AGGREGATE STABILITY, INFILTRATION, AND GLOMALIN IN ERODED AND COMPACTED SOILS ON FORT HOOD MILITARY RESERVATION

A Thesis

by

JAMES KENNETH APPLEWHITE IV

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2008

Major Subject: Soil Science

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Approved by:

Chair of Committee,	Charles T. Hallmark
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ABSTRACT

Aggregate Stability, Infiltration, and Glomalin in Eroded and Compacted Soils on Fort Hood Military Reservation. (August 2008)

James Kenneth Applewhite IV, B.S., Texas A&M University

Chair of Advisory Committee: Dr. C.T. Hallmark

Fort Hood Military Reservation is a 900 km^2 military installation located between Killeen, Copperas Cove, and Gatesville in central Texas. It supports two full armored divisions which require year-round, live-fire maneuvers and training (Ft. Hood, 2003). As a result of the constant foot traffic and use of heavy equipment, the soils on the training ranges have become increasingly compacted, eroded, and stripped of vegetation. This study evaluated the impact that selected soil amendments would have on soil aggregation, infiltration, and levels of glomalin. A field study was done on plots located inside Fort Hood on a Nuff silty clay (fine-silty, carbonatic, thermic Udic Calciustoll). The plots were amended with composted dairy manure, inorganic fertilizers, and native grass seed. Aggregate stability was determined using a wet sieving procedure and total glomalin values were quantified using a Bradford assay. Field measurements of infiltration rates were taken using a drip-type rainfall simulator.

Aggregate stability exhibited decreased values over time for all treatments but two (Site Prep / No Seed and Site Prep / Compost / Seed). In addition, three treatments changed significantly over time (from before treatment application to after treatment

application). These treatments were the Site Prep / Compost / No Seed, No Prep / No Seed, and No Prep / Seed treatments. Levels of glomalin increased significantly over time for all treatments (p-value <0.001). Glomalin was correlated to aggregate stability after treatments were applied (p-value <0.01) but not before (p-value 0.89). In addition, infiltration rates were not related to glomalin (p-value 0.9) or aggregate stability (p-value 0.09).

Additional sampling of Fort Hood beyond the plot study demonstrates significant differences in aggregate stability, infiltration rates, and levels of glomalin. Measurements taken from ten sites showed no correlations between aggregate stability, infiltration rates, or glomalin. Organic C was correlated to percent water stable aggregates (%WSA) and levels of glomalin. These results illustrate the relationship between organic C and aggregate stability as well as glomalin levels in maintaining infiltration rates and reducing soil loss by erosion.

DEDICATION

I dedicate this thesis to my wife, Julianne. Her willingness to support me over many years and multiple degrees is humbling. I thank her for her love and sacrifice so I could achieve my goals.

ACKNOWLEDGEMENTS

I must acknowledge the aid and support of Dr. Hallmark throughout my time at Texas A&M University. From my undergraduate degree to my graduate degree, he has been paramount to my success and education. As a mentor and teacher his guidance and involvement have inspired and challenged me. My committee members, Dr. Feagley and Dr. Smeins, also deserve praise for helping me complete my research and obtain my degree.

I would also like to express my gratitude to Donna Prochaska, Annette Fincher, and Heidi Mjelde for their willingness to assist me and patience as I used their laboratories. In addition, I thank my fellow graduate students for their help and support as we navigated the challenges of graduate school.

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INTRODUCTION

Reducing soil erosion can be accomplished by improving aggregate stability which is defined as the ability of the soil to maintain its structure when exposed to various forces such as wind and water. Therefore, if the soil aggregates are better able to resist breakdown from these forces, then the soil is less likely to wash away or create a seal on the soil surface (USDA, 1996). In addition, improving aggregation can increase infiltration rates which can significantly decrease runoff and erosion (USDA, 1998).

The recent discovery of a soil protein known as glomalin, after Glomales (the order of fungi that produce this protein), has led to numerous studies linking this protein to improved aggregate stability (Wright and Upadhyaya, 1998; Rillig, 2004). Hyphae from arbuscular mycorrhizal fungi (AMF) produce the glomalin which helps to bind particles of soil together along with physical entanglement by the actual hyphae. The AMF contributions to plants include increasing uptake of nutrients, protection from pathogens, and increased drought tolerance. In return the AMF receive a soluble source of C valuable for supplying energy (Paul and Clark, 1996). Additionally, AMF have been shown to colonize about 80% of all plant taxa, including many grasses and crops, which make AMF an important component of aggregate stability (Allen, 1991). Knowing which plants AMF can colonize best could help determine what should be used to revegetate denuded areas to improve soil stability.

This thesis follows the style of Soil Science Society of America Journal.

Inorganic fertilizers and organic manures are both known to improve soil aggregation as well as other soil characteristics such as increases in porosity, infiltration capacity, hydraulic conductivity, and decreases in bulk density (Haynes and Naidu, 1998). However, Lovelock et al. (2004) showed that soils in old growth forests of Costa Rica that were higher in residual fertility correlated with lower levels of total glomalin (TG) and easily extractable glomalin (EEG). This inconsistency suggests other factors are involved with applications of manure that compensate for any negative impact added fertility may have on AMF (Bittman et al., 2005). Therefore, understanding which scenario would best improve aggregate stability and decrease erosion should be further evaluated. Furthermore, discharge of excess nutrients from concentrated animal feeding operations on the North Bosque River has been a problem for many years (TCEQ, 2003). By utilizing compost from these Central Texas dairies, it may be possible to decrease nutrient loads into the North Bosque River watershed and potentially reduce erosion problems facing Fort Hood.

OBJECTIVES

Objectives of this study are to: 1) elucidate the effect that various soil fertility treatments have upon glomalin levels and aggregate stability, 2) determine the relationships between aggregate stability and total glomalin levels, 3) measure infiltration rates in order to evaluate the effectiveness of aggregate stability, and 4) sample sites across Fort Hood to discover the range of values for aggregate stability, glomalin, and infiltration rates throughout the training areas of Fort Hood. Understanding the relationships among these variables should suggest management actions for Fort Hood personnel to improve the soil stability and decrease erosion in areas impacted by training exercises.

REVIEW OF LITERATURE

Soil Aggregation

Soil aggregation is defined as the process whereby aggregates of various sizes join together by means of an array of organic and inorganic materials (Amézketa, 1999). It is a complex process with many components, both biotic and abiotic (Rillig, 2004). Furthermore, this property of soils is essential for reducing erosion, which can seriously alter the productivity of land (Franzluebbers et al., 2000; Amézketa, 1999). The distribution of aggregates is typically differentiated between micro-aggregates (<250μm) and macro-aggregates (>250 μm). There exist different mechanisms of structure and stability for each size, as well as methods for quantifying each size class (Amézketa, 1999, Tisdall and Oades, 1982).

Arbuscular mycorrhizal fungi (AMF) are a group of fungi that form symbiotic relationships with many plant species and exist both inside the roots of plants and in the soil (Rillig, 2004). Arbuscules produced by AMF function to exchange nutrients and C with their host. In addition, AMF produce hyphae which explore the soil and absorb nutrients (Rillig, 2004). An extracellular compound, glomalin, produced by AMF, has been shown to increase aggregate stability among various soil types (Wright and Upadhyaya, 1998; Rillig, 2004). Rillig (2004) lists several characteristics of AMF that impact soil aggregation: AMF are abundant and ubiquitous; AMF have intraradical access to plant C and therefore have no need to contend for organic C in the soil; and

hyphae from AMF that contribute to stabilizing structures, along with their byproducts, are quite resistant to microbial decomposition.

Rillig and Steinberg (2002) showed that AMF can respond to the environment by producing more or less glomalin depending on the level of aggregation in the soil. They used an artificial system to simulate both aggregated and non-aggregated soils and observed that AMF hyphae in non-aggregated soils were considerably shorter than hyphae in aggregated soils, but showed substantially higher levels of glomalin in the non-aggregated system. Although this study suggests that AMF can respond and adapt to their environment, the specific mechanisms involved in the response are unknown.

Additions of inorganic fertilizers as well as organic compost are known to enhance soil aggregation, mainly by increasing crop and pasture yields which, in turn, increases soil organic matter and biological activity compared to unfertilized fields (Haynes and Naidu, 1998). This increase in organic matter is also of importance to forming water stable aggregates (Chaney and Swift, 1984). Noyd et al. (1996) also showed an increase in native grass cover in taconite iron ore plots in Minnesota that were amended with fertilizer. Additionally, animal manures have been utilized in the reclamation of mined lands to improve the soil ecosystem by lowering bulk density and increasing organic matter (Haering et al., 2000). There are negative impacts to soils from the addition of too much inorganic fertilizers and/or organic amendments. These include clay dispersion, surface crusting, and water repellency of soils (Haynes and Naidu, 1998). These problems are most often associated with high rates of applications

and poor soil conditions, such as applications of high amounts of NH_4^+ to low pH soils or soils with low soil moisture (Haynes and Naidu, 1998).

An increase in organic material has been shown to improve the stability of aggregates in the soil. Tisdall and Oades (1982) suggest a model of aggregate formation whereby organic matter is the main binding agent. They further proposed that organic binding agents be defined in three groups depending on the age of the organic material. These groups include transient agents, temporary agents, and persistent agents. Transient agents are those that decompose rapidly such as polysaccharides from microbes and plant roots. Temporary agents are the roots and hyphae themselves, in particular vesicular-arbuscular mycorrhizal hyphae. These organic materials are more persistent than transient binding agents, but not as recalcitrant as persistent binding agents. Persistent binding agents consist of material from amorphous iron, aluminum, and aluminosilicates which together form organomineral interactions.

Glomalin

O'Neill et al. (1991) suggested that AMF play an important role as 'keystone mutualists' within the rhizosphere. In return for C, AMF provide the host plant with supplemental water and nutrients and consequently produce the stable glycoprotein glomalin, which has not been found in any other group of fungi (Wright et al., 1996). Glomalin sloughs from the hyphae and helps to aggregate the soil by attaching to various mineral particles. In addition, glomalin has been shown to be present and abundant in most soils (Wright and Upadhyaya, 1996). Jastrow and Miller (1997) further suggested

that the hydrophobic properties of glomalin contribute to aggregate stability by dampening the disruptive force of water movement within the pores of aggregates. Wright and Upadhyaya (1998) showed that glomalin contains from 0.8–8.8% Fe and that cultures grown in Fe deficient media had little accumulation of glomalin. This suggests that glomalin is not as abundant in high pH soils that may contain low amounts of available Fe. Field sampling from selected Texas soils has proven that this is the case (Wright and Upadhyaya, 1998).

Glomalin has been separated into fractions by an extraction process (Wright and Upadhyaya, 1998). Total glomalin (TG) requires autoclaving at 121°C in 1 h increments using 50 m*M* Na-citrate (pH 8.0), while easily extractable glomalin (EEG) requires 30 min of autoclaving at 121°C in 20 m*M* Na-citrate (pH 7.0). These fractions are assayed using enzyme-linked immunosorbent assay (ELISA) to quantify immunoreactive easily extractable glomalin (IREEG) as well as immunoreactive total glomalin (IRTG). Similarly, a Bradford Assay is used to quantify TG and EEG. Easily extractable glomalin is thought to be mostly recently deposited material, whereas TG is the older more recalcitrant material, including a fraction that is tightly bound to clay minerals (Lovelock et al., 2004).

Recent discoveries suggest that the current methodology for extracting glomalin is not as precise as previously thought (Janos et al., 2007). Problems arise when glomalin denatures under the high heat and pressure required to extract it. This can be lessened to an extent by using equal amounts of extraction solutions, equal amounts of

extracting time, and centrifuging the extracts immediately after autoclaving (Janos et al., 2007).

Wright and Upadhyaya (1998) showed a positive correlation between IREEG and aggregate stability among various soils from Scotland and U.S. Mid-Atlantic States including Texas. The soils ranged in vegetation, pH, and soil order, with Fe-deficient calcareous soils from Texas showing the lowest amounts of glomalin. Rillig et al. (2001a) also found TG and EEG were correlated to water stable aggregates (WSA) in a clay loam sorghum field enriched with CO_2. However, Franzleubbers et al. (2000) studied the effects of grazing and conservation management strategies in the southeastern USA and concluded glomalin is not as strongly linked to aggregate stability. Rillig et al. (2003) reported similar findings in a study whereby glomalin pools were negatively correlated with WSA. The soils used in that study were rich in carbonates, which may suggest that glomalin is not an important stabilizer in calcareous soils. Furthermore, increasing levels of fertilization can negatively affect AMF in soils (McGonigle et al., 1990), whereas the effect on AMF by manure applications is not as well documented, with studies showing varied results. Kabir et al. (1997) did show that manure applications in clay soils in Canada increased hyphal density significantly more than clay soils amended with inorganic fertilizers containing only N and K. In addition, they observed no difference among amendments in sandy loam soils.

Few studies dealing with seasonal changes of glomalin within the soil are described in the literature. Kabir et al. (1997) looked at seasonal variations of AMF hyphae over a growing season with different tillage practices and concluded that there is

a significant variation among tillage practices. No tillage and reduced tillage practices showed higher amounts of fungal hyphae than did conventional tillage suggesting that soil disturbance has a negative impact upon AMF and ultimately glomalin levels. In addition, abundance of hyphae fluctuated over the growing season for all tillage practices, with the lowest density found in the spring. Glomalin appears to have a slow turnover rate in soils (6-42 years in tropical forests) and certain fractions will fluctuate more than others (Rillig et al. 2001b). For example, Lutgen et al. (2003) showed significant seasonal variation in only two fractions of glomalin (TG and IREEG). Due to the disparity in quantity among glomalin fractions, seasonal changes can be relatively small or large depending on the size of each glomalin pool.

Infiltration

When soil infiltration rates are slow, the movement of water is directed over the surface of the soil rather than into the soil. As a result local flooding can increase along with erosion and sedimentation (USDA, 1998). Infiltration rates are the product of numerous properties including texture, crusting, compaction, and soil aggregation (USDA, 1998). If a soil has poor aggregate stability, then it is less able to resist disruptive forces such as wind and raindrop impact. Small soil particles are broken from aggregates and clog pores to create a seal or crust on the surface which reduces the entry of water. This type of seal is also known as a depositional seal. Another type of seal known as a structural seal, is sometimes created by compaction from raindrop impact (Fox and Le Bissonnais, 1998). According to McIntyre (1958) the soil crust is

collectively composed of both types of seals. The upper seal is a structural seal, 0.1 mm thick, while the bottom seal is a depositional seal, 2 mm thick. However, this may be true only on soils with exchangeable sodium percentages (ESP) > 1.0 (Gal et al., 1984). Agassi et al. (1981) suggested that the formation of crusts in soils is a result of physical disruption of the soil due to raindrop impact and chemical dispersion due to the electrolyte concentration of the applied water. Furthermore, the permeability of the created seal depends in part on the rate of breakdown and the size of the particles involved (Roth and Eggert, 1994).

Ben-Hur and co-workers (1985) showed that crust formation decreased with increasing amounts of clay above ~20%, due to more stable soil structure. That study was done on calcareous and non-calcareous soils in Israel with varying textures and different water qualities (distilled and saline). In addition, levels of $CaCO_3$ were shown to have no effect on infiltration rates perhaps due to the release of electrolytes in amounts sufficient enough to prevent clay dispersion and clogging of soil pores (Ben-Hur et al., 1985). Roth and Eggert (1994) state that aggregates tend to be smaller and less stable with increasing intensity of tillage. This is due to mechanical disruption of aggregates and the destruction of soil structure. The main problems that managers at Fort Hood face are increases in runoff and erosion, therefore, improving infiltration rates could significantly reduce runoff and erosion.

MATERIALS AND METHODS

This research was conducted in the Grand Prairie region of Texas on the Fort Hood Military Reservation in Coryell County on previously established study plots (30° 52.74' N 096° 26.78' W). The dominant soil series for the chosen site was the Nuff series (fine-silty, carbonatic, thermic Udic Calciustoll) which is typified by high amounts of clay, organic matter, and calcium carbonate. The study area is composed of a limestone plain underlain by hard limestone on ridges and marly clay on hills and plateaus (USDA, 1985). Rainfall amounts are fairly constant throughout the year with a slight peak in the spring (Fig. 1).

Research plots consisted of eight treatments with three replicates laid across a gentle slope (1-3%). Treatment plots were 15.2 m by 9.14 m with treatments randomly assigned within each block (Fig. 2). The various treatments differed by the addition of either inorganic fertilizer or composted dairy manure in addition to either being disked or not disked to a depth of 15 cm. Some treatments included the addition of a native seed mix. The rate of application for the inorganic fertilizer was 975 kg ha^{-1} of 36-16-0 which supplied 351 kg ha^{-1} total N and 68 kg ha^{-1} total P. The rate of application for the organic compost was 28 m^3 ha^{-1} supplying 322 kg ha^{-1} total N and 211 kg ha^{-1} total P. At the time of purchase, the compost averaged approximately 801 kg m^{-3}. The seed blend was an experimental mix developed by the Natural Resources Conservation Service (NRCS) and contained a variety of native grasses and forbs (Table 1). It was seeded at a rate of 8 kg ha^{-1}.

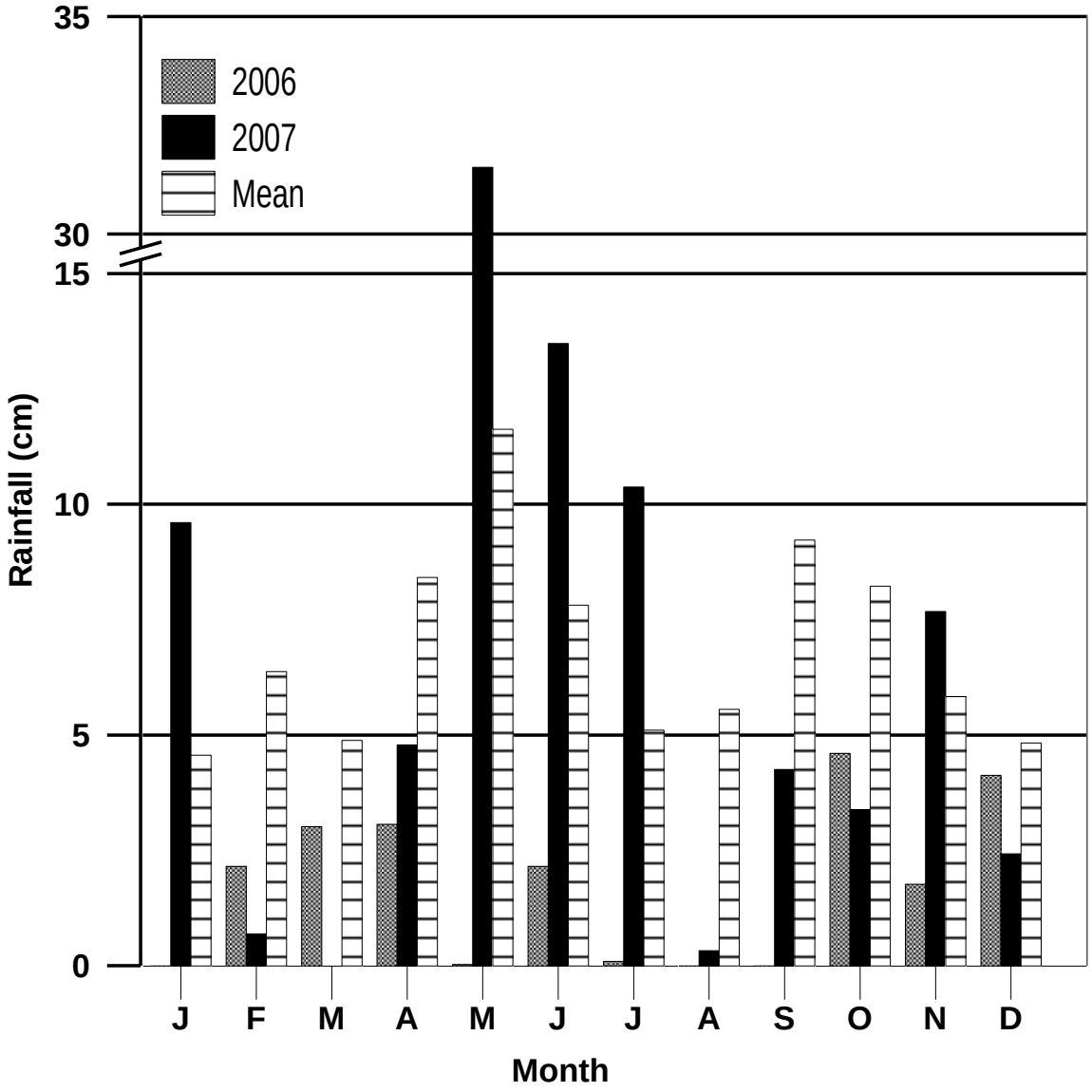

Fig. 1. Rainfall data for study sites at Fort Hood Military Installation. Values are totals for the month and means are 12 year averages. Rainfall data taken from http://www.wunderground.com.

Site Preparation **Compost** **No Seed**		**Site Preparation** **Compost** **Seed**
Site Preparation **Fertilizer** **No Seed**		**Site Preparation** **Fertilizer** **Seed**
Site Preparation **No Seed**		**Site Preparation** **Seed**
No Site Preparation **No Seed**		**No Site Preparation** **Seed**

Fig. 2. Layouts of treatments for study area on Fort Hood Military Reservation. Plots are 15.2 m by 9.1 m.

Table 1. Species names and percentages for the seed mix used in the study. Percentage is based on volume.

Common Name	Scientific Name	Mix
		--%--
Grasses		
Sideoats grama	*Bouteloua curtipendula* (Michx.) Torr.	25
Little bluestem	*Schizachyrium scoparium* (Michx.) Nash	10
Big bluestem	*Andropogon gerardii* Vitman	10
Indiangrass	*Sorghastrum nutans* (L.) Nash	10
Buffalograss	*Bouteloua dactyloides* (Nutt.) Columbus	25
Tall dropseed	*Sporobolus compositus* (Poir.) Merr.	5
Switchgrass	*Panicum virgatum* L.	10
Forbs		
Illinois bundleflower	*Desmanthus illinoensis* (Michx.) MacMill. ex B.L. Rob. & Fernald	2
Awnless Bush Sunflower	*Simsia calva* (A. Gray & Engelm.) A. Gray	2
Partridge pea	*Chamaecrista fasciculata* (Michx.) Greene	1

The study plots were established by researchers of the Blackland Research and Extension Center (BREC) and the Ecosystem Science and Management Department (ESSM) at Texas A&M University as part of an additional study evaluating the response of vegetation to the aforementioned soil amendments. In addition, all treatment applications were administered by BREC.

Soil samples for baseline measures of TG and percent water stable aggregates (%WSA) were taken prior to application of treatments to observe variations in soil properties by treatment. Furthermore, approximately 10 sites encompassing nine soil series throughout training areas of Fort Hood Military Reservation were selected to broaden the range of values for soil properties in the study and include varying levels of soil compaction and erosion. These sites were selected to include areas with visual indications of compaction and traffic. All sites were well vegetated with the exception of sites 8 and 10 that were shallow rocky and sandy, respectively. Additionally, the broader sampling also could contribute to understanding how much the soils of Fort Hood vary and allow for comparisons to values of infiltration rates reported by the NRCS (USDA, 1985). The same methods and procedures performed for the plot study were implemented for the additional sites. Information regarding the soils for the additional sites is summarized in Table 2.

Total glomalin was extracted and quantified using a Bradford assay with bovine serum albumin standards according to procedures slightly modified from Wright and Upadhyaya (1996). Total glomalin is a measure of total protein in the soil and gives an estimate of glomalin. However, Wright et al. (1999) showed that the percentage of

Table 2. Soil series and family classification for each of the additional sites sampled at Fort Hood.

Site	Series	Family Soil Classification[†]
1	Nuff	fine-silty, carbonatic, thermic Udic Calciustoll
2	Lewisville	fine-silty, mixed, thermic Udic Calciustoll
3	Brackett	loamy, carbonatic, thermic, shallow Typic Haplustept
4	Topsey	fine-loamy, carbonatic, thermic Udic Calciustoll
5	Brackett	loamy, carbonatic, thermic, shallow Typic Haplustept
6	Evant	clayey, smectitic, thermic, shallow Petrocalcic Paleustoll
7	Slidell	fine, smectitic, thermic Udic Haplustert
8	Cho	loamy, carbonatic, thermic, shallow Petrocalcic Calciustoll
9	Doss	loamy, carbonatic, thermic, shallow Typic Calciustoll
10	Cisco	fine-loamy, siliceous, superactive, thermic Typic Haplustalf

[†]Series as mapped in Soil Survey of Coryell County (USDA, 1985); family classifications as per the official soil series descriptions (Soil Survey Staff, 2008).

immunoreactive protein (the fraction associated with glomalin) found in crude extracts range from 81 to 100%. In addition, a study by Bolliger et al. (2008) determined that the TG pool was quite "pure" and contained very little extraneous proteins other than glomalin. This gives further confidence to using TG as an accurate estimate of glomalin levels in the soil.

The extraction process included autoclaving 1 g of soil in 8 mL of 50 *m*M Na-citrate (pH 8.0) in rounds of 60 min at 121°C until the extract was a golden amber color. After each extraction the sample was centrifuged at 3200 rpm for 20 min, and the supernatant was decanted into test tubes. In order to read the samples within the linear portion of the standard curve, extracts were diluted 15:1 in phosphate buffered saline (PBS, pH 7.4). Exactly 3.2 ml of each sample were added to 0.8 ml of Bradford protein dye reagent, mixed, and analyzed after 5 min. Absorbance was determined using a Spectrophotometer 20 at 595 nm.

The percentage of water stable aggregates (WSA) was quantified using a wet sieving process modified from methods described by Kemper and Rosenau (1986). The procedure involved placing 10 g of soil (1-2 mm) on sheets of fully wet Whatman #1 filter paper (24.0-cm diameter). After the soil was wetted by capillary action, it was transferred to a single 60-mesh sieve (0.25-mm diameter openings) to be raised and lowered a vertical distance of 1.3 cm at 44 cycles min^{-1} for 3 min in distilled water. Soil remaining on the sieve was rinsed into a beaker, oven dried, and weighed to give the stable aggregate mass (SA). The soil was then shaken overnight in 5 mL of 5% sodium hexametaphosphate (50 g L^{-1}) with approximately 250 mL distilled water and

subsequently passed through a 60-mesh sieve (0.25-mm diameter). Any remaining material was collected, oven dried, and weighed to give the sand mass (SM). The %WSA was calculated as:

$$\%WSA = [(SA-SM) / (Original\ soil\ mass-SM)]*100.$$

Kemper and Rosenau (1986) indicate that using a single sieve is as well correlated to field phenomena as using nested sieves and requires less time (Kemper and Rosenau, 1986). This study only measured the stability of macro-aggregates (>250 μm) in the soil. Tisdall and Oades (1982) suggest that polysaccharides and other organic materials from roots and fungi are closely associated with aggregates of this size range and would therefore be of interest in studying the effects of glomalin on aggregate stability.

Water dispersible clays (WDC) were determined as described by Harris (1971). Water dispersible clays represent the clay content of the sample determined by analyzing particle size distribution (PSD) using the pipette method without pretreatment of a chemical dispersant such as sodium hexametaphosphate. Total clay is similarly measured using the pipette method but with the addition of 5 mL of 10% sodium hexametaphosphate (pH 8.2) prior to running PSD. An aggregation index (AI) is calculated using the formula:

$$AI = 100 * [1 – (WDC / total\ clay)]$$

The values of AI range from 0 to 100 with higher numbers indicating more stable aggregates.

Infiltration rates were determined using a drip-type rainfall simulator similar to that described by Blackburn et al. (1974). The simulator was placed 20 cm above the soil surface and allowed to drip at a rate of 0.11 cm min^{-1} until runoff occurred at a steady rate. A flexible metal frame was pressed into the ground to contain any runoff under the simulator. The runoff was collected in drip pans, pumped into a bucket, and weighed at intervals of about 5 min. Total rainfall amount minus the runoff amount over intervals of time yielded the amount of infiltration over the time interval which was used to determine the infiltration rate. The area of the frame was determined by placing a grid over the frame and drawing the outline of the frame on graph paper. A polar compensating planimeter was used to determine the area.

The following equations were used to determine infiltration rates (Aydemir, 1996):

Infiltration Rate = [Application Rate – (Runoff (cm) / Time (min)] x 60 (min hr^{-1})
($cm\ hr^{-1}$) ($cm\ min^{-1}$)

Application Rate ($cm\ min^{-1}$) = Simulated Rainfall Rate ($cm\ hr^{-1}$) / 60 (min hr^{-1})

Runoff (cm) = [(# lbs of runoff) x (453.6g lb^{-1}) x (1 $cm^3\ g^{-1}$)] / area of plot (cm^2).

The source water for all simulations was well water taken from the Blackland Research and Extension Center in Bell County, Texas. Composition of the water is given in Table 3.

Table 3. Analysis of water used for infiltration study at Fort Hood.[†]

Analysis	Result
Ca^{+2}	60 mg L^{-1}
Mg^{+2}	7 mg L^{-1}
Na^{+}	11 mg L^{-1}
K^{+}	3 mg L^{-1}
B	0.01 mg L^{-1}
CO_3^{-2}	0 mg L^{-1}
HCO_3^{-1}	135 mg L^{-1}
SO_4^{-2}	39 mg L^{-1}
Cl^{-}	31 mg L^{-1}
NO_3^{-} - N	0.98 mg L^{-1}
P	0.03 mg L^{-1}
pH	7.57
Conductivity	0.35 dS m^{-1}
SAR	0.4

[†]Analysis was performed by the Soil, Water and Forage Testing Laboratory of the Texas Agrilife Extension Service.

Characterization of the soils, including particle size distribution (PSD), total C, and $CaCO_3$ equivalent (CCE), was done on all collected soil samples. Particle size distribution was completed according to the methods of Kilmer and Alexander (1949). This involved shaking 10 g of air-dry soil (<2mm) with 5 mL 10% sodium hexametaphosphate (pH 8.2) and distilled water overnight in glass shaker bottles. The samples were brought to 400-mL volume, stirred with a magnetic stir bar for 2 min and placed in a constant temperature water bath so separates could settle. After the settling period (dependent on temperature) was completed, a 5-mL pipet was lowered 5 cm into the bottle, and an aliquot was removed and transferred to a pre-weighed crucible. This first aliquot contained particles <20 µm in diameter which included total clay and fine silts. After an additional settling period, another 5-ml aliquot was removed and transferred to another pre-weighed crucible to measure the amount of total clay (<2µm).

To determine the amount of fine clays (<0.2µm), the samples were removed from the water bath and re-stirred for approximately 2 min followed by a 1.5-min settling period. Afterwards, a 25-mL aliquot was removed 4 cm below the surface and placed in a 90-mL centrifuge tube. Each aliquot was centrifuged at 2000 rpm for a period of time determined by the temperature of the aliquots. The samples were removed from the centrifuge and a 5-mL aliquot from a depth of 4 cm was placed into a pre-weighed crucible. The crucibles were placed in an oven at 105°C to dry then weighed to within 0.1 mg. Sediments remaining in the shaker bottles after all aliquots were removed were washed through a 300-mesh sieve (50-µm diameter) to retain the sands. The sands

remaining on the sieve were transferred into a beaker using distilled water and placed in an oven at 105°C to dry. The dried sands were placed into a nest of sieves in the following order: #18 (1.0-mm diameter), #35 (0.5-mm diameter), #60 (0.25-mm diameter), #140 (0.10-mm diameter), and #300 (0.05-mm diameter). The sieves are placed in a mechanical shaker for 5 min. Subsequent to shaking, the sand fraction remaining on each sieve was removed and weighed to within 0.01 g.

Total C was quantified according to methods described by Nelson and Sommers (1982). Briefly, a sample of air-dried and disk-mill ground soil was weighed (according to effervescence) and placed in a ceramic combustion boat along with 0.25 g of MnO_2. The sample was inserted into a combustion chamber heated to 950-1000°C and sealed. Purified O_2 was passed through the combustion chamber which oxidized the organic C to CO_2. Coincident, CO_2 from calcite and dolomite (inorganic C) were evolved. The CO_2 passed through a series of filters and traps which removed the water vapor, nitrogen oxides, and sulfur oxides. At the end of the system was a pre-weighed adsorption bulb containing ascarite and Mg-perchlorate which collected any CO_2 and water generated by the absorption of CO_2 from gases passing through. After the sample was combusted for 12 min, it was removed, and the adsorption bulb was weighed. The difference between the starting weight and ending weight of the adsorption bulb was the amount of CO_2 evolved which was expressed as the percentage of total C in the soil.

The procedure for determining calcium carbonate equivalent (CCE) was the method of Dreimanis (1962) using a Chittick gasometric apparatus. This involved weighing a sample of air-dried and disk-mill ground soil and placing it into a

decomposition flask along with a stir bar and 2 drops of amyl-alcohol. The amount of sample used varied based upon the anticipated CCE as indicated by reaction of the sample to HCl. A rubber stopper with an attached buret containing 20 mL of an HCl-$FeCl_2$ solution was placed on the decomposition flask. Another measuring buret containing displacement solution was leveled and the entire system was closed to the atmosphere. The HCl-$FeCl_2$ solution was added to the decomposition flask while the stir bar mixed the solution. While the solution stirred, CO_2 was evolved and forced the displacement solution down the measuring buret allowing for the volume of CO_2 to be measured. An initial reading was taken after 30 sec and subsequent readings were taken every 6 min for 30 min including readings for temperature and barometric pressure. The volume of CO_2 evolved during the initial 30-sec reaction was used to calculate the % calcite, while the final volume of CO_2 (after 30 min) was used for % dolomite. All volumes of CO_2 were corrected for temperature and atmospheric pressure. The CCE was then calculated based upon the quantities of calcite and dolomite.

All soil nutrient analyses were performed by the Soil, Water and Forage Testing Laboratory of the Texas Agrilife Extension Service (Appendix C). Mehlich III extractant was used for P, K, Ca, Mg, S, and Na while Fe, Zn, Mn, and Cu were extracted using 0.005 M DTPA, 0.01 M $CaCl_2$, and 0.10 M triethanolamine solution. (Mehlich, 1978; Mehlich, 1984). All analytes were determined by ICP. Nitrate-N was extracted using 1 N KCl and determined by reduction using a cadmium column followed by spectrophotometric analysis (Keeney and Nelson, 1982).

All data were analyzed with ANOVA and compared by least significant difference (α=0.05) using SAS statistical software (SAS, 2002).

RESULTS AND DISCUSSION

Plot Study

Aggregate Stability

Means for percent water stable aggregates (%WSA) before and after treatments were applied are shown in Table 4. The plots with the highest %WSA before treatment application were the No Prep / No Seed plots (control) and the Site Prep / Compost / No Seed plots at 73% while the plots with the lowest %WSA were the Site Prep / Seed plot as well as the Site Prep / Fertilizer / Seed plots at 68%. However, there were no significant differences among plots at a 95% confidence level (p-value 0.18) before the application of any treatments. Twelve months after treatments were applied, the greatest values for %WSA were the Site Prep / No Seed treatment and the Site Prep / Compost / Seed treatment at 71% while the lowest value was the Site Prep / Fertilizer / Seed treatment at 65% (Table 4). As before there were no significant differences among treatments for %WSA at the 95% confidence level (p-value 0.20). Comparing the means for each treatment over time revealed three treatments with significant differences (p-value 0.03), the No Prep / Seed, No Prep / No Seed, and Site Prep / Compost / No Seed treatments (Fig. 3). Furthermore, %WSA for every treatment but two decreased over time. The only treatments with an increase in %WSA were the Site Prep / No Seed treatment and the Site Prep / Compost / Seed treatment, but these increases were not statistically significant. With values only ranging from 65%-71% there was little possibility of observing major differences among treatments.

Table 4. Water stable aggregate means for each treatment before application and after application of respective treatments. Data are presented as mean ± one standard deviation.

Treatments[†]	**Before (July 06)**	**After (July 07)**
	----------%----------	
Site Prep / Seed	68 ± 0.1	67 ± 1.7
Site Prep / No Seed	71 ± 2.1	71 ± 1.8
Site Prep / Compost / Seed	70 ± 2.7	71 ± 3.3
Site Prep / Compost / No Seed	73 ± 4.8	66 ± 4.2
Site Prep / Fertilizer / Seed	68 ± 1.7	65 ± 1.1
Site Prep / Fertilizer / No Seed	70 ± 1.8	67 ± 5.1
No Prep / Seed	72 ± 3.4	67 ± 3.5
No Prep / No Seed	73 ± 2.7	67 ± 1.2

[†]Site Prep = disking to a depth of 15 cm
Seed = application of seed mix containing native grasses and forbs
Compost = application of composted dairy manure
Fertilizer = application of inorganic fertilizer.

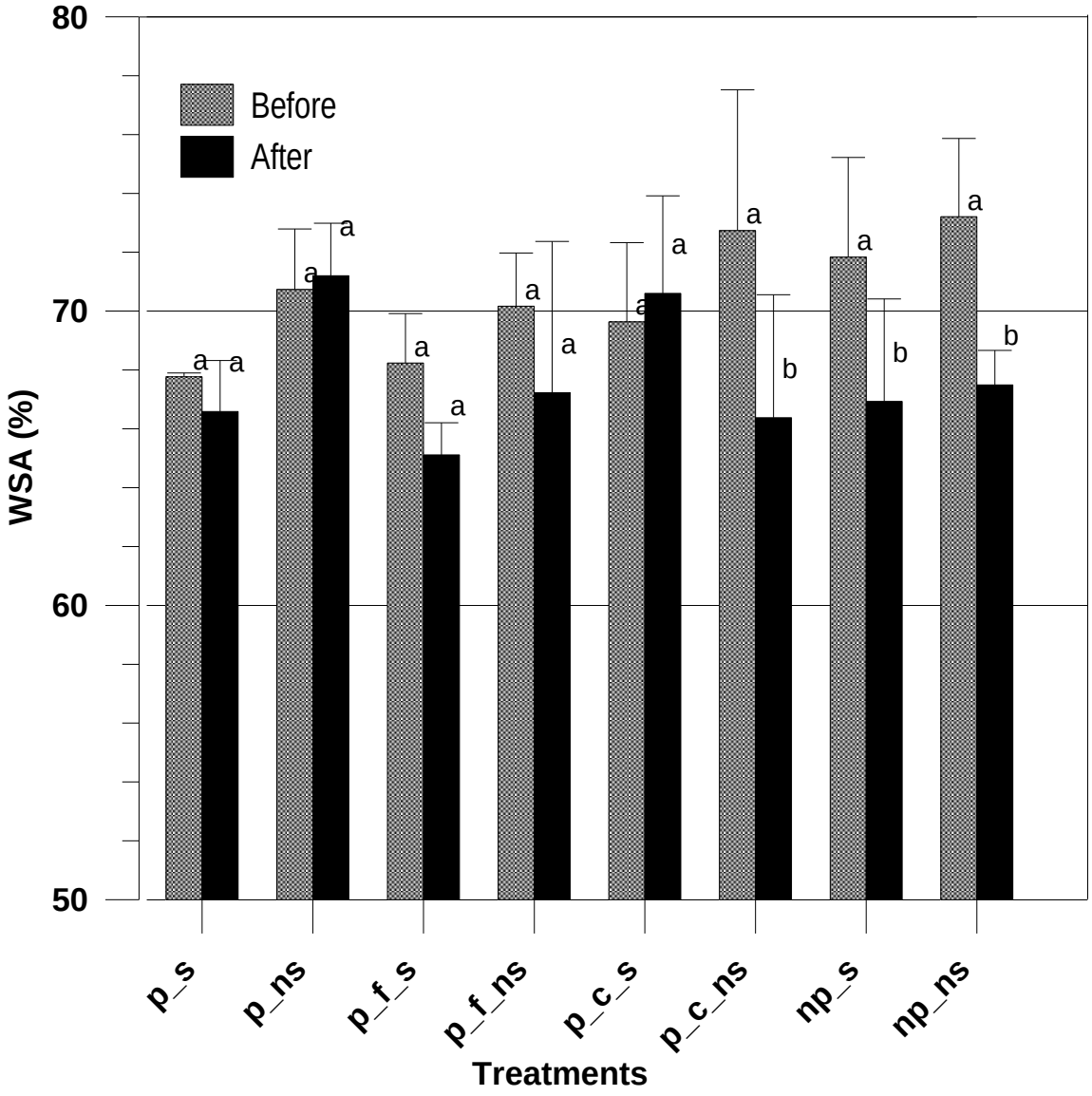

Fig. 3. Changes in percent water stable aggregates (%WSA) over time for each treatment. Data are presented as mean ± one standard deviation.

As the determination of %WSA is time consuming, requires specialized equipment, and is somewhat dependent on the analyst, an attempt to identify an alternate measure of soil structure was sought. A comparison was made between the means of %WSA for each post-treatment plot and aggregation index (AI) determined by WDC. The results are summarized in Fig. 4 and indicate a weak positive but nonsignificant relationship with a R^2 of 0.04. There have been significant correlations made between AI and a variety of soil parameters in the literature but none between %WSA and AI (Rhoton et al. 2007). Based on the results of this research, there appears to be no significant relationship between AI and %WSA.

Soil aggregate stability can be viewed as a hierarchial process by which silt and clay microstructures bind with fungal and bacterial debris to form microaggregates (2-20µm diameter). These microaggregates in turn form larger microaggregates (20-250µm diameter) by binding with plant remains (Jastrow and Miller, 1997). Because microaggregates are vital to the formation of stable aggregates, it was important to measure and observe the relationships between %WSA, organic C, and total clays. There was a significant correlation between %WSA and organic C (Fig. 5) before treatments were applied (p-value 0.02). This correlation has been observed in similar studies linking organic matter to increases in soil aggregation (Tisdall and Oades, 1982).

After treatment application there was no statistical relationship between %WSA and organic C (p-value 0.7) (Fig. 6). Organic C showed a significant increase over time (p-value <0.001) for all treatments but one (No Prep / Seed) rising from means of 3.5% to 4.0% over the twelve month period (Fig. 7). The cause for the increase over time is

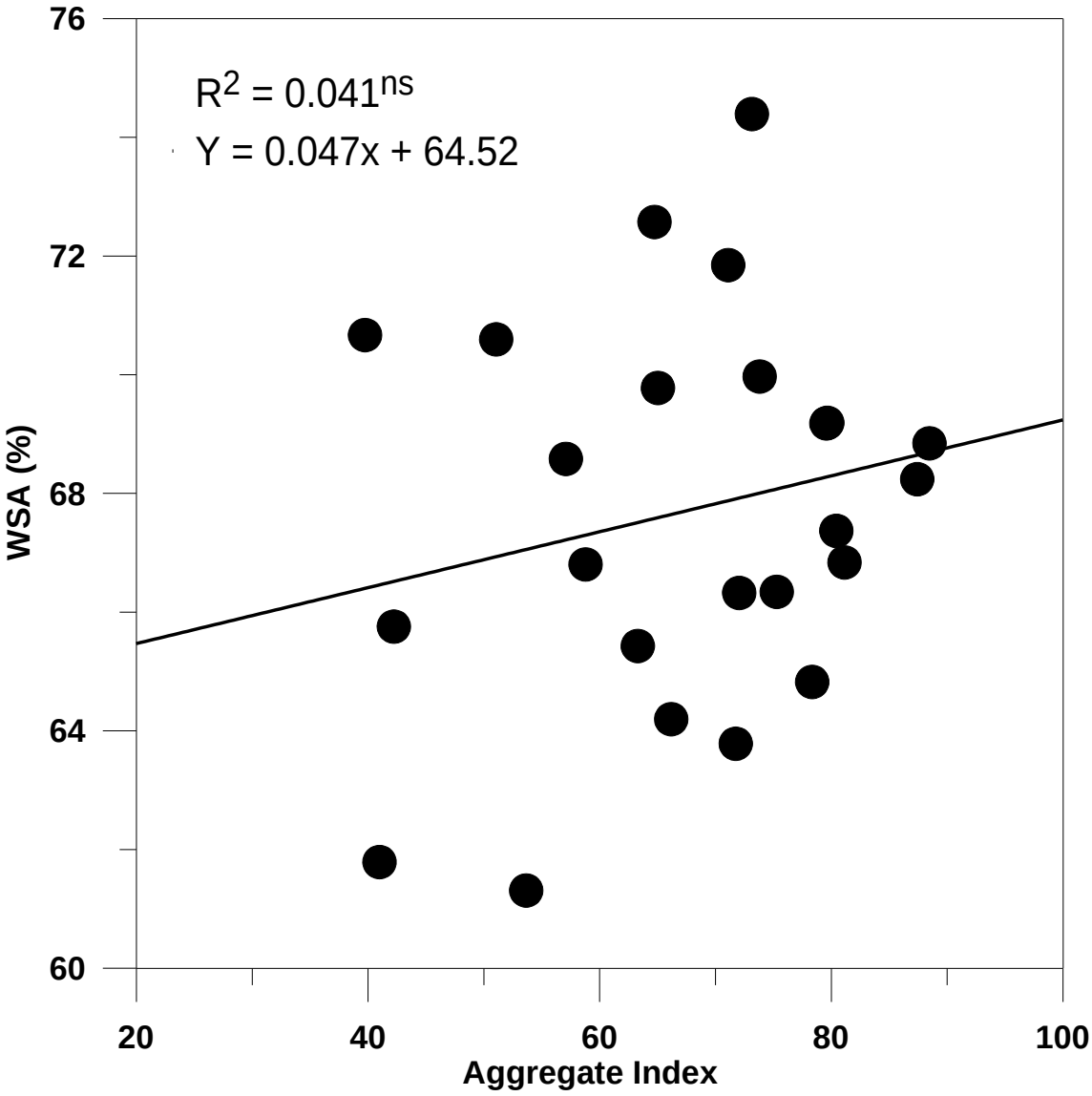

Fig. 4. The relationship of percent water stable aggregates (%WSA) with aggregate index. ns = not significant.

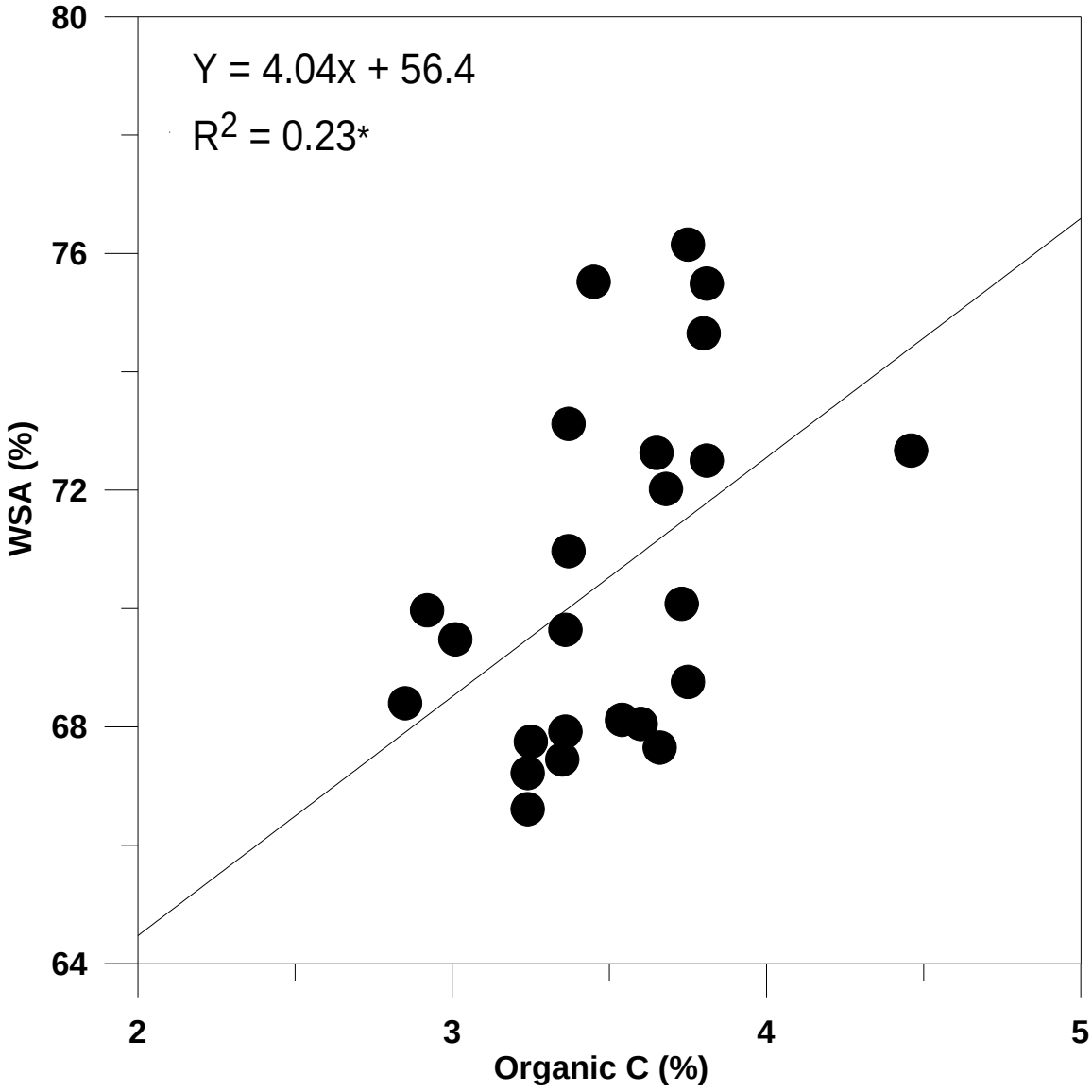

Fig. 5. The relationship between organic C and percent water stable aggregates (%WSA) before treatments were applied.
* Significant at the 0.05 probability level.

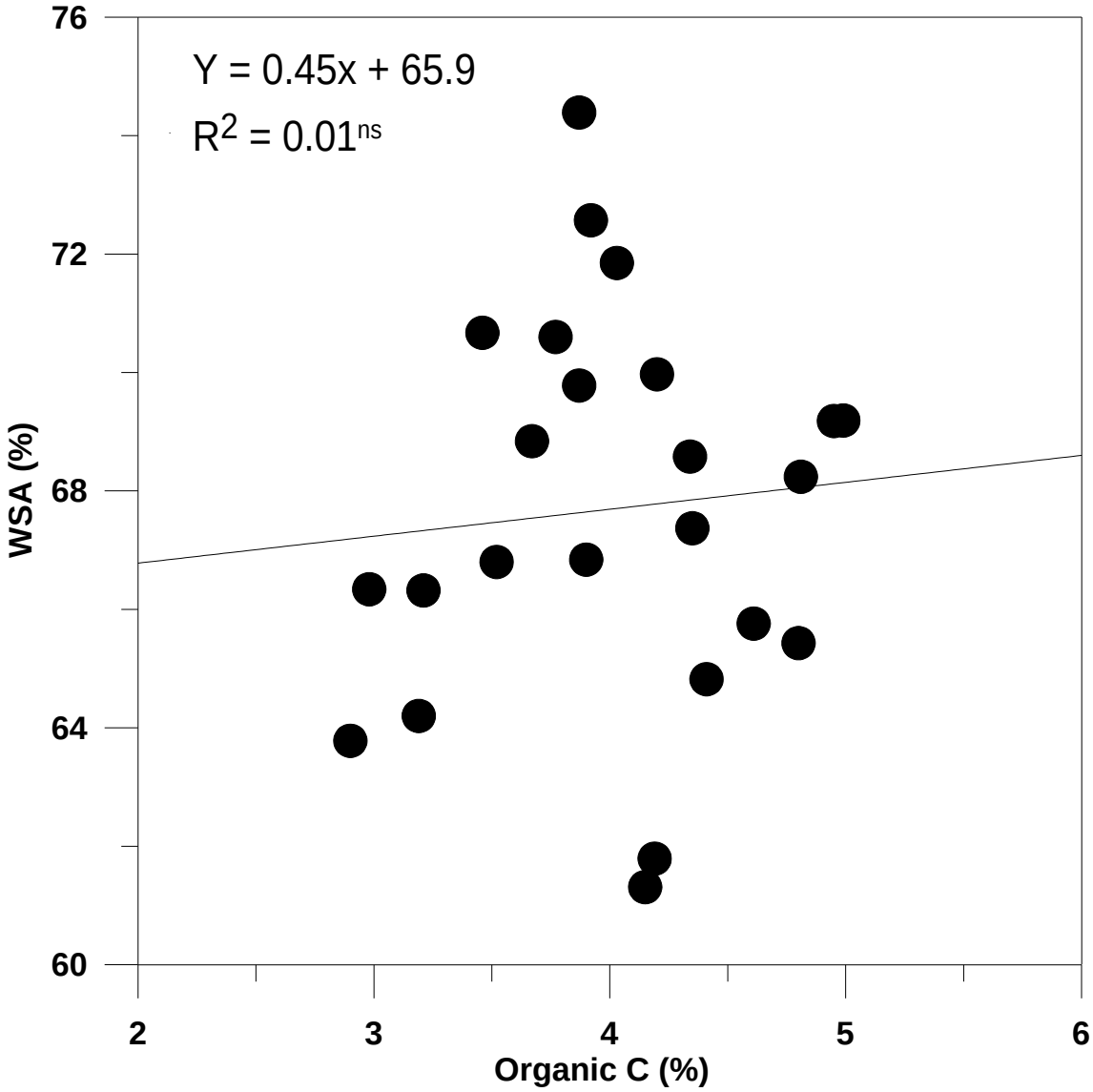

Fig. 6. The relationship between organic C and percent water stable aggregates (%WSA) 12 months after treatments were applied. ns = not significant.

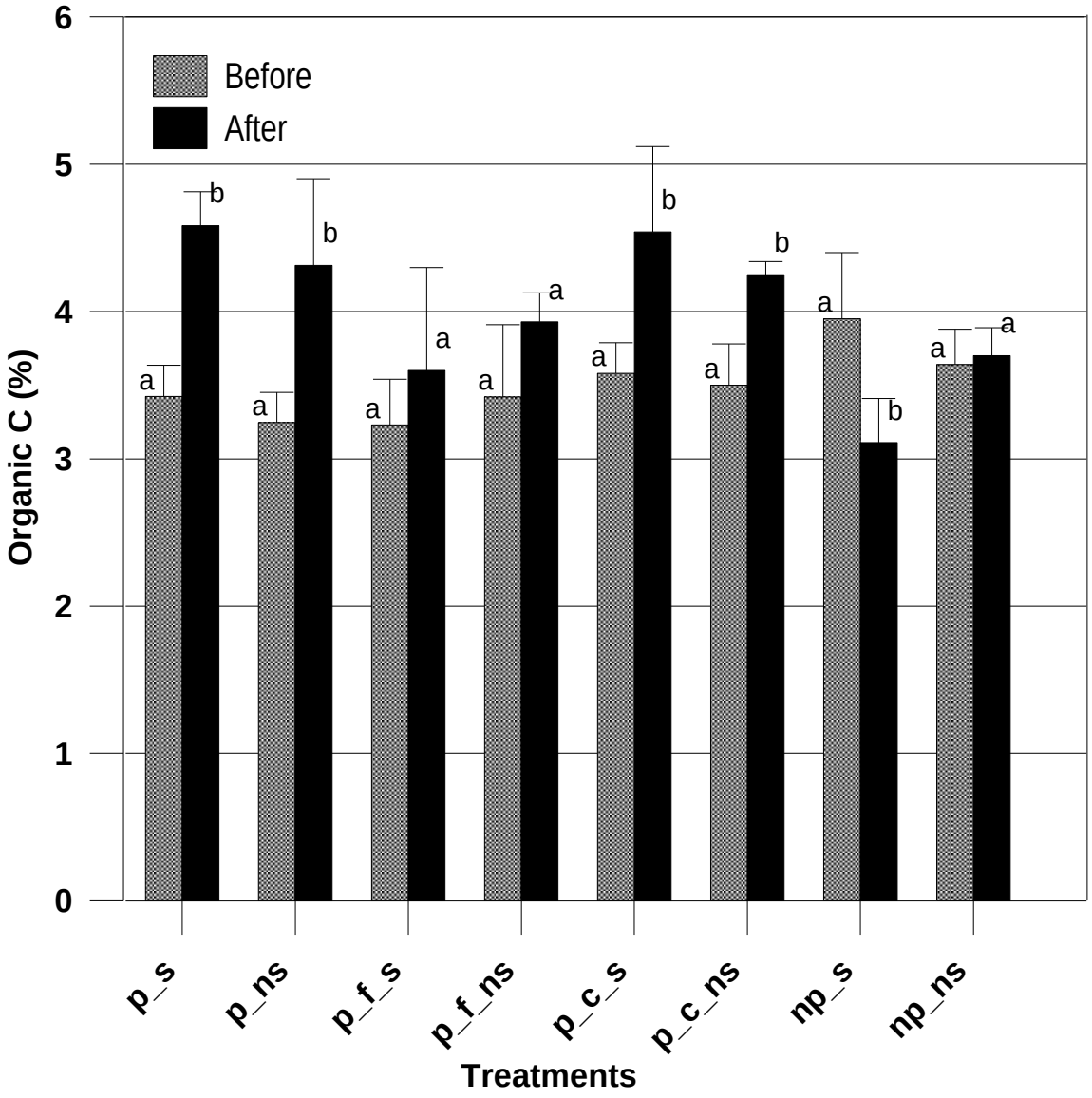

Fig. 7. Levels of organic C over time. Data are presented as mean ± one standard deviation.

uncertain but may be a function of sampling and/or quantification of organic C. While it seems unlikely that such a significant increase is due to rainfall patterns, the possibility does exist. Further, there were no significant correlations between %WSA and total clays before and after application of treatments with R^2 values of 0.001 and 0.001, respectively. Additionally, there was a negative relationship between %WSA and total sands before treatments were applied (p-value 0.09). One year later %WSA was still negatively related to total sands (p-value 0.053).

The decrease in %WSA seems logical given the fact that tillage was administered which would break up aggregates. Wright et al. (1999) examined the differences in no tillage systems and tillage systems and saw significantly higher values for aggregate stability with no-tillage. This suggests that tillage can significantly decrease aggregate stability which was confirmed by this study. It is well known that tillage systems contain less soil organic C compared to similar no-till systems. This study showed an increase in organic C over time even under the application of a tillage practice. This anomaly could be explained by the amount of precipitation received at the study site or sampling differences. The initial soil sampling was done prior to creation of plots and treatment application during a hot, dry summer (Fig. 1). Soil samples for %WSA and organic C were taken one year later during an unusually wet summer (Fig. 1). The increase in precipitation could have spurred the growth of vegetation, creating more organic matter for the soil. Additionally, there could be differences in how samples were taken between plots and years which could artificially inflate values for organic C. Because increases in organic C were observed among all treatments, it is not probable

that fertility treatments, either inorganic or organic, were responsible. As %WSA and organic C were correlated before treatments but not after suggests that the increase in organic C and decrease in %WSA disrupted the relationship that previously existed.

The lack of correlation between %WSA and total clays seems illogical but may be explained by the aggregate size measured. As clays are important for developing strong aggregate stability, perhaps there exist better correlations between clay and %WSA of other size classes of aggregates besides the macroaggregate fraction measured.

Soil Infiltration

The study plots were established and treatments applied prior to the commencement of this research project. Therefore, infiltration rates were measured one year after treatments were applied. Rates of infiltration were highest at 5 min and decreased until equilibrium was achieved, typically after 30 min with a few plots taking longer (Appendix E). Therefore, discussions that follow will use the rate at 30 min as the determined rate. The means and standard deviations for infiltration rates of each treatment are summarized in Table 5. The treatment with the highest rate of infiltration was the Site Prep / Fertilizer / No Seed treatment at 4.9 cm hr^{-1} (Fig. 8) while the lowest rate was the Site Prep / Compost / No Seed treatment at 2.1 cm hr^{-1} (Fig. 9). The infiltration rates for the remaining treatments are illustrated in Figs. 10-15. Statistically there were no significant differences among treatments for infiltration rates at a 95% confidence level (p-value 0.20).

Table 5. Means and standard deviation of infiltration rates of soils one year after application of treatments.

Treatments	**Infiltration Rates**[†]
	------cm hr^{-1}------
Site Prep / Seed	2.7 ± 0.48
Site Prep / No Seed	2.4 ± 0.89
Site Prep / Compost / Seed	2.2 ± 1.6
Site Prep / Compost / No Seed	2.1 ± 1.2
Site Prep / Fertilizer / Seed	4.0 ± 1.1
Site Prep / Fertilizer / No Seed	4.9 ± 1.6
No Prep / Seed	2.4 ± 1.9
No Prep / No Seed	2.3 ± 1.0

[†]Rate at 30-min after runoff is observed.

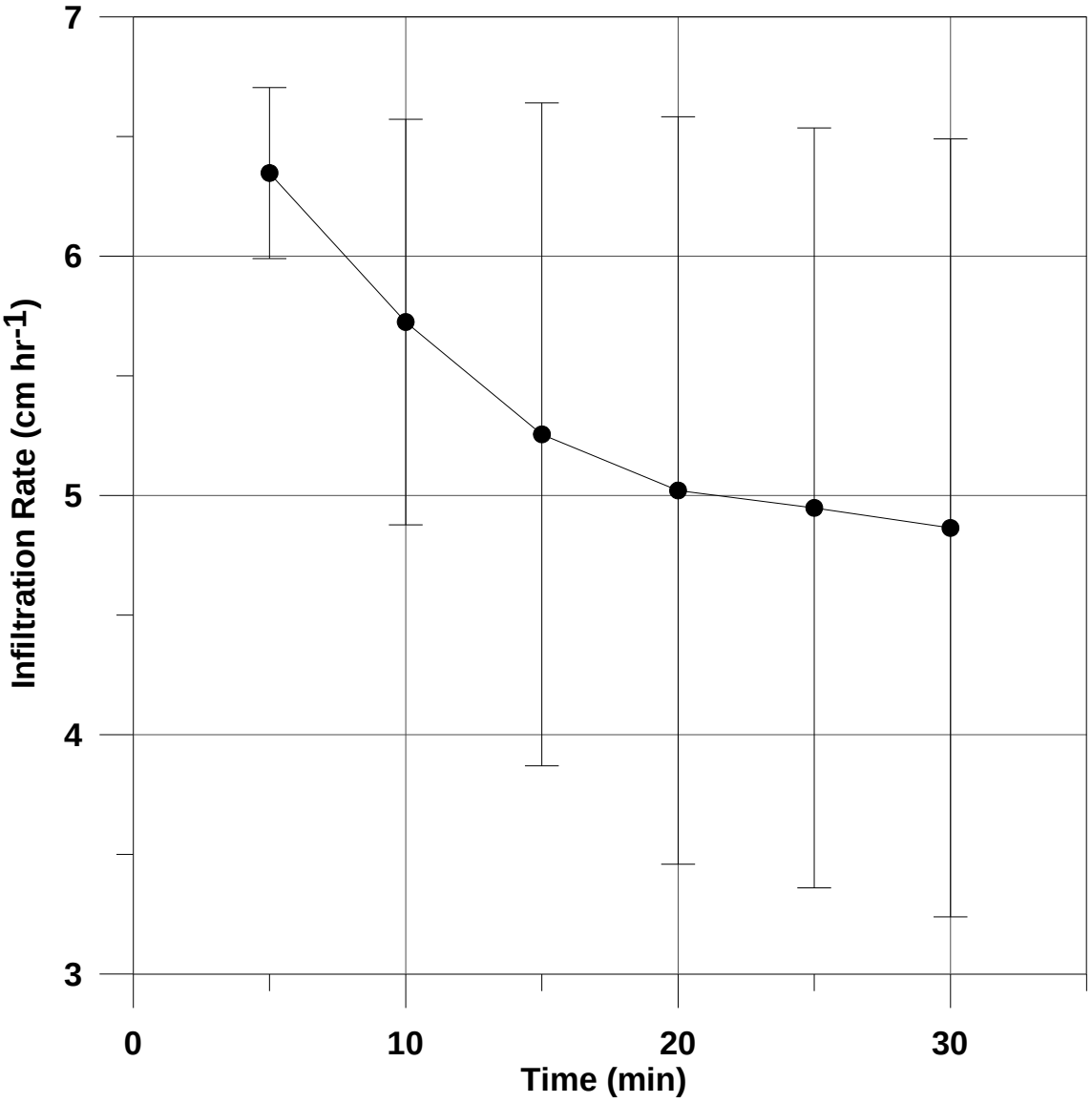

Fig. 8. Infiltration rate over time for the Site Prep / Fertilizer / No Seed treatment. Each point is the mean for the three replicates ± one standard deviation.

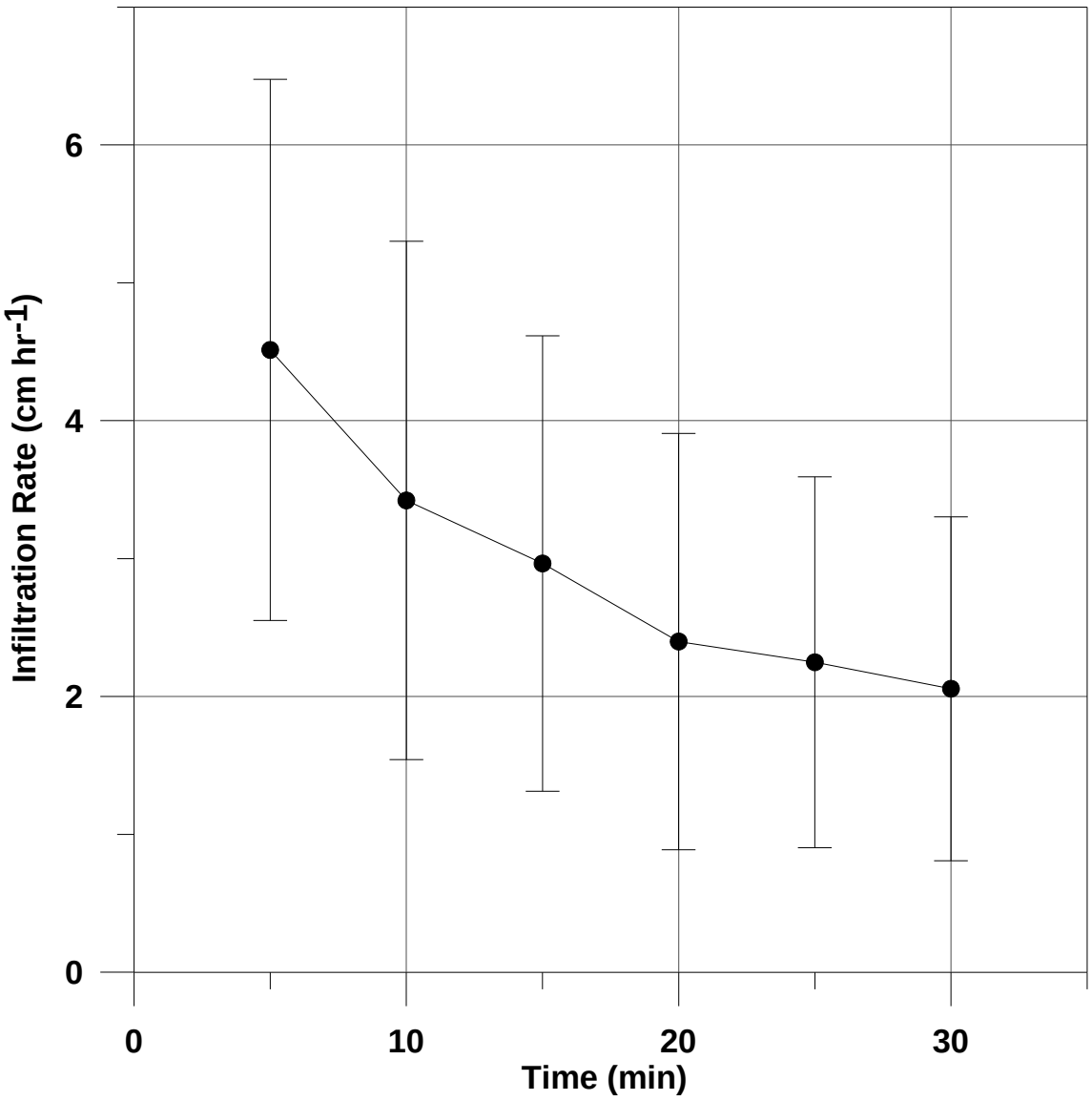

Fig. 9. Infiltration rate over time for the Site Prep / Compost / No Seed treatment. Each point is the mean for the three replicates ± one standard deviation.

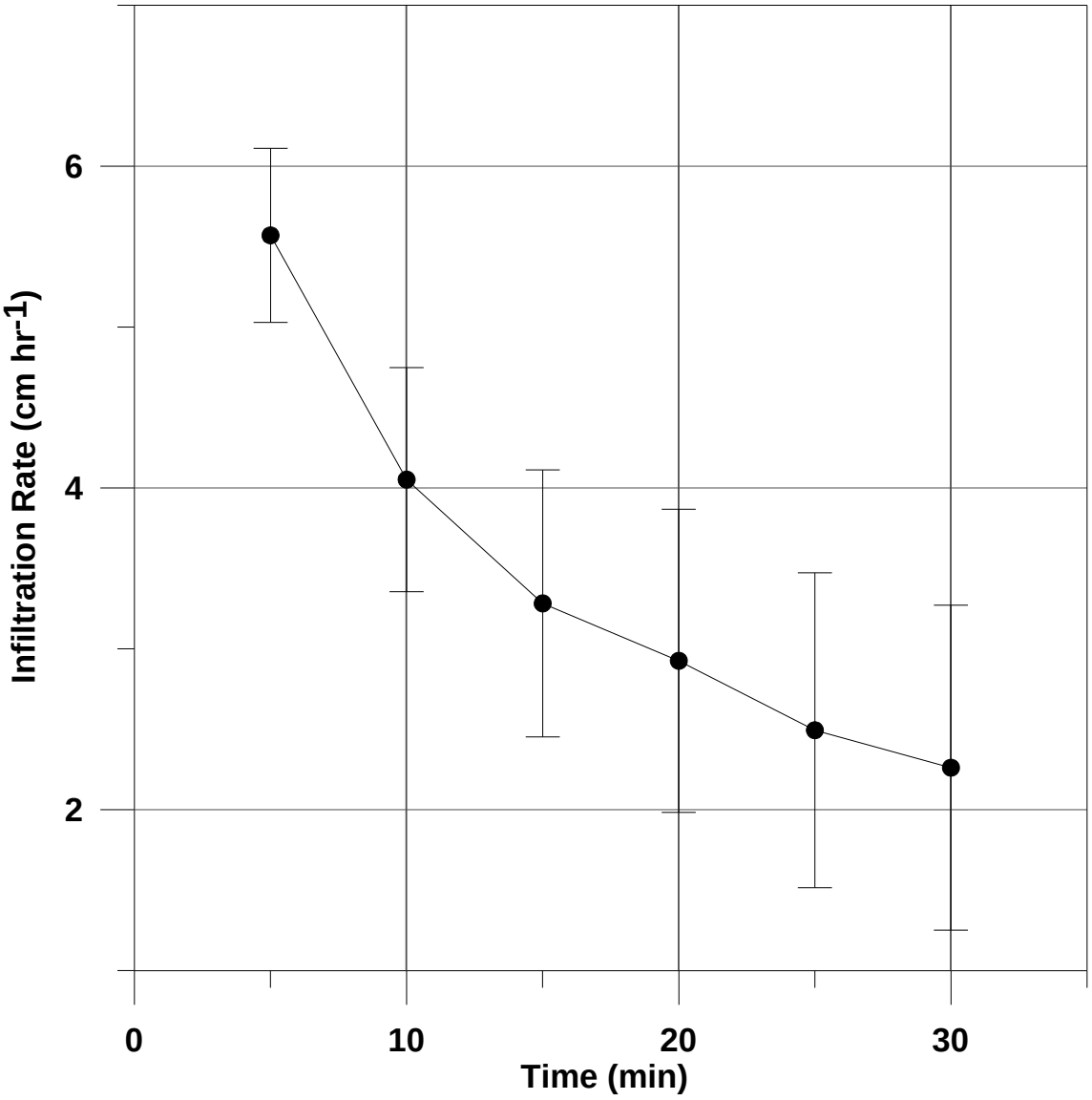

Fig. 10. Infiltration rate over time for the No Prep / No Seed treatment. Each point is the mean of the three replicates ± one standard deviation.

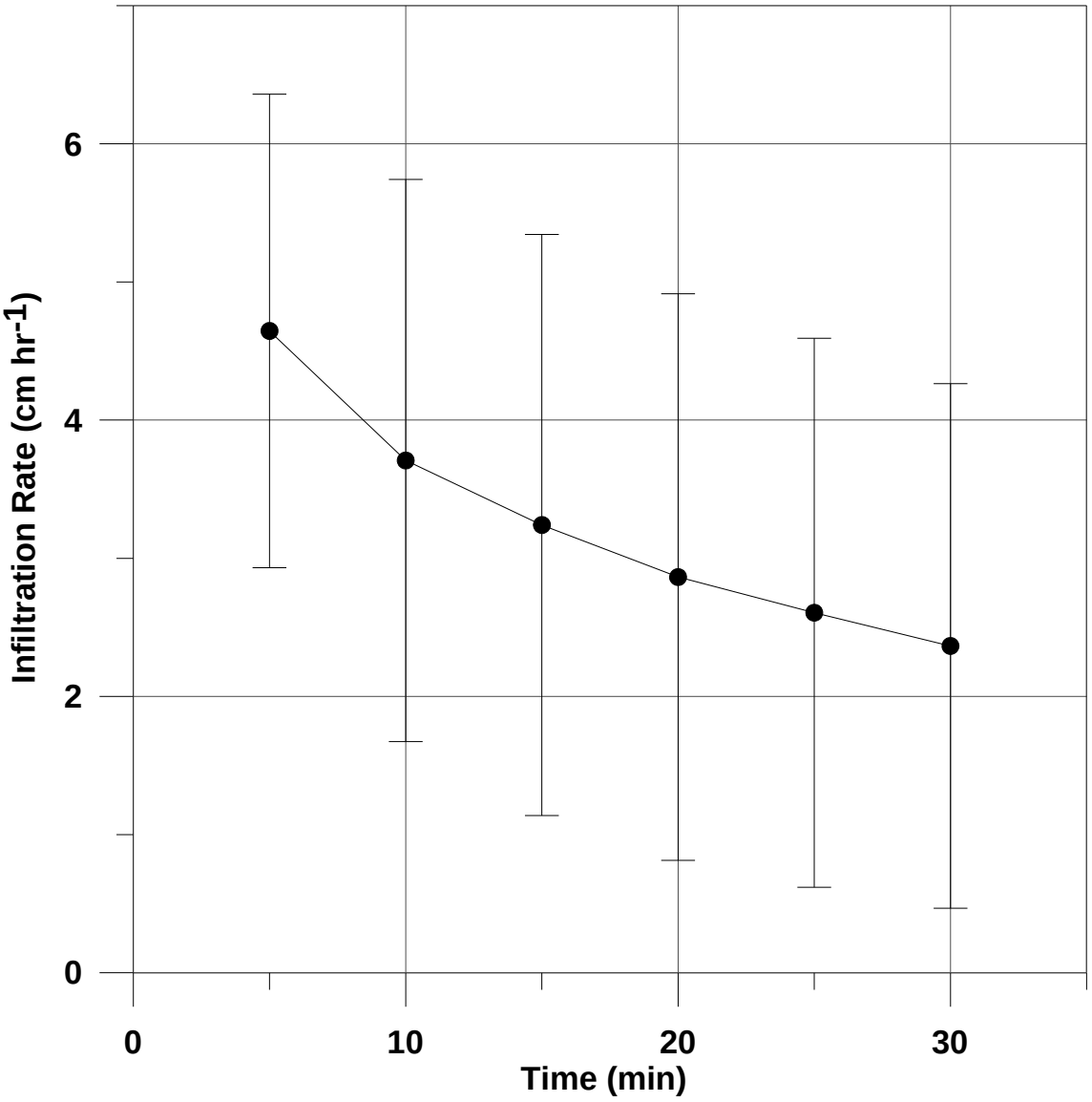

Fig. 11. Infiltration rate over time for the No Prep / Seed treatment. Each point is the mean of the three replicates ± one standard deviation.

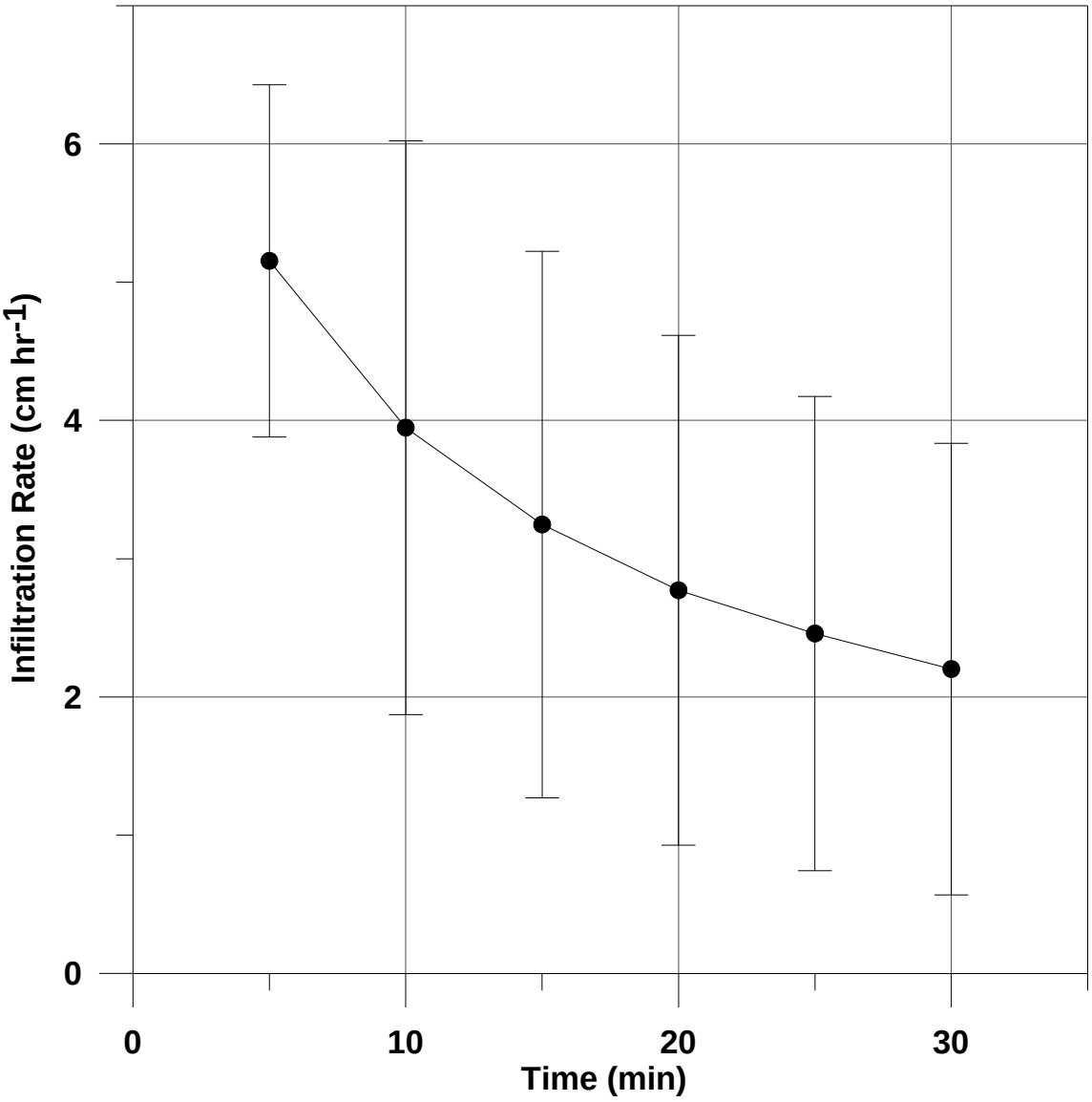

Fig. 12. Infiltration rate over time for the Site Prep / Compost / Seed treatment. Each point is the mean of the three replicates ± one standard deviation.

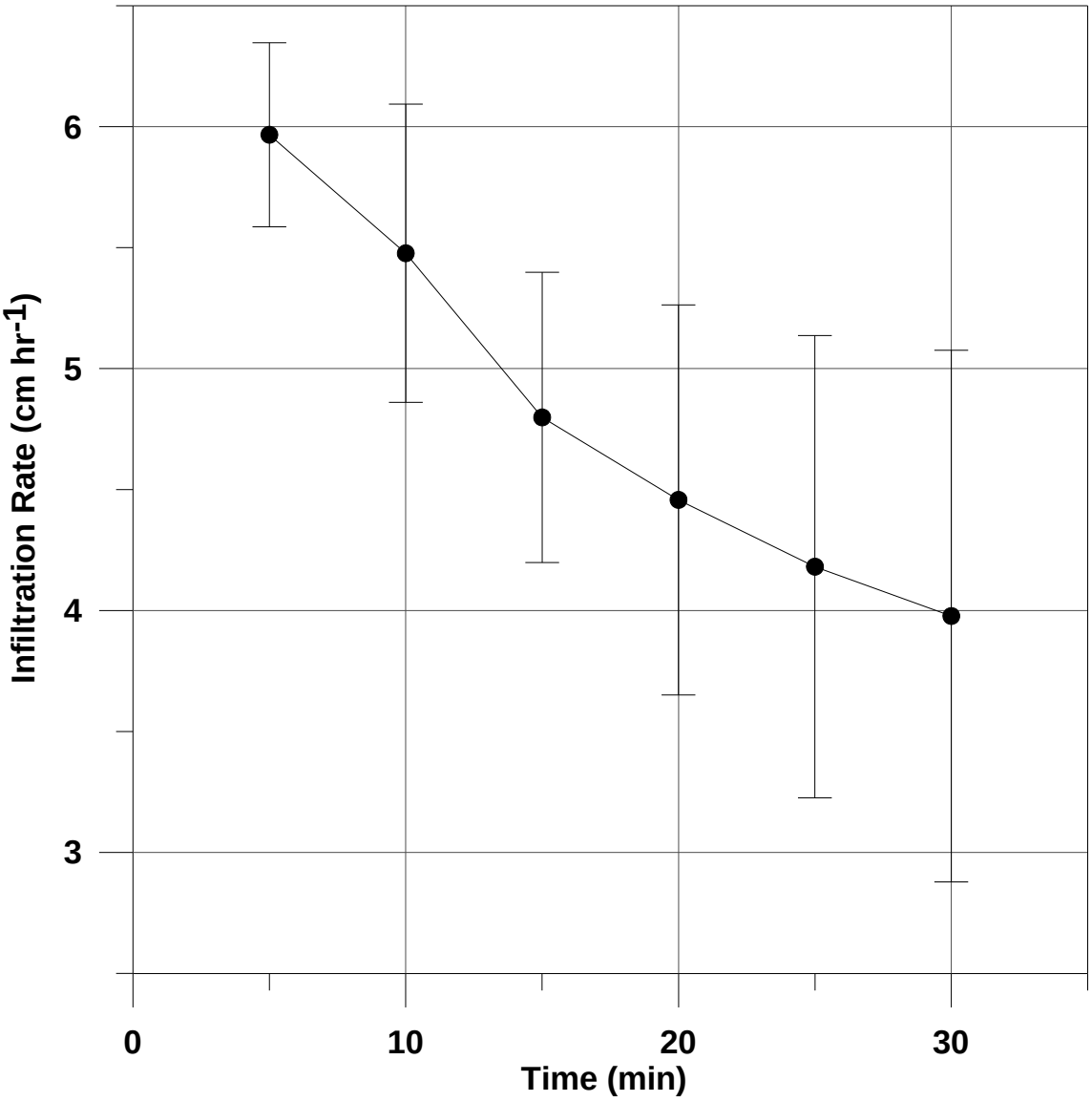

Fig. 13. Infiltration rate over time for the Site Prep / Fertilizer / Seed treatment. Each point is the mean of the three replicates ± one standard deviation.

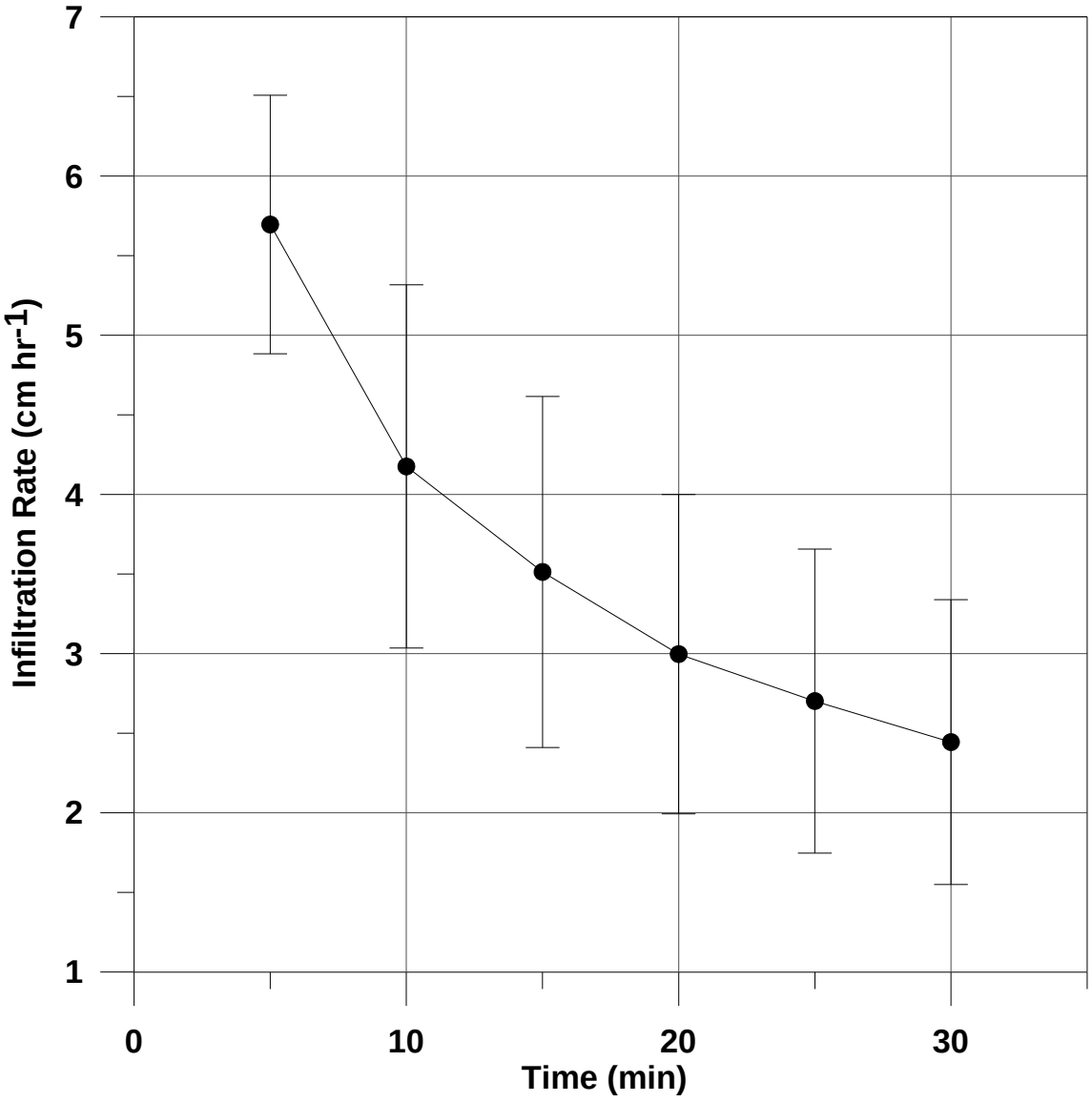

Fig. 14. Infiltration rate over time for the Site Prep / No Seed treatment. Each point is the mean of the three replicates ± one standard deviation.

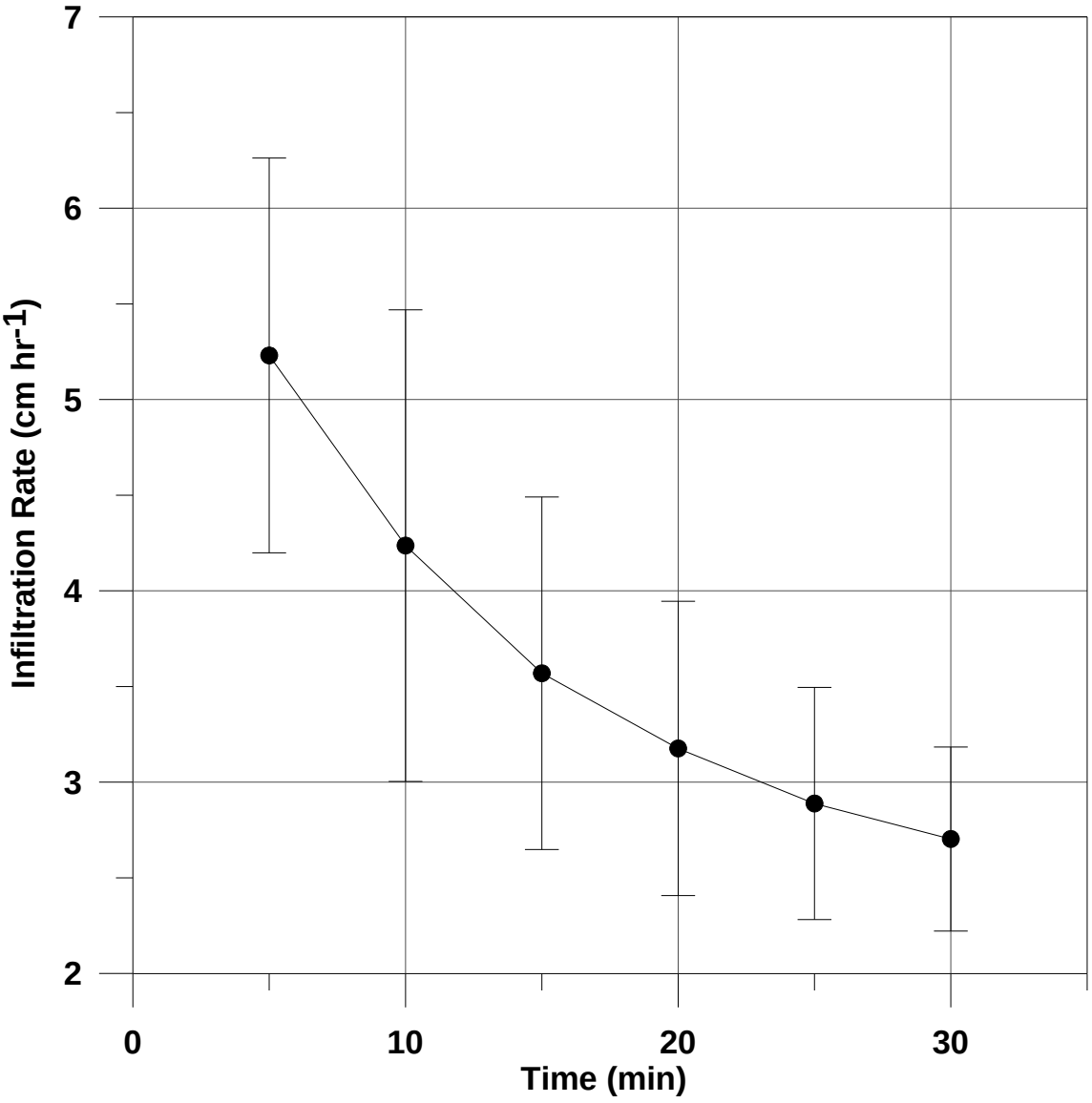

Fig. 15. Infiltration rate over time for the Site Prep / Seed treatment. Each point is the mean of the three replicates ± one standard deviation.

It was determined that infiltration rates were not correlated to levels of TG (p-value 0.9) nor %WSA (Fig. 16 and 17). The %WSA after treatments were applied yielded a slightly negative relationship with infiltration rates that was not significant (p-value 0.09), but Fig. 17 shows how narrow the range in values for %WSA were. Similarly, the correlation between infiltration rates and organic C (Fig. 18) was not significant at the 95% confidence level (p-value of 0.09). Total clays were not correlated to infiltration rates at a 95% confidence level (p-value 0.11).

These results are contrary to those discussed in much of the literature regarding infiltration rates and aggregate stability (Bissonnais and Arrouays, 1997). This inconsistency may be the result of other factors influencing infiltration rates. Bissonnais and Arrouays (1997) suggest that specific portions of the organic pool might be the main agent in stabilizing soils and that the measurement of total organic C may not be discriminating enough. Furthermore, the uniformity of organic C across the plots may explain the lack of differences in infiltration rates. Figure 18 illustrates the relationship between infiltration rates and organic C, which was not significant (p-value 0.09). Organic C plays a direct role in aggregate stability thus an indirect role in infiltration (Bissonnais, 1996). If there is a narrow range of values for organic C across the plots then it stands to reason that infiltration rates would not be significantly different either, especially since there were no significant differences in %WSA.

The flexible metal frame used to contain the runoff beneath the rainfall simulator did not give a uniform area across all plots so it was necessary to determine if a bias existed between infiltration rates and the variability of the frame area. A scatter diagram

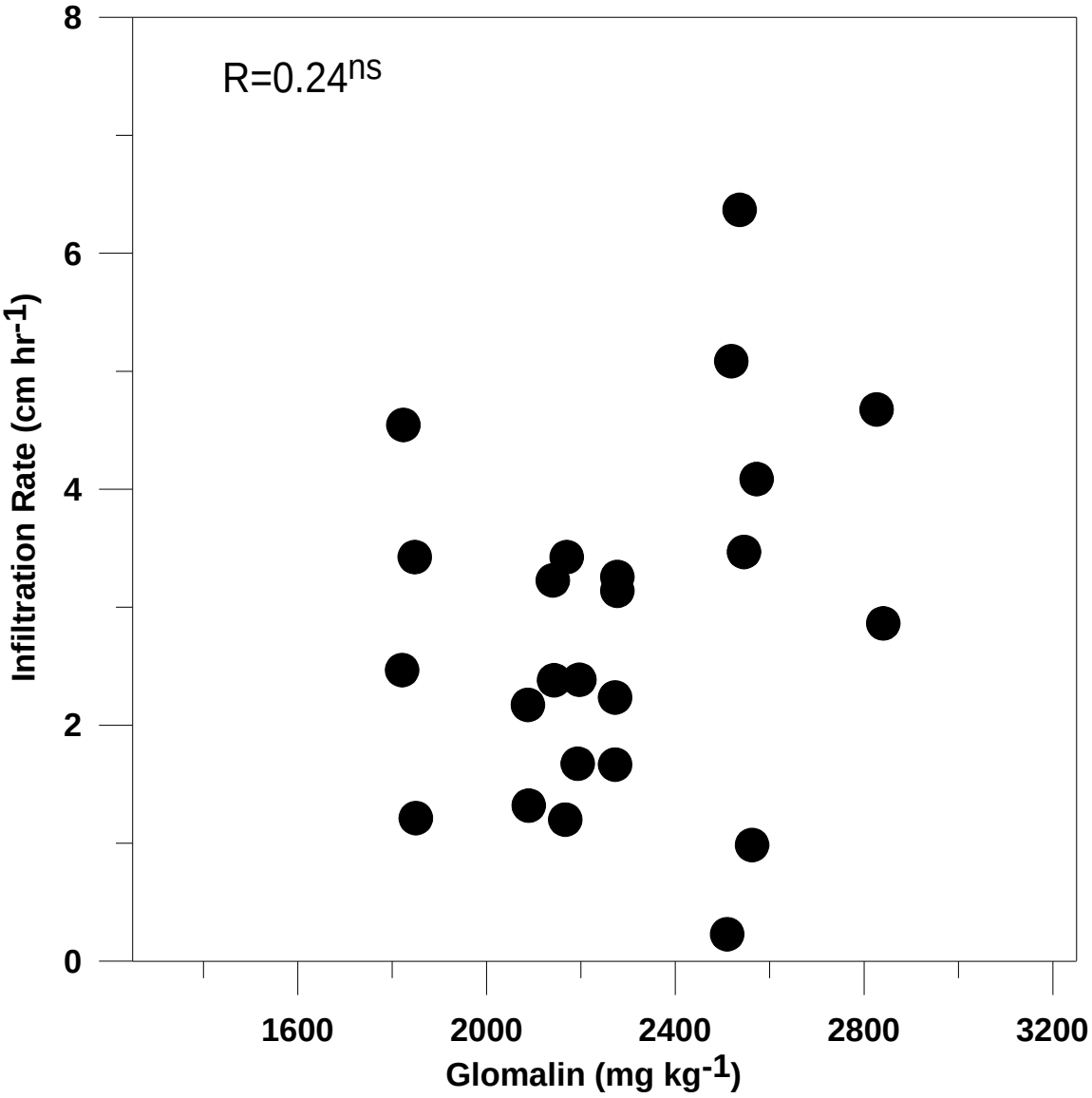

Fig. 16. Scatter diagram between total glomalin and infiltration rates.
ns = not significant.

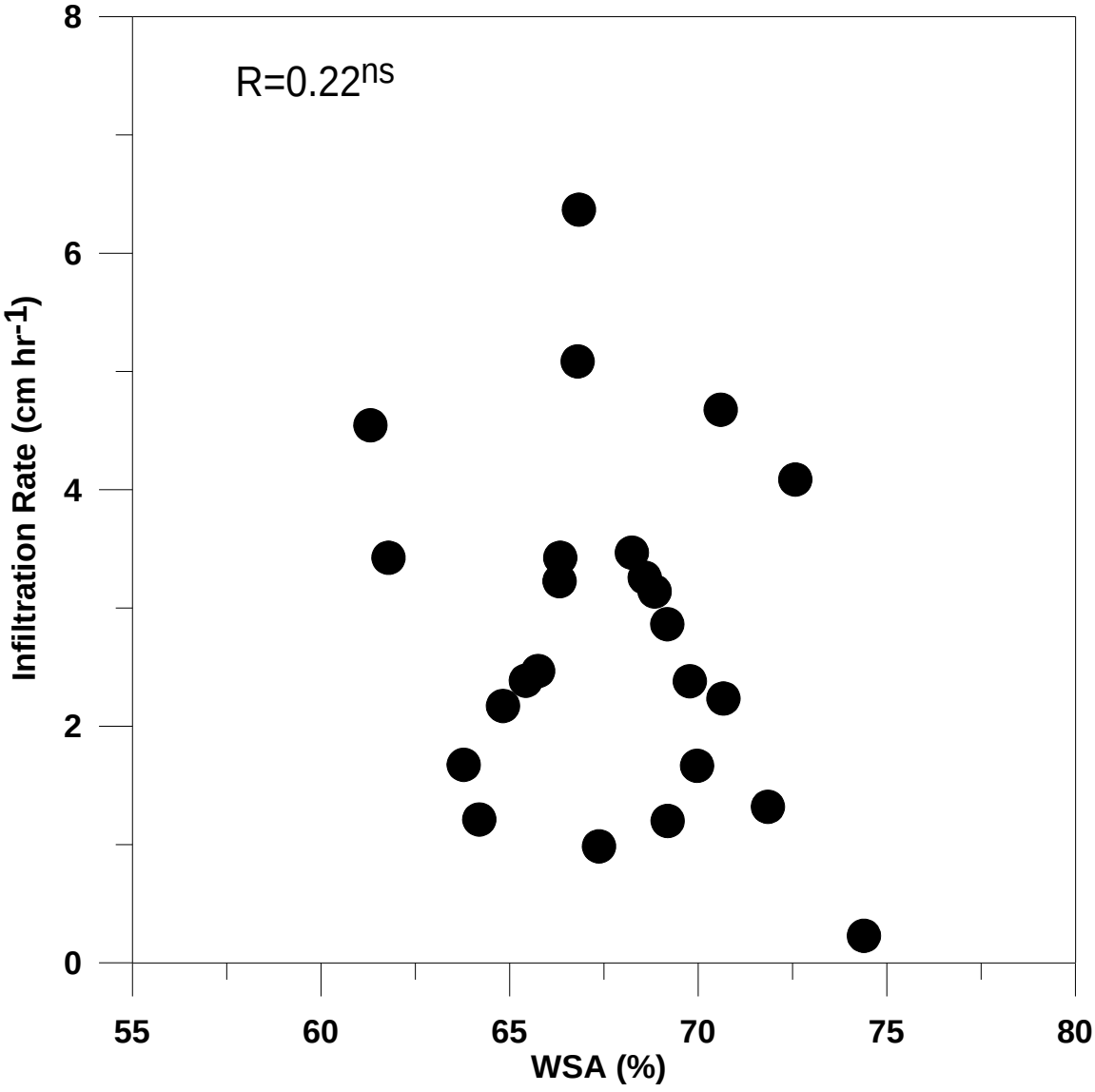

Fig. 17. Scatter diagram between aggregate stability (%WSA) and infiltration rates. ns = not significant.

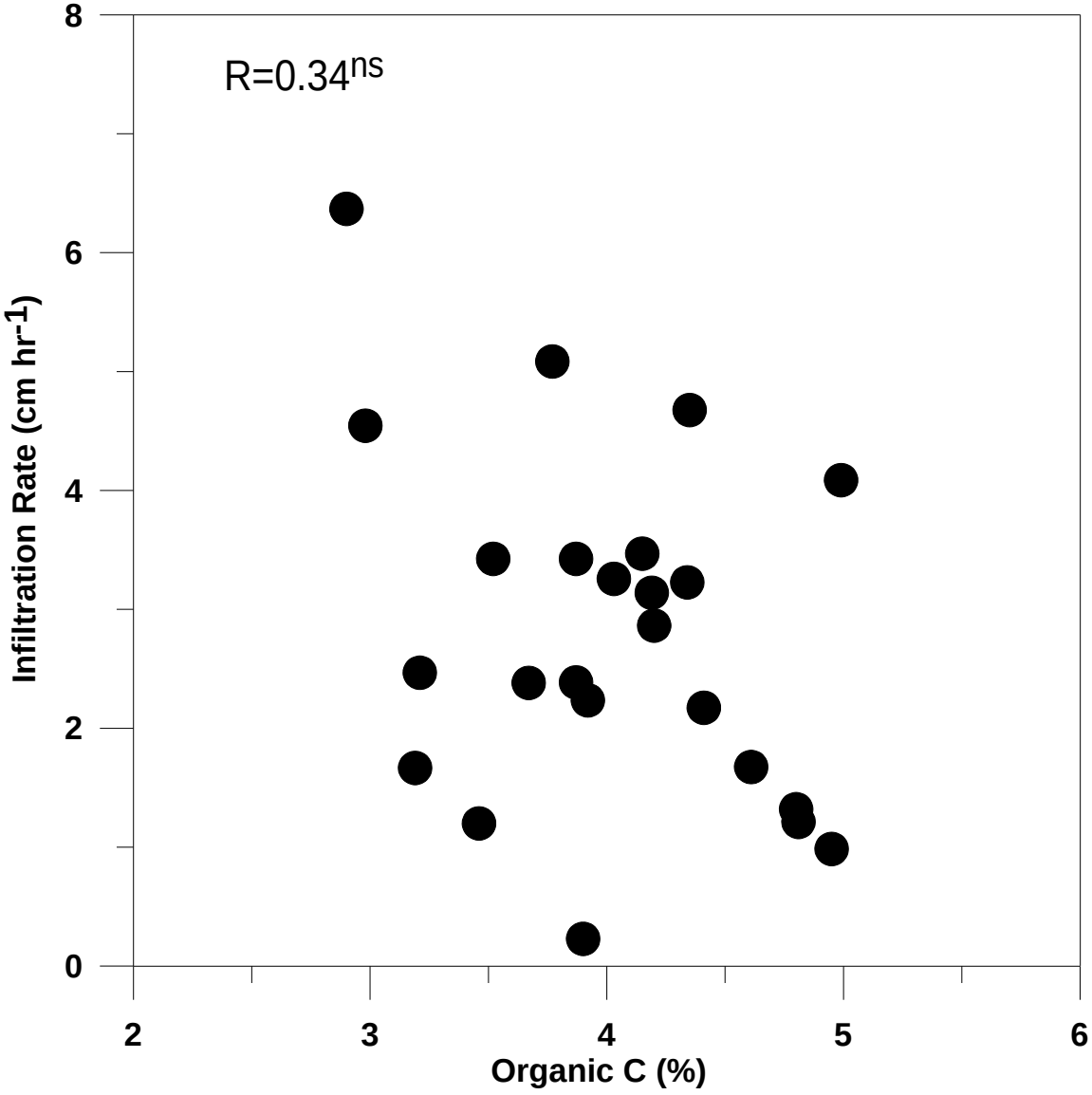

Fig. 18. Scatter diagram between organic C and infiltration rates one year after treatments were applied. ns = not significant.

of area with infiltration rate is presented in Fig. 19. The grid size frame area was not correlated to infiltration rate at the 95% confidence level but a weak relationship did exist (p-value 0.07). Additionally, there were no significant differences between treatments for grid size (p-value 0.65). This indicates that while the frame was not of uniform size across plots, its size was not a significant consideration.

Glomalin

Levels of total glomalin (TG) were measured before treatments were applied and one year after application of treatments. Before treatments were applied the highest values were the No Prep / Seed treatments with a concentration of 1820 mg kg^{-1} while the lowest value was 1530 mg kg^{-1} on the Site Prep / Compost / No Seed treatment (Table 6). One year after treatments were applied, the plot with the highest quantity of glomalin was the Site Prep / Compost / Seed treated plot while the lowest concentration of TG was found on the Site Prep / Fertilizer / Seed plot. The concentrations were 2630 mg kg^{-1} and 2030 mg kg^{-1} respectively (Table 6). Total glomalin concentrations before treatments were significantly different at a 95% confidence level (p-value 0.035); however, there was no significant difference among treatments one year after treatments were applied (p-value 0.14). Comparing TG levels before and after treatments were applied showed highly significant changes (p-value <0.001) with every treatment showing a significant increase over time (Fig. 20).

Previous studies have shown significant correlations between glomalin and a variety of soil properties including organic C and %WSA (Wright et al., 1999). Wright

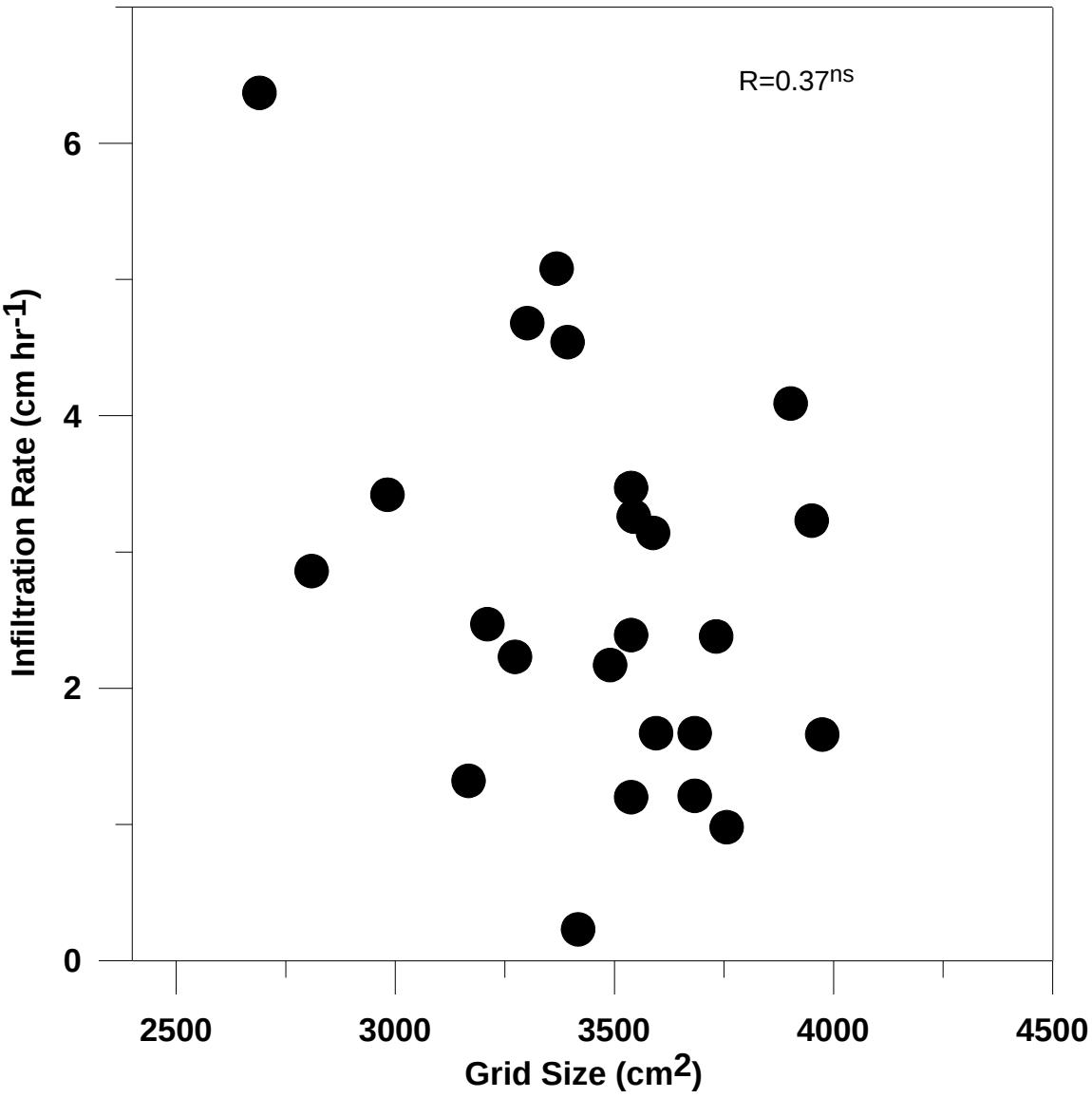

Fig. 19. Scatter diagram between the area used for infiltration that was enclosed in the flexible frame (grid size) and infiltration rate. ns = not significant.

Table 6. Glomalin means and standard deviations for plots of each treatment before and after application of amendments.

Treatments	Before (July 06)		After (July 07)	
	Mean	Std Dev	Mean	Std Dev
	----------mg kg^{-1}----------			
Site Prep / Seed	1580^{b†}	71	2090^{ns}	391
Site Prep / No Seed	1690^{ab}	203	2280^{ns}	27
Site Prep / Compost / Seed	1770^{a}	148	2630^{ns}	385
Site Prep / Compost / No Seed	1530^{b}	110	2230^{ns}	389
Site Prep / Fertilizer / Seed	1640^{ab}	44	2030^{ns}	395
Site Prep / Fertilizer / No Seed	1790^{a}	80	2260^{ns}	161
No Prep / Seed	1820^{a}	88	2210^{ns}	163
No Prep / No Seed	1780^{a}	139	2440^{ns}	26

†Superscripts within a column indicate means that are the same group at the 95% confidence level. ns = not significant.

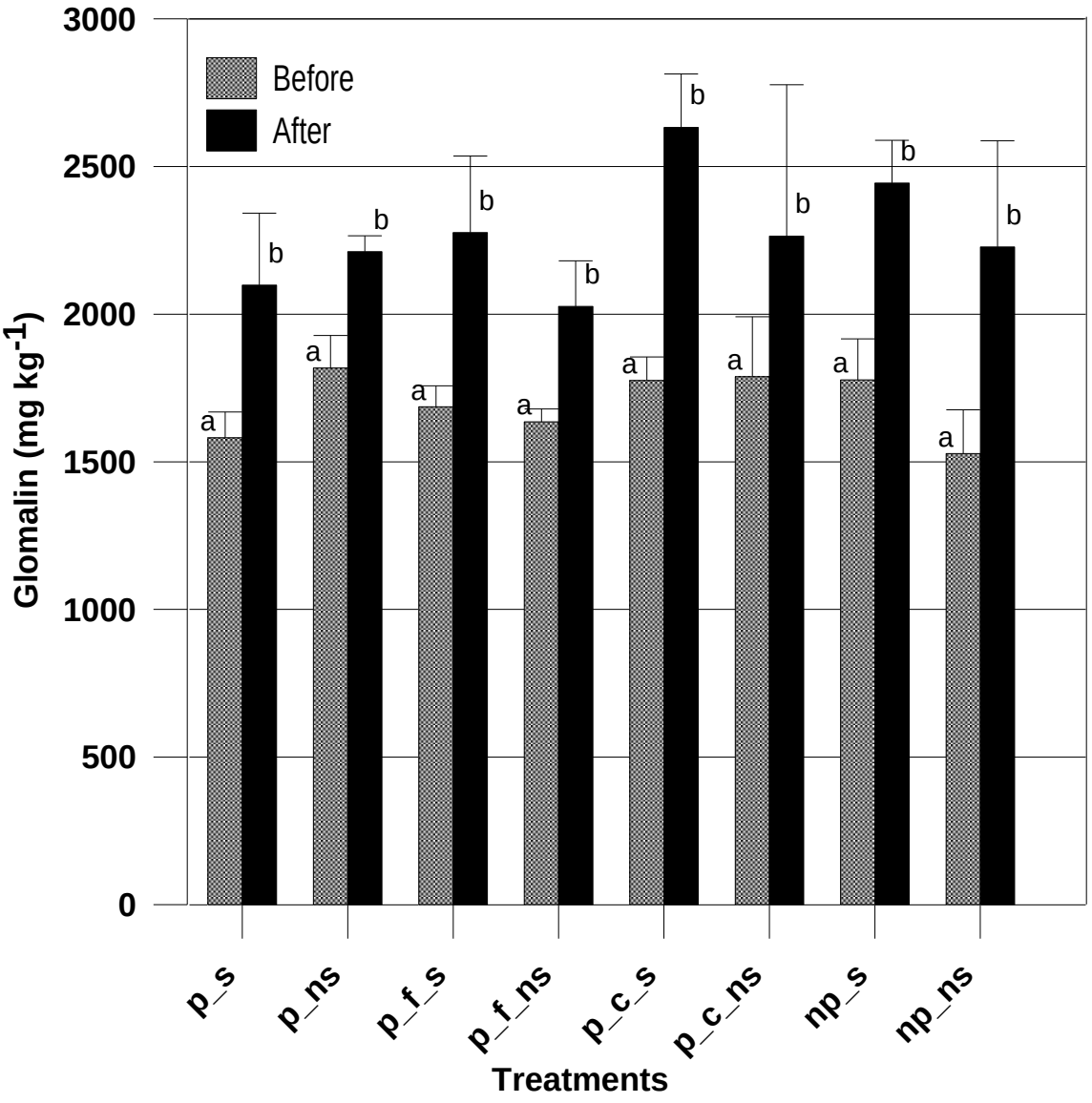

Fig. 20. Changes in total glomalin over time for each treatment. Data are presented as mean ± one standard deviation.

and Upadhyaya (1998) demonstrated TG was positively correlated to aggregate stability using 37 different soils with varying cropping histories. Additionally, Franzluebbers et al. (2000) showed that soil organic C was highly correlated to TG in the Southern Piedmont on soils that varied by grazing regime and land management practices. The results of this study also confirm these relationships. Total glomalin values from before and after treatment applications combined were significantly correlated to combined organic C values (p-value <0.001)(Fig. 21). The slopes from before treatments and after treatments were statistically the same (p-value <0.001), indicating that the relationship between organic C and TG remained the same over time. However, the relationships between glomalin and %WSA changed over time (Fig. 22 and 23). Before the treatments were applied, there was no correlation (Fig. 22) (p-value 0.89), but one year after treatments were applied, there was a significant positive correlation (Fig. 23) (p-value <0.01). The correlation between aggregate stability and glomalin after treatments were applied is verified in much of the literature; however, it is unclear why this relationship was not observed before treatments were applied (Franzluebbers et al., 2000; Wright et al., 1999; Wright and Upadhyaya, 1998). The aggregates measured in this study were all >250µm which may suggest that TG was not associated with these larger aggregates but perhaps with another aggregate size class. Furthermore, Wright and Upadhyaya (1998) found that %WSA was better correlated to IREEG rather than TG which was the fraction measured in this study.

The values observed for TG are similar to values reported in the literature. Wright and Upadhyaya (1998) found TG levels as high as 2000 mg kg^{-1} in soils from

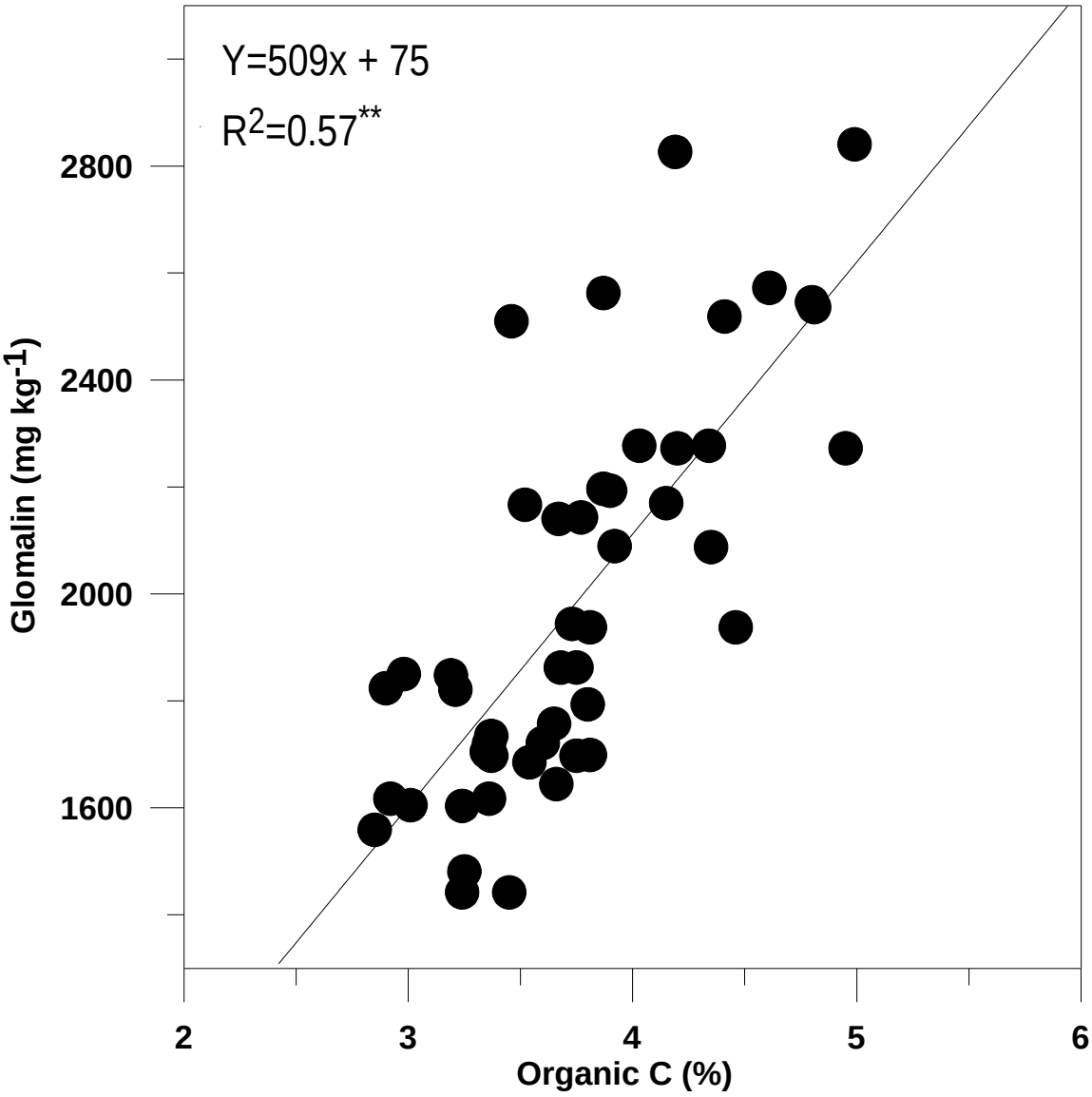

Fig. 21. The relationship between organic C and levels of total glomalin using combined data from before and after treatments were applied.
** Significant at the 0.01 probability level.

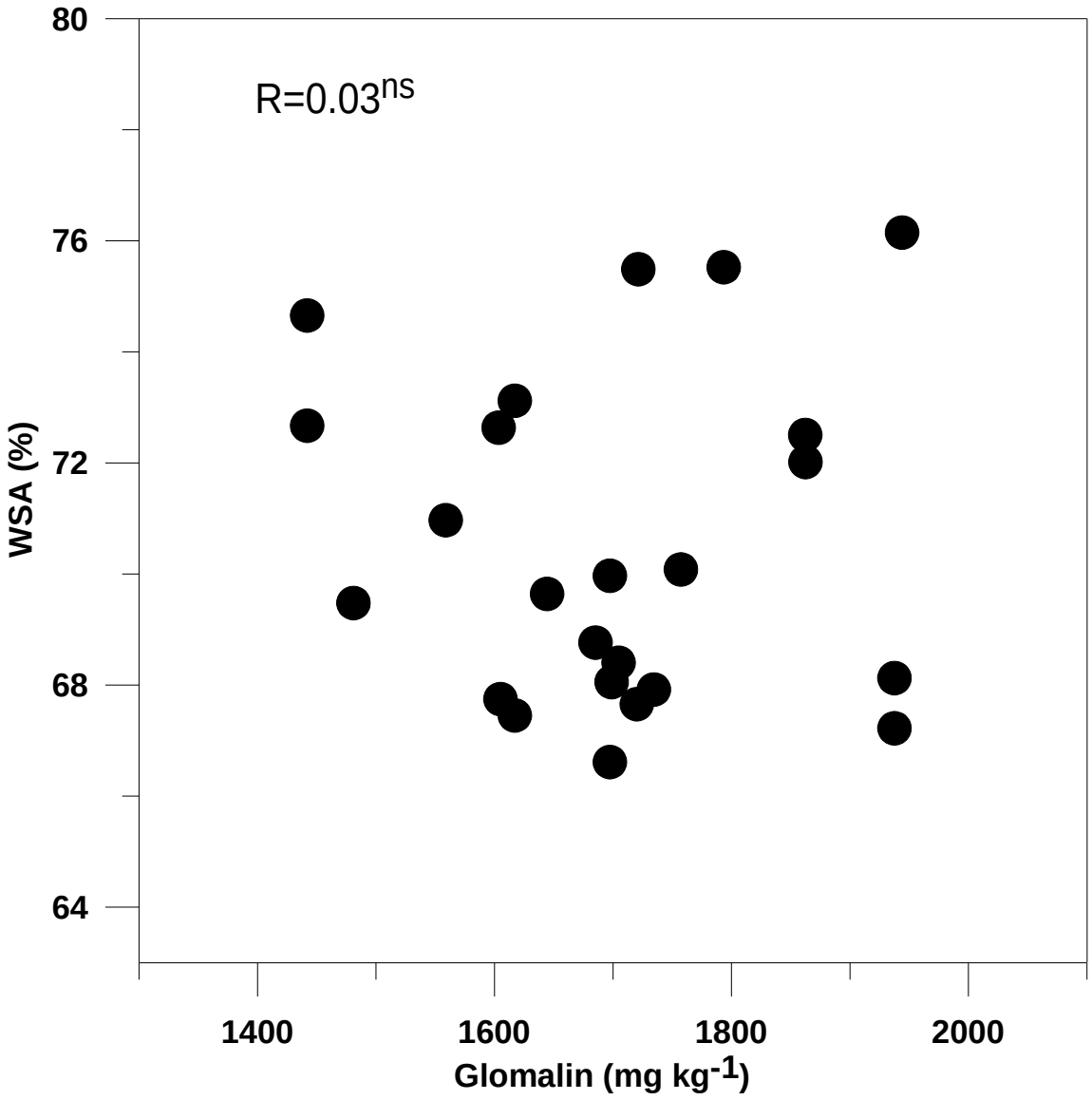

Fig. 22. The relationship between glomalin and aggregate stability (%WSA) before treatments were applied. ns = not significant.

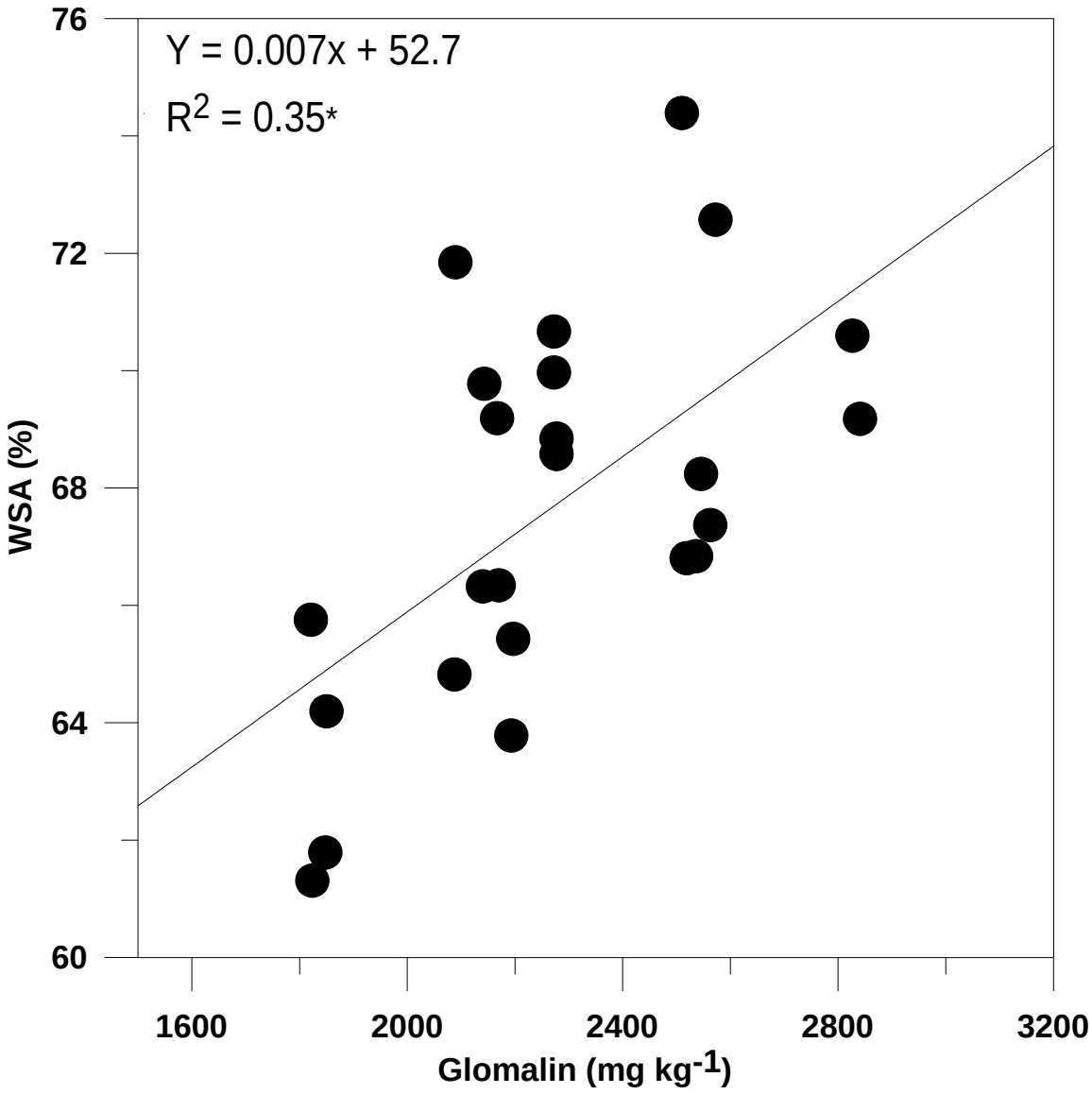

Fig. 23. The relationship between glomalin and aggregate stability (%WSA) after treatments were applied.
* Significant at the 0.05 probability level.

Texas. These soils were similar to the Fort Hood soils in amount of carbonates and pH, but had less organic C. Additionally, they observed TG levels in excess of 14,000 mg kg^{-1} on soils taken from Scotland that had similar organic C levels but lower pH values. The increase in glomalin over time may be a function of precipitation. Samples for TG from before application of treatments were taken during a dry summer compared to the subsequent year which was wetter. The increase in rainfall over time could have increased vegetation, which theoretically would create the potential for increased glomalin production, given that glomalin is a product of AMF that colonize the roots of plants. However, current literature does not address the time-scale for glomalin production and direct response to rainfall patterns.

Soil Fertility

The main factor in this study was the kind and amount of soil amendment being applied. Some treatments included organic composted dairy manure while others received inorganic fertilizer. Therefore, it was vital to measure the level of nutrients in the soil to determine if there were any antecedent deficiencies and to understand the role that these amendments may have played in altering levels of glomalin. Soil samples gathered from the plots before treatments were applied and samples taken one year later were analyzed for a number of soil nutrients (Table 7). These nutrients included nitrate-N, P, K, Ca, Mg, S, Na, Fe, Zn, Mn, and Cu. Only nitrate-N, P, and Fe were analyzed statistically because all other nutrient levels were deemed acceptable for adequate agronomic plant growth.

Table 7. Means for available P and Fe before treatments were applied.

Treatments	Nutrients	
	P	Fe
	----------mg kg^{-1}----------	
Site Prep / Seed	$6.7^{ab\dagger}$	$8.2^{ab\dagger}$
Site Prep / No Seed	$6.0b^{c}$	9.3^{a}
Site Prep / Compost / Seed	5.7^{bcd}	8.6^{a}
Site Prep / Compost / No Seed	4.7^{d}	6.7^{c}
Site Prep / Fertilizer / Seed	5.3^{cd}	7.2^{bc}
Site Prep / Fertilizer / No Seed	7.3^{a}	6.8^{bc}
No Prep / Seed	4.7^{d}	6.5^{c}
No Prep / No Seed	5.0^{cd}	7.0^{bc}

† Superscripts within a column indicate means that are the same group at the 95% confidence level.

Statistically there were no differences in nitrate-N levels across all plots before treatments were applied (p-value 0.42) or after (p-value 0.85). However, both P and Fe had significant differences among the plots before any treatments were applied with p-values of 0.002 and 0.005 respectively (Table 7). This might suggest that there were differences to begin with that may have masked any real changes observed during the study. However, one year later the differences among the plots were non-significant for any nutrient. This indicates that levels of nutrients probably did not hinder or alter any differences that were observed for aggregate stability, infiltration rates, or TG. Over time only three treatments showed significant changes in levels of nutrient for P. These treatments included Site Prep / Fertilizer / Seed, Site Prep / Compost / Seed, and Site Prep / Compost / No Seed (Fig. 24). For Fe there were also three treatments with significant changes, which included Site Prep / Compost / Seed, Site Prep / Fertilizer / Seed, and No Prep / No Seed treatments (Fig. 25). Statistically NO_3-N did not change over time with a p-value of 0.73.

Since Wright and Upadhyaya (1998) found that glomalin was not as abundant in high pH soils with low Fe levels, the relationship of extractable Fe and TG was considered. Statistically there was no correlation (p-value 0.37) in this study across all treatment plots and all levels of TG. It appears initially that glomalin is unaffected by Fe levels in these soils. However, the range in extractable Fe was rather narrow in the study, and all of the soils were calcareous.

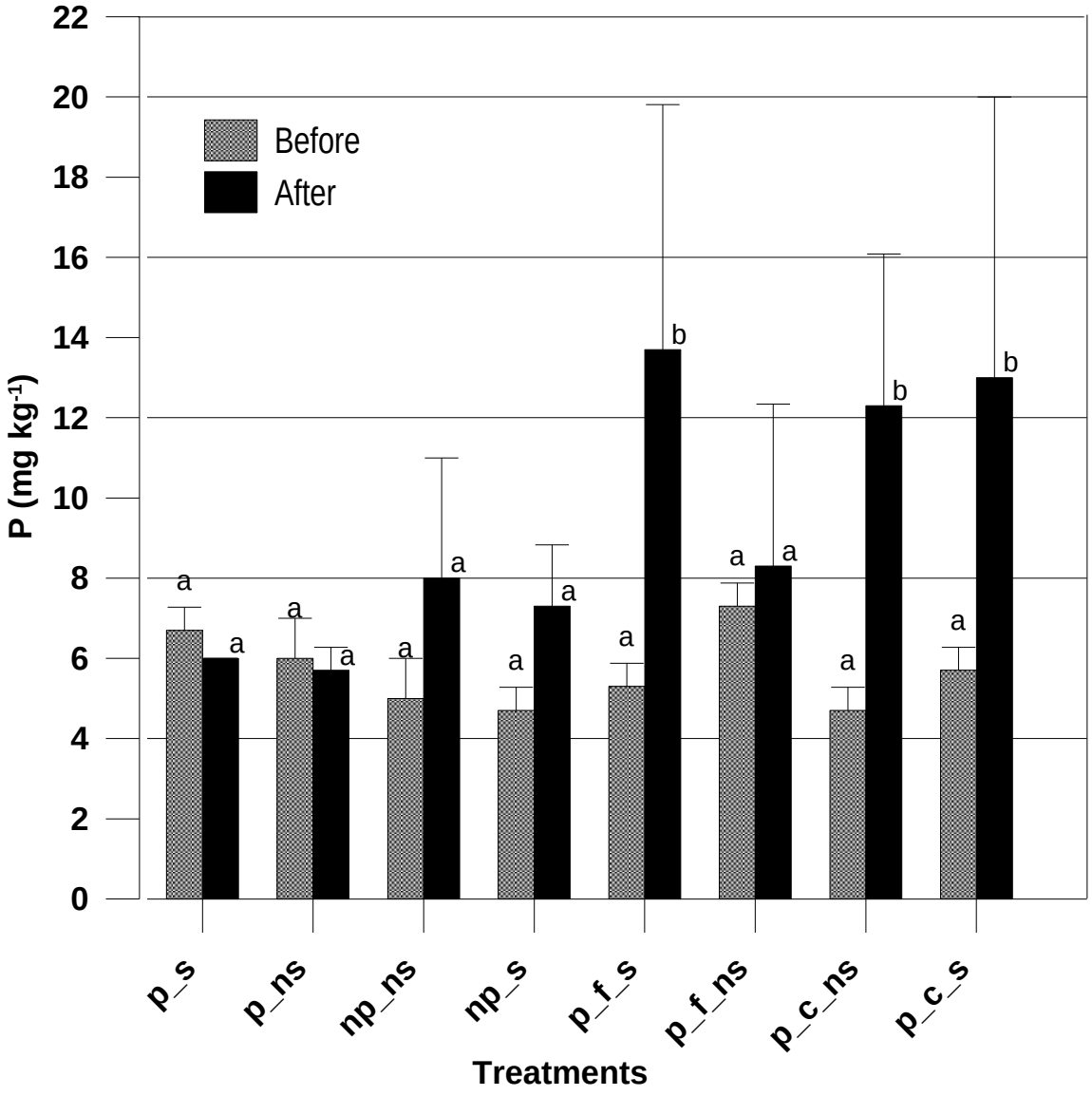

Fig. 24. Levels of available P over time. Data are presented as mean ± one standard deviation.

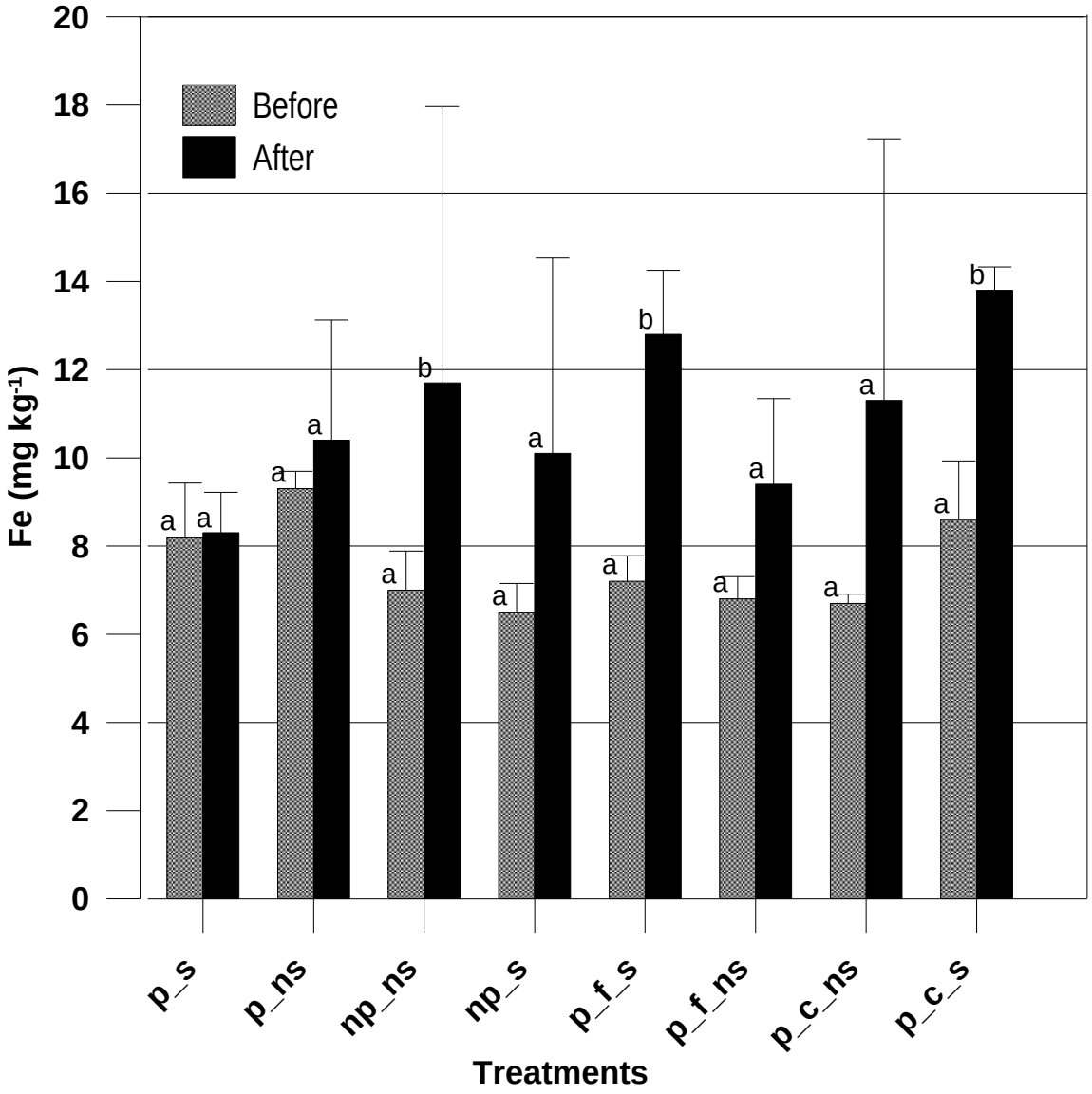

Fig. 25. Levels of available Fe over time. Data are presented as mean ± one standard deviation .

Given the amount of nutrients that were applied during this study, it is surprising how low some of the nutrient levels were. Phosphorus levels across all plots averaged 9.3 mg kg^{-1} for samples taken one year after application while nitrate-N averaged 6.5 mg kg^{-1} and Fe averaged 11.0 mg kg^{-1}. The values for N and P are low considering 322 kg ha^{-1} of total N and 211 kg ha^{-1} of total P were applied with organic compost and 351 kg ha^{-1} total N and 68 kg ha^{-1} total P were applied with the inorganic fertilizer. These soils appear to be so deficient in available P that even when high amounts are added the soil reacts with the P and buffers it against changes in available P levels to the point that there is little extra P to aid in plant growth. The high amounts of Ca as both exchangeable Ca and as calcite in the soils are reacting with the applied P to make it unavailable. This is possibly a reversion to forms of P similar to apatite (Appendix D).

Nitrogen levels were also quite low given the amount of nutrient that was applied. Potential explanations for these low levels are losses from NH_3 volatilization, leaching of NO_3^-, and denitrification. Applying NH_4^+-containing fertilizers to calcareous soils like the ones on Fort Hood can result in volatilization of NH_3. This is generally greater with liquid fertilizers and with urea fertilizers. Additionally, NO_3^- is susceptible to leaching especially during periods of high water movement as was the case throughout this study. Lastly, losses of N from denitrification are possible when soils are waterlogged creating anaerobic conditions. While the losses from any one of these cases are probably not great, collectively the potential for losses of N are plausible which may explain the low N levels found on these soils.

Additional Sites

In an effort to expand the soil base studied on Fort Hood, a variety of compacted soils were included for aggregate stability, infiltration, and glomalin from other training areas. These sites were chosen to illustrate the range of compaction and degradation that is found throughout Fort Hood. The same procedures and techniques utilized for the plot study were used for the ten supplemental sites which included nine major soil series. In addition, rates of infiltration were compared against values reported by NRCS (USDA, 1985). Such values are commonly used for modeling runoff and erosion.

The additional soils evaluated showed differences in many soil properties including texture, organic C, bulk density, and CCE (Appendix D). Textural classes varied from a silt loam to a silty clay. Organic C ranged from 0.55% at site 10 to 3.55% at site 8. Additionally, bulk density (0.33 bar) ranged from 1.07 g cm^{-3} at site 6 to 1.52 g cm^{-3} at site 5, while CCE varied between 6.5% and 64.3% at sites 10 and 5, respectively. Measured rates of infiltration were within the ranges reported by NRCS in four of the soils (2,3,5,8) and was of a greater infiltration rate for five of the soils (1,4,6,7, and 9) (Table 8). In only case (Cisco series) was the infiltration rate determined to be lower than the range reported by NRCS.

Values for %WSA (Table 9) ranged from a minimum of 37% at site 10 to a maximum of 73% at sites 7 and 8. This difference was to be expected given the differences in soil characteristics among sites including texture, organic C, and bulk

Table 8. Reported rates of infiltration from the Natural Resources Conservation Service (NRCS) and observed rates of infiltration. NRCS rates were taken from the soil survey for Coryell County (USDA, 1985).

	----------NRCS Values----------			-----Observed Values-----	
Sites	**Map Unit**	**Major Series**	**Infiltration Rate**	**Infiltration Rate**	**Std Dev**
			----------cm hr^{-1}----------		
1	NuC	Nuff	0.51-1.52	4.5	0.71
2	LeB	Lewisville	1.52-5.08	2.3	1.9
3	BtC2	Brackett	1.52-5.08	2.6	1.4
4	TpC	Topsey	1.52-5.08	6.1	0.70
5	BtC2	Brackett	1.52-5.08	3.6	0.12
6	EvB	Evant	0.51-1.52	2.4	0.85
7	SlB	Slidell	<0.15	3.5	0.69
8	ChB	Cho	1.52-5.08	4.8	0.42
9	DrC	Doss	0.51-1.52	2.7	1.5
10	CoB2	Cisco	5.08-15.24	1.3	0.81

Table 9. Aggregate stability, infiltration rates, and total glomalin values for the additional sites at Fort Hood. Each value represents the mean value for the site.

Site #	WSA	Infiltration	Glomalin
	---% ---	---cm hr^{-1}---	---mg kg^{-1}---
1	70	$4.5^{abc\dagger}$	710
2	64	2.3^{cd}	2420
3	66	2.6^{cd}	570
4	65	6.1^{a}	2680
5	57	3.6^{bc}	1600
6	65	2.4^{cd}	670
7	73	3.5^{bcd}	3420
8	73	4.8^{ab}	4700
9	64	2.7^{bcd}	2930
10	37	1.3^{d}	380

† Superscripts within a column indicate means that are the same group at the 95% confidence level.

density. Values of %WSA were highly correlated to organic C (p-value <0.001) as shown in Fig. 26. This suggests that organic C plays a major role in the stability of soil peds or that it can be used to predict %WSA. Published research supports both increases and decreases in %WSA with corresponding increases in organic C (Amézketa, 1999). This research indicates a positive correlation between the two. However, a relationship did not exist between %WSA and total clays (p-value 0.11).

Infiltration rates were significantly different across the sites (p-value 0.02). The greatest rate was 6.1 cm hr^{-1} and the lowest rate was 1.3 cm hr^{-1} for sites 4 and 10 respectively (Table 9). Aggregate stability was correlated to infiltration rates (Fig. 27) using data across all the additional sites (p-value 0.03). Infiltration rates were also correlated to organic C levels (Fig. 28) but not total clays (p-value 0.03 and 0.77, respectively). This would suggest that organic C accounts for more of the variability in infiltration rates as opposed to total clays. Similar to the plot study, an ANOVA was used to compare changes in the grid size and rates of infiltration. There were no significant differences between sites for grid size (p-value 0.96), and grid size was not effecting infiltration rate. This supports the assumption that differences in infiltration rates were not a factor of changes in the size of the grid used for measurements.

The additional sites studied showed a wide range in values of TG from 380 mg kg^{-1} at site 10 to 4700 mg kg^{-1} at site 8 (Table 9). Further, there was a positive correlation between %WSA and TG across all sites with a p-value of 0.02 (Fig. 29). Similarly, the relationship between log transformed TG and infiltration rates (Fig. 30) of all sites was significant (p-value 0.04). Also, TG was positively correlated to organic C

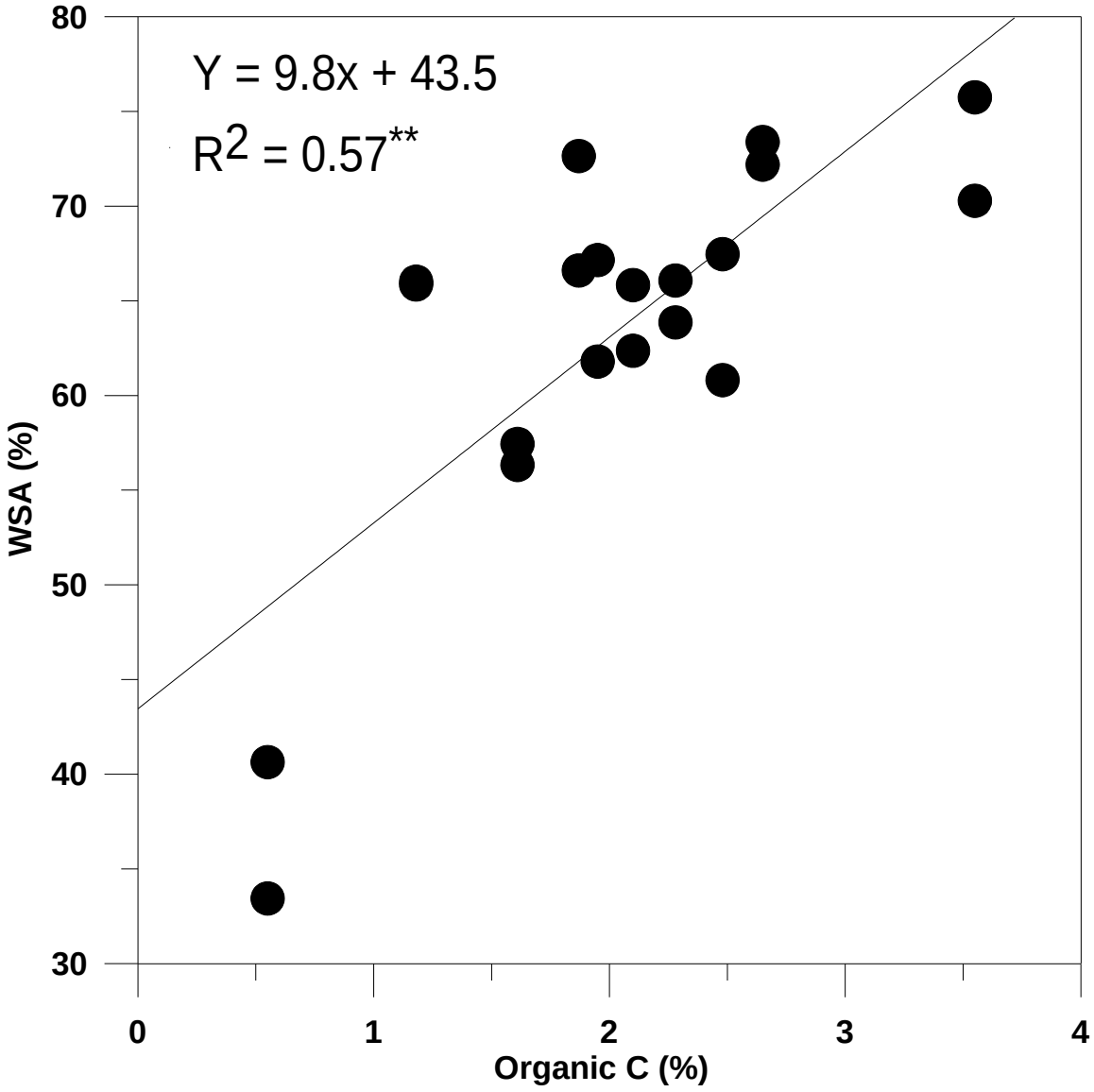

Fig. 26. The relationship between organic C and aggregate stability for the additional study soils.
** Significant at the 0.01 probability level.

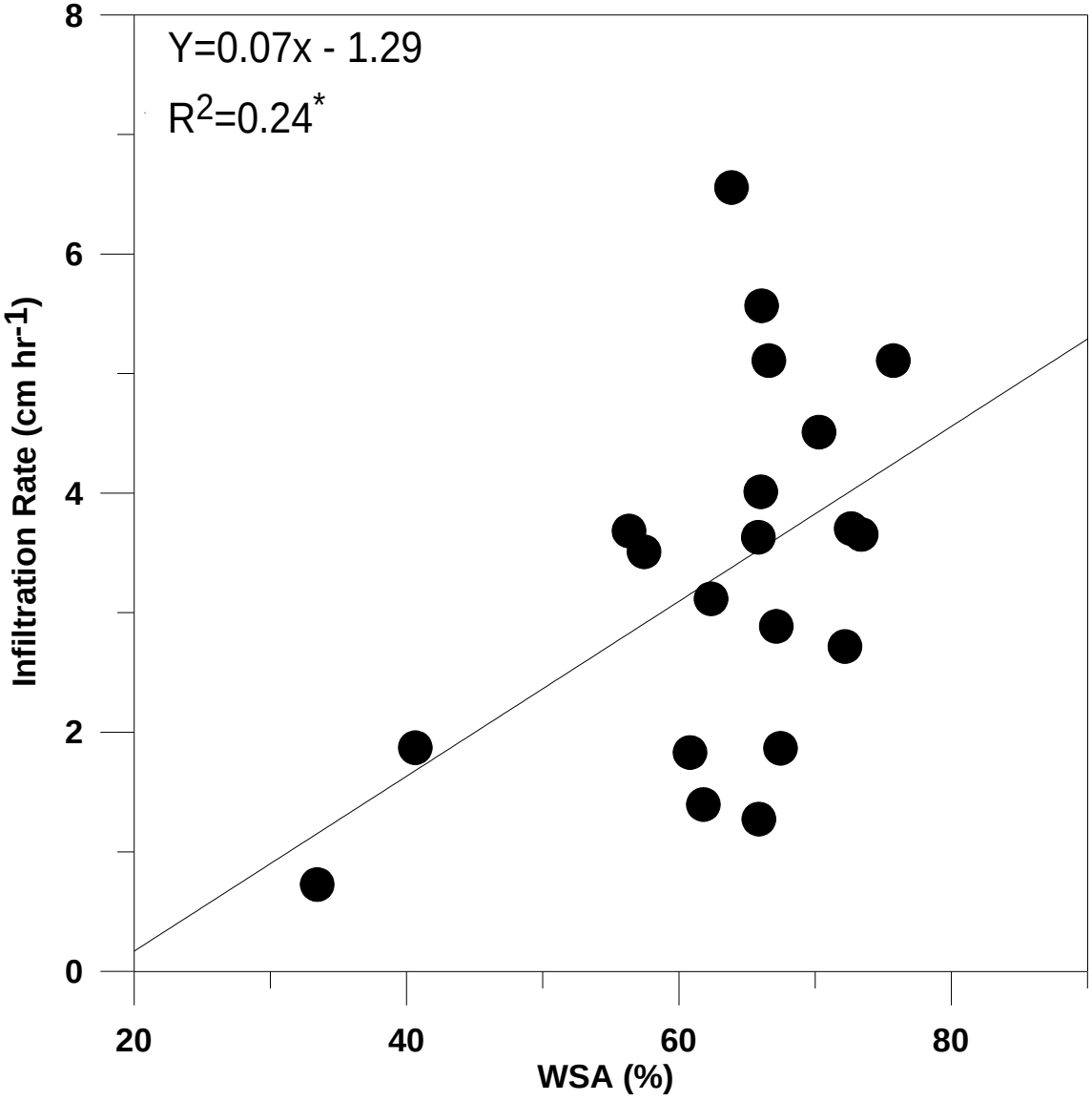

Fig. 27. The relationship between infiltration rates and aggregate stability for the additional sites study.
* Significant at 0.05 probability level.

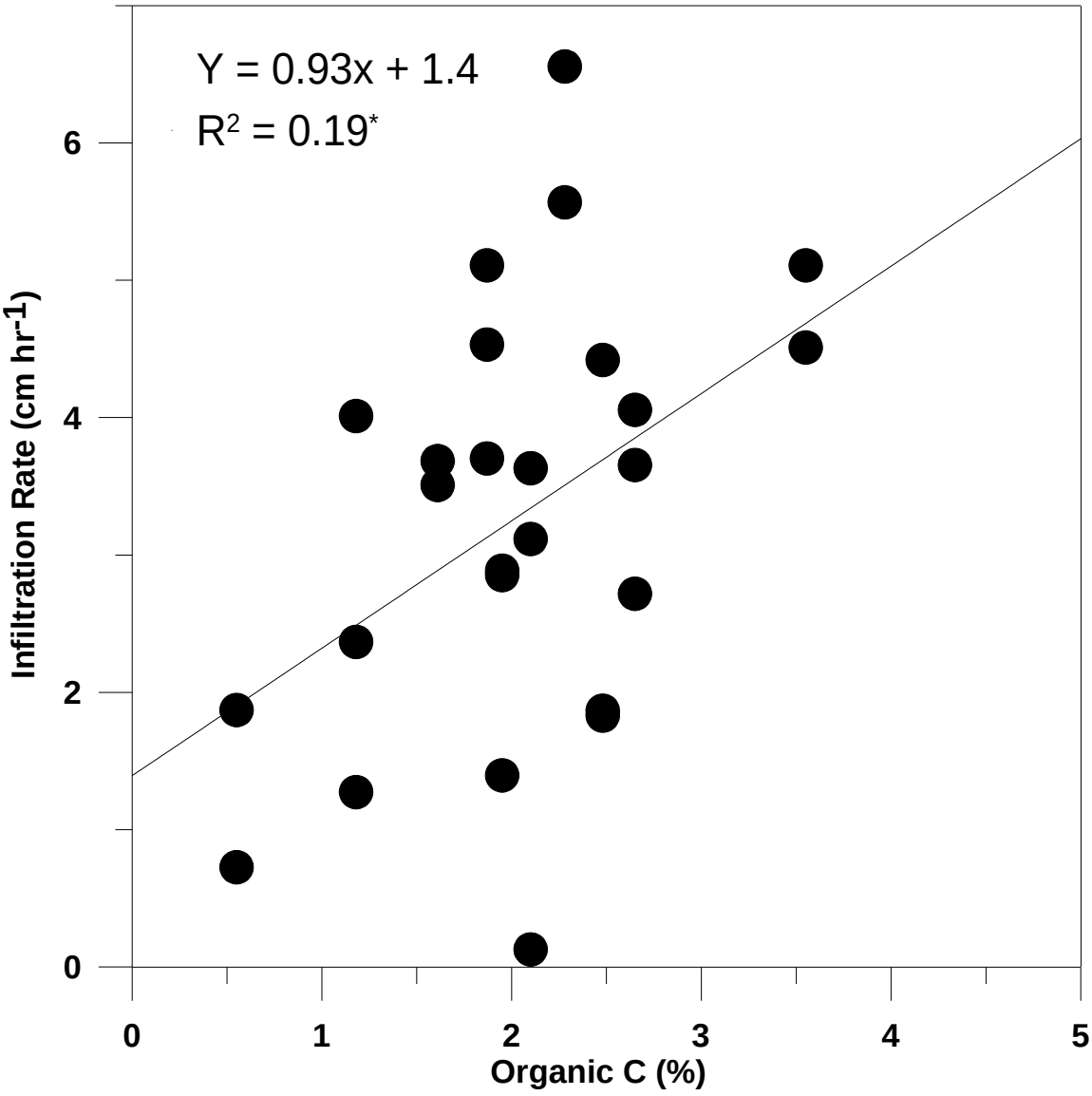

Fig. 28. Scatter diagram between organic C and infiltration rates for all additional sites.
* Significant at the 0.05 probability level.

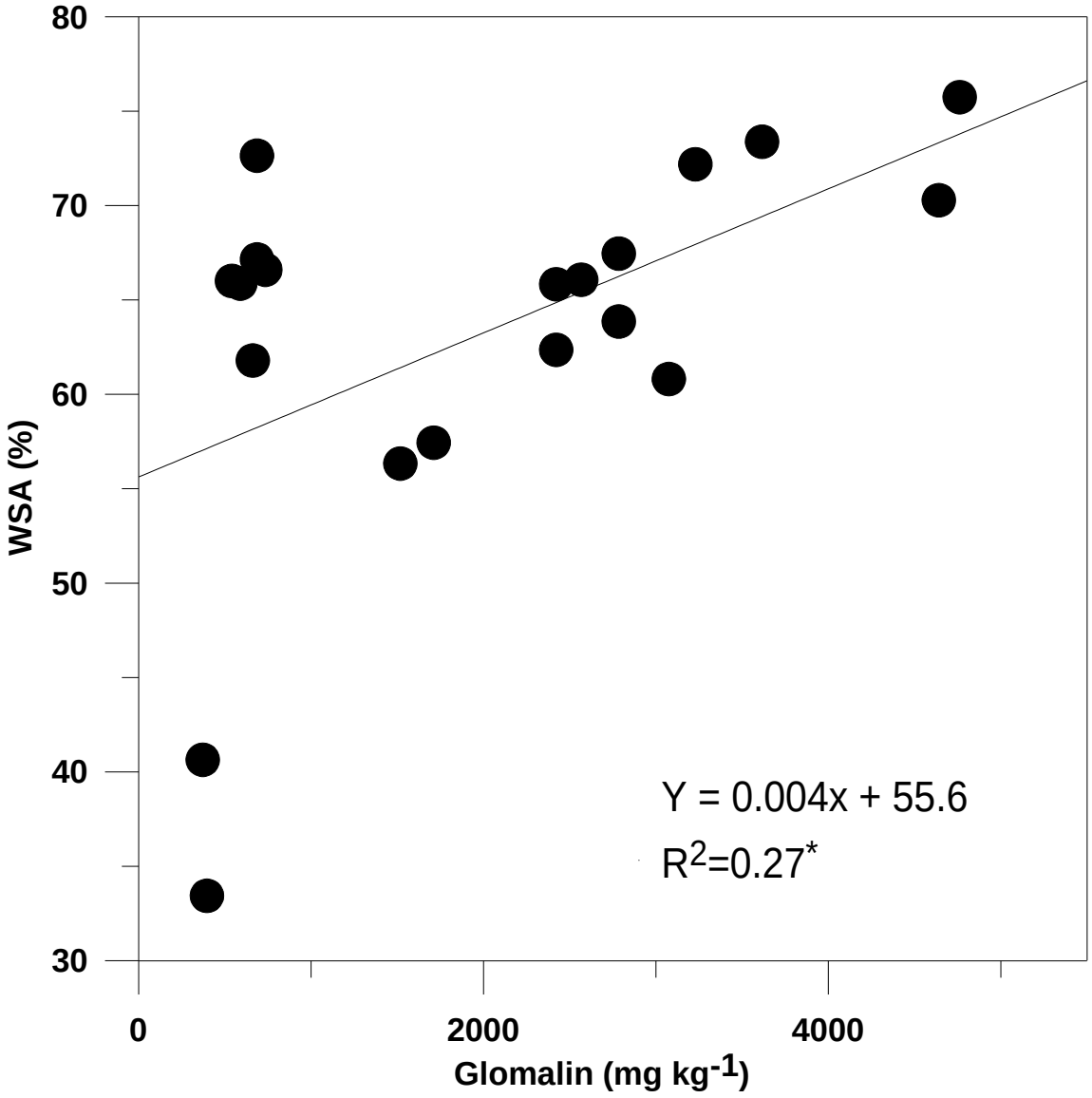

Fig. 29. The relationship of aggregate stability to glomalin for the additional sites study.
* Significant at the 0.05 probability level.

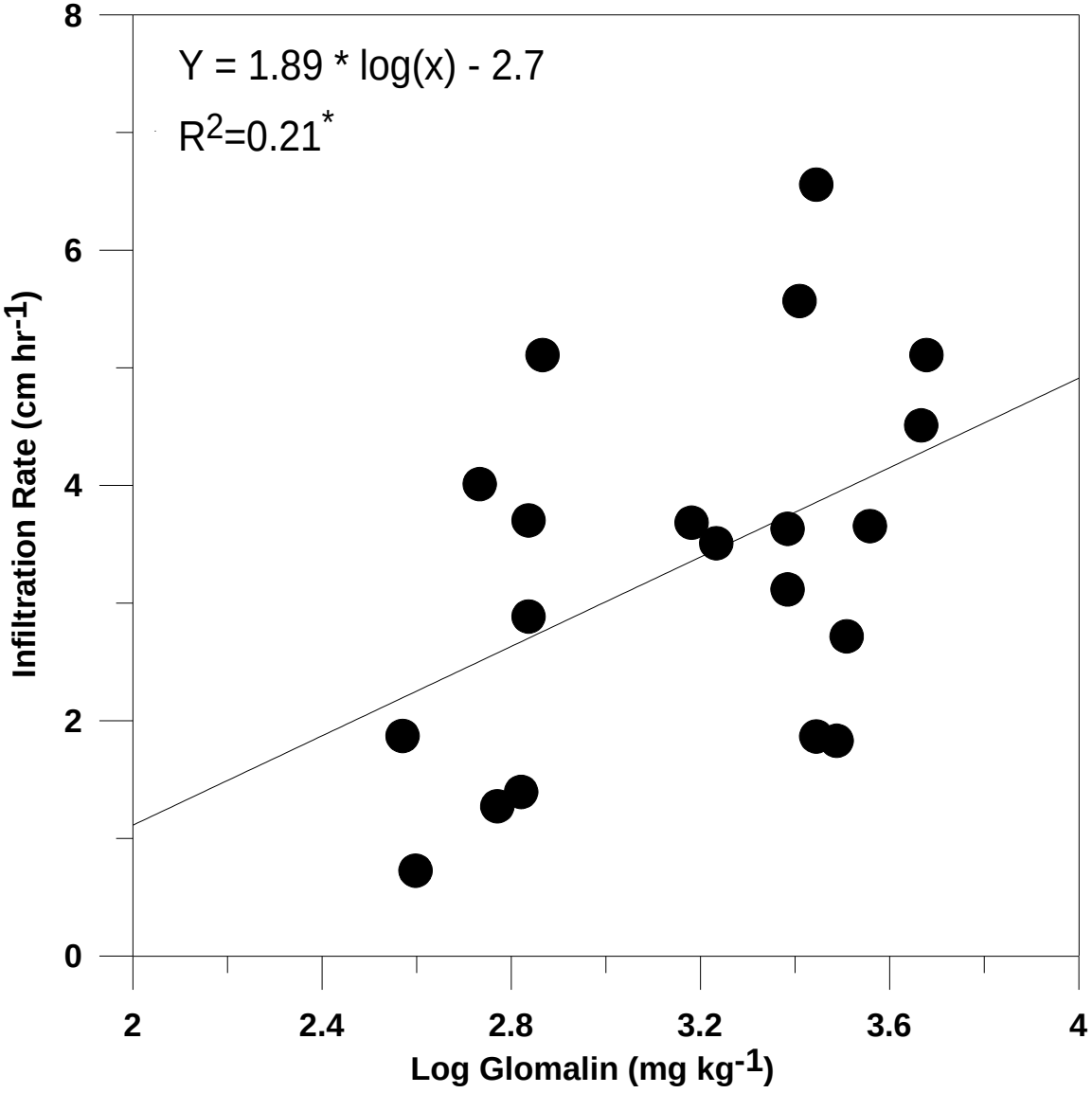

Fig. 30. The relationship of infiltration rate and log transformed glomalin for the additional sites study.
* Significant at the 0.05 probability level.

(p-value <0.001) including the plot data (Fig. 31), but not to total clays (p-value 0.4). The relationship between TG and organic C is no surprise considering TG is a product of AMF that colonize plant roots. Therefore, if there is more root biomass there should be more glomalin present and similarly there should be higher levels of organic C.

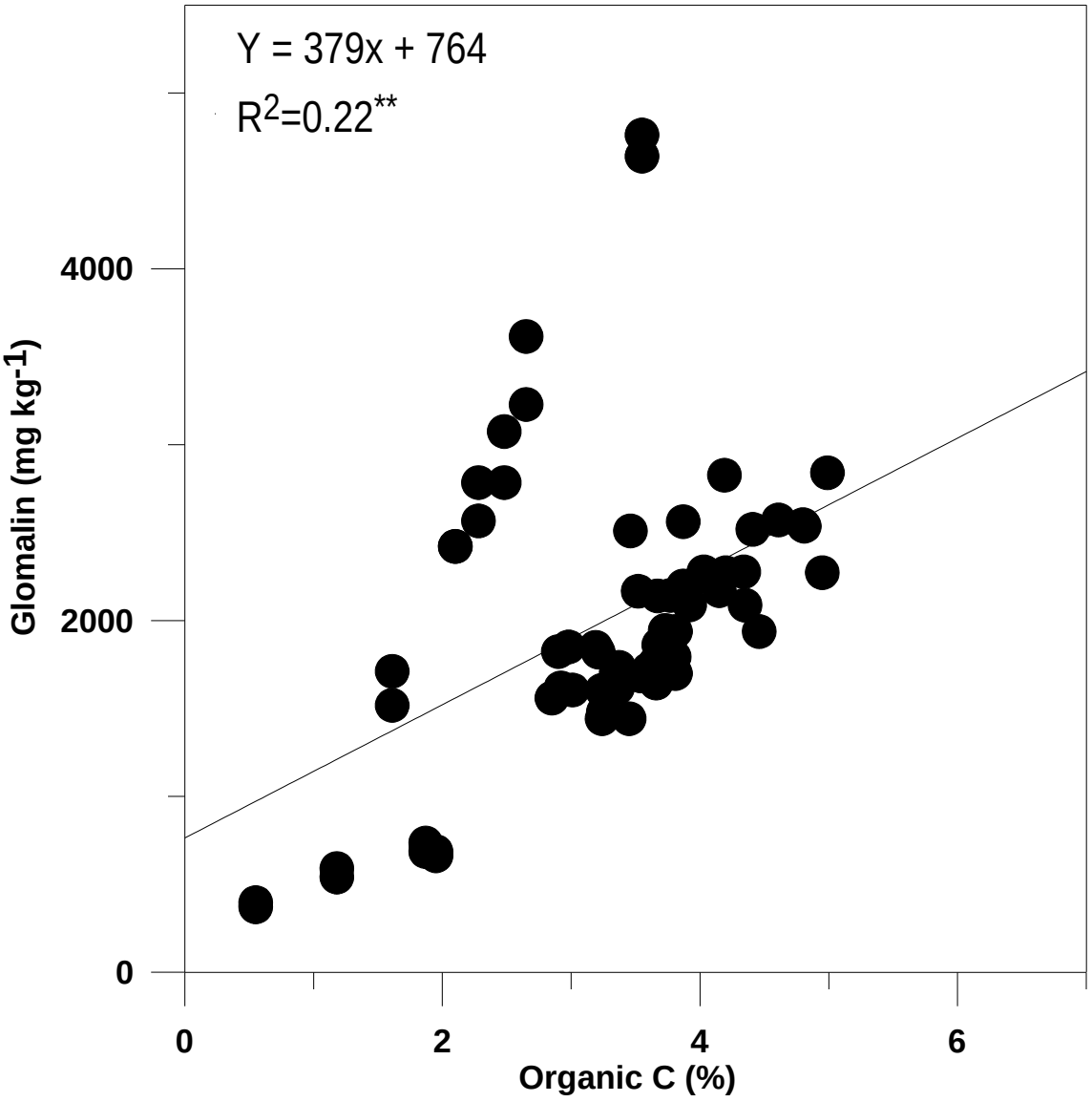

Fig. 31. A comparison between glomalin and organic C including both the study plots and the additional sites.
** Significant at the 0.01 probability level.

CONCLUSIONS

Attempting to improve soil properties with soil amendments is a common and often effective practice (Haynes and Naidu, 1998; Celik et al., 2004). This study was designed to assess the efficacy of soil amendments in improving soil infiltration rates through increased aggregate stability. Additionally, glomalin has been extensively studied and shown to be correlated to aggregate stability which suggests that increasing levels of glomalin could alter aggregate stability and improve infiltration rates. Therefore, it was important to determine what effect, if any, the prescribed soil amendments would have upon glomalin.

The results from this research project indicate that none of the treatments significantly altered soil physical conditions. Aggregate stability overall decreased over time with the exception of two treatments. This suggests that the treatments were not beneficial in improving aggregate stability. The decrease in values is probably due to the effects of tillage administered to the plots. Furthermore, all treatments had significant increases in levels of TG but were not significantly different from one another, indicating that the treatments themselves were not influential in changing TG over time. Observed increases in TG could be a result of rainfall and/or sampling techniques over time. Furthermore, aggregate stability as measured by %WSA was not correlated to AI. This relationship has not been evaluated in the literature and was not significant in this study.

Organic C plays an important role in the formation and stabilization of soil aggregates (Jastrow and Miller, 1997). As the major binding agent in aggregates, it is important to understand how organic C related to the soil properties measured in this study. Organic C increases were observed for all treatments except the No Prep / Seed plot. However, these increases were not correlated to infiltration rates or %WSA after treatments were applied. They were positively correlated to TG, which is no surprise given the origin of TG.

There were few significant correlations among soil parameters in this study. Perhaps extending the study might improve relationships between soil characteristics by allowing more time for soil processes to respond to the soil amendments. Infiltration rates showed no significant correlations with any soil physical properties measured. Total glomalin was positively correlated to aggregate stability one year after treatments were applied but not before treatments were applied. Overall, a time frame of only one year may not be long enough for biotic and abiotic processes to differentiate among treatments. Future sampling and analyses may reveal correlations that are now too subtle to detect.

Examining the results from the additional sites indicates positive correlations between TG, %WSA, and organic C. This suggests that organic C is vital to the stability of the soils of Fort Hood. The values of organic C observed are probably responsible for the relatively 'normal' rates of infiltration. Given the amount of compaction observed visually and use the soils of Fort Hood receive, it would seem that lower infiltration rates would have been observed, however this was not the case. Therefore, by maintaining

high levels of organic C, Fort Hood may sustain levels of TG and %WSA which could reduce runoff and erosion problems that might otherwise occur. Additionally, the observed rates of infiltration were either similar or slightly higher than rates reported by NRCS with the exception of a couple of sites. This gives confidence that NRCS is utilizing proper values of infiltration rates for creation of runoff and erosion models.

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APPENDIX A

SOIL CHARACTERIZATION DATA FOR STUDY PLOTS

(BEFORE TREATMENTS)

	Particle Size Distribution (mm)												
	----------Sand----------						-------Silt--------		---------Clay---------				
Treatments	VC (2.0-1.0)	C (1.0-0.5)	M (0.5-0.25)	F (0.25-0.10)	VF (0.10-0.05)	Total (2.0-0.05)	Fine (0.02-0.002)	Total (0.05-0.002)	Fine (<0.0002)	Total (<0.002)	Texture Class	Coarse Fragments	Organic C
	----------%----------											%	%
Site Prep / No Seed	1.1	1.2	1.1	1.8	3.7	8.9	31.2	46.2	16.9	44.9	SiC	1	3.37
Site Prep / No Seed	0.8	0.9	1.0	1.7	3.6	8.0	31.9	49.1	13.7	42.9	SiC	1	3.36
Site Prep / No Seed	1.1	1.0	1.0	1.9	4.2	9.2	34.9	49.7	12.7	41.1	SiC	2	3.01
Site Prep / Seed	0.4	0.6	1.0	1.8	4.2	8.0	33.0	48.2	15.9	43.8	SiC	0	3.36
Site Prep / Seed	0.5	0.7	0.9	1.8	3.7	7.6	31.8	48.6	13.3	43.8	SiC	1	3.66
Site Prep / Seed	0.8	1.0	1.3	2.5	4.7	10.3	29.7	46.2	11.7	43.5	SiC	3	3.25
Site Prep / Fertilizer / No Seed	0.5	0.9	1.1	2.1	4.2	8.8	32.6	49.6	13.0	41.6	SiC	1	3.68
Site Prep / Fertilizer / No Seed	1.2	1.0	1.0	1.7	3.7	8.6	33.4	47.9	13.4	43.5	SiC	2	3.73
Site Prep / Fertilizer / No Seed	0.6	1.4	1.5	3.1	5.0	11.6	35.4	47.2	12.5	41.2	SiC	3	2.85
Site Prep / Fertilizer / Seed	0.6	1.4	1.4	2.5	4.4	10.3	32.4	46.4	15.8	43.3	SiC	1	3.54
Site Prep / Fertilizer / Seed	1.0	1.2	1.3	2.6	4.7	10.8	33.0	44.4	13.7	44.8	SiC	1	3.24
Site Prep / Fertilizer / Seed	0.9	1.4	1.9	3.7	6.0	13.9	37.7	49.0	11.0	37.1	SiCL	1	2.92
Site Prep / Compost / No Seed	0.7	1.2	1.5	2.5	3.8	9.7	32.6	45.3	15.5	45.0	SiC	0	3.81
Site Prep / Compost / No Seed	0.9	1.2	1.2	2.3	4.0	9.6	32.1	42.4	18.3	48.0	SiC	1	3.45
Site Prep / Compost / No Seed	1.5	1.4	1.3	2.5	4.4	11.1	31.3	45.5	13.2	43.4	SiC	3	3.24
Site Prep / Compost / Seed	0.7	0.9	1.0	1.7	3.6	7.9	31.6	42.6	19.4	49.5	SiC	1	3.75
Site Prep / Compost / Seed	0.5	0.6	0.8	1.6	3.6	7.1	32.5	49.2	13.0	43.7	SiC	1	3.65
Site Prep / Compost / Seed	0.4	0.8	0.8	2.1	4.8	8.9	35.0	52.1	10.2	39.0	SiCL	1	3.35
No Prep / No Seed	0.7	0.8	0.8	1.6	3.5	7.4	31.6	45.2	18.5	47.4	SiC	1	3.81
No Prep / No Seed	0.4	0.7	0.8	1.7	4.0	7.6	32.2	46.1	16.0	46.3	SiC	1	3.75
No Prep / No Seed	0.5	0.8	1.0	2.0	3.8	8.1	32.7	46.1	11.7	45.8	SiC	2	3.37
No Prep / Seed	0.5	0.9	1.5	2.8	5.3	11.0	33.2	49.6	13.5	39.4	SiCL	1	3.60
No Prep / Seed	0.3	0.7	0.9	2.0	4.2	8.1	33.6	50.0	12.3	41.9	SiC	1	3.80
No Prep / Seed	0.7	0.7	0.9	2.0	4.0	8.3	31.2	48.5	13.6	43.2	SiC	2	4.46

Treatments	pH (H2O) 1:1	NH_4OAc EXTR BASES Ca	Mg	Na	K	Total	NaOAc CEC	BASE SAT	ESP	Calcite	Dolomite	CCE
		----------Meq 100 g^{-1} ----------						-------%--------		----------%----------		
Site Prep / No Seed	7.7	66.9	2.2	0.0	1.2	70.3	53.0	100	0	20.2	3.4	23.9
Site Prep / No Seed	7.7	66.4	2.9	0.1	1.2	70.6	52.0	100	0	22.9	2.3	25.4
Site Prep / No Seed	7.8	65.8	2.9	0.1	0.9	69.7	45.2	100	0	28.1	2.1	30.4
Site Prep / Seed	7.8	66.8	1.8	0.0	1.0	69.6	48.2	100	0	24.4	2.4	27.0
Site Prep / Seed	7.8	67.9	3.1	0.1	1.1	72.2	53.6	100	0	20.3	2.0	22.5
Site Prep / Seed	7.8	70.9	2.9	0.1	1.1	75.0	53.4	100	0	20.6	1.9	22.7
Site Prep / Fertilizer / No Seed	7.8	71.0	1.9	0.1	1.3	74.3	49.6	100	0	20.2	3.2	23.7
Site Prep / Fertilizer / No Seed	7.7	72.9	3.2	0.1	1.2	77.4	51.9	100	0	23.5	2.0	25.8
Site Prep / Fertilizer / No Seed	7.9	69.3	2.5	0.1	0.9	72.8	43.7	100	0	27.1	2.1	29.5
Site Prep / Fertilizer / Seed	7.8	70.5	1.8	0.0	1.2	73.5	47.8	100	0	24.1	1.8	26.1
Site Prep / Fertilizer / Seed	7.8	71.3	3.0	0.1	1.1	75.5	47.7	100	0	25.5	1.9	27.6
Site Prep / Fertilizer / Seed	7.9	60.0	2.1	0.1	0.9	63.1	40.0	100	0	32.2	1.2	33.5
Site Prep / Compost / No Seed	8.0	70.5	2.2	0.1	1.4	74.2	52.3	100	0	18.8	2.1	21.1
Site Prep / Compost / No Seed	7.7	72.0	2.7	0.1	1.0	75.8	50.2	100	0	24.0	2.2	26.4
Site Prep / Compost / No Seed	7.8	71.2	2.9	0.2	1.1	75.4	51.3	100	0	21.5	1.7	23.3
Site Prep / Compost / Seed	7.7	69.5	2.7	0.1	1.1	73.4	51.9	100	0	19.9	2.2	22.3
Site Prep / Compost / Seed	7.7	72.5	3.2	0.1	1.3	77.1	51.0	100	0	18.3	3.6	22.2
Site Prep / Compost / Seed	7.8	70.7	2.7	0.1	1.0	74.5	46.7	100	0	23.8	3.1	27.1
No Prep / No Seed	7.6	72.5	3.0	0.1	1.2	76.8	52.9	100	0	19.3	3.4	23.0
No Prep / No Seed	7.7	73.0	2.6	0.1	1.3	77.0	53.5	100	0	19.3	2.2	21.7
No Prep / No Seed	7.8	73.4	3.0	0.1	1.2	77.7	54.3	100	0	18.4	2.5	21.1
No Prep / Seed	7.8	69.5	1.5	0.0	1.1	72.1	42.7	100	0	29.0	1.8	31.0
No Prep / Seed	7.8	71.6	3.0	0.1	1.2	75.9	50.8	100	0	21.7	2.6	24.5
No Prep / Seed	7.6	72.2	3.4	0.1	1.3	77.0	57.2	100	0	13.8	2.8	16.9

APPENDIX B

SOIL CHARACTERIZATION DATA FOR STUDY PLOTS

(AFTER TREATMENTS)

	Particle Size Distribution (mm)												
	----------Sand----------						-------Silt--------		---------Clay---------				
Treatments	VC (2.0-1.0)	C (1.0-0.5)	M (0.5-0.25)	F (0.25-0.10)	VF (0.10-0.05)	Total (2.0-0.05)	Fine (0.02-0.002)	Total (0.05-0.002)	Fine (<0.0002)	Total (<0.002)	Texture Class	Coarse Fragments	Organic C
	----------%----------											%	%
Site Prep / No Seed	0.6	1.0	1.1	1.8	3.8	8.3	33.1	48.0	14.3	43.7	SiC	1	3.92
Site Prep / No Seed	0.9	0.9	1.1	1.9	3.6	8.4	34.7	50.3	10.5	41.3	SiC	3	4.61
Site Prep / No Seed	0.6	0.8	0.8	1.8	4.0	8.0	35.3	51.1	10.9	40.9	SiC	1	3.52
Site Prep / Seed	0.3	0.8	1.0	1.9	4.2	8.2	33.6	51.4	12.2	40.4	SiC	0	4.03
Site Prep / Seed	1.0	0.9	0.9	2.1	4.1	9.0	32.2	45.8	13.1	45.2	SiC	1	3.87
Site Prep / Seed	1.0	0.9	1.0	2.5	5.8	11.2	30.5	46.2	14.0	42.6	SiC	3	3.21
Site Prep / Fertilizer / No Seed	0.6	0.8	1.0	1.9	3.7	8.0	34.1	47.8	12.7	44.2	SiC	1	3.77
Site Prep / Fertilizer / No Seed	0.5	0.5	0.9	1.8	3.9	7.6	35.1	51.9	13.6	40.5	SiC	0	4.19
Site Prep / Fertilizer / No Seed	0.6	1.0	1.1	2.4	5.0	10.1	34.0	49.0	8.6	40.9	SiC	1	2.90
Site Prep / Fertilizer / Seed	0.3	0.8	1.2	2.8	5.7	10.8	33.6	49.7	12.0	39.5	SiCL	0	4.35
Site Prep / Fertilizer / Seed	0.6	0.6	0.6	1.6	3.8	7.2	34.0	50.0	12.1	42.8	SiC	1	3.67
Site Prep / Fertilizer / Seed	0.4	0.9	1.1	2.5	5.1	10.0	36.3	49.7	9.1	40.3	SiC	1	2.98
Site Prep / Compost / No Seed	0.6	1.1	1.2	2.8	5.7	11.4	33.0	48.3	11.2	40.3	SiC	1	3.19
Site Prep / Compost / No Seed	0.3	0.7	1.1	2.3	4.4	8.8	33.7	48.7	15.9	42.5	SiC	1	4.95
Site Prep / Compost / No Seed	0.4	0.8	1.2	2.7	4.5	9.6	32.8	44.6	15.4	45.8	SiC	1	3.87
Site Prep / Compost / Seed	0.3	1.0	1.5	3.1	4.3	10.2	31.4	45.8	15.0	44.0	SiC	1	4.99
Site Prep / Compost / Seed	0.3	0.7	0.9	2.0	3.9	7.8	30.8	47.8	14.2	44.4	SiC	1	4.80
Site Prep / Compost / Seed	0.6	0.9	1.1	2.5	4.3	9.4	35.0	48.7	9.7	41.9	SiC	1	3.46
No Prep / No Seed	0.4	0.9	1.0	2.0	3.7	8.0	30.4	45.5	18.2	46.5	SiC	1	4.34
No Prep / No Seed	0.7	0.8	1.0	2.2	4.5	9.2	31.3	47.6	17.0	43.2	SiC	2	4.41
No Prep / No Seed	0.7	0.9	1.0	2.1	4.1	8.8	33.9	49.0	13.2	42.2	SiC	1	4.81
No Prep / Seed	0.4	0.6	0.9	1.9	3.9	7.7	31.3	48.2	17.0	44.1	SiC	1	4.15
No Prep / Seed	0.2	0.9	1.8	3.9	6.6	13.4	32.4	50.4	12.7	36.2	SiCL	1	4.20
No Prep / Seed	0.4	0.4	0.6	1.7	4.2	7.3	32.3	48.7	14.9	44.0	SiC	1	3.90

Treatments	Calcite	Dolomite	CCE	Bulk Density 0.33 Bar	Bulk Density Oven Dry	COLE	Water Content 0.33 Bar
	----------%		----------	--------g cm^{-3}	-------	$cm\ cm^{-1}$	-------Wt%-------
Site Prep / No Seed	23.4	1.1	24.6	1.07	1.66	0.16	47.4
Site Prep / No Seed	24.2	0.4	24.6	0.89	1.38	0.16	59.8
Site Prep / No Seed	21.8	2.1	24.2	1.01	1.55	0.15	48.3
Site Prep / Seed	22.3	1.8	24.2	0.91	1.44	0.17	60.5
Site Prep / Seed	19.1	2.3	21.6	1.06	1.71	0.17	48.1
Site Prep / Seed	20.3	2.5	23.0	1.10	1.60	0.13	44.2
Site Prep / Fertilizer / No Seed	21.5	3.1	24.9	1.01	1.55	0.15	52.5
Site Prep / Fertilizer / No Seed	23.1	2.1	25.4	1.00	1.49	0.14	48.8
Site Prep / Fertilizer / No Seed	23.2	3.0	26.5	1.03	1.49	0.13	45.9
Site Prep / Fertilizer / Seed	23.7	0.9	24.6	1.00	1.50	0.15	49.5
Site Prep / Fertilizer / Seed	22.1	2.8	25.1	1.10	1.59	0.13	42.9
Site Prep / Fertilizer / Seed	26.4	3.3	30.0	1.09	1.52	0.12	42.2
Site Prep / Compost / No Seed	22.9	2.3	25.4	1.11	1.62	0.13	43.5
Site Prep / Compost / No Seed	16.7	3.1	20.0	0.97	1.43	0.14	50.5
Site Prep / Compost / No Seed	23.1	0.9	24.1	1.12	1.63	0.13	44.1
Site Prep / Compost / Seed	19.4	2.6	22.2	0.99	1.56	0.16	52.4
Site Prep / Compost / Seed	18.3	2.0	20.5	1.00	1.57	0.16	54.5
Site Prep / Compost / Seed	23.7	0.5	24.2	1.05	1.57	0.14	46.4
No Prep / No Seed	19.6	2.3	22.1	1.04	1.62	0.16	49.1
No Prep / No Seed	17.8	1.0	18.9	1.00	1.56	0.16	48.8
No Prep / No Seed	20.7	2.4	23.3	0.92	1.42	0.16	55.7
No Prep / Seed	18.5	1.9	20.5	1.06	1.65	0.16	47.1
No Prep / Seed	30.6	1.6	32.3	1.13	1.52	0.10	40.2
No Prep / Seed	19.2	3.4	22.9	1.17	1.68	0.13	42.0

APPENDIX C

SOIL CHARACTERIZATION DATA FOR ADDITIONAL SITES

	Particle Size Distribution (mm)												
	----------Sand----------						-------Silt-------		---------Clay---------				
	VC (2.0-1.0)	**C (1.0-0.5)**	**M (0.5-0.25)**	**F (0.25-0.10)**	**VF (0.10-0.05)**	**Total (2.0-0.05)**	**Fine (0.02-0.002)**	**Total (0.05-0.002)**	**Fine (<0.0002)**	**Total (<0.002)**	**Texture Class**	**Coarse Fragments**	**Organic C**
Site	----------%----------											**%**	**%**
1	0.2	0.4	0.7	3.0	4.8	9.1	31.2	43.9	10.8	47.0	SiC	1	1.87
2	0.7	1.4	2.1	8.4	8.5	21.1	24.3	37.3	16.0	41.6	C	3	2.10
3	1.7	2.2	3.9	6.5	6.5	20.8	32.1	42.7	9.6	36.5	CL	13	1.18
4	0.7	2.2	4.1	7.9	10.0	24.9	26.1	43.2	6.5	32.0	CL	2	2.28
5	1.6	2.3	2.2	3.4	5.4	14.9	46.2	59.3	10.3	25.8	SiL	3	1.61
6	0.7	0.9	1.0	1.9	3.5	8.0	27.9	42.1	8.0	49.9	SiC	2	1.95
7	0.8	1.3	1.6	2.9	4.6	11.2	36.3	48.6	9.7	40.2	SiC	2	2.65
8	2.5	3.1	3.6	5.5	6.3	21.0	29.7	46.6	7.7	32.4	CL	15	3.55
9	1.3	3.4	5.7	9.2	8.5	28.1	33.5	50.3	4.8	21.6	SiL	12	2.48
10	0.5	0.5	1.1	37.8	24.6	64.5	6.2	12.7	16.6	22.8	SCL	2	0.55

	pH	NH_4OAc EXTR BASES					NaOAc	BASE	Calcite	Dolomite	CCE	Bulk Density		
	(H2O)	Ca	Mg	Na	K	Total	CEC	SAT				0.33 Bar	Oven Dry	COLE
Treatments	1:1	----------Meq 100 g^{-1} ----------						---%---	----------%----------			--------g cm^{-3}-------		cm cm^{-1}
1	7.9	48.4	1.4	0.1	1.1	51.0	51.7	99	18.5	3.2	22.1	1.09	1.56	0.13
2	7.9	47.3	1.6	0.1	1.3	50.3	40.9	100	18.2	3.3	21.8	1.11	1.52	0.11
3	8.1	35.3	0.8	0.1	0.4	36.6	19.5	100	60.4	0.7	61.3	1.25	1.37	0.03
4	8.0	35.3	1.1	0.1	0.5	37.0	25.6	100	52.4	1.4	53.9	1.17	1.40	0.06
5	8.0	35.2	1.0	0.1	0.3	36.6	15.3	100	62.8	1.3	64.3	1.52	1.68	0.03
6	7.9	61.7	2.5	0.1	1.0	65.3	60.7	100	7.3	1.8	9.2	1.07	1.60	0.14
7	7.8	47.5	1.6	0.1	0.7	49.9	37.7	100	42.4	1.4	43.9	1.27	1.63	0.09
8	7.9	48.3	3.0	0.1	0.7	52.1	48.6	100	22.2	3.5	26.0	1.23	1.65	0.10
9	8.0	35.3	0.9	0.2	0.4	36.8	18.4	100	58.3	0.8	59.2	1.49	1.61	0.03
10	8.1	36.0	1.3	0.1	0.5	37.9	16.5	100	5.2	1.1	6.5	1.40	1.65	0.06

APPENDIX D

NUTRIENT DATA FOR STUDY PLOTS

(BEFORE AND AFTER TREATMENTS)

Treatments	pH	Conductivity	NO_3^-N	P	K	Ca	Mg	S	Na	Fe	Zn	Mn	Cu
Before		µmhos cm^{-1}	----------					mg kg^{-1}					----------
Site Prep / Seed	7.9	426	3	7	334	14044	277	19	179	8.4	0.32	6.08	1.09
Site Prep / Seed	7.8	418	8	6	387	13663	338	21	196	9.2	0.37	5.00	1.00
Site Prep / Seed	8.0	412	9	7	373	14323	309	24	184	6.8	0.48	4.31	0.79
Site Prep / No Seed	7.9	422	7	5	311	15171	209	18	192	9.2	0.26	4.56	1.01
Site Prep / No Seed	7.9	429	5	6	378	14959	229	19	189	9.0	0.32	4.95	1.20
Site Prep / No Seed	7.9	454	8	7	307	13889	239	16	185	9.7	0.31	4.05	1.01
Site Prep / Compost / Seed	8.0	465	8	6	364	11898	206	16	168	7.1	0.30	6.48	0.85
Site Prep / Compost / Seed	7.9	402	3	6	378	12890	244	16	160	9.1	0.23	6.05	0.98
Site Prep / Compost / Seed	8.0	387	4	5	277	12945	251	12	148	9.7	0.17	3.84	0.93
Site Prep / Compost / No Seed	7.9	412	2	5	344	12481	174	16	160	6.8	0.32	6.94	0.84
Site Prep / Compost / No Seed	8.0	388	9	4	354	12761	193	16	164	6.8	0.40	5.68	0.85
Site Prep / Compost / No Seed	7.9	397	7	5	365	12734	192	16	143	6.4	0.30	5.78	0.85
Site Prep / Fertilizer / Seed	8.0	394	4	5	377	14087	321	16	212	7.0	0.22	4.71	0.71
Site Prep / Fertilizer / Seed	8.0	376	5	5	348	14540	320	19	227	7.8	0.21	3.81	0.62
Site Prep / Fertilizer / Seed	7.9	472	10	6	352	14295	307	19	198	6.7	0.17	4.19	0.57
Site Prep / Fertilizer / No Seed	8.0	374	6	7	321	13441	298	23	198	6.4	0.50	4.46	0.67
Site Prep / Fertilizer / No Seed	8.0	432	6	8	356	14140	338	21	229	6.8	0.24	4.50	0.75
Site Prep / Fertilizer / No Seed	7.9	437	1	7	368	12468	305	18	185	7.4	0.30	7.36	0.91
No Prep / Seed	7.9	445	8	4	301	15041	271	20	174	7.1	0.27	4.22	0.66
No Prep / Seed	8.0	391	9	5	263	14084	248	18	172	6.7	0.17	3.46	0.60
No Prep / Seed	8.0	456	11	5	270	15159	236	17	201	5.8	0.18	3.11	0.44
No Prep / No Seed	7.9	474	6	5	347	14146	325	18	162	7.9	0.22	3.74	1.05
No Prep / No Seed	7.9	416	3	6	366	12406	304	20	164	6.2	0.28	4.68	0.83
No Prep / No Seed	7.9	457	5	4	267	14513	285	14	142	7.0	0.19	3.95	0.71

Treatments	pH	Conductivity	NO_3^-N	P	K	Ca	Mg	S	Na	Fe	Zn	Mn	Cu
After		µmhos cm^{-1}	---------- mg kg^{-1} ----------										
Site Prep / Seed	7.9	395	7	6	352	14304	197	21	171	9.2	0.42	5.88	0.89
Site Prep / Seed	8.0	341	6	6	288	14387	293	17	157	7.4	0.25	4.80	0.70
Site Prep / Seed	7.9	451	10	6	371	15119	350	19	146	8.3	0.36	6.03	0.81
Site Prep / No Seed	7.9	401	7	6	367	14984	215	21	169	10.6	0.55	6.98	1.36
Site Prep / No Seed	7.9	368	6	6	353	13149	290	20	148	7.6	0.61	4.49	0.74
Site Prep / No Seed	7.7	418	6	5	360	14919	373	18	174	13.1	0.38	7.30	0.91
Site Prep / Compost / Seed	7.8	398	5	21	392	14124	274	25	178	13.8	1.09	7.68	1.38
Site Prep / Compost / Seed	7.9	395	5	8	381	13793	282	22	146	14.3	0.53	6.05	1.10
Site Prep / Compost / Seed	7.8	368	4	10	415	16689	410	20	170	13.2	0.71	7.16	0.87
Site Prep / Compost / No Seed	7.9	419	10	15	428	12892	243	23	188	8.2	0.93	7.69	0.89
Site Prep / Compost / No Seed	8.0	369	4	8	360	14408	297	20	161	7.7	0.39	4.79	0.68
Site Prep / Compost / No Seed	7.7	400	8	14	439	14466	384	23	203	18.2	0.85	7.37	1.54
Site Prep / Fertilizer / Seed	7.8	372	6	19	353	12305	176	21	174	11.3	0.52	8.40	0.89
Site Prep / Fertilizer / Seed	7.8	396	8	15	378	16009	372	18	177	14.2	0.51	7.44	1.10
Site Prep / Fertilizer / Seed	8.0	366	3	7	313	17132	263	16	183	12.8	0.30	5.95	0.73
Site Prep / Fertilizer / No Seed	7.9	455	4	6	310	13760	280	17	165	8.2	0.31	4.79	0.86
Site Prep / Fertilizer / No Seed	7.9	415	11	13	397	14103	188	22	198	8.4	0.71	7.94	0.75
Site Prep / Fertilizer / No Seed	7.8	365	4	6	388	16781	323	16	173	11.7	0.25	6.17	0.71
No Prep / Seed	7.8	363	4	7	311	12672	203	22	190	7.3	0.63	7.70	0.65
No Prep / Seed	7.9	498	7	9	380	15115	368	21	161	7.7	0.41	7.74	1.03
No Prep / Seed	7.7	401	11	6	387	14840	357	21	163	15.2	0.45	8.44	1.04
No Prep / No Seed	7.8	431	5	5	365	14895	275	20	154	11.1	0.64	9.28	1.51
No Prep / No Seed	7.9	444	7	8	375	13599	312	20	149	5.7	0.34	6.83	0.67
No Prep / No Seed	7.5	430	9	11	571	16389	354	25	183	18.2	0.73	9.81	1.27

APPENDIX E

INFILTRATON RATES FOR STUDY PLOTS AND ADDITIONAL SITES

Time	Infiltration Rate			Mean	SD
min	Rep 1	Rep 2	Rep 3		
	----------cm hr^{-1}----------				
	Site Prep / Seed				
5	6.4	4.5	4.8	5.2	1.0
10	5.6	3.3	3.7	4.2	1.2
15	4.6	2.9	3.2	3.6	0.92
20	4.1	2.6	2.8	3.2	0.77
25	3.6	2.5	2.6	2.9	0.61
30	3.3	2.4	2.5	2.7	0.48
	Site Prep / No Seed				
5	5.5	5.0	5.9	5.5	0.45
10	3.8	3.3	3.7	3.6	0.28
15	3.2	2.6	2.8	2.9	0.30
20	2.8	2.1	2.3	2.4	0.34
25	2.6	1.8	1.9	2.1	0.39
30	2.2	1.7	1.7	1.9	0.33
	Site Prep / Compost / Seed				
5	4.7	6.6	4.2	5.2	1.3
10	2.9	6.3	2.6	3.9	2.1
15	2.2	5.5	2.0	3.2	2.0
20	1.8	4.9	1.7	2.8	1.8
25	1.5	4.4	1.4	2.5	1.7
30	1.3	4.1	1.2	2.2	1.6
	Site Prep / Compost / No Seed				
5	4.2	2.7	6.6	4.5	2.0
10	3.1	1.8	5.5	3.4	1.9
15	2.7	1.5	4.7	3.0	1.7
20	1.9	1.2	4.1	2.4	1.5
25	1.8	1.1	3.7	2.2	1.4
30	1.8	1.0	3.4	2.1	1.2

Time	Infiltration Rate			Mean	SD
min	Rep 1	Rep 2	Rep 3		
	----------cm hr^{-1}----------				
	Site Prep / Fertilizer / Seed				
5		6.2	5.7	6.0	0.38
10	6.2	5.1	5.2	5.5	0.62
15	5.4	4.2	4.9	4.8	0.60
20	5.1	3.6	4.8	4.5	0.81
25	4.8	3.1	4.7	4.2	0.96
30	4.7	2.7	4.5	4.0	1.1
	Site Prep / Fertilizer / No Seed				
5	6.3	6.6	6.1	6.3	0.26
10	4.9	6.5	5.8	5.7	0.85
15	3.8	6.5	5.5	5.3	1.4
20	3.4	6.5	5.3	5.0	1.6
25	3.3	6.4	5.2	5.0	1.6
30	3.1	6.4	5.1	4.9	1.6
	No Prep / No Seed				
5	6.1	5.0	5.6	5.6	0.54
10	4.3	3.3	4.6	4.1	0.70
15	3.5	2.4	4.0	3.3	0.83
20	3.2	1.9	3.7	2.9	0.94
25	2.6	1.5	3.4	2.5	0.98
30	2.3	1.2	3.2	2.3	1.0
	No Prep / Seed				
5	2.8	4.9	6.2	4.6	1.7
10	1.6	3.8	5.7	3.7	2.0
15	1.1	3.4	5.3	3.2	2.1
20	0.7	3.2	4.7	2.9	2.1
25	0.4	3.1	4.3	2.6	2.0
30	0.2	3.0	3.9	2.4	1.9

Time	Infiltration Rate			Mean	SD
min	Rep 1	Rep 2	Rep 3		
	----------cm hr^{-1}----------				
			Site 1		
5	6.6	6.4	6.5	6.5	0.11
10	6.4	5.9	5.7	6.0	0.34
15	6.1	5.2	5.3	5.5	0.47
20	5.9	4.7	5.0	5.2	0.58
25	5.7	4.4	4.7	4.9	0.67
30	5.4	4.0	4.5	4.6	0.69
			Site 2		
5	4.6	6.0	2.4	4.3	1.8
10	4.0	5.2		4.6	0.85
15	3.5	4.6	0.83	3.0	2.0
20	3.2	4.2	0.45	2.6	1.9
25	3.1	3.9	0.25	2.4	1.9
30		3.6	0.13	1.9	2.5
			Site 3		
5	2.8	6.1		4.5	2.3
10	2.3	5.0	4.4	3.9	1.4
15	2.0	4.4	3.3	3.2	1.2
20	1.7	4.2	2.7	2.9	1.3
25	1.4	4.1	2.4	2.6	1.3
30	1.3	4.0		2.6	1.9
			Site 4		
5	6.6	6.6		6.6	0.0
10	6.6	6.3		6.5	0.18
15	6.6	6.2		6.4	0.27
20	6.6	6.0		6.3	0.46
25	6.6	5.8		6.2	0.58
30	6.6	5.6		6.1	0.71

Time	Infiltration Rate			Mean	SD
min	Rep 1	Rep 2	Rep 3		
	----------cm hr^{-1}----------				
			Site 5		
5	4.7	4.6	4.6	4.6	0.06
10	4.3	4.1	4.2	4.2	0.13
15	4.1	3.8	4.0	4.0	0.20
20	4.0	3.7	3.8	3.8	0.22
25	3.8	3.5	3.7	3.7	0.20
30	3.7				
			Site 6		
5	4.5	6.0	5.5	5.3	0.72
10	3.5	4.9	4.6	4.3	0.73
15	2.8	4.2	4.0	3.7	0.76
20	2.3	3.6	3.5	3.1	0.75
25	2.0	3.2	3.1	2.8	0.68
30	1.6	2.9	2.9	2.5	0.72
			Site 7		
5	6.2	5.4	5.3	5.6	0.48
10	5.3	4.7	4.9	4.9	0.31
15	4.8	3.8	4.5	4.4	0.51
20	4.5	3.3	4.3	4.0	0.65
25	4.1	2.9	4.2	3.8	0.70
30	3.9	2.7	4.1	3.6	0.72
			Site 8		
5	6.5			6.5	
10		6.2		6.2	
15	6.4	5.8		6.1	0.38
20	5.9	5.5		5.7	0.28
25	5.6	5.3		5.5	0.20
30	5.3	5.1		5.2	0.18

Time	Infiltration Rate			Mean	SD
min	Rep 1	Rep 2	Rep 3		
	----------cm hr^{-1}----------				
			Site 9		
5	5.8	4.8	4.9	5.1	0.55
10	5.4	3.6	3.9	4.3	0.95
15	5.1	2.9	3.0	3.7	1.2
20	4.8	2.4	2.5	3.3	1.4
25	4.5	2.0	2.1	2.9	1.4
30	4.4	1.8	1.9	2.7	1.5
			Site 10		
5	4.5	5.9		5.2	1.0
10	3.1	3.8		3.5	0.48
15	2.5	2.6		2.5	0.08
20	2.1	1.9		2.0	0.16
25	1.9	1.4		1.6	0.34
30		0.95		0.95	

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