the only cover crop that was significantly suppressive in every year evaluated. However, not all cover crops were evaluated for more than one year, such as sorghum-sudangrass and arugula, which were suppressive in a single season but not evaluated thereafter. In a related container experiment, Darby (2003) reported that sudangrass reduced the severity of corn root rot by 32 and 64% in each of two soils, while oats reduced root rot severity by 28 and 49%. Other cover crops such as annual ryegrass and cereal rye were not suppressive.

Few studies have successfully demonstrated soilborne disease suppression as the result of high biomass cover cropping in field experiments. Broccoli, sudangrass, Austrian winter pea, and field corn have been shown to suppress Verticillium wilt severity (Subbarao et al, 1998; Davis et al, 1996; Ochiai et al, 2007). In contrast, a recent study on the impact of high biomass mustard cover crops for improving plant health and productivity in tomato production systems in California reported no impact on soilborne disease severity (e.g. Verticillium and Fusarium wilt) and varying impacts on yield (Hartz et al, 2005).

Relative suppressiveness of summer and winter cover crops

There is insufficient data from this project to determine whether planting cover crops in late summer or winter is more likely to generate suppressiveness. In 2004, there were few species grown in both seasons, but both summer and winter oat treatments were similarly suppressive to root rot. In 2005, the cover crop treatments oat, rape, and mustard mix 'Caliente' in the winter experiment were all suppressive to root rot in field grown corn, but the same species grown as summer cover crops were not. There was no summer treatment in 2006.

Variability in disease suppression

The variability in disease suppression observed over the course of this three year project could be due to many factors. Root rot of sweet corn is a poorly characterized disease complex. As it is currently understood, it is caused by at least three pathogens – *Pythium arrhenomanes*, *Drechslera* sp., and *Phoma terrestris* (Hoinacki, 2003). It is likely that the pathogens generating necrosis could vary in importance from soil to soil, through the course of the season, and in different years, depending on environmental conditions and cropping history. In a container experiment, Darby (2003) reported significantly different levels of cover crop-mediated corn root rot suppression in two different field soils.

In addition, it is likely that different pathogens are differentially suppressed, and suppressed through different mechanisms or combinations of mechanisms. This was demonstrated for manure-mediated corn root rot suppression by Darby (2003); compost amendments reduced root rot severity in soils infested with *Drechslera* sp. or *Phoma terrestris* inoculum to a greater degree than manure amendment, but the reverse was true for *Pythium arrhenomanes* -infested soils. The mechanism(s) for these phenomena are unknown. Plant and soil nutrient status, soil moisture content, specific microbial populations, and many other factors could influence one or more mechanisms, and in addition there could be interactions amongst those factors.

Overall, there appears to be much more variability in suppressiveness of single season cover crop-amended soils than in high rate compost- or manure-amended soils. This could be due to the fact that single season cover crop-mediated suppression, when it occurs, is likely due to mechanisms other than organic matter-mediated general suppression (OMGS). OMGS requires a high soil content of labile organic matter (Stone et al, 2004; Darby et al 2006). The dry matter input in the Darby et al (2006) field trial ranged from 16.8 in the low rate to 56.0 Mg ha^{-1} in the high rate – much higher than the DM generated by single season cover cropping. Therefore, when suppressiveness is observed, it is likely to be generated by other, less well understood and less stable or less frequently-generated mechanisms.

Relationship between disease severity in greenhouse bioassays and in field-grown corn

Disease severity in greenhouse bioassays did not in general correlate well with disease severity in field-grown corn. The cone tube bioassay for assaying field soils for root rot severity was developed by Hoinacki (2003). It was adapted by Darby et al (2006) for use in a manure and compost amendment root rot suppression study conducted at the OSU research farm. In those studies, root rot severity in corn grown to the six leaf stage in greenhouse bioassays was, overall, correlated with root rot severity in corn grown in the same soil/treatment in the field. A striking exception was in bioassays conducted on soils from the organic amendment trial at 12 months after amendment. At that sampling date in greenhouse bioassays, root rot severity increased linearly with increasing amendment rate, and this was observed in each of three seasons. When corn was grown in those treatments in the field, there was no relationship between amendment rate and disease severity. Interestingly, this phenomenon was not observed for root rot of snap bean in bioassays conducted on the same treatment soils (Darby et al, 2006).

Soils sampled, sieved, placed in cone tubes and watered have different physical properties than the same soil *in situ*; it is only logical to assume that the changes in physical properties also affect the chemical and biological properties of the soil, and, subsequently, root rot severity. Because of this lack of correlation, cone tube bioassays should not be used to assess the impact of a cover crop on root rot of sweet corn.

Corn productivity

In general, cover crops increased or had no impact on shoot and root dry matter in greenhouse bioassays, but impacts on DM of corn in the field were more variable. There was only one significant cover crop treatment effect on yield; in 2006, the oat treatment increased yield by 11.6% compared to the fallow. Ochiai et al (2007) also reported cover crop-mediated suppression of disease (Verticillium wilt), and in those experiments, cover cropping reduced potato yield. Hartz et al (2005) investigated the

impact of winter mustard cover crops on soilborne disease severity and yield of processing tomato; in three trials there was no impact on tomato yield, and in one trial tomato yield was increased and in two others tomato yield was reduced. In our work, the lack of yield response is likely due to the interaction between the many soil factors affected by cover cropping, and the many soil factors that affect yield potential in a field-grown corn crop.

Microbial activity

Almost without exception, cover crop treatments increased soil microbial activity. The magnitude of the increase varied depending on factors such as cover crop species, cover crop DM, and days after incorporation. This is not surprising, as the cover crop biomass is a substrate for the general microbial community. An increase in microbial activity (as FDA activity) has been shown in previous studies on high biomass cover cropping (Darby, 2003; Davis et al, 1994; Ochiai et al, 2007).

Relationships between cover crop dry matter, soil microbial activity, and root rot severity

Dry matter:

Cover crop dry matter has been suggested as an important determinant of the potential for a cover crop to suppress some soilborne diseases (Davis et al, 1994; Ochiai et al, 2007). Organic amendment rate is an important determinant of organic matter-mediated general suppression (OMGS); OMGS is typically generated by high rate amendment with manure or compost (Stone et al, 2004). As an example, the dry matter input in a trial investigating the impact of manure and compost amendments on severity of corn root rot ranged from approximately 6 to 56.0 Mg ha^{-1}. The higher rates (16 Mg ha^{-1} and above) were suppressive 1 month after the first amendment; the lowest rate amendment was not suppressive to root rot of corn in the first season, but was suppressive in the second season after re-amendment at the same rate (Darby et al, 2006). These high rates of amendment are viable in container systems, and might be

viable in some high value, small acreage horticultural crops, but are not viable in low value, large scale agricultural systems.

Supplying dry matter through high biomass cover cropping would be a less expensive and more agronomically viable alternative to high rate organic manure and compost applications. However, there are few studies that have actually demonstrated a reduction in soilborne disease severity as the result of cover cropping and then related suppression to cover crop DM. Davis et al (1999) reported a negative correlation between sudangrass DM and severity of Verticillium wilt of potato. Berlanger (2000) reported a positive relationship between broccoli residue DM and destruction of Verticillium inoculum. Ochiai et al (2007) applied aboveground Austrian winter pea, broccoli, and sudangrass at 6, 12, and 24 Mg ha^{-1} DM to field plots infested with *Verticillium dahliae*. None of the cover crops reduced disease severity at the lowest rate, while all cover crops suppressed wilt at the highest rate. Only Austrian winter pea suppressed wilt at the 12 Mg ha^{-1} rate. The authors concluded that both cover crop species and DM affected Verticillium wilt suppressive potential.

The results of the Darby et al (2006) and Ochiai et al (2007) studies suggest that single season dry matter amendments must be in the range of 12-24 Mg ha^{-1} to generate general suppression. As observed in this project, single season cover cropping in western Oregon will rarely generate 12 Mg ha^{-1}, even when growing species of very high DM yield potential. In this work, there was a significant negative relationship in 2004 between cover crop DM and radicle rot severity at 3 months after summer cover crop incorporation but not at any other date, and there was no relationship between cover crop DM and GH root rot severity at any sampling date in 2005 or 2006. However, overall, there was a significant negative relationship in 2004-2006 greenhouse experiments between DM and radicle rot severity (Fig. 6.1). Nonetheless, there was no relationship between cover crop DM and root rot severity in any field experiment. Therefore, in this work, cover crop DM does appear to be a factor related to suppressiveness to root rot of sweet corn in greenhouse but not field experiments.

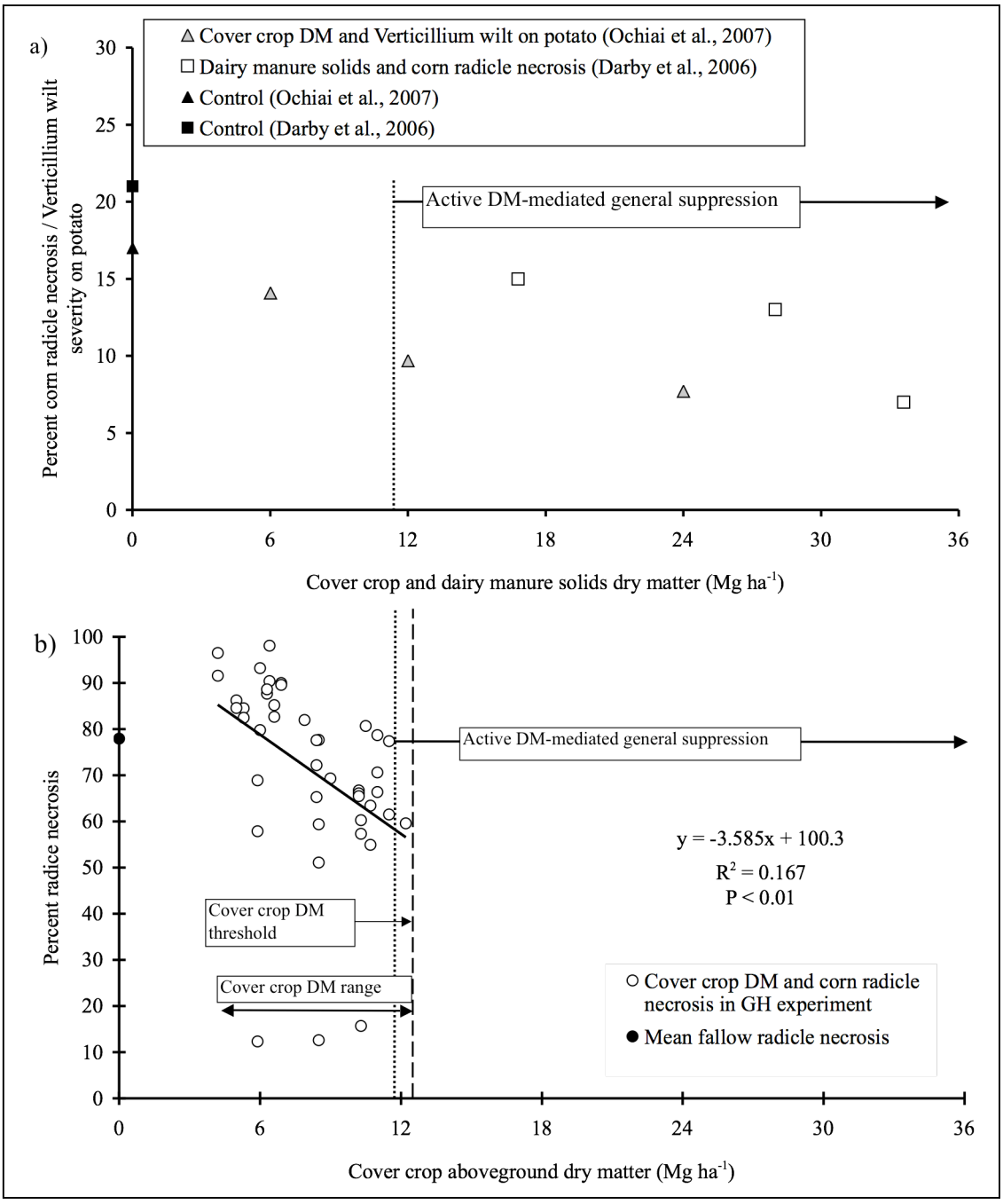

Fig. 6.1. Relationship between a) cover crop / dairy manure solids DM and potato Verticillium wilt severity /corn radicle rot and b) overall correlation between cover crop DM and radicle rot severity in greenhoues experiment.

§ Greenhouse bioassay data includes: 2003-2004 research station experiment, 2004-2005 research station experiment, 2004-2005 on-farm experiment, 2006 rape experiment, and 2006 oat experiment. Sources: Ochiai et al., 2007; Darby et al., 2006.

Microbial activity

In general, there was a significant negative correlation between microbial activity and root rot severity in greenhouse bioassays early after cover crop incorporation, but the correlation weakened over time and ultimately was lost by about 80 days after incorporation.

In 2004 there was a significant negative correlation between microbial activity and root rot severity at 2 months but there was no correlation at 8 months after incorporation. In 2005, the relationship was strongest and the slope steepest at 26 days, intermediate at 51 days, and weakest (and no longer significant) at 84 days after incorporation in soils collected from the summer cover crop experiment. In soils collected from the winter experiment, however, there was only a significant negative correlation between FDA activity and radicle rot severity at 55 days after incorporation and not at the other two sampling dates. In 2006, there was no correlation between microbial activity and radicle rot severity at 80 days in the oat experiment and at 84 days in the rape experiment (the only date microbial activity was measured in that season).

A significant negative correlation between FDA activity and severity of root rot of corn was reported previously in a compost and manure-amended field trial; again, the relationship was lost several months after amendment (Darby et al, 2006). A significant negative correlation between FDA activity and severity of Verticillium wilt in cover crop-amended field soils planted to potato was reported by Davis et al (1994) and Ochiai et al (2007). In contrast, in container research in which oat and sudangrass cover crops suppressed root rot of corn, microbial activity was not correlated with root rot severity (Darby, 2003).

In this work, microbial activity was related to suppressiveness of root rot of corn at early stages of cover crop decomposition. This is an indication that 'general suppression', or suppressiveness generated by a group of diverse soil microbes whose collective activities are supported by the decomposition of labile organic matter (Stone et al, 2004), may play a role in cover crop-mediated suppression of root rot of sweet corn. In 2005, the cover crop treatments oat, rape, and mustard mix 'Caliente' in the

winter experiment were all suppressive to root rot in field grown corn, but the same species grown as summer cover crops were not; this data supports the idea that suppressiveness is sustained for a short period after cover crop incorporation – phenomenology that appears similar to 'general suppression'. However, suppressiveness was also observed in field grown corn planted in summer oat cover crop treatments, long after the decomposition of the labile constituents of the incorporated cover crops. Therefore, at least for cover crops such as oat, it is likely that other mechanisms also play a role.

The idea that some cover crops act as 'biofumigants' has gained traction recently with both researchers and farmers. 'Biofumigant' cover crops are thought to destroy pathogen propagules through the release of toxic plant constituents into the soil upon cover crop flailing and incorporation. Oats, sudangrass, and mustard family plants all contain toxic compounds, such as avenecin, dhurrin, and isothiocyanates, respectively, that in laboratory experiments can directly reduce pathogen propagule survival (see literature review). Nonetheless, while some of these crops do suppress soilborne diseases and in some cases inoculum density is reduced, there is little or no evidence that 'biofumigation' actually occurred. Instead, research suggests that specific plant residues alter microbiological properties of the soils, and these changes in the microbial community/activities then impact pathogen survival and/or infection. However, these interactions are complex and at this time are very poorly understood (Subbarao et al, 1999; Davis et al, 1999).

In this project, all cover crops showed some potential to suppress root rot of sweet corn, but oat was the cover crop most consistently suppressive over the three years of the project. Previous work in containers also documented suppression of root rot of sweet corn by oat cover crops (Darby, 2003). It is possible that oat residues are particularly suppressive to root rot of sweet corn due to some aspect or aspects of their chemistry (e.g. avenecin) and/or impacts on the soil microbial community, or some combination of these and other factors. The mechanisms involved in the suppressiveness of oat cover crops should be investigated in future work. The root rot suppressive potential of sudangrass should also be investigated further, as it was also

suppressive in previous container studies and in the summer cover crop experiment in 2004.

Nitrogen immobilization

It has been reported frequently that oat cover crops immobilize nitrogen, and in some cases this reduces subsequent crop yields (Baggs et al., 2000; Francis et al., 1998). In 2006, soil nitrogen was immobilized at 21 to 63 days after incorporation in the oat treatment. Extractable N content of the F treatment was approximately 75% greater than the O treatment at day 35. In the laboratory incubation, constant moisture, temperature, and excellent residue-to-soil contact should result in rapid decomposition and subsequent mineralization; however, the data (Fig. 5.18 and 5.19) suggests there was no available N at day 63. The oat C : N ratio was high (approximately 51), and oat % total nitrogen was less than 1%. Therefore, there was very little total N in the oat residue. Even if net available N became positive after 63 days, the net available N value from the oat residue would be very small.

If net available N in the oat treatment was lower than in the fallow, one would expect to see lower corn dry matter content in the oat treatment. However, while that was observed in some trials on some sampling dates, there was no consistency in above- or below-ground dry matter reduction in oat treatment over the three years of data collection. In 2005, the oat treatment soils generated higher corn biomass in greenhouse bioassays at 27, 50, and 80 days. In contrast, in 2005 in the research station field-grown corn and the Kenagy on-farm trial, aboveground corn dry matter in the oat treatment was lower than in all other treatments, although this was not statistically significant in the on-farm trial. In 2006, the oat treatment had no significant effect on corn DM but increased yield by 11.1%.

Corn grown in the oat treatment soils had lower SPAD values, but they were not extremely low compared to the 77 kg N ha^{-1} fallow. The sufficiency index (Shapiro and Francis, 2006; Peterson et al., 1993) [(26 kg ha^{-1} side-dressing in oat treatment / 77 kg ha^{-1} side-dressing in fallow) * 100] at 0, 7, 14, 21, and 28 days after side-dressing was 96.1, 94.6, 98.0, 93.8, and 93.1%, respectively. A mean index

above 95 % indicates that corn yield will not increase if additional N is supplied (Shapiro and Francis, 2006; Peterson et al., 1993); in the case of the oat treatment, the sufficiency index values at days 0, 7 and 14 were at or above 95%. In addition, Marvel et al. (1997) suggested that if a corn plant was above a sufficiency index value of 90.0 % at the V8 to V10 stage it would not respond to additional N inputs. Days 0, 7 and 14 are approximately equivalent to the corn developmental stage V7 to VT. Although oat did immobilize N in the soil and the corn grown in the oat treatment did have lower SPAD values than in the fallow treatment, there was no cover crop treatment effect on aboveground dry matter and corn yield. In conclusion, the results from 2006 suggest that while the oat treatment in 2006 did immobilize N, it is possible that that immobilization had little effect on corn yield. More work is necessary to better understand the impact of oat incorporation on N availability and corn yield.

In addition to problems associated with nutrient management, two drawbacks to the widespread use of oat cover crops in western Oregon are unreliable winter-hardiness and susceptibility to BYDV. There are many *A. sativa* cultivars and also other *Avena* species, and some of these are more winter hardy (Livingston et al, 2004) and more tolerant of BYDV (Comeau, 1984), so it is possible that other *Avena* species and/or cultivars could be identified that are more winter hardy, less BYDV susceptible, and as suppressive or more suppressive than *A. sativa* 'Saia'.

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APPENDIX

Appendix 1. Extractable NO_3-N (mg kg^{-1}) after 70 days incubation: research station in 2005.

Block	Treatment	Extractable NO_3-N	Treatment	Extractable NO_3-N
	--- Summer ---	--- mg kg^{-1} ---	--- Winter ---	--- mg kg^{-1} ---
1	F	29.33	F	43.21
2	F	31.08	F	33.64
3	F	28.38	F	44.88
4	F	29.11	F	35.06
5	F	35.07	F	42.84
6	F	23.28	F	40.58
1	Mc	35.78	Mc	49.43
2	Mc	33.18	Mc	53.02
3	Mc	31.33	Mc	54.15
4	Mc	36.57	Mc	61.77
5	Mc	37.06	Mc	57.86
6	Mc	34.69	Mc	49.32
1	R	35.98	R	72.33
2	R	34.36	R	69.91
3	R	34.92	R	66.34
4	R	40.07	R	59.99
5	R	38.95	R	79.85
6	R	38.95	R	59.53
1	O	36.48	O	45.70
2	O	38.89	O	43.87
3	O	31.71	O	47.68
4	O	41.06	O	54.56
5	O	32.87	O	51.91
6	O	38.03	O	46.98

§Treatment F, Mc, R, and O represents fallow, mustard mix 'Caliente', rape 'Dwarf Essex', and oat 'Saia', respectively.

Appendix 2. Extractable NO_3-N and NH_4-N (mg kg^{-1}) at 19 and 84 days after incorporation in field soil: rape 'Dwarf Essex' experiment (2006).

Block	Treatment	Day 19		Day 84	
		NO_3-N	NH_4-N	NO_3-N	NH_4-N
--In-field--	----- Winter -----	---------- mg kg^{-1} ----------			
1	F	11.85	0.05	5.08	0.08
2	F	11.78	0.06	8.30	0.08
3	F	11.47	0.06	12.15	0.11
4	F	13.42	0.04	9.53	0.09
5	F	10.36	0.07	7.70	0.08
6	F	12.12	0.02	6.13	0.12
7	F	9.15	0.02	10.12	0.07
8	F	9.18	0.02	6.08	0.10
9	F	8.73	0.07	12.03	0.05
10	F	8.61	0.06	7.98	0.06
11	F	7.47	0.08	7.06	0.02
12	F	7.49	0.09	7.56	0.04
1	R	8.08	0.03	14.19	0.10
2	R	11.84	0.05	14.31	0.15
3	R	10.57	0.04	9.66	0.06
4	R	8.86	0.04	11.75	0.09
5	R	9.60	0.04	14.19	0.08
6	R	10.66	0.04	15.16	0.10
7	R	11.74	0.04	9.48	0.11
8	R	10.07	0.02	12.24	0.07
9	R	6.48	0.08	10.72	0.03
10	R	5.83	0.09	10.92	0.11
11	R	8.92	0.11	9.30	0.02
12	R	6.96	0.13	12.11	0.02

§Treatment F and R represents fallow and rape 'Dwarf Essex', respectively.

Appendix 3. Extractable NO_3-N and NH_4-N (mg kg^{-1}) at 0, 21, 42, and 63 days after amendment in laboratory incubation: rape 'Dwarf Essex' experiment in 2006.

Rep.	Treatment	Day 0		Day 21		Day 42		Day 63	
		NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N
--Laboratory--		mg kg^{-1}							
1	F	37.95	0.04	49.69	0.02	58.36	0.23	62.93	0.11
2	F	40.24	0.04	44.71	0.01	56.17	0.25	60.58	0.07
3	F	40.38	0.04	49.97	0.02	61.28	0.24	66.49	0.10
4	F	38.44	0.04	51.45	0.02	57.62	0.24	61.29	0.10
5	F	39.03	0.05	53.59	0.02	58.64	0.21	65.26	0.10
6	F	38.35	0.05	50.97	0.02	58.02	0.20	63.99	0.09
7	F	35.48	0.06	53.77	0.01	66.16	0.14	63.65	0.09
8	F	38.56	0.05	51.18	0.05	58.07	0.11	64.12	0.08
9	F	38.96	0.07	54.70	0.03	58.69	0.16	58.07	0.08
10	F	36.72	0.07	53.89	0.01	64.10	0.18	59.39	0.08
11	F	38.85	0.06	50.89	0.03	61.97	0.18	59.88	0.06
12	F	38.26	0.06	50.65	0.01	56.66	0.17	61.32	0.05
1	R	38.42	0.07	45.72	0.02	58.35	0.23	66.23	0.12
2	R	41.02	0.04	48.79	0.01	56.68	0.26	57.52	0.10
3	R	39.18	0.04	40.41	0.01	46.55	0.24	51.40	0.10
4	R	37.34	0.04	45.77	0.01	52.68	0.24	56.38	0.10
5	R	37.41	0.06	45.96	0.01	54.11	0.20	59.71	0.09
6	R	38.30	0.05	48.85	0.01	57.72	0.20	61.82	0.09
7	R	38.45	0.06	46.97	0.01	49.39	0.13	64.17	0.09
8	R	38.36	0.06	43.65	0.02	52.19	0.13	64.83	0.09
9	R	38.19	0.07	45.27	0.01	56.30	0.15	59.74	0.07
10	R	39.05	0.06	48.76	0.11	55.34	0.19	59.27	0.06
11	R	36.87	0.06	48.34	0.01	55.96	0.19	60.34	0.05
12	R	35.32	0.05	52.75	0.01	62.10	0.17	59.84	0.04

§Treatment F and R represents fallow and rape 'Dwarf Essex', respectively.

Appendix 4. Extractable NO_3-N and NH_4-N (mg kg^{-1}) at 35 and 80 days after incorporation in field soil: oat 'saia' experiment in 2006. Page 1/2.

Block	Treatment	Day 35		Day 80	
		NO_3-N	NH_4-N	NO_3-N	NH_4-N
-- In-field --	----- Winter -----	---------- mg kg^{-1} ----------			
1	F	25.60	0.06	8.83	0.03
1	F	27.92	0.05	6.93	0.03
1	F	25.18	0.05	12.58	0.03
1	F	36.35	0.05	12.56	0.03
2	F	23.05	0.02	11.25	0.05
2	F	22.97	0.02	6.88	0.04
2	F	31.40	0.04	8.17	0.06
2	F	26.69	0.02	6.26	0.05
3	F	39.78	0.02	9.84	0.01
3	F	26.65	0.02	7.96	0.04
3	F	23.09	0.02	9.74	0.01
3	F	26.65	0.02	10.35	0.01
3	F	20.93	0.02	7.94	0.01
3	F	33.37	0.02	7.30	0.01
3	F	20.71	0.02	7.35	0.01
3	F	23.53	0.01	10.35	0.02
4	F	27.05	0.01	7.25	0.01
4	F	22.94	0.02	9.63	0.01
4	F	21.02	0.02	4.79	0.01
4	F	25.98	0.02	4.20	0.02
1	O	5.46	0.05	8.21	0.04
1	O	6.64	0.07	6.34	0.04
1	O	4.27	0.05	12.60	0.05
1	O	4.85	0.05	9.49	0.03
1	O	4.84	0.07	6.96	0.03
1	O	3.00	0.04	8.76	0.03
1	O	19.66	0.07	7.61	0.03
1	O	20.83	0.06	6.96	0.03
2	O	5.36	0.02	5.67	0.08
2	O	4.21	0.04	10.62	0.06
2	O	4.25	0.02	8.17	0.06
2	O	6.01	0.04	6.28	0.03
2	O	5.94	0.06	9.33	0.07
2	O	7.10	0.02	7.43	0.09
2	O	6.55	0.05	6.82	0.09
2	O	8.25	0.04	6.17	0.06
3	O	7.01	0.02	6.14	0.01
3	O	4.73	0.02	5.53	0.01
3	O	5.21	0.02	5.44	0.02
3	O	5.75	0.02	5.48	0.01
4	O	2.89	0.02	6.02	0.02

Appendix 4. Extractable NO_3-N and NH_4-N (mg kg^{-1}) at 35 and 80 days after incorporation in field soil: oat 'saia' experiment in 2006. Page 2/2.

Block	Treatment	Day 35		Day 80	
		NO_3-N	NH_4-N	NO_3-N	NH_4-N
-- In-field --	----- Winter -----	---------- mg kg^{-1} ----------			
4	O	2.32	0.02	4.23	0.02
4	O	5.73	0.02	9.62	0.02
4	O	18.33	0.02	6.04	0.02
4	O	2.29	0.02	4.20	0.02
4	O	5.17	0.02	7.82	0.02
4	O	2.86	0.02	7.20	0.01
4	O	5.16	0.01	12.07	0.01

§Treatment F and O represents fallow and oat 'Saia', respectively.

Appendix 5. Extractable NO_3-N and NH_4-N (mg kg^{-1}) at 0, 21, 42, and 63 days after amendment in laboratory incubation: oat 'saia' experiment in 2006. Page 1/2.

Rep.	Treatment	Day 0		Day 21		Day 42		Day 63	
		NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N
-- Laboratory --		mg kg^{-1}							
1	F	34.23	0.02	45.63	0.03	51.60	0.10	53.27	0.06
2	F	34.10	0.02	47.91	0.08	47.31	0.10	56.77	0.06
3	F	31.61	0.04	47.89	0.04	54.64	0.11	54.81	0.05
4	F	35.46	0.04	47.97	0.06	51.61	0.10	56.03	0.06
5	F	35.19	0.04	40.36	0.04	50.08	0.09	54.50	0.06
6	F	34.62	0.04	51.65	0.02	53.44	0.09	59.60	0.06
7	F	35.99	0.04	51.42	0.01	55.44	0.09	60.28	0.06
8	F	35.14	0.04	52.07	0.01	56.41	0.08	58.75	0.05
9	F	33.65	0.02	49.26	0.01	58.05	0.10	57.50	0.06
10	F	34.60	0.04	49.83	0.01	55.08	0.09	59.15	0.05
11	F	36.03	0.04	49.35	0.05	55.63	0.10	59.16	0.06
12	F	36.14	0.03	52.66	0.01	51.26	0.09	57.11	0.06
13	F	35.62	0.04	46.91	0.01	54.46	0.09	57.80	0.05
14	F	36.84	0.04	51.59	0.01	53.71	0.10	60.39	0.05
15	F	42.01	0.04	52.77	0.01	56.15	0.09	59.84	0.06
16	F	40.70	0.04	56.72	0.01	55.01	0.10	63.06	0.05
17	F	40.59	0.05	51.91	0.01	54.38	0.10	69.64	0.06
18	F	42.46	0.05	54.55	0.01	59.51	0.10	64.98	0.06
19	F	39.44	0.04	50.37	0.01	59.06	0.10	66.43	0.06
20	F	40.01	0.04	56.12	0.01	57.90	0.10	63.34	0.06
1	O	34.59	0.02	36.16	0.05	40.84	0.10	45.25	0.06
2	O	34.18	0.02	31.25	0.09	39.98	0.10	43.59	0.06
3	O	34.09	0.04	36.32	0.05	45.10	0.10	52.68	0.06
4	O	33.29	0.04	36.56	0.04	43.74	0.09	46.13	0.05
5	O	34.44	0.04	22.06	0.08	24.55	0.10	28.91	0.06
6	O	34.56	0.04	25.07	0.04	26.51	0.09	32.73	0.06
7	O	33.93	0.04	34.35	0.05	38.35	0.09	55.08	0.08
8	O	34.94	0.03	32.01	0.08	39.89	0.09	45.00	0.05
9	O	34.96	0.03	35.47	0.02	42.74	0.08	50.72	0.06
10	O	35.29	0.02	18.18	0.04	19.21	0.09	24.05	0.05
11	O	35.26	0.04	31.81	0.02	38.68	0.09	43.96	0.06
12	O	35.20	0.04	33.67	0.01	36.56	0.09	41.95	0.06
13	O	35.44	0.08	38.39	0.05	41.77	0.11	45.40	0.06
14	O	35.24	0.04	27.51	0.04	33.61	0.10	40.07	0.06
15	O	34.99	0.03	40.66	0.03	43.48	0.10	49.69	0.06
16	O	36.88	0.04	35.18	0.01	40.01	0.11	47.25	0.05
17	O	34.32	0.03	39.09	0.01	6.84	0.10	53.52	0.06
18	O	35.52	0.03	39.95	0.01	50.18	0.10	50.08	0.05
19	O	37.08	0.03	43.08	0.01	45.33	0.09	55.76	0.06
20	O	34.39	0.03	8.93	0.03	49.30	0.10	6.30	0.06

Appendix 5. Extractable NO_3-N and NH_4-N (mg kg^{-1}) at 0, 21, 42, and 63 days after amendment in laboratory incubation: oat 'saia' experiment in 2006. Page 2/2.

Rep.	Treatment	Day 0		Day 21		Day 42		Day 63	
		NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N
-- Laboratory --		---------- mg kg^{-1} ----------							
21	O	40.34	0.05	42.42	0.01	51.56	0.11	62.62	0.07
22	O	40.46	0.06	49.28	0.01	53.42	0.10	58.91	0.05
23	O	41.98	0.06	46.75	0.01	54.87	0.10	62.39	0.05
24	O	40.12	0.06	47.24	0.01	54.73	0.10	64.47	0.05
25	O	40.38	0.05	50.44	0.01	52.71	0.10	58.66	0.05
26	O	40.32	0.06	44.94	0.01	52.93	0.10	58.65	0.05
27	O	39.84	0.04	46.67	0.01	53.66	0.10	57.37	0.06
28	O	38.14	0.04	45.84	0.01	54.23	0.11	58.57	0.05

§Treatment F and O represents fallow and oat 'Saia', respectively.

Appendix 6. Mean SPAD-502 reading at 0, 7, 14, 21, and 28 days after side-dressing: oat 'saia' experiment in 2006. Page 1/2.

Block	Treatment	Days after side-dressing				
		0	7	14	21	28
		SPAD-502 reading				
1	F-26	51.7	55.5	55.8	54.3	52.0
1	F-77	49.2	53.6	58.0	54.5	49.3
1	F-77	53.6	54.4	57.6	57.7	54.2
1	F-26	51.1	54.9	53.3	56.2	52.7
2	F-77	51.0	56.2	54.0	56.5	49.2
2	F-26	48.9	56.5	51.7	51.8	52.5
2	F-77	49.7	57.3	54.1	54.2	50.7
2	F-26	50.0	58.0	58.0	57.8	51.6
3	F-26	52.6	58.1	57.3	55.7	46.8
3	F-77	49.9	54.5	53.1	56.6	52.6
3	F-77	52.7	56.9	57.7	53.3	51.5
3	F-26	48.9	55.6	58.0	60.2	55.7
3	F-26	47.5	55.0	55.6	57.6	57.9
3	F-77	49.5	57.6	55.4	58.2	53.1
3	F-77	50.9	56.6	50.6	55.1	54.7
3	F-26	51.4	58.5	57.7	55.1	56.7
4	F-26	52.2	54.5	57.5	55.8	53.5
4	F-77	51.5	54.9	55.9	57.5	59.5
4	F-26	53.4	55.7	54.6	52.6	53.3
4	F-77	53.1	57.6	54.3	59.3	58.8
1	O-77	48.7	52.0	54.5	54.8	47.8
1	O-26	50.5	53.9	55.4	54.3	51.3
1	O-77	47.4	53.2	53.8	54.4	51.6
1	O-26	50.8	51.6	52.8	50.5	42.8
1	O-26	51.2	52.1	54.2	53.1	48.6
1	O-77	47.4	52.5	52.5	55.6	55.0
1	O-77	46.7	53.7	54.4	52.9	51.0
1	O-26	50.6	55.3	55.3	54.9	51.7
2	O-77	45.8	52.6	54.2	57.2	50.3
2	O-26	47.8	52.8	54.9	53.1	47.5
2	O-26	46.9	55.0	50.5	52.5	51.8
2	O-77	49.6	53.0	55.0	61.0	50.1
2	O-26	47.4	52.9	53.8	50.8	44.0
2	O-77	50.8	53.6	58.7	54.7	55.4
2	O-77	48.2	55.0	55.3	56.0	51.0
2	O-26	49.4	53.4	57.8	55.9	56.2
3	O-26	50.6	53.8	55.0	51.8	48.1
3	O-77	48.5	54.1	58.3	55.3	54.8
3	O-77	47.6	55.8	52.4	57.2	50.5
3	O-26	49.8	52.2	55.8	54.2	46.4
4	O-77	49.8	52.7	53.0	58.3	53.5

Appendix 6. Mean SPAD-502 reading at 0, 7, 14, 21, and 28 days after side-dressing: oat 'saia' experiment in 2006. Page 2/2.

Block	Treatment	Days after side-dressing				
		0	7	14	21	28
		SPAD-502 reading				
4	O-26	50.6	51.9	53.9	57.1	53.2
4	O-26	47.4	52.4	52.3	53.0	49.6
4	O-77	51.4	54.7	57.1	56.1	57.4
4	O-26	48.2	50.8	52.6	49.7	50.2
4	O-77	48.8	55.1	54.8	55.3	55.2
4	O-26	47.5	53.0	51.8	48.0	55.1
4	O-77	50.7	51.6	57.3	52.6	51.5

§Treatment F-26, F-77, O-26 and O-77 represents fallow with 26 kg N ha^{-1}, fallow with 77 kg N ha^{-1}, oat 'Saia' with 26 kg N ha^{-1}, and oat 'Saia' with 77 kg N ha^{-1}, respectively.