# Effects of time and tillage on soil water infiltration

by

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| BD | bulk density |
| cm | centimeters |
| DB | dry basis |
| INF1 | 1 minute cumulative infiltration |
| INF30 | 30 minute cumulative infiltration |
| km | kilometers |
| l | liter |
| m | meter |
| MC | moisture content |
| Mg | megagram |

# I. INTRODUCTION

One of the important hydraulic properties of soil is the infiltration of water into the soil. Hillel (1980) defined soil water infiltration as the process of water entry into the soil by downward movement through the soil surface. The rate and volume of this phenomenon are important factors in determining surface runoff and soil erosion due to excessive water in the event of rain or irrigation.

Different tillage treatments which disturb the soil, affect the residue cover, and change the surface topography can vary the infiltration capacity of the soil thereby affecting the amount of water infiltrated during rainstorms or irrigation events. If the type of tillage system used is important to obtain the desired soil conditions for seed germination, root growth, weed control, soil erosion control, and moisture control, a knowledge of the results which can be expected from individual tillage systems must be available. Use of conservation tillage with minimum manipulation of the soil surface can play a significant role in varying the soil water infiltration.

The paraplow is a newly introduced tillage tool in North America that breaks up the soil surface layer without soil inversion, leaving essentially all the crop residue cover on the soil surface. In the first part of this study, considerable emphasis was placed on evaluating the effect of this new tillage implement on soil water infiltration as compared to the existing tillage tools and practices.

Besides evaluating the effects of tillage treatments on soil water infiltration, it is interesting to observe the infiltration pattern over a crop growing season. Soil surface condition is one of the major factors which controls soil water infiltration and it can be affected by crop residue, surface crusting, soil moisture, and compaction under rainfall impact, all of which can vary with time. The final part of this study was to determine the temporal dependence of soil water infiltration for different tillage treatments.

## A. Objectives

Specifically, the main objectives of this study were:

1. To evaluate the effects of different tillage treatments on soil water infiltration.
2. To determine the temporal variations in soil water infiltration for different tillage treatments.

## II. LITERATURE REVIEW

Cylinder or ring infiltrometers are a proven popular method to determine rates of soil water infiltration. They are easy and inexpensive to manufacture and conveniently operated by the individual research worker. Muntz (1908) first conducted field and laboratory experiments of water infiltration into a soil mass from rings and compared his results with the field water infiltration capacity. Free et al. (1940) extensively investigated the application of ring infiltrometers to an analysis of erosion control practices.

The infiltrometer used by Aronovici (1954) consisted of a single ring, and he found that head variations in the range of 2.5 to 5 cm made little or no difference in soil water infiltration rates. Tricker (1978) commented on the use of infiltration rings. He related the errors in the measured rates of water infiltration due to lateral seepage to the size of ring. The errors were reduced for the ring diameters of 31 to 50 cm.

In recent studies, single and double ring infiltrometers have been used to measure the infiltration of water into soil. In a study on the spatial variability of field-measured infiltration rates, Vieira et al. (1981) used a single ring, 46 cm in diameter, to make measurements at 1,280 locations. Pidgeon (1983) discussed the water infiltration rates in response to different tillage treatments. A double ring infiltrometer apparatus was used to determine water infiltration rates at four sites under trial (his results are discussed later).

In some infiltration studies, water stage recorders have been used to measure the subsidence of ponded water during infiltration into soil. Jensen and Sletten (1965) used a water stage recorder for intake measurements to evaluate the effects of crop sequence and tillage practices on soil water infiltration rates of a Pullman silty clay loam. Similarly, Allmaras et al. (1977) measured water intake during surface flooding. A water stage recorder was used to measure water height in the center drum of a group of interconnected drums with the center drum used as a reservoir and the other drums used as infiltrometers.

A. Effects of Tillage on Soil Water Infiltration

The effect of the physical condition of a soil surface on the water infiltration has been studied by a number of research investigators over several years (Duley, 1939; Duley and Kelly, 1941; Horton, 1940; Kidder et al., 1943; and Musgrave, 1955). They all agree in general that surface conditions often control the amount of water entering the soil during a rain.

It is also evident that the total porosity, or bulk density, and the thickness of a soil layer are changed when the soil is loosened or packed during a tillage operation, and according to Allmaras et al. (1966), the average pore size of a soil is related to the overall porosity of the tilled layer. Thus, an increase in the total porosity can increase the infiltration rate and amount of water in the soil at saturation because of improved water conduction and water storage in large pores.

Tillage-induced surface roughness is another important factor that can significantly affect the soil water infiltration process. Burwell et al. (1966) studied the effect of different tillage treatments on soil surface conditions. The soil was a Barnes loam under an alfalfa-brome sod, with an average slope of 4%. Tillage treatments involved in their study were no-till, plowed, plowed-disked-harrowed, cultivated, and rotovated. The tillages that included plowing or rotovating were performed 15 cm deep while the cultivated tillage was performed to a 7.5 cm depth on untilled soil. Their data indicated that the surface condition of soil surfaces was such that the plowed surfaces had the greatest random roughness, whereas, the untilled surface had the least random roughness and pore space. They also used simulated rain to observe cumulative infiltration affected by these tillage treatments. The data indicated that the cumulative infiltration was significantly affected by the tillage treatments. In the case of plowed and plowed-disked-harrowed treatments, most of the infiltration occurred prior to the initial runoff. Infiltration for the period between initial and 5 cm of cumulative runoff was still measureably greater for plowed than for the plowed-disked-harrowed treatment. This trend suggests that the degree of improvement in soil water infiltration can vary with the type of implement involved in the tillage operation.

In a discussion on the effects of tillage on soil properties and water content, Bertrand (1967) associated the increased water storage due to tillage with an increase in at least one or more of the following:

1. Rate and amount of water infiltration into the soil.

2. Total surface area of soil particles in the storage zone.

3. Depth of the storage zone.

The fact that tillage can significantly improve the intake of water into soil has been reported in many research studies. Wischmeier (1973) reported that the increased roughness and cloddiness of the soil due to tillage increased the soil water infiltration and reduced runoff velocities. Miller and Arstad (1971) found that a cultivation before each surface irrigation generally increased furrow infiltration into a sandy loam soil. Johnson et al. (1979) showed that rough cloddy surfaces decreased runoff by 77%, compared to that from a smooth surface, while maintaining a higher infiltration rate. Mannering et al. (1966) reported that surface crusting can significantly reduce infiltration and that the distruction of these surface crusts by tillage increased infiltration rates by 80% (more discussion on crusting is found in the next section).

In another study, Oschwald (1973) reported that shallow chiseling improved water infiltration, soil water storage, and reduced soil erosion due to water as compared to moldboard plowing. In a recent study on the paraplow (a newly introduced tillage tool in North America), Pidgeon (1983) summarized the infiltration rate measurements made at four experimental sites in Britain in the spring of 1981. Three sites had silty clay loam textures and one site had a loamy sand, with trials having either three or four replicates. Though the analysis of data did not show statistically significant differences due to large variations, the infiltration rate means of the paraplow treatment were higher than the moldboard plow treatment with the exception of one site.

Interest in no-tillage corn production has developed rapidly since the initiation of the studies on growing corn without tillage by Moody et al. (1961). Blevins et al. (1971) suggested that regions with sloping lands, adequate rainfall, and medium textured surface soils are particularly suited to the no-tillage system because of the prevailing high erosion hazards under conventional tillage.

In conservation tillage systems, surface residue acts as a determent to soil erosion and runoff in part by absorbing the energy contained in falling raindrops. A number of reports have been made concerning the soil erosion protection and increased infiltration provided with conservation tillage systems where crop residue remained on the soil surface.

On a silt loam in Ohio, Triplett et al. (1968) found an increase in both the infiltration rate and total infiltration with increasing soil cover by corn stalks. The zero-tillage normal residue treatment resulted in higher values than the conventional tillage treatment.

Smith and Lillard (1976), in a study on the development of no-tillage cropping systems, concluded that the mulches de-energize the rainfall, aid in increasing water infiltration rates, decrease runoff velocities and drastically reduce soil erosion. Their measurements showed that the no-tillage system reduced runoff up to 90 percent. Other reports have also been published by several research investigators (Harrold and Edwards, 1972; Harrold et al., 1970; Jones et al., 1969; Lal, 1976; Langdale et al., 1979) who have concluded that soil erosion protection and increased infiltration is provided with no-tillage systems where crop residue is left on the soil surface.

However, other studies (Laflen and Colvin, 1981; McGregor et al., 1975; Siemens and Oschwald, 1978) indicate that no-tillage systems while effective in erosion control do not necessarily reduce water runoff or increase the soil water infiltration rates.

## B. Temporal Variations in Soil Water Infiltration

Infiltration of water into the soil can vary noticeably during the crop growth period. One of the important factors that can substantially decrease the water intake is surface sealing. Soils without residue cover or with little crop canopy are susceptible to surface sealing due to raindrop impact. Morin and Benyamini (1977) studied infiltration into mulched and bare soils and concluded that raindrop impact destroys the surface aggregates of bare soils and gradually forms a continuous crust. Their study showed that the major factor causing reduction of the infiltration rate with time, under conditions of their experiment, was crust formation.

Moore (1981) predicted the effect of surface sealing on infiltration by generating numerical solutions to the Richards' equation. He considered three conditions of no surface seal, gradual surface seal formation under the action of rainfall, and a well-established stable surface seal. All model inputs were derived from measurements for nine Minnesota soils. He showed that surface sealing can have a significant effect on infiltration. He further documented that on cultivated and highly disturbed soils, subjected to aggregate breakdown by raindrop impact, surface sealing is probably the major factor influencing infiltration.

In addition to surface sealing, a system of large, surface-connected pores and cracks are important to infiltration and can be built by the activity of soil animals such as worms or ants, by rooting of plants, and by physical processes such as swelling, shrinkage, freezing and thawing. Gardner (1962) showed that pores not connected with the surface are ineffective in transmitting water rapidly, but holes and cracks that are open to the surface can definitely move significant amounts of free surface water deep into the soil quickly.

Wild (1972) studied the effect of water percolation through cracks and channels with regard to nitrate leaching. He found that nitrate leaching was more gradual than predicted by miscible displacement. Wild suggested that this was due to water passing quickly through cracks and channels without leaching the nitrate that was contained within peds. It has been shown that through macropores water can move into or below the rooting depth in a matter of minutes after addition of water to the soil surface (Quisenberry and Phillips, 1976).

The random roughness and cloddiness caused by various tillage treatments decreases with time due to weathering of tilled surfaces. Rainfall action, wetting, drying, and freeze-thaw cycles between fall tillage and spring planting disperse soil material which can seal the surface by filling the depressions and open channels created by tillage. Burwell et al. (1968) applied artificial rain at the rate of 13 cm per hour to various surface conditions on four soils. They determined the effects of fall-to-spring weathering of clean-tilled and mulch-tilled surfaces on infiltration rates. Their study indicated that infiltration before runoff started on freshly tilled bare surfaces increased as tillage-induced random roughness increased, but that infiltration was not closely related to this roughness after rainfall or fall-to-spring weathering that caused surface seal development. In contrast, a fall-mulch-tilled surface had an infiltration capacity eight times greater before runoff started and four times greater during runoff the following spring than did the fall-clean-tilled surfaces. In addition, spring infiltration for fall-mulch-tilled surfaces was about three times more than for spring-plowed surfaces, both before and after the runoff started.

In a five-year study on a moderately eroded Russell silt-loam soil in Indiana, Mannering et al. (1966) compared several tillage treatments to determine infiltration and soil loss during the crop growing period. The average infiltration for three years was 37% greater with minimum tillage than conventional tillage shortly after planting. After cultivating selected treatments, infiltration differences among conventional-cultivated, minimum tillage-cultivated, and minimum tillage-noncultivated were measured again. It was found that infiltration increased in cultivated treatments, and cultivation to destroy the surface crust was very beneficial in maintenance of greater surface storage which allowed more time for water to infiltrate. The third series of tests were made after corn harvest. Infiltration rates were high on all treatments with the minimum tilled-noncultivated treatment having the highest rate.

Most scientists agree that the compacted surface layer reduces the soil water infiltration rate, but according to Neal (1938), the initial moisture content had a greater effect in his study on infiltration capacity during the first 20 minutes of rainfall than any other factor.

In a very recent study, Shirmohammadi and Skaggs (1983) examined the effects of soil surface conditions on infiltration for shallow water table soils. The experiments were conducted in the laboratory on nine large columns of fine sand containing growing crops. These columns were exposed to atmospheric conditions, and the effects of surface covers and initial water table depths were measured at different times of the year. Based on their findings they concluded that the soil was loosened due to fescue root action and infiltration rates were increased. In general, the infiltration rate decreased with time for all dry and wet profiles but the exceptions were increases in infiltration rates due to initial dry conditions and due to cultivation. The cumulative infiltration for dryer profiles was up to four times greater than for the wetter profiles. They further concluded that infiltration rates for bare surfaces decreased due to raindrop impact, while rainfall did not significantly affect the profiles planted to grass and soybeans.

# III. MATERIALS AND METHODS

A field experiment in which double-ring infiltrometers were used to study the effects of tillage and time on soil water infiltration is described in this chapter.

## A. Field Experiment

### 1. Location

This study was undertaken at three different locations in Iowa. One site was located in the field number 45 at the Agronomy-Agricultural Engineering Research Center, 11 km west of Ames in central Iowa. The soils are from Clarion-Nicollet-Webster soil association. The major soil type at the study site was Webster silty clay loam. All the plots in this field were chisel plowed in 1981, and untilled in 1982 with continuous corn production. Various tillage treatments for 1983 were established in the fall of 1982.

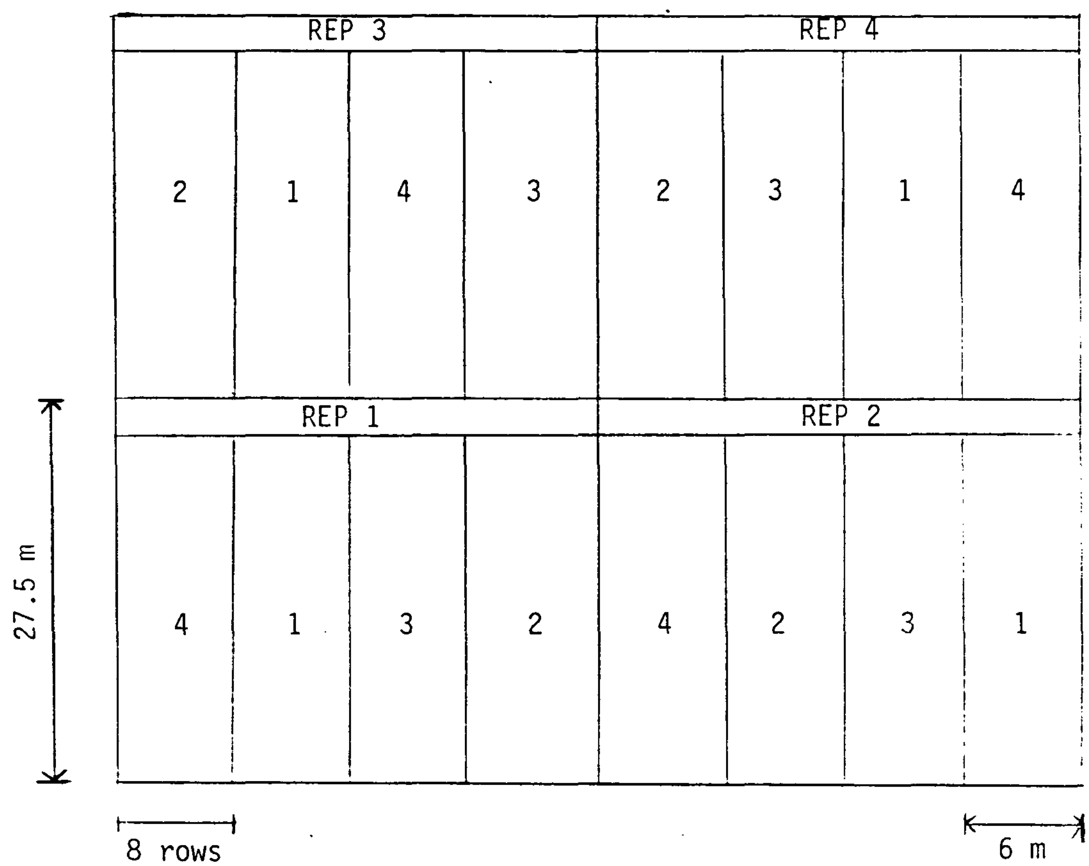
The second site was located at McNay Research Farm near Chariton in southeast Iowa. The soils are from the Grundy-Haig-Shelby soil association and the major soil type at the study site was Haig silt loam. The experimental plots were under continuous corn production with the no-tillage system used in 1981 and 1982. Different tillage treatments for 1983 were established in the fall of 1982. The third reserach site was located at the Northeast Iowa Research Center near Nashua. The soils are from Kenyan-Floyd-Clyde soil association and the major soil type at this site was Readlyn loam. The tillage system used for continuous corn production in 1981 and 1982 was chisel plowing. Various tillage treatments for 1983 were established in the fall of 1982.

2. Tillage-treatments

Four different tillage-treatments established at all three sites were the moldboard plow, chisel plow, paraplow, and no-tillage systems. The tillage plots for the Ames site were eight rows wide or 6 by 27.5 m in size with a row to row spacing of 0.76 m. Of the five replications of each tillage-treatment at this site, the first four were used for determining tillage effects on the soil water infiltration (Figure 1). The fifth replication was used for the temporal part of the study.

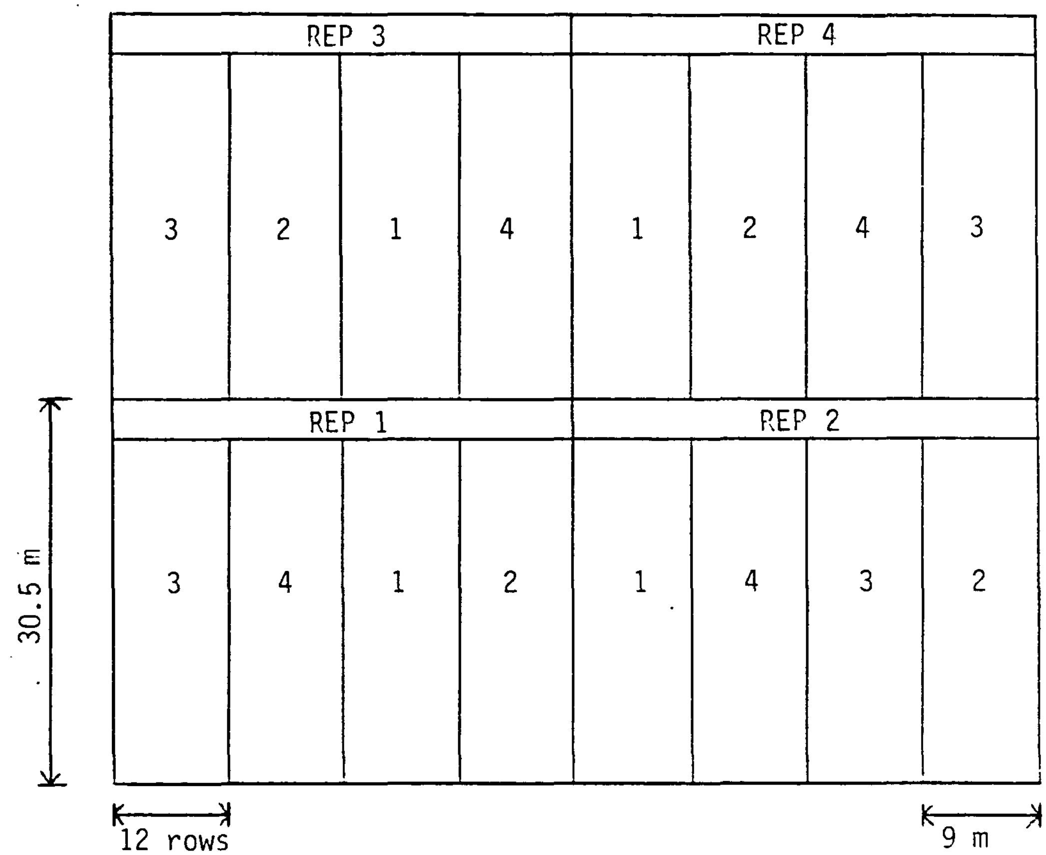
The tillage plots for the Chariton site were 12 rows wide or 9 by 30.5 m in size with a row to row spacing of 0.76 m (Figure 2). The plot size for the Nashua site was 6 by 30.5 m with a 0.76 m row to row spacing with eight rows per plot (Figure 3). There were four replications of each tillage-treatment at both of these sites and each site was used to determine the tillage effects on the soil water infiltration (no temporal determinations were made at these sites). The four tillage systems adopted for this study are discussed briefly below.

a. No-tillage system The no-tillage system has been widely used in the United States as a conservation tillage practice. In this system, there is no longer any turning and loosening of the soil material with tillage. Plant residues are left on the soil surface where they form a mulch cover. The no-tillage experiment plots near Ames and Nashua were fertilized in the fall while the plots near Chariton were fertilized at the time of planting in the spring. The unshredded stalks were left standing over the winter and shredded in the spring. Then the plots were



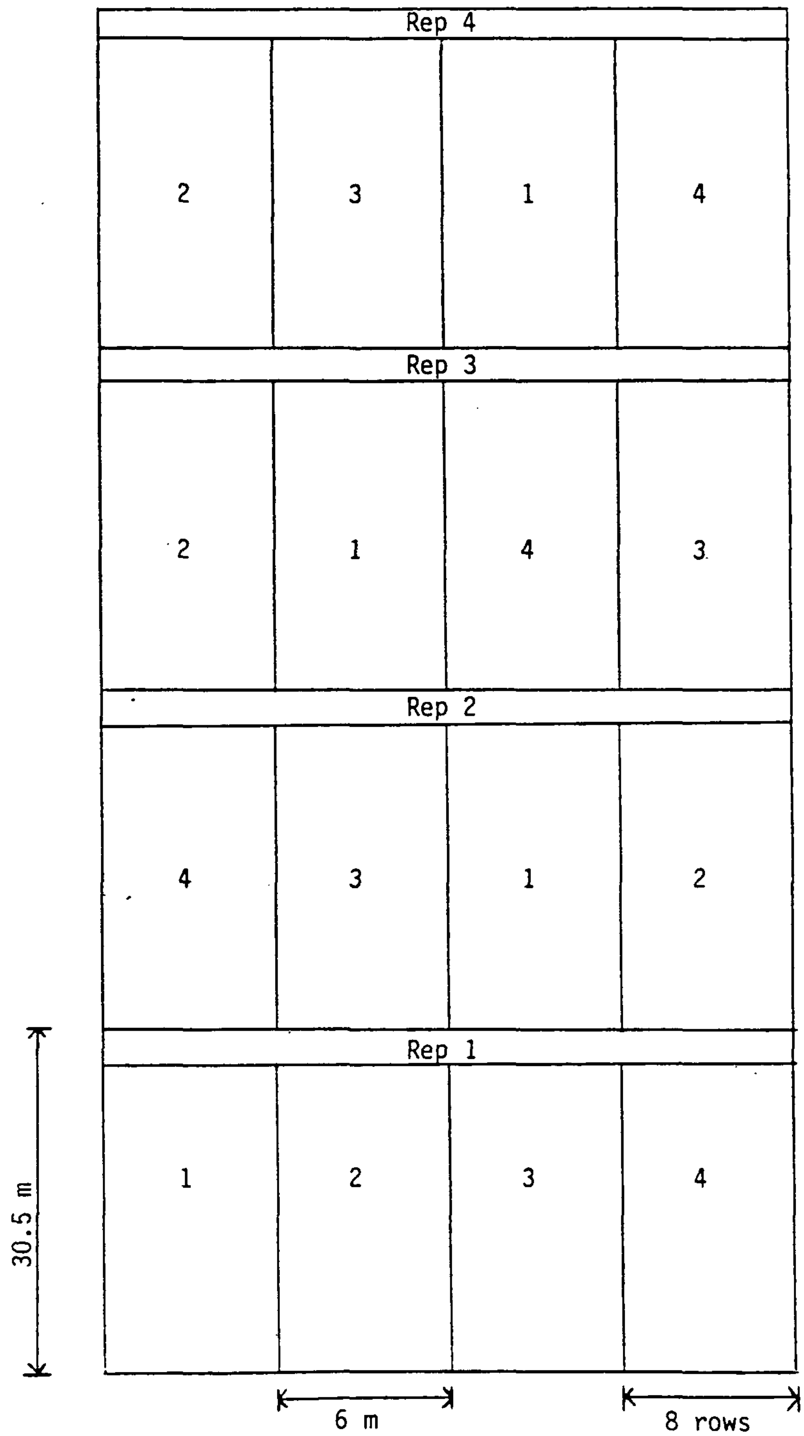

Legend: 1. moldboard plow treatment
2. chisel plow treatment
3. paraplow treatment
4. no-tillage treatment

Figure 1. Plot layout for the tillage treatment effects. Agronomy-Agricultural Engineering Research Center (Ames)




Legend: 1. moldboard plow treatment
2. chisel plow treatment
3. paraplow treatment
4. no-tillage treatment

Figure 2. Plot layout for the tillage treatment effects. McNay Research Farm (Chariton)




Legend: 1. Moldboard plow treatment
2. Chisel plow treatment
3. Paraplow treatment
4. No-tillage treatment

Figure 3. Plot layout for tillage treatment effects. Northeast Iowa Research Center (Nashua)

planted using a planter with double disk openers and coulters. Herbicide was applied shortly after planting with a tricycle sprayer at the Ames site and with a tractor mounted sprayer at the Chariton and Nashua sites.

b. Fall-chisel plowing system The chisel plow is a tillage tool used to replace the moldboard plow. There is little soil inversion with this tool and much of the crop residue and many large clods of soil remain on the soil surface. The plots were chisel plowed to a depth of 15 to 20 cm in the fall. There were unshredded stalks in all the plots at the time of plowing. Fertilizer and herbicides were applied exactly the same way as for the no-tillage system. The plots were left in a rough condition over the winter. In the spring, the plots were double disked, harrowed, and field cultivated at the site near Ames and disked and harrowed at the site near Chariton. The Nashua site was field cultivated only. The planting was done with the same planter as used for all the other treatments.

c. Paraplow system The paraplow is a newly introduced tillage tool in North America (Figure 4). The paraplow is a slant legged soil loosener. When pulled through the ground, soil flows over the slant legs and is loosened by lifting and failure in tension. This gives the type of natural cracking desired with no soil inversion or mixing and without appreciable disturbance of the residue cover. The plots with unshredded stalks were paraplowed in the fall to a depth of 25 to 30 cm. The field was left in a rough condition over the winter. The fertilizer and herbicide application procedure was the same as described earlier. In the

Figure 4. The paraplow

spring, the plots were planted without any disking, harrowing, or field cultivation at all three sites.

d. Moldboard plow system   Moldboard plowing is considered as part of the conventional system used as a standard of comparison. This plow is designed to cut a narrow strip of soil (also called a furrow slice) completely loosen and invert it. In the process of doing so, much of the surface crop residue and other material is completely buried under the furrow slice. Tillage plots with unshredded stalks were plowed to a depth of 15 to 20 cm in the fall. The field was left in a rough surface condition over the winter. In the spring, plots were disked, harrowed, and field cultivated in the same way as in the chisel plow treatment prior to planting. The procedure for planting, fertilizing, and herbicide application was the same as described earlier.

3. Data acquisition

Infiltration data for tillage treatment effects during 1983 were collected four times at the Nashua site and two times each at the Ames and Chariton sites. To study the temporal effects on soil water infiltration, three sets of data were collected at the Ames site. The time sequence for all the runs was somewhat different for every site due to weather constraints. Sampling dates of data acquisition for all the three sites are presented in Table 1.

4. Procedure description

A double-ring infiltrometer apparatus was used to measure the cumulative infiltration of water into the soil for 1 and 30 minutes with

Table 1. Data acquisition

| Sampling Date mo/da/yr | Site | Treatments[a] | Event | Crop Stage |
|---|---|---|---|---|
| 5/23/83 | Ames | 1 | Temporal Study | <10% canopy |
| 5/26/83 | Ames | 2 | Temporal Study | <10% canopy |
| 5/29/83 | Ames | 3 | Temporal Study | <10% canopy |
| 5/27/83 | Ames | 4 | Temporal Study | <10% canopy |
| 7/14/83 | Ames | 1 | Temporal Study | >50% canopy |
| 7/12/83 | Ames | 2 | Temporal Study | >50% canopy |
| 7/11/83 | Ames | 3 | Temporal Study | >50% canopy |
| 7/13/83 | Ames | 4 | Temporal Study | >50% canopy |
| 10/28/83 | Ames | 1,2,3,4 | Temporal Study | After harvest |
| 5/16/83 | Ames | 1,2,3,4 | Tillage Study | <10% canopy |
| 6/ 1/83 | Chariton | 1,2,3,4 | Tillage Study | <10% canopy |
| 6/ 9/83 | Nashua | 1,2,3,4 | Tillage Study | <10% canopy |
| 6/22/83 | Ames | 1,2,3,4 | Tillage Study | <50% canopy |
| 7/20/83 | Nashua | 1,2,3,4 | Tillage Study | 75% canopy |
| 10/27/83 | Chariton | 1,2,3,4 | Tillage Study | After harvest |
| 11/ 1/83 | Nashua | 1,2,3,4 | Tillage Study | After harvest |
| 11/ 8/83 | Nashua | 1,2,3,4 | Tillage Study | After tillage |

[a]1 = Moldboard plow treatment; 2 = Chisel plow treatment; 3 = Paraplow treatment; 4 = No-tillage treatment

the exception of data collection after fall tillage 1983 at the site near Nashua, where a deeper, single-ring assembly was used.

For the double-ring apparatus, the inner ring, also called the measuring ring, was 37 cm in diameter and 20 cm tall. The outer ring, providing a buffer zone to minimize the lateral seepage of water into the soil from the inner-ring was 56 cm in diameter and 15 cm tall. Both of the rings were fabricated from a cold drawn sheet metal (20 gauge or 0.22 cm thick). The single-ring used for infiltration measurements on freshly tilled soil was also 37 cm in diameter but 41 cm tall. This ring was also manufactured from cold drawn sheet metal. This ring was forced into the soil to the untilled depth for each tillage treatment. The purpose of constructing this taller ring was to avoid any lateral seepage that could otherwise occur if a double-ring infiltrometer apparatus was used to depths shallower than the recently tilled zone.

A vertical hydraulic ram, mounted on a tractor was used to press the inner rings into the soil to a depth of approximately 10 cm when the double-ring infiltrometer was used, and up to a depth of nearly 30 cm when the single-ring was used on freshly tilled soil. The objective of using a hydraulic ram with its vertical and nearly constant rate of travel was to minimize the undesirable disturbance of the soil matrix during ring installation, as well as to prevent the deformation of the rings that could otherwise be caused by hammering them in. The outer rings were driven into the soil up to a depth of about 5 cm. This was done by placing a plywood board over the top of the outer rings and driving them down with a sledge hammer.

The location of each ring for the temporal part of the study at the Ames site is illustrated in Figure 5. Four inner rings were forced into the soil, such that there were two rings in one furrow. A furrow here is referred to the area between two rows. Spacing between two rings within a furrow was 3 m and the lateral distance of the rings between two furrows was 3 m also. The same procedure was repeated for all the four tillage treatments. These inner rings were left in place after first measurement and throughout the study to obtain second and third measurements for the sampling dates listed in Table 1.

All three sites were set up to study the effects of tillage treatments on soil water infiltration. There were four replications for each treatment at each site and one infiltration determination was made per replication. Thus for every infiltration run, for either tillage or temporal effects, 16 determinations were made.

To make water depth measurements during ponding in the inner-ring, a plywood platform was built to carry a portable water stage recorder on top of the infiltrometer assembly, as shown in Figure 6. This wooden structure was closed from one side and posts were provided on the bottom. The closed side kept unwanted movement of the styrofoam float of the water stage recorder with wind to a minimum, and the posts prevented the wooden platform from sliding sideways on top of the infiltrometer assembly. Water stage recorders (FW-1) were used to record the recession of water in the inner-measuring ring as a function of time. When the float attached to the recorder subsided with water, this subsidence was recorded directly onto a chart and infiltration of water into the soil for a

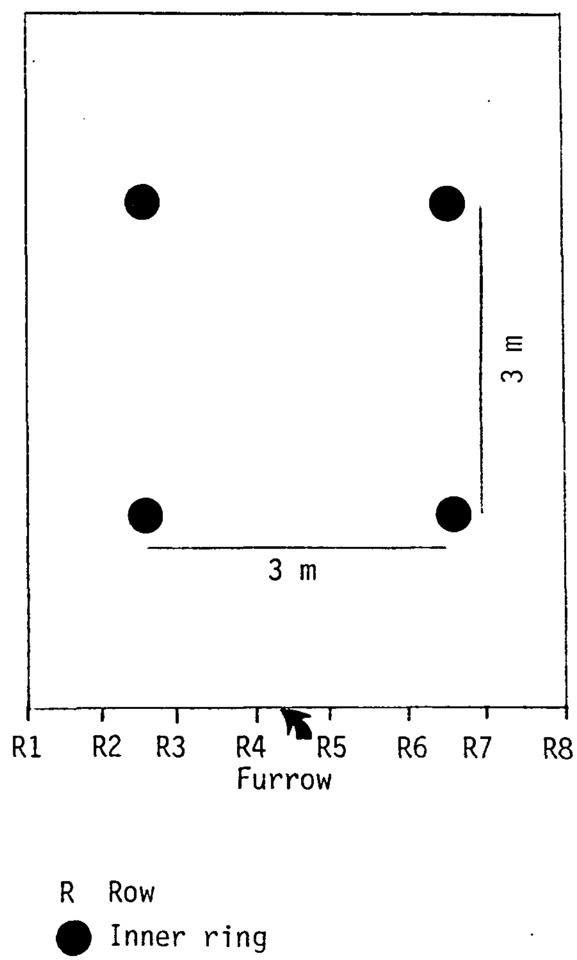



Figure 5. Location of inner rings allocated to different tillage treatment plots for temporal study

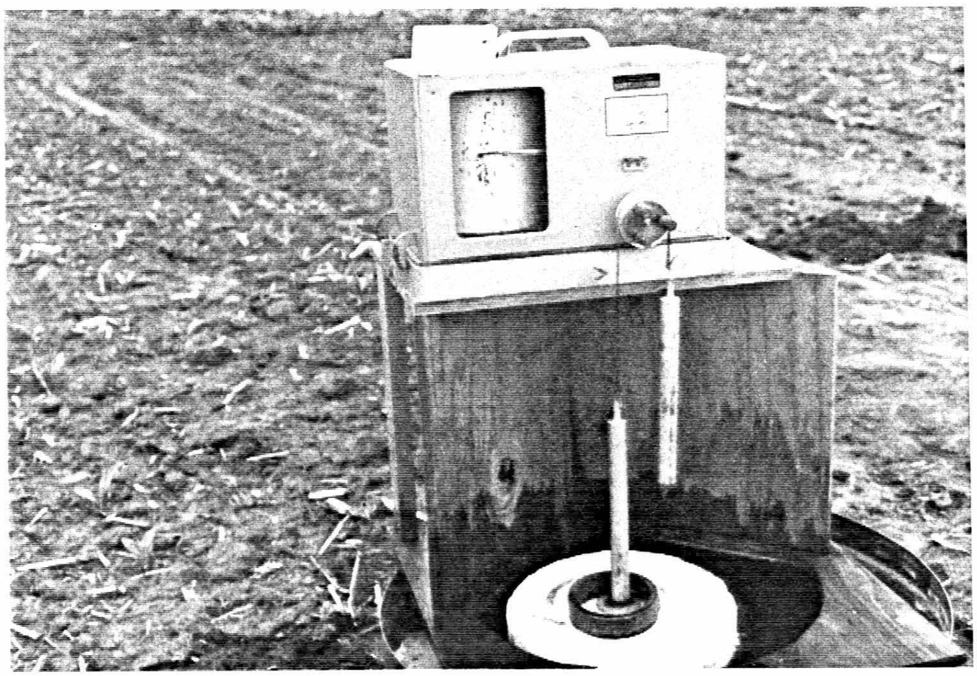


Figure 6. Wooden platform and portable water stage recorder

given time period was read from the charts.

The accuracy of reading the chart was such that the water recession in the inner ring could be read to about ±0.05 cm and time to about ±5 seconds. Consequently, for a typical value of 1 cm for the 1 minute cumulative infiltration, the maximum measurement error should be about 15 percent. For 30 minute cumulative infiltration values, the errors would be much less.

To begin the experiment, a Fiberglas screen was placed on the soil surface within the inner-ring to avoid soil puddling. Water was quickly poured in both the inner and outer rings simultaneously from 12-l stainless steel pails, to a ponded depth of nearly 10 cm (Figure 7). The subsidence of water within the inner ring was recorded for a minimum of 30 minutes for all the measurements at all sites. During this process, both the inner and outer rings were filled simultaneously any time the water level of the inner ring decreased about 2.5 cm below its original level, thus approximating a constant head. The same procedure was repeated for every location, in each experimental plot, for all the sampling dates listed in Table 1. A 830-l capacity water tank was used as a source of water.

Besides determining the infiltration rate of water into the soil, the moisture content of the soil on a dry-weight basis was determined by taking soil samples to a depth of 10 cm from a point near each infiltrometer before the infiltration determinations were made. A 2 cm diameter soil sampler was used to obtain the soil sample and the oven

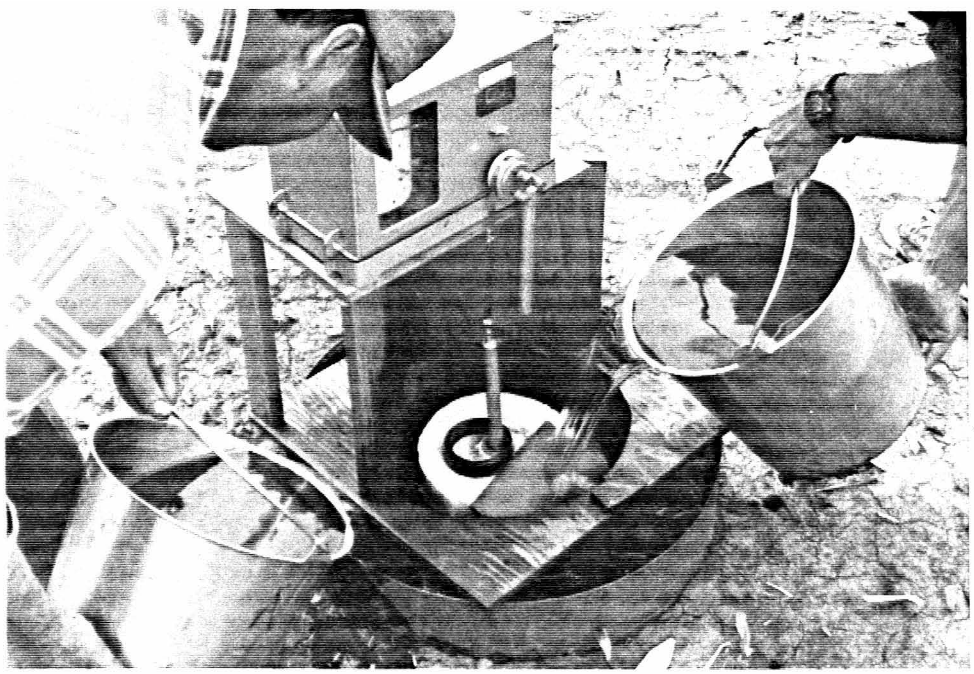


Figure 7. Simultaneous pouring of water into inner and outer rings

method (105 C for 24 hours) was used to obtain the dry weight of the samples. The moisture content was computed using the following formula:

$$P_w = \frac{W_w - W_{od}}{W_{od}} \times 100$$

where

$P_w$ = percent moisture content on the dry weight basis

$W_w$ = weight of wet soil, g.

$W_{od}$ = weight of oven-dry soil, g.

Undisturbed soil samples were obtained to determine soil bulk density before each infiltration run at the Chariton and Nashua sites only. The powered sampler developed by Buchele (1961) was used to obtain soil samples from a point near every infiltrometer. The sample was encased into liners supported by the inner-tube. The internal diameter of the cutting and trimming edge of the inner-tube (7.50 cm) is equal to the outer-diameter of the soil column. The soil column is then sectioned using the edge of 5 cm long liners as a guide. Two samples (sampled at a depth of 10 cm) per treatment per replicate were taken. The oven method (105 C for 24 hours) was used to obtain the dry weight of the samples. The bulk densities at 2 depths (5 cm each) determined by the following formula were averaged to estimate the bulk density for the total 10 cm depth.

$$BD = W_{od}/V_t$$

where

BD = dry bulk density of soil, $Mg/m^3$.

$W_{od}$ = weight of oven dry soil, Mg.

$V_t$ = total volume of undisturbed sample, $m^3$.

## B. Data Analysis

### 1. Experimental design for tillage treatment effects

A randomized block design for comparing the effects of different tillage treatments on soil moisture, bulk density, and 1 and 30 minute cumulative infiltration was used. The usual model for a randomized block design was fit to 1 and 30 minute cumulative infiltration data. This model assumes block effects and experimental errors are additive with treatment effects. For additive experimental errors, the variations around the mean should be about the same for each treatment. An analysis of the residuals from this model indicated that the variations of the observed 1 and 30 minute cumulative infiltration values for each treatment increased as the means increased. This suggested that the experimental errors were not additive, but that the size of the errors tended to be a percentage of the average response, consequently, the observed 1 and 30 minute cumulative infiltration data were transformed to a logarithmic scale before fitting the randomized block model.

Residuals from the transformed data indicated that the variation in the experimental errors was about the same for all treatments. Furthermore, the residuals from the transformed data appeared to be a nearly normal distribution, but the residuals from fitting the randomized block model to the nontransformed 1 and 30 minute cumulative infiltration data appeared to have a skewed distribution. Normal probability plots and the Shapiro and Wilk (1965) statistic were used to assess normality.

Using the logarithmic transformation for 1 and 30 minute cumulative infiltration resulted in F-tests and t-tests that were more reliable since the assumptions of additive and normally distributed errors were more nearly satisfied on this scale. First, the data for each sampling date at each site were analyzed separately; then, the pooled data for all the sampling dates for all sites were analyzed. These analyses were done using Proc GLM (General Linear Model) on SAS (1982).

At the Ames location, the moisture content, and 1 and 30 minute cumulative infiltration data obtained from the first replication for the no-tillage treatment in May, and from the third replication for the chisel plow treatment in June were deleted from the statistical analyses because the infiltration rings in these cases were unwittingly placed in furrows compacted by the front wheel of the tricycle herbicide sprayer.

2. Experimental design for temporal effect

For the temporal part of the study, a repeated-measures design was appropriate. The statistical analysis was done using Proc GLM on SAS (1982). The observed 1 and 30 minute cumulative infiltration data were transformed to a logarithmic scale before fitting the repeated measures model for the same reasons discussed for the experimental design of tillage treatment effects.

The fifth replication at Ames location was allocated to this part of the study. One out of two furrows of paraplow and no-tillage treatment plots, sampled for moisture content, and 1 and 30 minute cumulative infiltration were compacted by the front wheel of the tricycle herbicide sprayer. Wheel tracks of some unknown machinery were also observed on one of the two furrows sampled in the moldboard plow treatment plot. No wheel tracks of any agricultural machinery could be detected on either of the two furrows sampled in the chisel plow treatment plot due to the presence of the crop residue, yet one of the two furrows was regarded as compacted.

The above situation is further explained with the help of Figures 8 through 11. All of these figures present the 30 minute cumulative infiltration data determined on the fifth replication at the Ames site in the month of May for a different study. Three furrows in each treatment plot were sampled and eight or less observations of 30 minute cumulative infiltration per furrow per plot were taken at 3 m intervals. It should be noted that these observations were taken at the same times listed in Table 1 for the temporal part of this study. Furthermore, the two outside furrows sampled in each plot were exactly those allocated to the temporal part of this study. Figures 8 through 11 show that furrow 1 and furrow 3 should be treated as compacted and noncompacted, respectively, for all treatment plots. It may be noted that although no wheel tracks could be observed on the chisel plow treatment plot, the compaction effect was evident (see Figure 9).

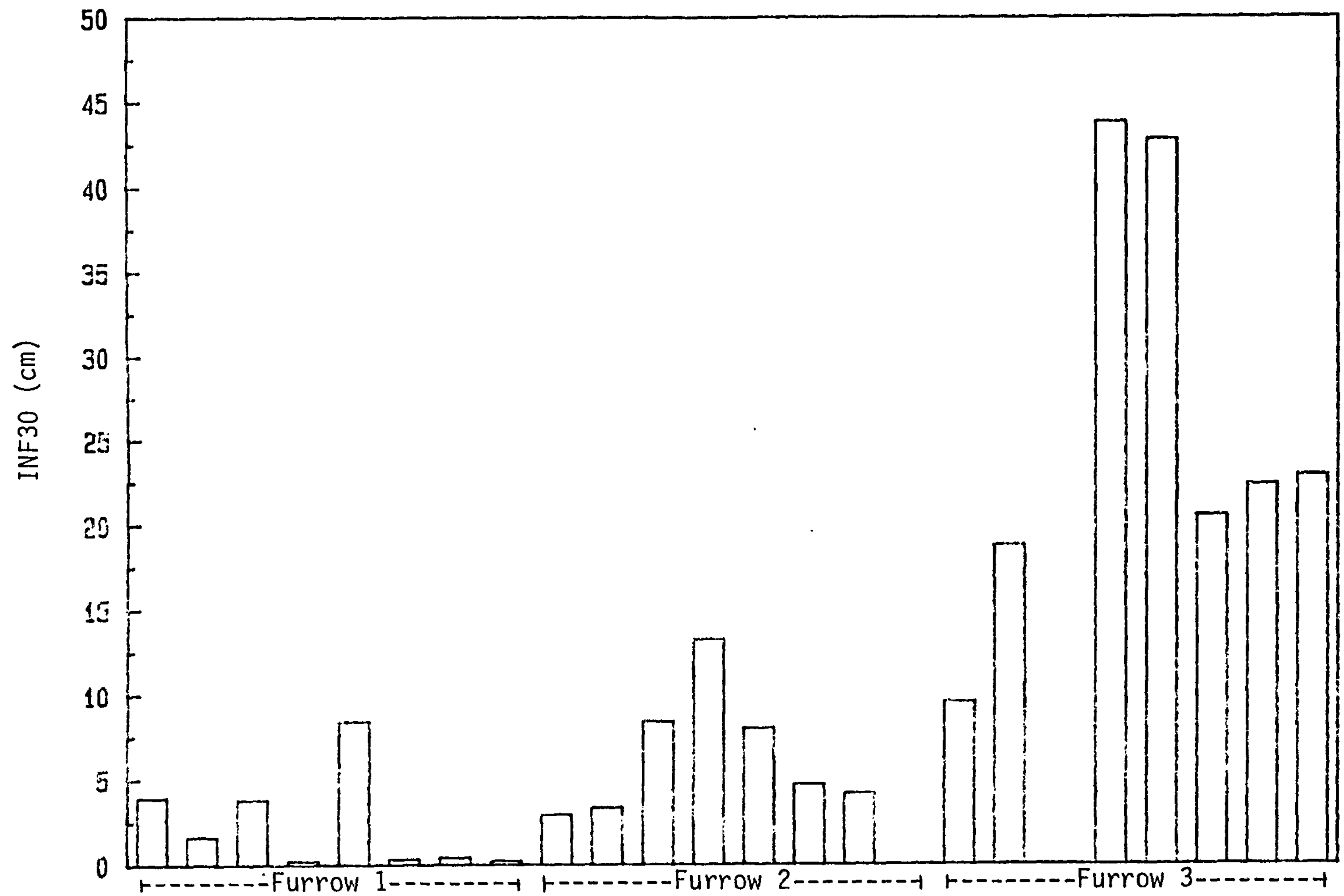



Figure 8. 30 minute cumulative infiltration determined from the moldboard plow treatment plot in May (fifth replication, Ames location)

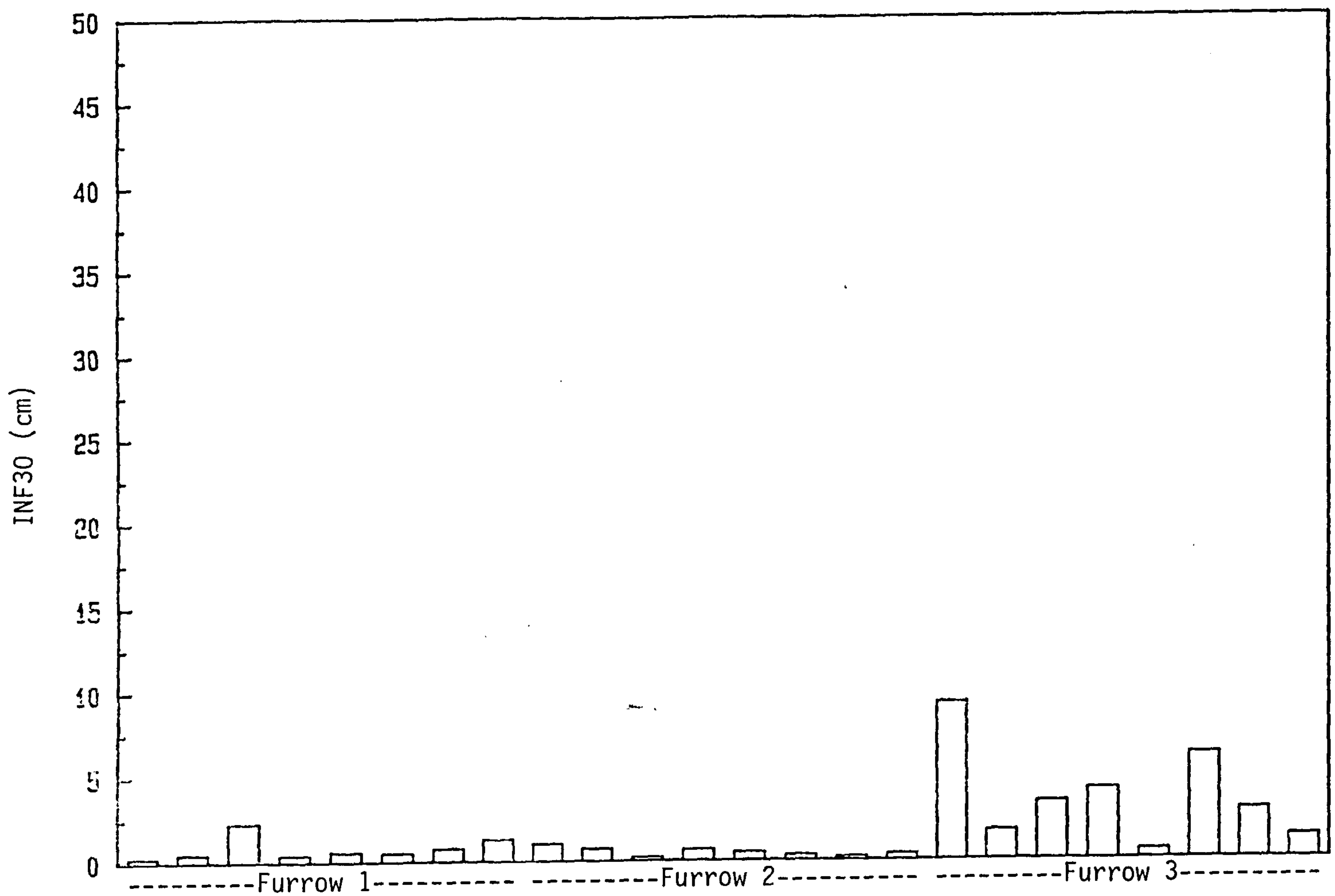



Figure 9. 30 minute cumulative infiltration determined from the chisel plow treatment plot in May (fifth replication, Ames location)

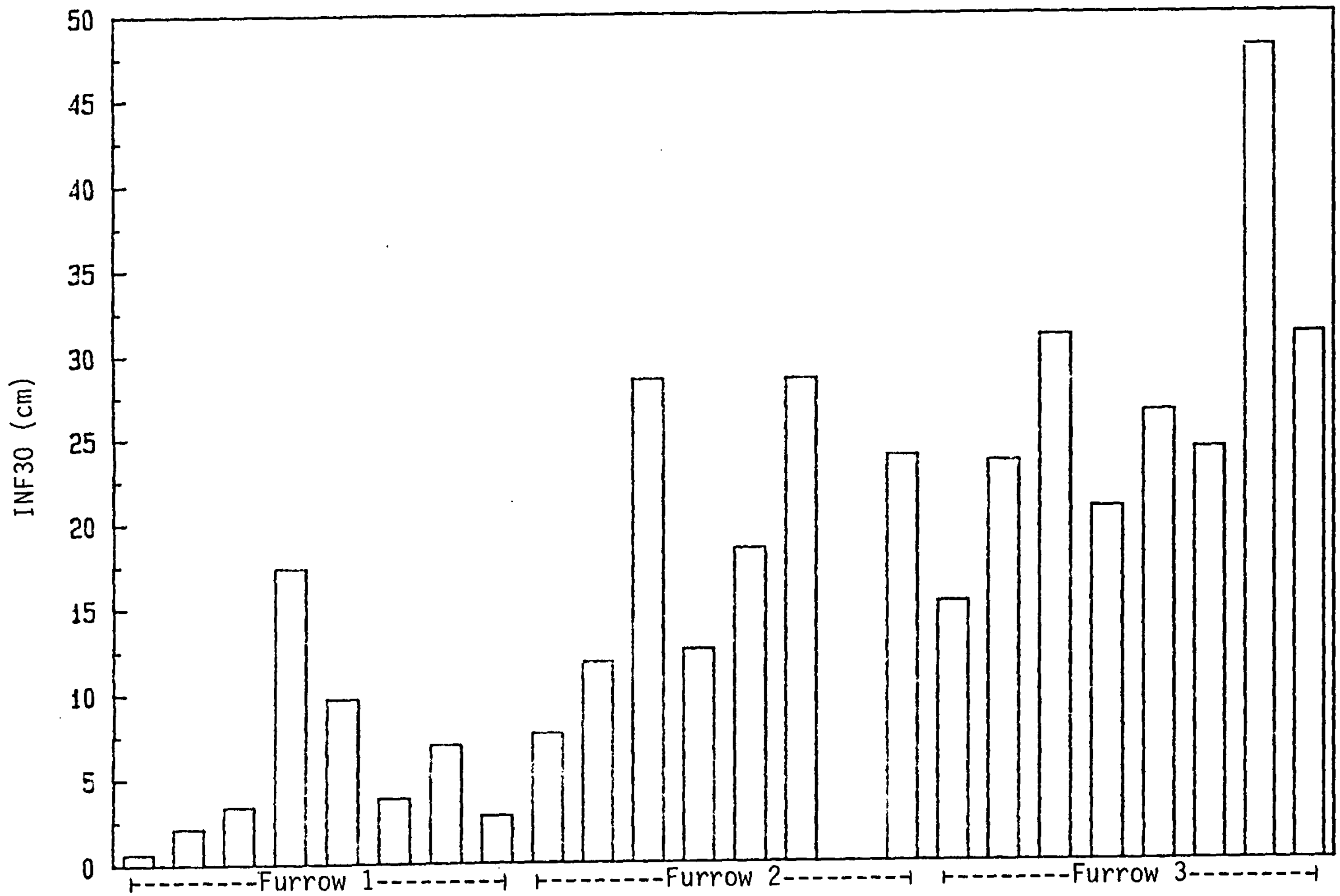



Figure 10. 30 minute cumulative infiltration determined from the paraplow treatment plot in May (fifth replication, Ames location)

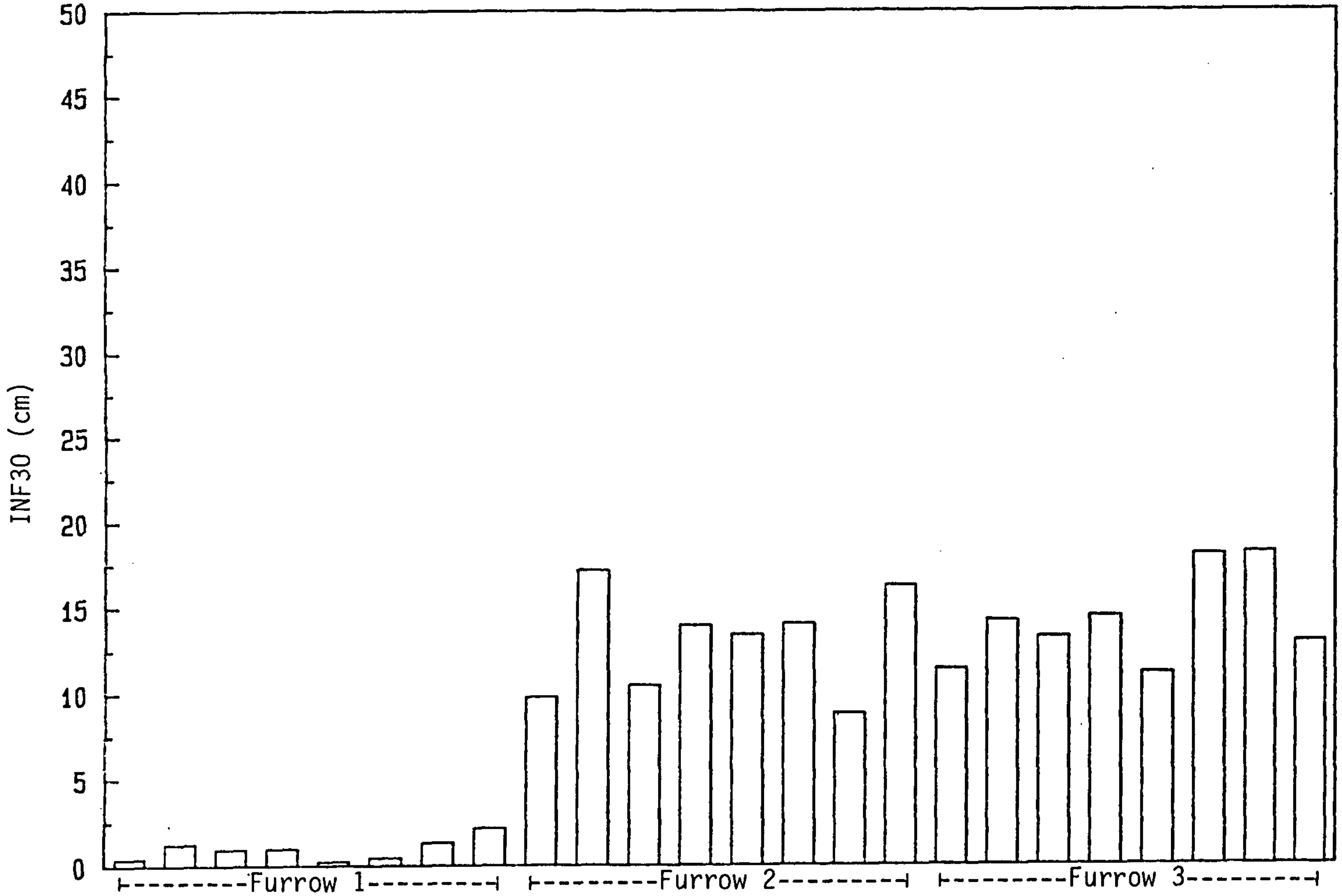



Figure 11. 30 minute cumulative infiltration determined from the no-tillage treatment plot in May (fifth replication, Ames location)

# IV. RESULTS AND DISCUSSION

## A. Tillage Treatment Effects

Results of soil moisture content, bulk density, and 1 and 30 minute cumulative infiltration amounts determined to compare various tillage treatments are presented in Tables 2 through 5. The results for the Ames site are summarized in Tables 2a and 2b. The results for the Chariton site are presented in Tables 3a and 3b, while Tables 4a through 4d show the results for the Nashua site. The results for the pooled analysis for all sites are presented in Table 5. Figures 12 and 13 show the averages of soil moisture content, and 1 and 30 minute cumulative infiltration for all the tillage treatments at the Nashua site for four sampling dates.

### 1. Soil moisture content

The moisture content differences between at least some tillage treatments were statistically significant at each site on all the sampling dates except at Nashua on June 9, 1983 (Table 4a). The average moisture content for the no-tillage treatment was significantly greater than for the moldboard plow and chisel plow treatments at Chariton on June 1, 1983 (Table 3a); and at Nashua on November 1, 1983; and November 8, 1983 (Tables 4c and 4d). It was also significantly greater than for the chisel plow treatment at Ames on June 22, 1983 (Table 2b) and for the moldboard plow treatment at Nashua on July 20, 1983 (Table 4b). The average moisture content for the paraplow treatment was significantly greater than for moldboard plow treatment at Chariton on June 1, 1983 (Table 3a); and for both moldboard plow and chisel plow treatments at

Table 2a. Effect of tillage treatments on soil moisture, and 1 and 30 minute cumulative infiltration (Ames 5/16/83)

| Treatment | MC | INF1 | INF30 |
|---|---|---|---|
| | -- %DB -- | -------- cm# | --------- |
| Moldboard plow | 26.1 ab* | 1.25 a | 14.0 ab |
| Chisel plow | 30.3 a | 0.57 a | 6.5 a |
| Paraplow | 24.7 b | 1.60 a | 23.0 b |
| No-tillage | 27.9 ab | 1.11 a | 15.5 ab |

#Averages of nontransformed data for 1 and 30 minute cumulative infiltration.

*Averages followed by different letters are different at 5% level.

Table 2b. Effect of tillage treatments on soil moisture, and 1 and 30 minute cumulative infiltration (Ames 6/22/83)

| Treatment | MC | INF1 | INF30 |
|---|---|---|---|
| | -- %DB -- | -------- cm# | --------- |
| Moldboard plow | 25.8 ab* | 0.70 a | 3.8 a |
| Chisel plow | 24.7 a | 0.65 a | 5.8 ab |
| Paraplow | 27.8 ab | 2.51 b | 34.6 b |
| No-tillage | 29.8 b | 0.43 a | 3.8 a |

#Averages of nontransformed data for 1 and 30 minute cumulative infiltration.

*Averages followed by different letters are different at 5% level.

Table 3a. Effect of tillage treatments on soil moisture, bulk density, and 1 and 30 minute cumulative infiltration (Chariton 6/1/83)

| Treatment | MC | BD | INF1 | INF30 |
|---|---|---|---|---|
| | -- %DB -- | - $Mg/m^3$ - | -------- cm# | --------- |
| Moldboard plow | 27.1 a* | 1.08 a | 0.85 a | 10.5 a |
| Chisel plow | 28.3 ab | 1.06 a | 0.83 a | 15.3 a |
| Paraplow | 31.0 bc | 1.02 a | 0.98 a | 17.8 a |
| No-tillage | 33.6 c | 1.12 a | 0.02 b | 0.3 b |

#Averages of nontransformed data for 1 and 30 minute cumulative infiltration.

*Averages followed by different letters are different at 5% level.

Table 3b. Effect of tillage treatments on soil moisture, bulk density, and 1 and 30 minute cumulative infiltration (Chariton 10/27/83, after harvest)

| Treatment | MC | BD | INF1 | INF30 |
|---|---|---|---|---|
| | -- %DB -- | - $Mg/m^3$ - | -------- cm# | --------- |
| Moldboard plow | 27.2 a* | 1.07 a | 1.66 ab | 20.9 a |
| Chisel plow | 29.0 b | 1.03 a | 0.82 a | 12.0 a |
| Paraplow | 27.7 ab | 1.11 a | 2.80 b | 42.0 b |
| No-tillage | 27.9 ab | 1.13 a | 1.01 a | 19.8 a |

#Averages of nontransformed data for 1 and 30 minute cumulative infiltration.

*Averages followed by different letters are different at 5% level.

Table 4a. Effect of tillage treatments on soil moisture, bulk density, and 1 and 30 minute cumulative infiltration (Nashua 6/9/83)

| Treatment | MC | BD | INF1 | INF30 |
|---|---|---|---|---|
| | -- %DB -- | - $Mg/m^3$ - | -------- cm# | --------- |
| Moldboard plow | 18.5 a* | 1.19 a | 0.41 a | 1.9 a |
| Chisel plow | 19.3 a | 1.12 a | 0.50 a | 3.0 ab |
| Paraplow | 19.2 a | 1.08 a | 2.03 b | 18.0 c |
| No-tillage | 18.2 a | 1.11 a | 0.81 ab | 6.2 bc |

#Averages of nontransformed data for 1 and 30 minute cumulative infiltration.

*Averages followed by different letters are different at 5% level.

Table 4b. Effect of tillage treatments on soil moisture, bulk density, and 1 and 30 minute cumulative infiltration (Nashua 7/20/83)

| Treatment | MC | BD | INF1 | INF30 |
|---|---|---|---|---|
| | -- %DB -- | - $Mg/m^3$ - | -------- cm# | --------- |
| Moldboard plow | 16.3 a* | 1.17 a | 3.10 a | 16.6 a |
| Chisel plow | 18.1 b | 1.27 a | 2.53 a | 7.5 b |
| Paraplow | 17.2 ab | 1.28 a | 5.03 a | 37.0 a |
| No-tillage | 18.2 b | 1.25 a | 2.03 a | 9.0 b |

#Averages of nontransformed data for 1 and 30 minute cumulative infiltration.

*Averages followed by different letters are different at 5% level.

Table 4c. Effect of tillage treatments on soil moisture, bulk density, and 1 and 30 minute cumulative infiltration (Nashua 11/1/83, after harvest)

| Treatment | MC | BD | INF1 | INF30 |
|---|---|---|---|---|
| | -- %DB -- | - $Mg/m^3$ - | -------- cm# | --------- |
| Moldboard plow | 19.3 a* | 1.24 a | 1.00 a | 10.7 a |
| Chisel plow | 20.3 a | 1.17 a | 0.50 a | 4.8 a |
| Paraplow | 21.7 b | 1.17 a | 3.42 b | 36.1 b |
| No-tillage | 22.1 b | 1.17 a | 0.70 a | 10.7 a |

#Averages of nontransformed data for 1 and 30 minute cumulative infiltration.

*Averages followed by different letters are different at 5% level.

Table 4d. Effect of tillage treatments on soil moisture, bulk density, and 1 and 30 minute cumulative infiltration (Nashua 11/8/83, after tillage)

| Treatment | MC | BD | INF1 | INF30 |
|---|---|---|---|---|
| | -- %DB -- | - $Mg/m^3$ - | -------- cm# | --------- |
| Moldboard plow | 21.3 a* | 0.97 a | 1.00 ab | 15.3 a |
| Chisel plow | 21.4 a | 0.98 a | 0.74 ab | 9.3 a |
| Paraplow | 22.2 ab | 1.04 ab | 1.20 a | 20.6 a |
| No-tillage | 23.3 b | 1.12 b | 0.31 b | 4.7 a |

#Averages of nontransformed data for 1 and 30 minute cumulative infiltration.

*Averages followed by different letters are different at 5% level.

Table 5. Effect of tillage treatments on soil moisture, bulk density, and 1 and 30 minute cumulative infiltration (pooled data set)

| Treatment | MC | BD | INF1 | INF30 |
|---|---|---|---|---|
| | -- %DB -- | - $Mg/m^3$ - | -------- cm# | --------- |
| Moldboard plow | 22.7 a* | 1.12 a | 1.24 a | 11.7 a |
| Chisel plow | 23.9 b | 1.11 a | 0.90 ab | 8.1 a |
| Paraplow | 24.0 b | 1.12 a | 2.44 c | 28.6 b |
| No-tillage | 25.0 b | 1.15 a | 0.80 b | 8.5 a |

#Averages of nontransformed data for 1 and 30 minute cumulative infiltration.

*Averages followed by different letters are different at 5% level.

Nashua on November 1, 1983 (Table 4c).

In general, the average moisture contents for both the paraplow and no-tillage treatments were higher than for either the moldboard plow or chisel plow treatments. The analysis of pooled data showed that the moldboard plow treatment had significantly reduced moisture content compared to the rest of the tillage treatments (Table 5). This trend of greater moisture contents for the chisel plow, paraplow, and no-tillage treatments may be due to the presence of greater surface residue cover on these tillage treatment plots that minimized the soil surface exposure to the atmosphere and reduced evaporation. Unger and Phillips (1973) noticed reduced evaporation in the no-tillage treatment plots with residue cover. Significantly higher moisture contents in the upper 0 to 8 cm of the soil for no-tillage treatment as compared to the conventional tillage treatment were also reported by Blevins et al. (1983) throughout the growing season. The higher levels of moisture contents observed for conservation tillage in this study may help protect a growing crop from severe moisture stress during a short-term drought.

2. Bulk density

Average bulk density was not statistically different for any of the tillage treatments at either of the two sites it was measured on any of the sampling dates except for immediately after fall tillage at Nashua on November 8, 1983 (Table 4d). There the averages of the bulk density for the moldboard plow and chisel plow treatments were significantly lower than that for the no-tillage treatment. The paraplow also had a lower bulk density but not by a statisitically significant amount. This reduced bulk density for the tillage treatments no doubt resulted from the fresh tillage performed.

The analysis of pooled data shows no statistical differences in the bulk density for any of the tillage treatments. Statistically similar bulk density for no-tillage treatment compared to the conventional tillage treatments has also been reported by Blevins et al. (1983), while studying the influence of conservation-tillage on soil properties on a Maury silt loam.

Similar bulk density for the no-tillage treatment compared to the rest of the tillage treatments suggests that the residue cover available on the soil surfaces of the untilled plots may prevent compaction of soil surface due to raindrop action in the event of an intense rainfall. Furthermore, worm or other insect activity and the freezing and thawing during the winter months can help reduce the compaction due to the planter wheel track used in a no-tillage system. On the other hand, the tillage induced loosening and fluffiness of the soil may decrease with time due to intensive use of agricultural machinery for secondary tillage operations, and due to little or no surface mulches available to protect the bare tilled surfaces, particularly for the moldboard plow treatment.

3. <u>1 minute cumulative infiltration--INF1</u>

The effect of tillage on 1 minute cumulative infiltration was statistically significant for at least some treatments at every site on all the sampling dates except at Ames on May 16, 1983 (Table 2a), and at

Nashua on July 20, 1983 (Table 4b). The average 1 minute cumulative infiltration for the paraplow treatment was significantly greater than for the rest of the tillage treatments at Ames on June 22, 1983 (Table 2b), and at Nashua on November 1, 1983 (Table 4c). It was also significantly greater than for the moldboard plow and chisel plow treatments at Nashua on June 9, 1983 (Table 4a), and for the chisel plow and no-tillage treatments at Chariton on October 27, 1983 (Table 3b). In general, the 1 minute cumulative infiltration for the paraplow treatment plots was higher at every site on nearly all the sampling dates. This trend suggests that the surface roughness and cloddiness created by the soil fracturing from this tillage implement, and protected by the surface residue, was greater and more persistent than for the other treatments.

On June 1, 1983, at Chariton (Table 3a), the average 1 minute cumulative infiltration for the no-tillage treatment was significantly lower than for the rest of the tillage treatments, while at the same site on October 27, 1983 (Table 3b), the average 1 minute cumulative infiltration for the no-tillage treatment was statistically similar to that for moldboard plow and chisel plow treatments. This trend in the 1 minute cumulative infiltration for the no-tillage treatment may be due to the dry conditions during the summer drought when all the tillage plots were subjected to surface cracking. In fact, in July at Chariton, the surface cracking made it impossible to take a planned reading. In October when the second determination was made, most of these surface cracks still existed on nearly all the tillage treatment plots, thereby increasing the

1 minute cumultaive infiltration with the exception of the chisel plow treatment.

The analysis for the pooled data from all sites showed that the average 1 minute cumulative infiltration for the paraplow treatment was significantly greater than for the rest of the tillage treatments (Table 5). The no-tillage treatment had significantly lower 1 minute cumulative infiltration than the moldboard plow and paraplow treatments but was similar to that for the chisel plow treatment (Table 5).

4. 30 minute cumulative infiltration--INF30

The 30 minute cumulative infiltration for at least some tillage treatments showed statistically significant differences at all the sites and on all the sampling dates except at Nashua on November 8, 1983 (Table 4d). The average 30 minute cumulative infiltration for the paraplow treatment was significantly greater than for the rest of the tillage treatments at Chariton on October 27, 1983 (Table 3b), and at Nashua on November 1, 1983 (Table 4c). However, in general, the average 30 minute cumulative infiltration for the paraplow treatment was significantly greater than for at least one or two of the other tillage treatments at each site, on all the sampling dates, except immediately after tillage at Nashua on November 8, 1983 (Table 4d). Increased infiltration for paraplow as compared to conventional tillage treatments was also observed by Pidgeon (1983).

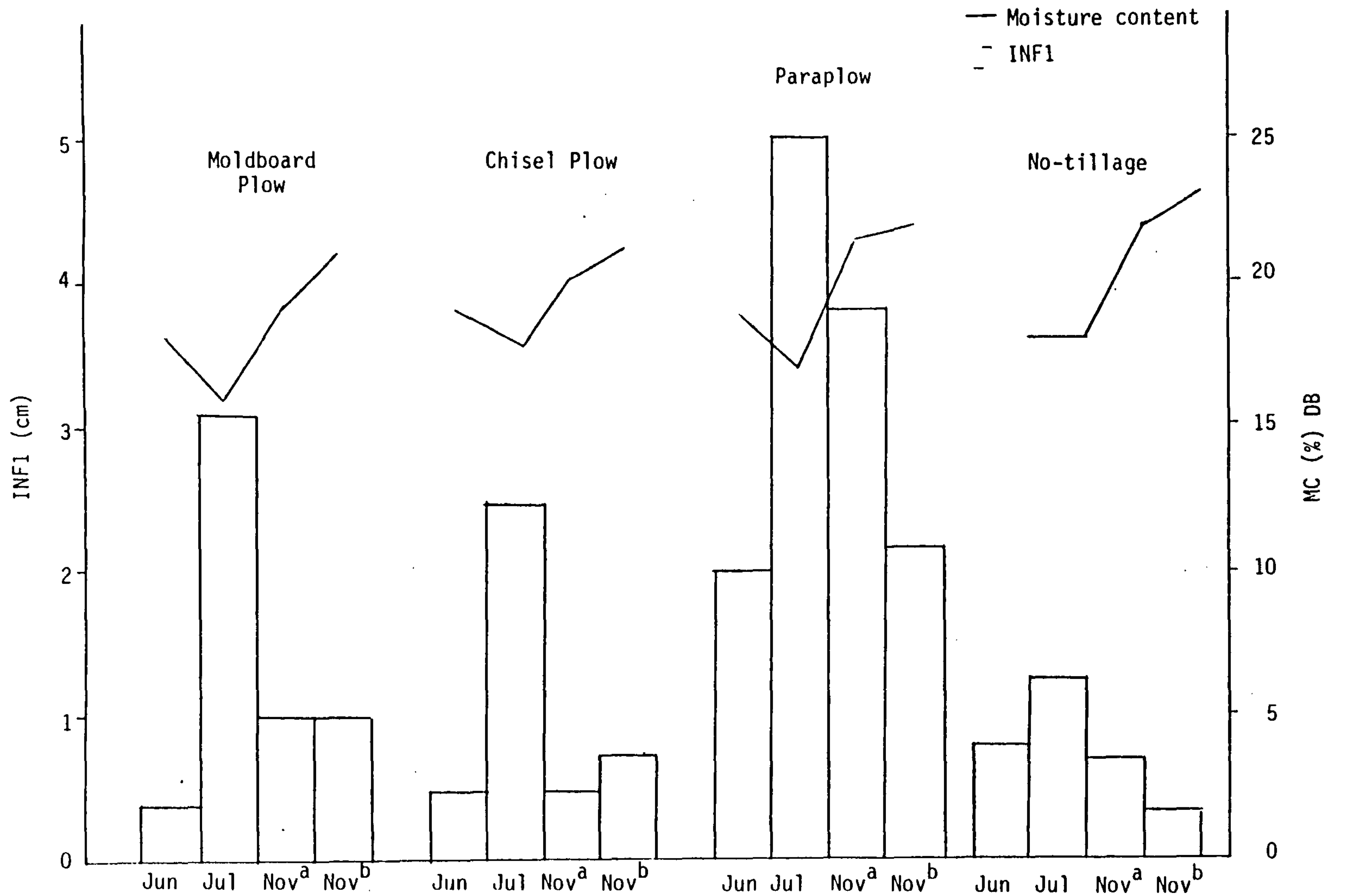
The greater 30 minute cumulative infiltration for the paraplow treatment may be attributed to greater depth of soil disturbance, possibly higher porosity and greater and more persistent surface roughness and cloddiness created by this implement and protected by the surface residue cover. Greater soil water infiltration for the paraplow treatment observed in this study is in accord with that of Long (1982) who stated that the paraplow breaks the plow pan that may form at a depth of 18 to 20 cm, and increases the infiltration capacity of soil while causing little disturbance of the soil surface.

The average 30 minute cumulative infiltration for the no-tillage treatment was significantly lower than for the rest of the tillage treatments at Chariton on June 1, 1983 (Table 3a). On October 27, 1983, at the same site (Table 3b) the 30 minute cumulative infiltration for no-tillage treatment was statistically similar to moldboard plow and chisel plow treatments. This similarity may be attributed to the increased water transmission into the soil through soil surface cracks resulting from the summer drought, as discussed earlier for the 1 minute cumulative infiltration.

The analysis of the pooled data (Table 5) showed that the average 30 minute cumulative infiltration for the paraplow treatment was significantly greater than the rest of the tillage treatments, while the rest of the tillage treatments were statistically similar.

The effects of tillage treatments on soil water infiltration were studied at Nashua for a complete growing season (June, July, November after harvest, and November after fall tillage). No statistical analysis was done to determine temporal variations in the 1 and 30 minute cumulative infiltration for any of the tillage treatments at that site since the experiment was not designed that way. However, it is interesting to observe that in July the averages of both the 1 and 30 minute cumulative infiltration amounts for all the tillage treatments were increased considerably from those determined in June (Figures 12 and 13). This increased soil water infiltration was no doubt due to the soil surface cracking and lower moisture contents resulting from the dry weather conditions during the month of July. In November after harvest, the 1 and 30 minute cumulative infiltration for nearly all the tillage treatments was decreased from that determined in July (Figures 12 and 13). The reduced 1 and 30 minute cumulative infiltration amounts suggest the partial clogging and sealing of soil surface cracks due to soil movement during rainstorms and runoff. Higher moisture contents in the month of November may also be a cause of this lower soil water infiltration.

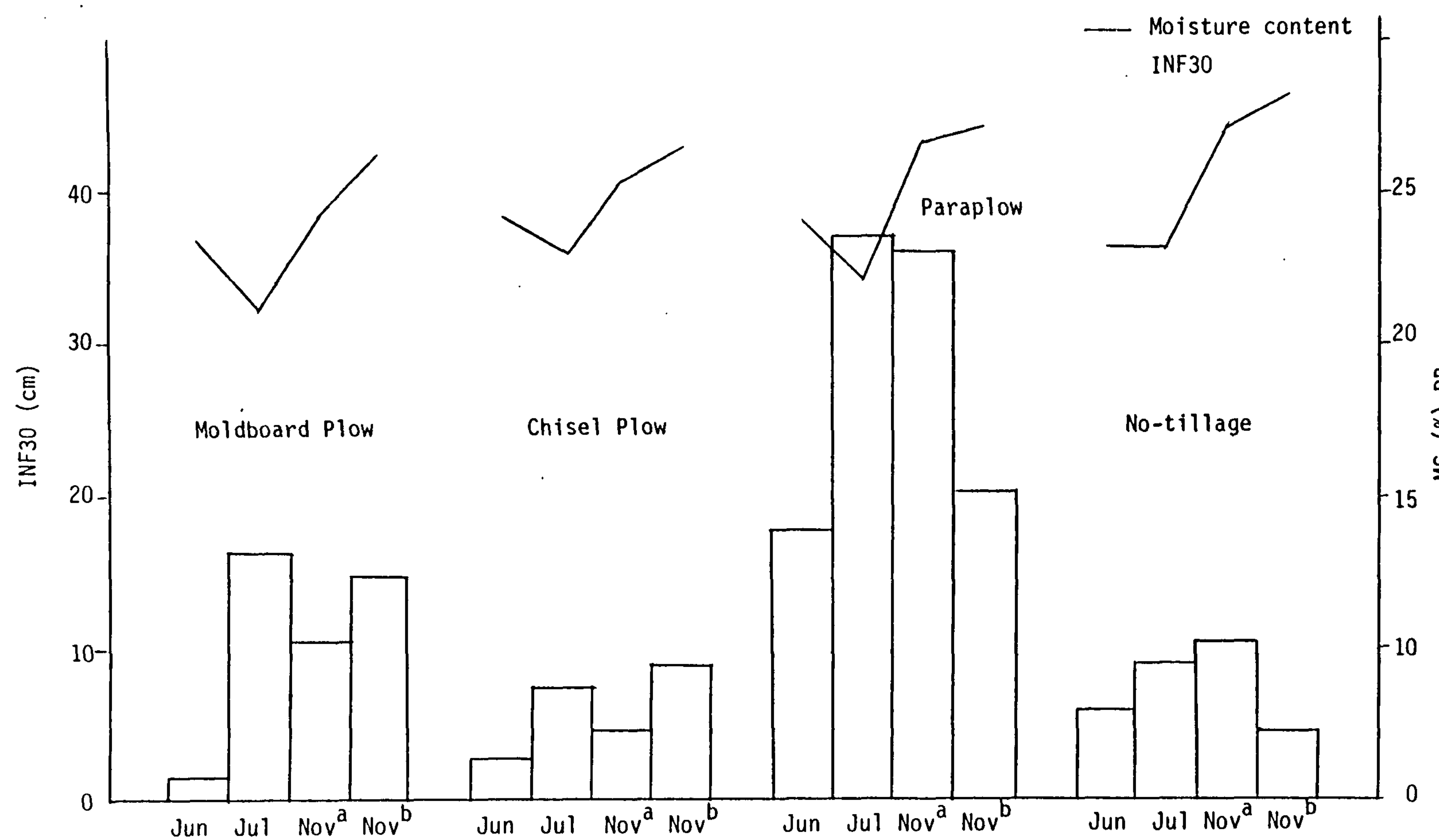
The average 1 and 30 minute cumulative infiltration for paraplow and no-tillage treatments determined after fresh tillage in November were considerably lower than those determined after harvest (November 1) but before tillage (Figures 12 and 13). The lower infiltration for the paraplow treatment may be due to destruction of some surface cracks and a higher soil moisture content due to a small rain (0.8 cm) that occurred between the two measurements. The reduced infiltration for no-tillage plots and the less than expected increases for the effect of recent tillage for moldboard plow and chisel plow treatments could also be attributed to higher soil moisture contents.




[a]November after harvest

[b]November after tillage

Figure 12. Temporal variations in soil moisture, and 1-minute cumulative infiltration for different tillage treatments




[a]November after harvest.
[b]November after tillage.

Figure 13. Temporal variations in soil moisture, and 30 minute cumulative infiltration for different tillage treatments

## B. Temporal Effects

Results of soil moisture and 1 and 30 minute cumulative infiltration amounts determined to study the effect of time on these parameters are presented in Table 6. Table 7 shows the results of soil moisture, and 1 and 30 minute cumulative infiltration amounts determined from the compacted and noncompacted furrows of moldboard plow, chisel plow, paraplow, and no-tillage treatment plots. Figures 14 through 17 illustrate the effect of time on soil moisture, and 1 and 30 minute cumulative infiltration amounts, determined from the compacted and noncompacted furrows of different tillage treatment plots. Figures 18 and 19 compare the effect of tillage on soil moisture, and 1 and 30 minute cumulative infiltration determined for different tillage treatments.

### 1. Soil moisture content

Moisture content determined on different sampling dates showed statistically significant differences for some of the tillage treatments. The average moisture contents for moldboard plow, paraplow, and no-tillage treatments determined in July were significantly lower than those determined in May and October (Table 6), while for the chisel plow treatment the average moisture content determined in July was significantly lower than that determined in May only (Table 6). The significantly reduced moisture content in the month of July was the result of dry weather conditions.

The moisture contents determined in October were statistically similar to those determined in May for all the tillage treatments except for

Table 6. Effect of time on soil moisture, and 1 and 30 minute cumulative infiltration for different tillage treatments (fifth replication, Ames location)

| Sampling Date | MC | | | | INF1 | | | | INF30 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mold-board | Chisel | Para | No-till | Mold-board | Chisel | Para | No-till | Mold-board | Chisel | Para | No-till |
| | %DB | | | | cm# | | | | | | | |
| May | 30.1a* | 27.8a | 27.8a | 26.5a | 0.52a | 0.26a | 1.35a | 0.35a | 5.6a | 1.4a | 18.6a | 6.7ab |
| July | 21.8b | 23.0b | 22.4b | 20.4b | 2.50b | 1.06b | 2.00a | 1.47b | 16.8b | 6.4b | 24.6b | 8.2a |
| October | 25.8c | 26.1ab | 28.5a | 28.6a | 1.00ab | 0.32a | 1.90a | 0.33a | 9.7ab | 3.5ab | 24.6b | 4.5b |

#Averages of nontransformed data for 1 and 30 minute cumulative infiltration.

*Averages in a column followed by different letters are different at 5% level.

Table 7. Effect of compaction on soil moisture, and 1 and 30 minute cumulative infiltration (fifth replication, Ames location)

| Treatment | MC | | | | INF1 | | | | INF30 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Moldboard | Chisel | Para | No-till | Moldboard | Chisel | Para | No-till | Moldboard | Chisel | Para | No-till |
| | %DB | | | | cm# | | | | | | | |
| Noncompacted | 25.4a* | 26.6a | 24.0a | 23.4a | 1.54a | 0.38a | 1.90a | 0.78a | 16.2a | 4.0a | 24.81a | 10.4a |
| Compacted | 26.3a | 24.7a | 28.5a | 28.9b | 1.13a | 0.71a | 1.60a | 0.73b | 5.2b | 3.5a | 20.41a | 3.5b |

#Averages of nontransformed data for 1 and 30 minute cumulative infiltration.

*Averages in a column followed by different letters are different at 5% level.

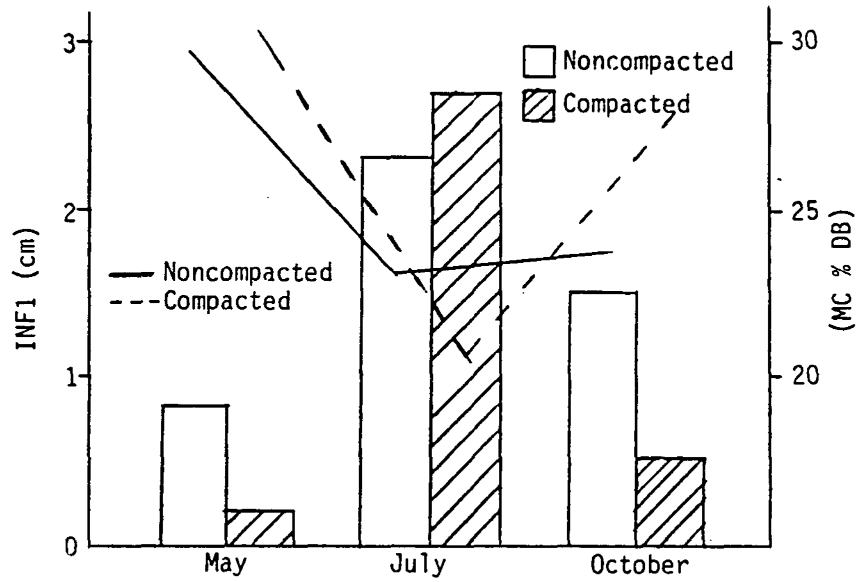



Figure 14a. Moisture content, and 1 minute cumulative infiltration from the noncompacted and compacted furrows of moldboard plow treatment plot

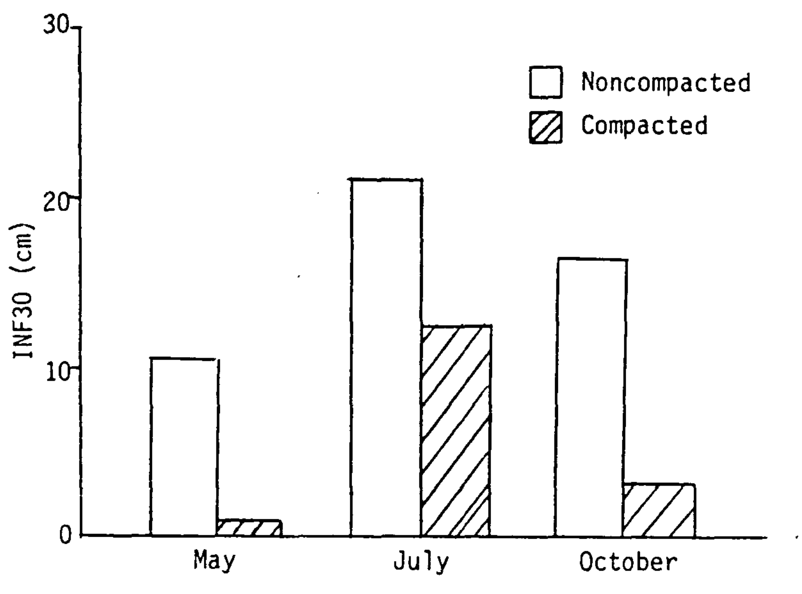
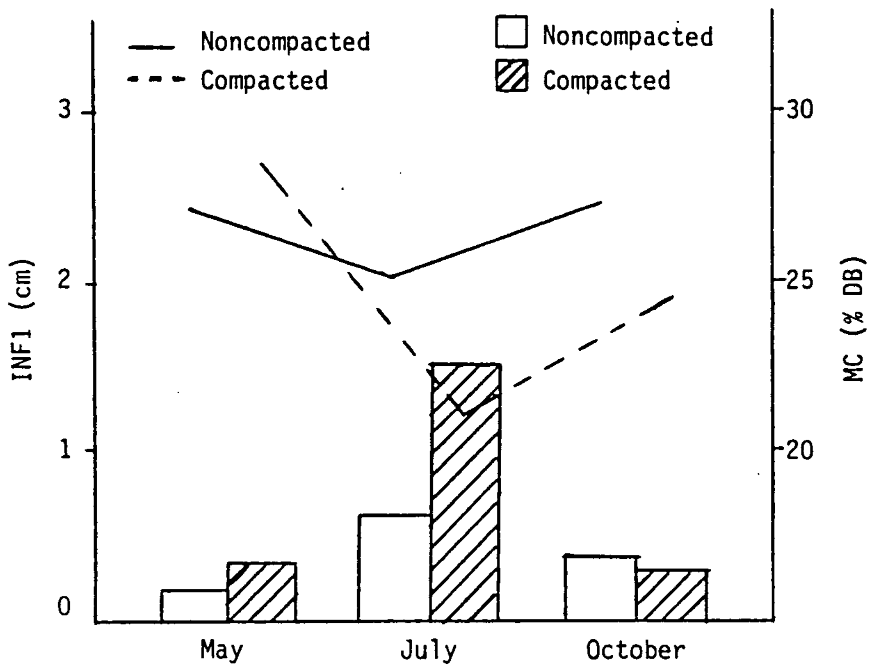



Figure 14b. 30 minute cumulative infiltration from noncompacted and compacted furrows of moldboard plot treatment plot




Figre 15a. Moisture content, and 1 minute cumulative infiltration from noncompacted and compacted furrows of chisel plow treatment plot

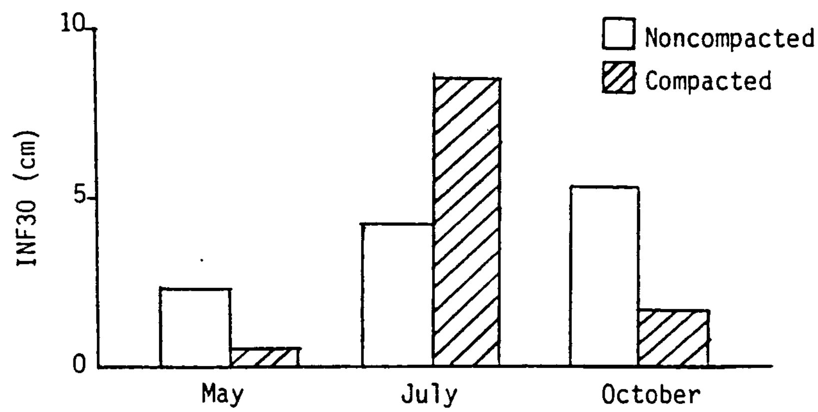



Figure 15b. 30 minute cumulative infiltration from noncompacted and compacted furrows of chisel plow treatment plot

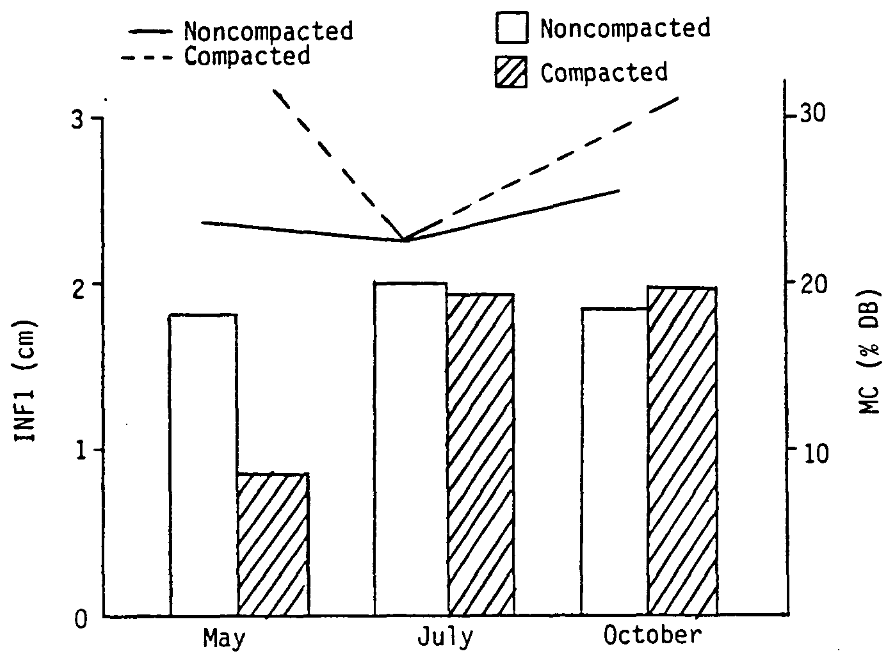



Figure 16a. Moisture content, and 1 minute cumulative infiltration from the noncompacted and compacted furrows of paraplow treatment plot

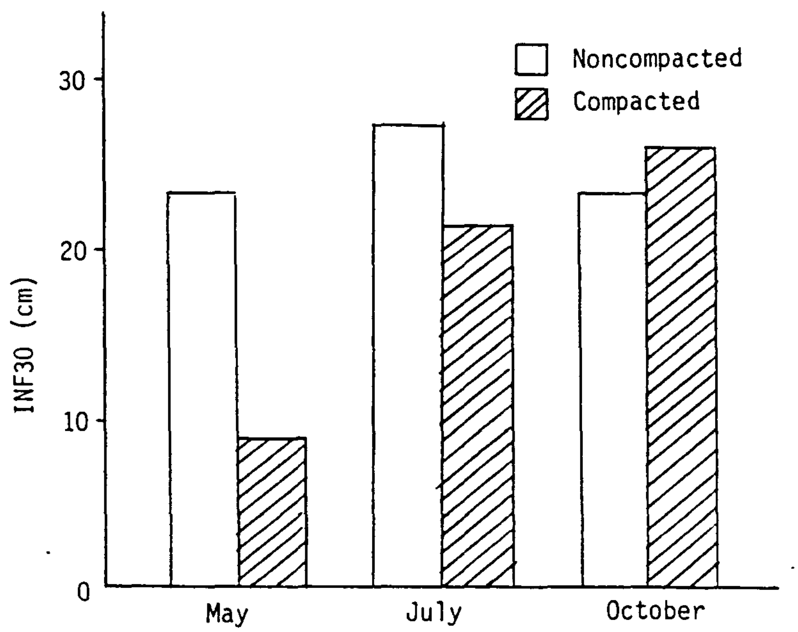



Figure 16b. 30 minute cumulative infiltration from noncompacted and compacted furrows of paraplow treatment plot

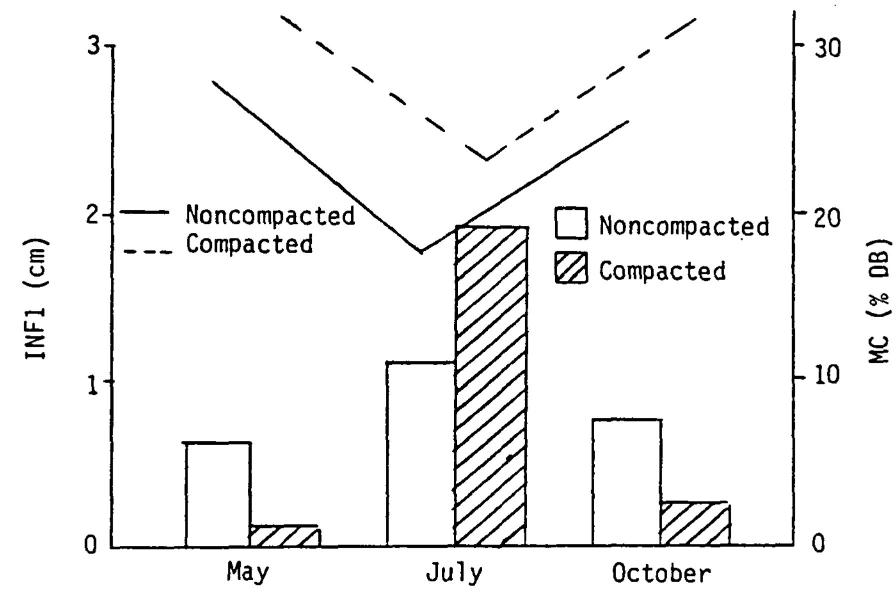



Figure 17a. Moisture content, and 1 minute cumulative infiltration from noncompacted and compacted furrows of no-tillage treatment plot

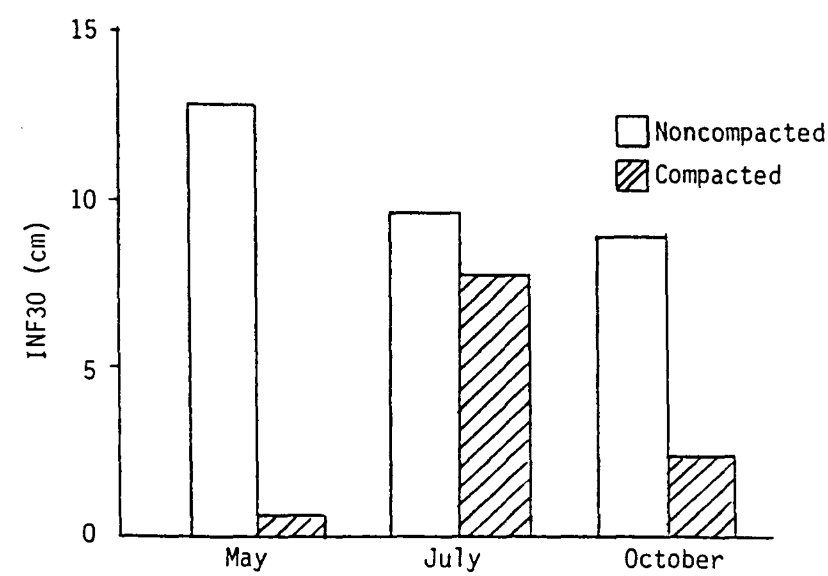



Figure 17b. 30 minute cumulative infiltration from the noncompacted and compacted furrows of no-tillage treatment plot

the moldboard plow treatment where the October moisture content was significantly reduced from the May moisture content (Table 6). The lower moisture content may be attributed to little or no surface residue available on the moldboard plow treatment plots. The increased moisture contents relative to those in July for all the tillage treatments determined in October (Table 6), were due to rains during September-October period, low temperatures, and minimum evapotranspiration from all the tillage plots after harvest.

The moisture content in the compacted furrow was significantly greater than for the noncompacted furrow of the no-tillage treatment plot (Table 7). However, in general, the moisture contents in the compacted furrow of the rest of the tillage treatment plots were also higher than those determined in the noncompacted furrow of these tillage treatment plots (Table 7 and Figures 14-17).

2. <u>1 minute cumulative infiltration--INF1</u>

The averages of 1 minute cumulative infiltration for the chisel plow and no-tillage treatments determined in July were significantly greater than those determined in May and October (Table 6), while the average 1 minute cumulative infiltration for moldboard plow treatment determined in July was significantly greater than that determined in May (Table 6). However, in general, greater 1 minute cumulative infiltration was observed for all the tillage treatments in the month of July (Table 6). This trend could be due to soil surface cracks on the surfaces of all the tillage-plots, and lower moisture contents resulting from dry weather conditions. Increased soil water infiltration through cracked surfaces has also been reported by Gardner (1962) and Wild (1972).

In October after harvest, the averages of 1 minute cumulative infiltration for chisel plow and no-tillage treatments were significantly reduced from those determined in July (Table 6). It was observed that most of the surface residue on the no-tillage plots was swept away in the runoff due to intensive rain storms during the September-October period. For this reason most of the surface cracks on the no-tillage treatment plots were sealed and clogged in October. In general, the October 1 minute cumulative infiltration was lower than the July 1 minute cumulative infiltration for all the tillage treatments (Table 6). This trend indicates that at the Ames location, the sealing and partial clogging of the soil surface cracks due to raindrop action and transportation of finer soil particles into the cracks through runoff, plus the observed higher moisture contents can substantially reduce the 1 minute cumulative infiltration of water into the soil.

The averages of 1 minute cumulative infiltration (determined three times) from the noncompacted furrow were statistically similar to those determined from the compacted furrow of all the tillage treatments except for no-tillage treatment where the average 1 minute cumulative infiltration from noncompacted furrow was significantly greater than that from the compacted furrow (Table 7 and Figures 17a and 17b). The lack of statistical differences in the averages of 1 minute cumulative infiltration between compacted and noncompacted furrows of moldboard plow, chisel plow, and paraplow treatments may be attributed to surface cracking and low moisture contents in July, that masked the compaction effect and also enhanced the 1 minute cumulative infiltration from the compacted furrows (Figures 14-16).

3. <u>30 minute cumulative infiltration--INF30</u>

The averages of 30 minute cumulative infiltration for moldboard plow, chisel plow, and paraplow treatments in the month of July were significantly greater than those in the month of May (Table 6). This greater 30 minute cumulative infiltration may be attributed to the deeper surface connected cracks on the soil surface of these tillage plots, and significantly reduced moisture contents as a result of dry weather conditions.

In October, the average 30 minute cumulative infiltration for the paraplow treatment was significantly greater than that in the month of May (Table 6). This suggests that surface cracks on the paraplow treatment may have been protected by the surface residue available on the paraplow treatment plots. The average 30 minute cumulative infiltration determined for the no-tillage treatment in October was reduced significantly from that determined in July (Table 6). This may be attributed to the sealing and clogging of most of the surface cracks on the no-tillage treatment plots due to little or no surface residue available on the no-tillage treatment plot for the reasons mentioned earlier. Partial clogging of cracks or surface sealing and higher moisture contents in the month of October reduced the averages of 30 minute cumulative infiltration for moldboard plow and chisel plow treatments also.

The averages of 30 minute cumulative infiltration from noncompacted furrows of the moldboard plow and no-tillage treatments were significantly greater than from compacted furrows of these tillage treatments (Table 7). The significantly increased 30 minute cumulative infiltration from the noncompacted furrows of these tillage treatment plots suggests that the effect of compaction may not be apparent until after water is ponded on the soil surface for a longer time period (note that the average 1 minute cumulative infiltration from the noncompacted furrow of moldboard plow treatment is statistically similar to that from the compacted furrow (Table 7). Generally, the 30 minute cumulative infiltration from the noncompacted furrow was higher than that from the compacted furrow of all the tillage treatments (Figures 14-17).

No statistical analysis for the effect of tillage on soil water infiltration was conducted because the exepriment was designed for temporal study only. However, a general idea about the tillage treatment effect on soil moisture and 1 and 30 minute cumulative infiltration is presented. Figures 18 and 19 show that the averages of 1 and 30 minute cumulative infiltration for the paraplow treatments were higher than for the rest of the tillage treatments throughout the growing season with the one exception in July, when the 1 minute cumulative infiltration for moldboard plow treatment was higher than for the rest of the tillage treatments. Figures 18 and 19 also show that the averages of 1 and 30 minute cumulative infiltration amounts for the chisel plow treatment were lower than for the rest of the tillage treatments throughout the growing season.

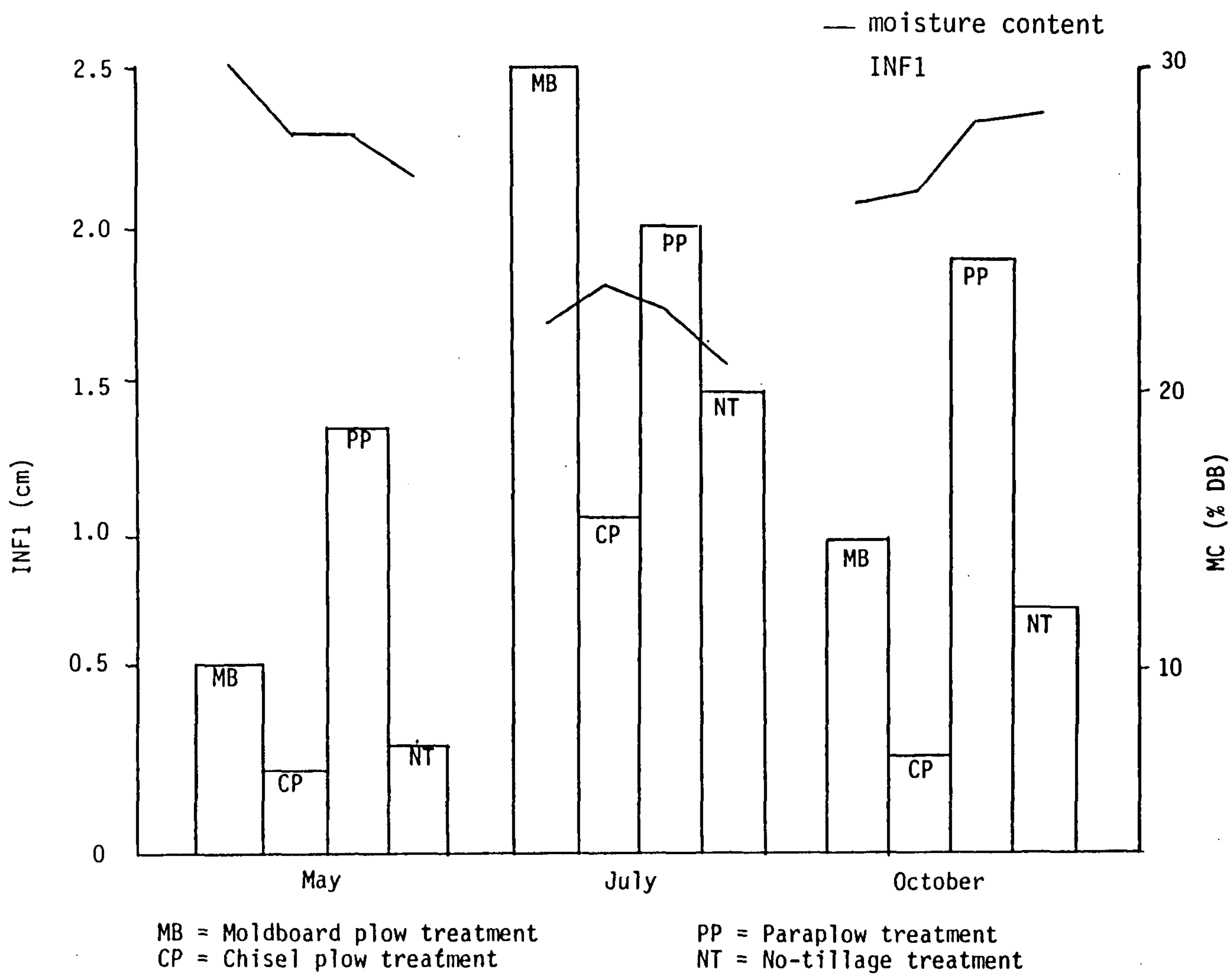



Figure 18. Moisture content and 1 minute cumulative infiltration for different tillage treatments

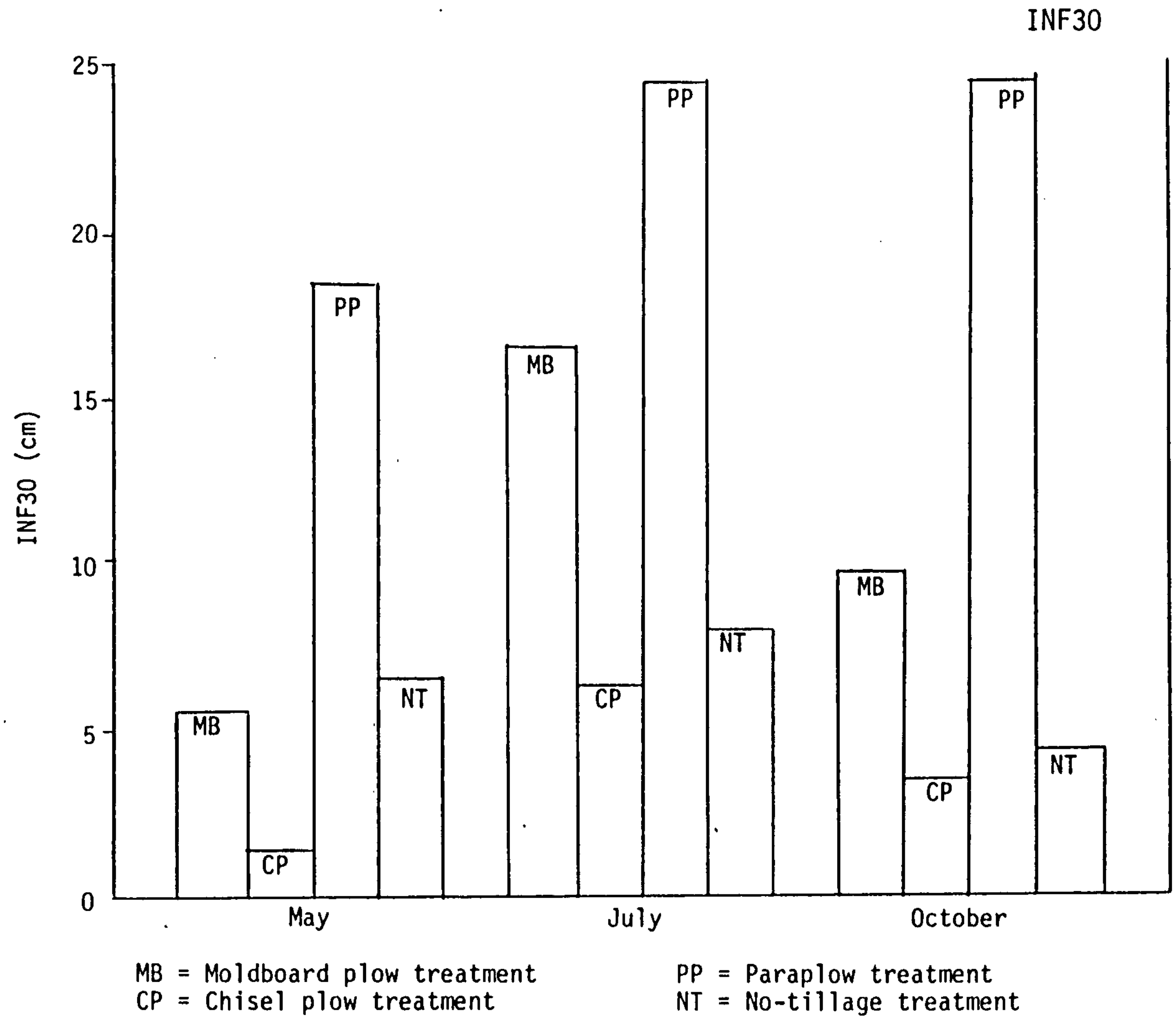



Figure 19. 30 minute cumulative infiltration for different tillage treatments

# V. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

## A. Conclusions

1. The effects of different tillage treatments on soil water infiltration varied somewhat with site and sampling date in this study; however, the newly introduced paraplow generaly had the highest infiltration rates.

2. The increased soil water infiltration with the paraplow may help reduce the runoff and erosion hazards.

3. The higher moisture levels due to leaving essentially all the residue on the soil surface for the paraplow and no-tillage systems may prevent growing crops from severe stress development during the short-term droughts.

4. Soil water infiltration increases signficantly through the deep surface connected cracks.

5. Surface sealing due to rainfall, runoff, and compaction due to wheel traffic can substantially restrict soil water infiltration.

6. Surface mulches are important to prevent soil surface sealing and crusting.

7. Soil water infiltration is highly temporally dependent.

## B. Recommendations for Future Work

It is difficult to draw decisive conclusions from a one-year study about the paraplow as an efficient soil and residue manager; therefore, it is important to explore further the potential of this tool in enhancing soil water infiltration. It is also suggested that a different (other than ring infiltrometer) method to determine soil water infiltration for this tillage implement be used because the cylinder or ring infiltrometers are restricted to measuring infiltration of only a small area in the field. A sprinkler type infiltrometer might be used to apply rainfall over larger areas in a tillage plot.

The wide range in the actual observed values for 1 and 30 minute cumulative infiltration in this study may be an indication of spatial variability in the field measured infiltration. A study on the spatial dependence of soil water infiltration using geostatistical concepts is recommended.

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# VIII. APPENDIX I: EXPERIMENTAL DATA

## A. Tillage Treatment Effects

### 1. Ames

5/16/83

| Tillage Treatment | Repli- cation | MC - %DB - | INF1 ---- cm | INF30 ----- |
|---|---|---|---|---|
| Moldboard | 1 | 29.5 | 0.35 | 1.3 |
| Moldboard | 2 | 20.3 | 2.56 | 31.2 |
| Moldboard | 3 | 30.2 | 1.83 | 19.9 |
| Moldboard | 4 | 24.5 | 0.24 | 3.2 |
| Chisel plow | 1 | 34.2 | 0.08 | 1.7 |
| Chisel plow | 2 | 28.9 | 0.06 | 1.5 |
| Chisel plow | 3 | 31.0 | 0.91 | 5.8 |
| Chisel plow | 4 | 27.1 | 1.22 | 16.9 |
| Paraplow | 1 | 27.5 | 1.83 | 20.4 |
| Paraplow | 2 | 19.2 | 1.22 | 17.1 |
| Paraplow | 3 | 24.2 | 1.07 | 26.4 |
| Paraplow | 4 | 27.8 | 2.29 | 28.0 |
| No-tillage | 1 | 30.5 | 0.08 | 2.0 |
| No-tillage | 2 | 27.0 | 0.12 | 3.2 |
| No-tillage | 3 | 26.6 | 1.22 | 23.3 |
| No-tillage | 4 | 30.2 | 1.98 | 20.0 |

6/22/83

| Tillage Treatment | Repli- cation | MC - %DB - | INF1 | INF30 |
|---|---|---|---|---|
| | | | ---- cm | ----- |
| Moldboard | 1 | 26.7 | 0.80 | 3.0 |
| Moldboard | 2 | 25.6 | 0.64 | 8.9 |
| Moldboard | 3 | 23.6 | 0.76 | 2.4 |
| Moldboard | 4 | 27.2 | 0.61 | 0.9 |
| Chisel plow | 1 | 26.6 | 0.95 | 8.7 |
| Chisel plow | 2 | 26.6 | 0.32 | 3.3 |
| Chisel plow | 3 | 26.9 | 0.49 | 2.0 |
| Chisel plow | 4 | 21.0 | 0.70 | 5.6 |
| Paraplow | 1 | 28.7 | 1.11 | 30.8 |
| Paraplow | 2 | 29.3 | 0.80 | 9.1 |
| Paraplow | 3 | 24.9 | 4.30 | 49.6 |
| Paraplow | 4 | 28.5 | 4.00 | 48.8 |
| No-tillage | 1 | 27.1 | 0.18 | 0.5 |
| No-tillage | 2 | 36.5 | 0.18 | 0.7 |
| No-tillage | 3 | 26.8 | 0.82 | 9.6 |
| No-tillage | 4 | 28.8 | 0.55 | 4.2 |

2. <u>Chariton</u>

6/1/83

| Tillage Treatment | Repli- cation | MC - %DB - | BD - Mg/m$^3$ - | INF1 ---- cm | INF30 ----- |
|---|---|---|---|---|---|
| Moldboard | 1 | 28.2 | 1.05 | 1.52 | 16.3 |
| Moldboard | 2 | 25.3 | 1.04 | 0.60 | 10.4 |
| Moldboard | 3 | 29.8 | 1.10 | 0.76 | 7.4 |
| Moldboard | 4 | 25.0 | 1.14 | 0.55 | 7.7 |
| Chisel plow | 1 | 31.1 | 1.10 | 1.20 | 25.5 |
| Chisel plow | 2 | 27.8 | 1.09 | 0.14 | 1.2 |
| Chisel plow | 3 | 27.6 | 1.05 | 0.30 | 4.6 |
| Chisel plow | 4 | 26.8 | 1.02 | 1.67 | 30.0 |
| Paraplow | 1 | 28.6 | 1.20 | 0.33 | 14.0 |
| Paraplow | 2 | 28.3 | 0.92 | 0.85 | 15.2 |
| Paraplow | 3 | 32.3 | 0.94 | 2.60 | 39.0 |
| Paraplow | 4 | 34.9 | 1.02 | 0.15 | 2.9 |
| No-tillage | 1 | 33.9 | 1.24 | 0.02 | 0.1 |
| No-tillage | 2 | 34.7 | 1.12 | 0.003 | 0.2 |
| No-tillage | 3 | 33.5 | 1.09 | 0.03 | 0.5 |
| No-tillage | 4 | 32.4 | 1.04 | 0.03 | 0.2 |

10/27/83 (after harvest)

| Tillage Treatment | Repli- cation | MC - %DB - | BD - $Mg/m^3$ - | INF1 | INF30 |
|---|---|---|---|---|---|
| | | | | ---- cm | ----- |
| Moldboard | 1 | 26.7 | 1.08 | 0.88 | 8.3 |
| Moldboard | 2 | 28.1 | 1.15 | 3.66 | 45.6 |
| Moldboard | 3 | 28.3 | 0.94 | 1.07 | 13.2 |
| Moldboard | 4 | 25.5 | 1.09 | 1.02 | 16.5 |
| Chisel plow | 1 | 28.2 | 1.08 | 0.91 | 8.1 |
| Chisel plow | 2 | 29.5 | 1.03 | 1.11 | 14.3 |
| Chisel plow | 3 | 29.9 | 1.04 | 0.66 | 12.1 |
| Chisel plow | 4 | 28.3 | 0.97 | 0.61 | 13.8 |
| Paraplow | 1 | 28.3 | 1.23 | 4.00 | 55.2 |
| Paraplow | 2 | 29.8 | 0.98 | 4.14 | 51.9 |
| Paraplow | 3 | 27.3 | 1.10 | 1.73 | 38.5 |
| Paraplow | 4 | 25.4 | 1.13 | 1.22 | 22.3 |
| No-tillage | 1 | 27.6 | 1.16 | 0.24 | 4.7 |
| No-tillage | 2 | 28.5 | 1.18 | 1.34 | 29.8 |
| No-tillage | 3 | 27.1 | 1.11 | 0.91 | 15.1 |
| No-tillage | 4 | 28.6 | 1.08 | 1.52 | 29.5 |

3. Nashua

6/9/83

| Tillage Treatment | Replication | MC - %DB - | BD - $Mg/m^3$ - | INF1 | INF30 |
|---|---|---|---|---|---|
| | | | | ---- cm | ----- |
| Moldboard | 1 | 19.4 | 1.23 | 0.46 | 1.5 |
| Moldboard | 2 | 19.3 | 1.06 | 0.23 | 1.1 |
| Moldboard | 3 | 17.5 | 1.22 | 0.49 | 3.1 |
| Moldboard | 4 | 17.8 | 1.24 | 0.46 | 1.7 |
| Chisel plow | 1 | 22.0 | 1.15 | 0.80 | 4.7 |
| Chisel plow | 2 | 20.5 | 1.02 | 0.76 | 4.7 |
| Chisel plow | 3 | 16.6 | 1.17 | 0.17 | 1.0 |
| Chisel plow | 4 | 18.2 | 1.15 | 0.24 | 1.6 |
| Paraplow | 1 | 18.6 | 1.15 | 3.25 | 18.6 |
| Paraplow | 2 | 21.2 | 1.10 | 1.00 | 11.3 |
| Paraplow | 3 | 19.6 | 1.02 | 0.61 | 4.4 |
| Paraplow | 4 | 17.2 | 1.05 | 3.30 | 37.7 |
| No-tillage | 1 | 17.1 | 0.94 | 0.76 | 5.4 |
| No-tillage | 2 | 19.5 | 1.02 | 0.76 | 7.6 |
| No-tillage | 3 | 19.5 | 1.40 | 0.66 | 3.1 |
| No-tillage | 4 | 16.6 | 1.10 | 1.05 | 8.8 |

7/20/83

| Tillage Treatment | Replication | MC - %DB - | BD - Mg/m³ - | INF1 ---- cm | INF30 ----- |
|---|---|---|---|---|---|
| Moldboard | 1 | 16.2 | 1.21 | 2.74 | 21.6 |
| Moldboard | 2 | 17.9 | 1.09 | 1.83 | 12.6 |
| Moldboard | 3 | 15.1 | 1.12 | 4.72 | 17.1 |
| Moldboard | 4 | 16.0 | 1.26 | 3.05 | 15.3 |
| Chisel plow | 1 | 18.1 | 1.24 | 3.60 | 12.3 |
| Chisel plow | 2 | 18.8 | 1.18 | 4.43 | 8.9 |
| Chisel plow | 3 | 17.0 | 1.26 | 1.52 | 5.3 |
| Chisel plow | 4 | 18.5 | 1.41 | 0.50 | 3.4 |
| Paraplow | 1 | 16.5 | 1.23 | 10.97 | 82.4 |
| Paraplow | 2 | 19.4 | 1.44 | 3.05 | 31.9 |
| Paraplow | 3 | 18.3 | 1.30 | 3.05 | 17.4 |
| Paraplow | 4 | 14.5 | 1.16 | 3.05 | 16.4 |
| No-tillage | 1 | 17.4 | 1.51 | 2.28 | 11.6 |
| No-tillage | 2 | 19.6 | 1.10 | 4.00 | 13.7 |
| No-tillage | 3 | 18.8 | 1.14 | 0.55 | 2.6 |
| No-tillage | 4 | 17.0 | 1.27 | 1.31 | 7.9 |

11/1/83 (after harvest)

| Tillage Treatment | Replication | MC - %DB - | BD - Mg/m$^3$ - | INF1 | INF30 |
|---|---|---|---|---|---|
| | | | | ---- cm | ----- |
| Moldboard | 1 | 19.7 | 1.23 | 0.67 | 8.0 |
| Moldboard | 2 | 21.4 | 1.11 | 1.36 | 18.4 |
| Moldboard | 3 | 19.1 | 1.28 | 1.52 | 14.2 |
| Moldboard | 4 | 17.0 | 1.35 | 0.40 | 2.1 |
| Chisel plow | 1 | 20.3 | 1.10 | 0.61 | 7.5 |
| Chisel plow | 2 | 22.6 | 1.15 | 0.37 | 3.0 |
| Chisel plow | 3 | 19.7 | 1.15 | 0.50 | 4.2 |
| Chisel plow | 4 | 18.4 | 1.28 | 0.53 | 4.5 |
| Paraplow | 1 | 23.8 | 1.13 | 3.20 | 35.7 |
| Paraplow | 2 | 23.9 | 1.15 | 3.93 | 33.3 |
| Paraplow | 3 | 20.9 | 1.16 | 3.66 | 30.6 |
| Paraplow | 4 | 18.1 | 1.22 | 2.90 | 44.7 |
| No-tillage | 1 | 21.7 | 1.18 | 0.85 | 11.0 |
| No-tillage | 2 | 25.3 | 1.28 | 0.75 | 12.1 |
| No-tillage | 3 | 21.7 | 1.16 | 0.31 | 5.5 |
| No-tillage | 4 | 19.8 | 1.08 | 0.82 | 14.1 |

11/8/83 (after tillage)

| Tillage Treatment | Replication | MC - %DB - | BD - Mg/m$^3$ - | INF1 ---- cm | INF30 ----- |
|---|---|---|---|---|---|
| Moldboard | 1 | 22.8 | 1.03 | 3.40 | 53.9 |
| Moldboard | 2 | 23.0 | 0.91 | 0.24 | 1.6 |
| Moldboard | 3 | 22.3 | 0.94 | 0.13 | 4.1 |
| Moldboard | 4 | 17.0 | 1.02 | 0.15 | 1.7 |
| Chisel plow | 1 | 21.9 | 1.05 | 1.35 | 15.1 |
| Chisel plow | 2 | 22.8 | 0.91 | 0.76 | 11.2 |
| Chisel plow | 3 | 22.3 | 0.90 | 0.24 | 2.2 |
| Chisel plow | 4 | 18.7 | 1.06 | 0.61 | 8.6 |
| Paraplow | 1 | 23.0 | 1.13 | 0.91 | 4.7 |
| Paraplow | 2 | 25.2 | 1.00 | 0.95 | 7.3 |
| Paraplow | 3 | 21.6 | 0.82 | 1.80 | 17.2 |
| Paraplow | 4 | 19.0 | 1.20 | 1.10 | 53.4 |
| No-tillage | 1 | 24.1 | 1.12 | 0.41 | 4.3 |
| No-tillage | 2 | 27.3 | 1.14 | 0.13 | 4.0 |
| No-tillage | 3 | 21.7 | 1.14 | 0.26 | 3.5 |
| No-tillage | 4 | 20.0 | 1.08 | 0.43 | 6.8 |

B. Temporal Effects (Ames, fifth replication)

1. Moldboard plow

| Sampling Date | Noncompacted Furrow | | | Compacted Furrow | | |
|---|---|---|---|---|---|---|
| | MC | INF1 | INF30 | MC | INF1 | INF30 |
| mo/da/yr | - %DB - | ---- cm ---- | | - %DB - | ---- cm ---- | |
| 5/23/83 | 28.5 | 0.61 | 8.0 | 30.8 | 0.34 | 0.8 |
| 5/23/83 | 30.9 | 1.07 | 13.3 | 30.1 | 0.06 | 0.2 |
| 7/14/83 | 21.6 | 1.80 | 20.0 | 20.2 | 0.98 | 6.1 |
| 7/14/83 | 24.3 | 2.74 | 22.7 | 21.2 | 4.44 | 18.4 |
| 10/28/83 | 25.0 | 1.22 | 10.3 | 27.0 | 0.44 | 3.2 |
| 10/28/83 | 22.4 | 1.83 | 22.7 | 28.7 | 0.52 | 2.5 |

2. Chisel plow

| Sampling Date | Noncompacted Furrow | | | Compacted Furrow | | |
|---|---|---|---|---|---|---|
| | MC | INF1 | INF30 | MC | INF1 | INF30 |
| mo/da/yr | - %DB - | ---- cm ---- | | - %DB - | ---- cm ---- | |
| 5/26/83 | 26.2 | 0.24 | 4.1 | 27.8 | 0.40 | 0.6 |
| 5/26/83 | 28.2 | 0.09 | 0.5 | 29.2 | 0.31 | 0.4 |
| 7/12/83 | 26.4 | 0.66 | 6.1 | 21.2 | 2.22 | 13.2 |
| 7/12/83 | 23.8 | 0.53 | 2.6 | 20.5 | 0.82 | 3.7 |
| 10/28/83 | 28.0 | 0.50 | 9.1 | 23.7 | 0.40 | 2.3 |
| 10/28/83 | 26.8 | 0.24 | 1.8 | 25.7 | 0.17 | 0.9 |

3. Paraplow

| Sampling Date | Noncompacted Furrow MC | Noncompacted Furrow INF1 | Noncompacted Furrow INF30 | Compacted Furrow MC | Compacted Furrow INF1 | Compacted Furrow INF30 |
|---|---|---|---|---|---|---|
| mo/da/yr | - %DB - | ---- cm ---- | | - %DB - | ---- cm ---- | |
| 5/29/83 | 22.4 | 1.92 | 20.8 | 33.0 | 0.50 | 9.7 |
| 5/29/83 | 25.4 | 1.72 | 26.4 | 30.5 | 1.22 | 17.4 |
| 7/11/83 | 21.0 | 1.87 | 25.4 | 22.3 | 2.03 | 18.8 |
| 7/11/83 | 23.9 | 2.13 | 29.4 | 22.6 | 1.90 | 24.7 |
| 10/28/83 | 25.4 | 2.44 | 26.0 | 31.6 | 1.22 | 20.4 |
| 10/28/83 | 25.9 | 1.22 | 20.8 | 31.2 | 2.74 | 31.4 |

4. No-tillage

| Sampling Date | Noncompacted Furrow MC | Noncompacted Furrow INF1 | Noncompacted Furrow INF30 | Compacted Furrow MC | Compacted Furrow INF1 | Compacted Furrow INF30 |
|---|---|---|---|---|---|---|
| mo/da/yr | - %DB - | ---- cm ---- | | - %DB - | ---- cm ---- | |
| 5/27/83 | 27.9 | 0.72 | 14.5 | 32.9 | 0.09 | 0.2 |
| 5/27/83 | 28.0 | 0.53 | 11.2 | 30.8 | 0.08 | 1.0 |
| 7/13/83 | 16.3 | 1.30 | 8.4 | 21.7 | 2.13 | 7.1 |
| 7/13/83 | 19.1 | 0.84 | 9.0 | 24.6 | 1.62 | 8.3 |
| 10/28/83 | 25.6 | 0.56 | 9.0 | 31.0 | 0.24 | 1.8 |
| 10/28/83 | -[a] | -[a] | -[a] | 32.4 | 0.20 | 2.8 |

[a]Missing values.

# IX. APPENDIX II: INFILTRATION DATA

## A. Introduction

The data for 30 minute cumulative infiltration determined in the month of May are presented here. These measurements were made on various tillage treatment plots in the fifth replication of the Ames location for a different study.

1. Moldboard plow

| | INF30 (cm) | |
|---|---|---|
| Furrow 1 | Furrow 2 | Furrow 3 |
| 3.9 | 3.0 | 9.6 |
| 1.6 | 3.3 | 18.8 |
| 3.8 | 8.4 | -[a] |
| 0.2 | 13.3 | 43.8 |
| 8.4 | 8.0 | 42.8 |
| 0.3 | 4.7 | 20.6 |
| 0.4 | 4.2 | 22.4 |
| 0.3 | -[a] | 23.0 |

[a]Missing values.

2. Chisel plow

| | INF30 (cm) | |
|---|---|---|
| Furrow 1 | Furrow 2 | Furrow 3 |
| 0.3 | 1.0 | 9.3 |
| 0.5 | 0.7 | 1.7 |
| 2.3 | 0.2 | 3.4 |
| 0.4 | 0.7 | 4.1 |
| 0.6 | 0.5 | 0.5 |
| 0.5 | 0.3 | 6.2 |
| 0.8 | 0.2 | 3.0 |
| 1.3 | 0.4 | 1.3 |

3. Paraplow

| INF30 (cm) Furrow 1 | Furrow 2 | Furrow 3 |
|---|---|---|
| 0.6 | 7.7 | 15.2 |
| 2.1 | 11.8 | 23.5 |
| 3.4 | 28.5 | 31.0 |
| 17.4 | 12.5 | 20.8 |
| 9.7 | 18.4 | 26.4 |
| 3.8 | 28.5 | 24.3 |
| 7.0 | -[a] | 48.0 |
| 2.8 | 23.9 | 31.1 |

[a]Missing values.

4. No-tillage

| INF30 (cm) Furrow 1 | Furrow 2 | Furrow 3 |
|---|---|---|
| 0.4 | 9.8 | 11.4 |
| 1.2 | 17.2 | 14.2 |
| 1.0 | 10.5 | 13.3 |
| 1.0 | 14.0 | 14.5 |
| 0.2 | 13.4 | 11.2 |
| 0.4 | 14.0 | 18.1 |
| 1.3 | 8.8 | 18.2 |
| 2.2 | 16.3 | 13.0 |