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Surface Water Infiltration in Loess Soils of the Lower Mississippi River Valley: An Emphasis on Land Use

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by

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Abstract

The Alluvial Aquifer is the shallowest and most heavily used groundwater aquifer in the Lower Mississippi River Valley, particularly in the Delta region of eastern Arkansas. However, the Alluvial Aquifer is being depleted faster than the rate of recharge, primarily due to excessive withdrawals for irrigated crop production. Since extensive irrigation in the highly agriculturally productive Delta region of eastern Arkansas has been a main culprit in the groundwater depletion issues the region faces, a better understanding of how ecological factors and/or agricultural best management practices could possibly increase infiltration, to consequently increase recharge, are needed in order to either slow down or reverse the declining aquifer levels through the Delta region of eastern Arkansas. Therefore, the objective of this study was to evaluate the effects of landuse on surface water infiltration into alluvial and loessial soils in the Delta region of eastern Arkansas. Landuse combinations of interest included conventional and no-tillage agricultural practices, deciduous and coniferous forests, and native/natural grasslands. Replicate infiltration measurements were conducted using a double-ring infiltrometer, with a 15-cm inner-ring diameter, across multiple sites representing each of the five landuses. Despite the initial soil water content being greater ($P < 0.05$) in the grassland than in all other ecosystems, the overall infiltration rate into the deciduous forest ecosystem (1.2 cm hr^{-1}) was greater ($P < 0.05$) than all other landuse types, which did not differ and averaged 0.10 cm hr^{-1}. In addition, though the slope of the relationship between the natural logarithm of the infiltration rate versus the mid-point of time was unaffected ($P > 0.05$) by landuse, the intercept parameter differed ($P < 0.05$) among landuses. Results of this study demonstrated that landuse significantly affects infiltration processes in the fine-textured loessial and alluvial soils in the Delta region of eastern Arkansas;

thus, further research is warranted into factors that can increase surface infiltration and potentially groundwater recharge.

Keywords: infiltration, infiltrometer, landuse, loess

Introduction and Literature Review

Since the advent of industrialized agriculture following World War II, the human race has witnessed a threefold increase in agricultural output (Gennari et al., 2013). Through the utilization of practices such as mechanized tillage, application of manufactured fertilizers, pesticide use, and various methods of irrigation, outputs from agricultural lands have actually managed to exceed the caloric requirements of every human being on Earth (FAO, 2009). While this may seem like nothing but an advantageous development, this increased production has come with some significant cost to the environment.

One of the environmental costs is the amount of water that is supplied to areas of intensive agricultural production as irrigation in addition to natural rainfall. The Lower Mississippi River Valley, which encompasses the Delta region of eastern Arkansas, is an area of the United States that is well-known for its long history of extensive rice (*Oryza sativa* L.) and soybean (*Glycine max* L.) production. A tremendously large amount of water is needed to facilitate maximum productivity of both rice and soybean. For example, the University of Arkansas recommends that 5- to 10-cm of water remain upon every hectare of planted rice, up to a point roughly two weeks before harvest (Henry et al., 2016). That means that for the approximate six-month growing season, producers must keep each hectare of their land flooded with no less than roughly 204-m^3 of water. With rice production across Arkansas estimated to be 607,000 hectares, the total water demand is almost 308.5 million m^3 per growing season in Arkansas (Hardke et al., 2014). This amount of water, however large as it may seem, still does not take into account plant-water needs (i.e., transpiration), nor does it account for evaporation, runoff, infiltration, or drainage below the root zone.

Similar to rice, though not requiring flooded-soil conditions to grow, soybean production utilizes an estimated 51- to 64-cm of soil moisture per growing season (Tacker et al., 2013). With an estimated 1.1 million hectares of irrigated soybean in Arkansas, approximately 204,500-m^3 of water per growing season is required for optimum soybean production. Although not nearly as startling as the water demand for rice, irrigated-soybean production is still a major contributor to groundwater depletion in Arkansas, especially considering that soybean occupies almost double the area as rice and shares the same groundwater aquifer in many cases (USDA, 2015).

One of the most prominent aquifers utilized for irrigation within the Lower Mississippi River Delta region of eastern Arkansas is the Alluvial Aquifer. The Alluvial Aquifer, which spans a land surface area of around 8.3 million hectares, sprawls across the borders of six states (i.e., Arkansas, Louisiana, Mississippi, Tennessee, Missouri, and Iowa). The Alluvial Aquifer has an estimated thickness of 15- to 30-m, and, in most places, the vadose zone is composed of a combination of silt- and clay-sized sediments. The vadose zone varies between 3- and 15-m thick, and discharge from wells drilled into the aquifer average a rate of 3000 L min^{-1} (Czarnecki et al., 2013). According to the Arkansas Natural Resources Commission (ANRC), 30.4 million m^3 d^{-1} were pumped out of the Alluvial Aquifer in 2012 for irrigating crops. This is an important amount due to the fact that this withdrawal rate stands in stark contrast with the estimated sustainable yield of 12.8 million m^3 d^{-1} for the Alluvial Aquifer (ANRC, 2015). This means that water is being withdrawn from the aquifer at an approximate rate of 17.6 million m^3 d^{-1} in excess of the sustainable rate of recharge (ANRC, 2015). Overall, the excessive pumping for irrigated crop production has led to a drop in the water table of around 30 cm per year for some areas within the Alluvial Aquifer (Freiwald, 2005).

Not only are these unsustainable, agriculturally related practices of water usage a problem for the Lower Mississippi River Valley and the Delta region of eastern Arkansas, but similar trends have been recorded across many areas of the globe. In Punjab, India, for example, a slow escalation of groundwater withdrawal for irrigated wheat (*Triticum aestivum*) production has led to an aquifer depletion rate of nearly 91 cm annually between 2000 and 2005 (Kaur et al., 2015). Central California, one of the most agriculturally productive regions of the world, has likewise experienced an increase in groundwater withdrawals, as water demands for increased crop yields grow. According to Wang et al. (2016), who utilized satellite imagery to determine groundwater depletion, an estimated 28 to 34 km^3 of groundwater storage in Central California were lost due to unsustainable withdrawals between 2006 and 2012. This means that, when combined with water loss due to a long-term, regional drought, the central valley of California experienced a loss of over 186 km^3 of groundwater storage in only six years (Wang et al., 2016). Numerous other examples of unsustainable groundwater withdrawal, associated at least in part with agricultural practices, have also occurred in the Middle East, Mexico, China, and regions of the African continent (Gleeson et al., 2012). In fact, Gleeson et al. (2012) calculated that the demand for groundwater on a global level is around 3.5 times greater than the estimated yields of all known aquifers combined (Gleeson et al., 2012).

With the depletion of groundwater due to agricultural practices established as a pressing concern, the next logical step is to then create more efficient methods, or best management practices, so that unsustainable groundwater withdrawals can be curbed. In a study conducted by

Verkler et al. (2008), a possible relationship was shown to exist between the maintenance of high surface residue and factors such as greater maximum soil water content, increased soil water residence time, and greater minimum soil water content (Verkler et al., 2008). Verkler et al. (2008) studied the effects of surface wheat residue level (i.e., high and low, achieved with differential nitrogen application rates), residue burning or non-burning, conventional tillage or no-tillage, and irrigation and dryland soybean production on near-surface soil properties in a loessial soil in eastern Arkansas. These factors were analyzed for their effects on soybean production in a wheat-soybean, double-crop production system. Water content reflectometers were installed at 7.5-cm into 16 of the 48 field plots so that growing-season averages for soil moisture could be attained for each of 16 possible treatment combinations. While the Verkler et al. (2008) study did not specifically focus on surface water infiltration, it is known that the velocity of surface water runoff is slowed significantly by the presence of surface residue (DeFauw et al., 2014). The decreased velocity of runoff would then, in turn, allow for a longer period of time during which surface water could infiltrate into the soil, pointing towards infiltration as a possible cause for the reduced runoff and greater soil water content that was exhibited in high-residue and no-tillage field treatments (Verkler et al., 2008).

Similar to Verkler et al. (2008), Harper et al. (2008) showed that conservation tillage practices had the potential to significantly reduce the amount of nutrient runoff from agricultural fields. Harper et al. (2008) conducted rainfall simulations on an alluvial silt-loam soil at the native, undisturbed Roth Prairie near Stuttgart, Arkansas, as well as in adjacent conventional-tillage and ridge-tilled soybean agroecosystems, in order to quantify the effects of landuse on surface runoff. Like Verkler et al. (2008), Harper et al. (2008) did not specifically identify increased surface water infiltration as a mechanism for reducing runoff, but showed that the runoff coefficient associated with conservation-tillage (i.e., ridge tillage) practices was similar to that of a native prairie ecosystem. Much like the Verkler et al. (2008) study, Harper et al. (2008) concluded that the maintenance of the soil's natural structure, as well as the presence of surface residue, could significantly increase the water residence time on the surface of the soil. Logically, this would then point towards either evaporation or infiltration as the driving forces behind reduced runoff. Evaporation, however, is the less likely of the two scenarios given the increased soil water content shown by Verkler et al. (2008).

An additional study, conducted in Hebei Province, China, was initiated in an effort to better understand surface water infiltration into soil columns with various straw applications (Cao et al., 2012). Methods utilized included straw mulching, or layering straw directly on top of the soil surface; straw mixing, where the straw was physically mixed into the top 10 cm of the soil; and straw inter-layering, where the straw was placed in a layer 20 cm below the soil surface (Cao et al., 2012). A constant-head method, combined with data recorders, was used to measure the infiltration rate in the soil columns. A control was also set up without straw amendment. Results indicated significant differences between all three straw-amendment methods and the control. Increased infiltration rates were exhibited in both the straw-mulching and straw-mixing methods, with straw mulching demonstrating the second largest increase in infiltration, while straw inter-layering somewhat reduced surface water infiltration, a result which was attributed to the compaction of the straw by the overlaying soil (Cao et al., 2012).

The Cao et al. (2012) study is valuable in that it points towards increased surface water infiltration as a result of increased surface residue and soil organic matter. While Cao et al.

(2012) focused exclusively on straw amendments to soil columns in an effort to curb water use in agricultural fields, field studies designed to investigate the effect of actual in-field residue level on infiltration would be beneficial and would provide more insight into the potential effects of varied landuse on surface infiltration.

Wang et al. (2012) also studied surface water infiltration into agroforestry systems in the Loess Plateau of north-central China. Loess is wind-blown, silt-sized sediments, and one of the most erodible soil parent materials. The Wang et al. (2012) study was designed to compare infiltration rates between systems that were planted as a walnut (*Juglans regia*) monoculture, a wheat monoculture, and an agricultural system that combined the two by planting wheat in the alleyways between the walnut trees. The study was conducted over an 11-year time period in order to observe the temporal effects of not only rainfall events, but also changes in infiltration rate over time as the inter-cropping technique became better established. The double-ring-infiltrometer method was used to measure infiltration rates in each agricultural environment. Results of the study indicated that the environments where wheat was planted with walnut trees had a significantly greater infiltration rate after 7 years compared to the walnut monoculture. Significant differences were achieved between the polyculture and monoculture wheat after nine years into the study. In fact, the polyculture out-performed both the walnut and wheat monocultures with infiltration rates being greater by a factor of 2 and 1.8, respectively, after 7 years. Infiltration rates over the entire 11-yr study period were 2.1 and 1.3 times greater in the alley-cropped system than in the walnut and wheat monocultures, respectively (Wang et al., 2012).

Since alluvial and loessial soils dominate the highly agriculturally productive Delta region of eastern Arkansas, and extensive irrigation has been a main cause for the groundwater depletion issues the region faces, a better understanding of how ecological factors and/or agricultural best management practices could possibly increase infiltration are needed in order to either slow down or reverse the declining aquifer levels through the Delta region of eastern Arkansas. Therefore, the objective of this study was to evaluate the effects of landuse on surface water infiltration into alluvial and loessial soils in the Delta region of eastern Arkansas. Landuse combinations of interest included conventional and no-tillage agricultural practices, deciduous and coniferous forests, and native/natural grasslands. The comparison of infiltration rates across these different landuse designations will indicate which of the landuses, and/or agricultural management practices, are able to facilitate greater surface water infiltration, which is a precursor to increased groundwater recharge.

The primary hypothesis associated with this study was that the more naturally maintained the soil system, the greater the rate of surface water infiltration. More specifically, it was hypothesized that infiltration would differ among landuses, with conventionally tilled agriculture exhibiting the lowest rate of surface water infiltration, followed by no-tillage agriculture, grassland, and then the forested systems, coniferous and deciduous, respectively. Since the coniferous forest sites measured in this study were planted as a row crop, a formal comparison was also made for the between and in-row infiltration measurements, with in-row measurements expected to show greater infiltration rates. An additional formal comparison was conducted between two Conservation Reserve Program (CRP) sites and two native tallgrass prairie systems, which collectively constituted the grassland landuse for the purpose of the main objective of this study, where the native prairie was expected to exhibit a greater infiltration rate than the CRP.

Materials and Methods

Measurement Periods and Site Descriptions

Infiltration measurements were conducted in November 2015 and in March and May 2016 using a double-ring infiltrometer with a 15-cm inner-ring inside diameter. On 7 November 2015, measurements were conducted at the Lon Mann Cotton Branch Experiment Station (CBES) near Marinna, AR, in the Lower Mississippi River Valley (Figure 1). Measurements were conducted on 15 field plots of a long-term wheat-soybean, double-crop production system study that was initiated in 2001 (Brye et al., 2006). One infiltration measurement was conducted per field plot, which had dimensions of 3-m wide by 6.1-m long. Plots represented the combination of several agricultural management practices associated with a wheat-soybean, double-crop production system: conventional tillage and no-tillage, residue burning and non-burning, high and low surface residue level achieved with differential nitrogen fertilizer application, and irrigated and dryland soybean production.

Three replications of a conventionally tilled, non-burned, high-surface residue, and irrigated treatment combination were targeted for measurements. In addition, three replications of four no-tillage treatment combinations were selected, including no-burn/high-residue-level/irrigated, no-burn/low-residue-level/irrigated, no-burn/high-residue/non-irrigated, and no-burn/low-residue-level/non-irrigated treatment combinations. Three infiltration measurements were also conducted in an adjacent pecan (*Carya illinoinensis*) grove to represent an undisturbed, deciduous forest ecosystem.

Between 22 and 23 March 2016, infiltration measurements were conducted at the Pine Tree Branch Station (PTBS) near Colt, AR (Figure 2) in two conventionally tilled agricultural fields. The agricultural fields were fallow at the time that measurements were conducted, had minimal surface residue, had not been burned, and were likely irrigated in a rice-soybean rotation in the past.

In addition to the conventionally tilled fields at PTBS, two deciduous forest systems adjacent to the agricultural fields were targeted for infiltration measurements (Figure 2). The major tree species present were oak (*Quercus* spp.), hickory (*Carya* spp.), gum (*Eucalypus* spp.), and dogwood (*Cornus* spp.). Although these forested sites had likely been cleared at some point in the past, based on the height of the trees present, the forest stands were estimated at 30 years old and likely had not been disturbed during that period.

A CRP field was also located in the vicinity of the agricultural fields and forested areas at PTBS, within which infiltration measurements were conducted (Figure 2). Species included within the CRP field consisted of switchgrass (*Panicum virgatum*), big bluestem (*Andropogon gerardi*), and Indiangrass (*Sorghastrum nutans*). The CRP grassland was converted from cultivated agriculture at least 15 years earlier and had been only minimally disturbed by periodic mowing and removal of aboveground biomass.

On 23 March 2016, infiltration measurements were conducted at the Kenneth Gray and Seidenstricker Prairies near Stuttgart, AR (Figure 3). Both sites are undisturbed, native tallgrass prairie remnants. Both sites have been managed by periodic burning. The Gray Prairie had been burned within two weeks of the time of infiltration measurements. The Seidenstricker Prairie had been burned within the previous six months of the time of infiltration measurements. Since the Gray Prairie had been recently burned and the Seidenstricker Prairie appeared to have been recently mowed, much of the native vegetation was unavailable for species classification at the time of infiltration measurements.

On 24 May 2016, infiltration measurements were conducted in another conventionally tilled agricultural site at CBES (Figure 1). The site had recently been tilled, bedded, and was awaiting seeding to likely soybean. No surface residue was present, the field was set up to be irrigated, and there were no obvious indications of surface residue burning. Measurements were conducted near the field edge. A deciduous forest site (Figure 1) was located directly adjacent to the conventionally tilled site within which infiltration measurements were also conducted. Primary tree species were very similar to the two previous sites selected at PTBS, and consisted largely of oak (*Quercus* spp.) and gum (*Eucalypus* spp.). Also comparable to the previous forested systems at PTBS, the CBES forest site had at one time likely been cleared and allowed to naturally regenerate. However, this particular site was likely closer to 50+ years old based on average tree height.

On 25 May 2016, infiltration measurements were conducted at another CRP site at PTBS (Figure 2). Additionally, four coniferous forest plantation sites were targeted at PTBS (Figure 2). All four coniferous forest sites were at least 12 years old and had been under cultivated agriculture in the past. Infiltration measurements were conducted in and between the tree rows. Tree rows were roughly 3-m apart and trees within the rows were also an estimated 3-m apart. The plantation sites consisted of Loblolly pine (*Pinus taeda*) of varying heights between 5- and

10-m tall. Evidence of past burning and management of undergrowth (i.e., periodic mowing between rows) was also present at all four coniferous forest plantation sites.

In total, four separate sites, representing five landuses (i.e., cultivated agriculture, no-tillage agriculture, deciduous forest, coniferous forest, and grassland) on fine-textured, alluvial and/or loessial soils throughout the Delta region of eastern Arkansas were targeted for infiltration measurements. Table 1 summarizes additional specific information about each site where infiltration measurements were conducted and Figures 1 through 3 depict aerial photographs for each measurement site.

Infiltration Measurements

Random locations in each plot, or at a specific landuse site, were chosen. Surface residue, if present, was gently moved aside and the infiltrometer was installed manually to a depth of approximately 2.5 cm so that no water leakage would occur from the perimeter of the outer ring. Once the infiltrometer was installed, the soil water content in the 0- to 6-cm depth interval was measured in triplicate using a ML2x Theta Probe (Dynamax, Inc., Houston, TX) in the outer ring of the infiltrometer. The outer ring of the infiltrometer was then filled with water first, followed by the inner ring. All water used for infiltration was tap water transported to the site from the University of Arkansas – Fayetteville campus or obtained from a nearby experiment station building.

The height of the water column inside the inner ring was recorded immediately after filling the inner ring nearly to the top. After filling the inner ring to represent time zero, the height of the water column in the inner ring was subsequently recorded at 1, 2, 3, 4, 5, 8, 10, 12, 15, 18, and 20 minutes thereafter. If all water in the inner ring infiltrated before the 20-min measurement period ended, then the time into the infiltration measurement when all the water had infiltrated was recorded. Three separate infiltration measurements were conducted at each of the four separate sites representing each of the five different landuses.

The overall infiltration rate was calculated over the 20-min measurement period. If complete infiltration occurred before the 20-min measurement period elapsed, then the overall infiltration rate was calculated based on the time it took for complete infiltration to occur. In addition, infiltration rates were calculated between each time interval, then natural-logarithm (LN) transformed and regressed against the mid-point of time (i.e., 0.5, 1.5, 2.5, 3.5, 4.5, 6.5, 9, 11, 13.5, 16.5, and 19 minutes) to characterize the relationship of the LN of infiltration rate over time. The slope and intercept parameters from the resulting linear regression equations were recorded along with the coefficients of determination (i.e., R^2 values) for the relationships.

Soil Sample Collection, Processing, and Analyses

After each infiltration measurement, approximately eight soil samples were collected within the infiltration measurement area from the top 10 cm of soil using a 2-cm diameter push probe and mixed for one sample per infiltration measurement. Samples were dried in a forced-draft oven at 70°C for 48 hours, crushed, and then sieved through a 2-mm mesh screen.

Soil particle-size analyses were conducted on dried and sieved soil sub-samples according to a modified 12-hr hydrometer method (Gee and Or, 2002). Fifty (± 0.1)-gram subsamples of processed soil were combined with 50 mL of sodium hexametaphosphate to disperse soil particles. Soil suspensions were briefly mixed by manual swirling, quantitatively transferred into 1-L sedimentation cylinders, and then diluted to the 1-L mark with tap water. Cylinders were allowed to equilibrate to a uniform temperature overnight. Suspensions were then manually mixed with a plunger and suspension densities were recorded with a hydrometer after 40 seconds. The 40-sec hydrometer readings were conducted in triplicate.

After the third 40-sec hydrometer reading was recorded, the cylinders were left standing until a hydrometer reading was recorded again at the 6- and 11-hr marks after plunging. Blank (i.e., no soil, just 50 mL of sodium hexametaphosphate and water) cylinders were also prepared to judge the accuracy of the hydrometer. The temperature of the blank was measured at the start of each set of 40-sec, 6-, and 11-hr hydrometer readings. The percentage of sand, silt, and clay in each soil sample was calculated using standard equations (Gee and Or, 2002).

Statistical Analyses

A one-factor analysis of variance (ANOVA) using SAS (version 9.3, SAS Institute, Inc., Cary, NC) was conducted to evaluate the effect of landuse (i.e., cultivated agriculture, no-tillage agriculture, deciduous forest, coniferous forest, and grassland) on the overall infiltration rate, the volumetric soil water content prior to infiltration measurements, and the slope and intercept parameters from the linear regression equation characterizing the relationship between the LN of infiltration rate and the mid-point of time. Separate ANOVAs were also conducted to evaluate the effect of landuse (i.e., native prairie and CRP) using only the grassland sites, and to evaluate the effect of measurement position (i.e., in-row and between-row) using only the coniferous forest sites. When appropriate, means were separated by least significant difference (LSD) at the 0.05 level.

Results

Particle-size Distribution and Texture

The distribution of sand, silt, and clay, and the resulting soil texture, at the soil surface greatly influences the ability of water to infiltrate into the soil. Sand content ranged from a low of 1% at a cultivated agricultural site at PTBS (CT 2; Figure 1) to a high of 29% at the Gray and Seidenstricker prairies. Silt content ranged from a low of 49% at a PTBS CRP site (CRP 2; Figure 1) to a high of 82% at a CBES conventionally tilled site (CT 4; Figure 1). Clay content ranged from a low of 2% at a no-tillage agricultural site at CBES (NT 4; Figure 1) to a high of 23% at CRP site 2 (Figure 1). Despite several differences in particle-size distribution among landuses, 97% of the sites where infiltration measurements were conducted had a silt-loam texture in the top 10 cm, while the remainder had a silt texture (CT 4 & NT 2; Figure 1).

Initial Soil Water Content

In an effort to assess uniformity across all sites and landuses, volumetric soil water content (VWC) was measured prior to each infiltration reading. This was conducted in order to determine whether there may be a relationship between the rate of surface water infiltration and the antecedent water content present at each site. It is logical to hypothesize that larger volumetric soil water content readings would result in lower infiltration rates due to the fact that wetter soils would have less pore space into which surface water could infiltrate. It is also important to point out that a saturated soil possesses a greater propensity for directing water away from the soil surface due to an increased hydraulic conductivity.

The initial volumetric soil water content in the top 6 cm differed among landuses ($P < 0.05$; Table 2). Initial VWC prior to beginning infiltration measurements was greater in the grassland (0.41 m^3 m^{-3}) than in all other landuses. Furthermore, initial VWC was greater in the deciduous forest (0.32 m^3 m^{-3}) than in the coniferous forest and agricultural landuses, which did not differ and averaged 0.18 m^3 m^{-3} (Table 2). Assuming the hypothesis that wetter soils lead to lower infiltration rates is true, grasslands and deciduous forests should exhibit lower infiltration rates as they indicated much greater antecedent soil water contents. However, these results also indicate that the soil conditions prior to conducting the infiltration measurements were not as uniform as desired and the initial VWC differences may be somewhat responsible for potential landuse effects on infiltration.

Overall Infiltration Rate

With the primary hypothesis of this study focused on the effect of landuse on infiltration rates, it was expected that this was where the greatest number of differences would become evident. However, the overall infiltration rate was greater ($P < 0.05$) only in the deciduous forest (1.2 cm hr^{-1}) compared to all other landuses, which did not differ and averaged 0.66 cm hr^{-1} (Table 2). Interestingly, these results indicate that the forested systems facilitated the greatest rate of surface water infiltration, despite having the second wettest initial VWC behind the grassland.

Slope Characterizing the Relationship between LN Infiltration Rate and Time

The LN transformation of the overall infiltration rates resulted in a relationship with the mid-point of time that was reasonably strong. The coefficients of determination (i.e., r^2 values) ranged from 0.0023 to 1.0 across all infiltration measurements, with 27% of the coefficient values exceeding 0.60. However, in contrast to results for overall infiltration rate and VWC, the slope parameter characterizing the LN of the infiltration rate and the mid-point of time was unaffected by landuse (Table 2), indicating the process of infiltration over the 20-min measurement period was relatively uniform across all landuses. It is interesting that, despite large differences in initial VWC (Table 2), there were no differences in the slope of the relationship between the LN of the infiltration rate over time among landuses. This result indicates that the slope parameter may have been affected by factors other than the antecedent soil water content.

Intercept Characterizing the Relationship between LN Infiltration Rate and Time

In addition to the slope, the intercept parameter characterizing the linear relationship was analyzed. The intercept parameter of the relationship between the LN of the infiltration rate and the mid-point of time relates to the soil's innate structure, porosity, and water-holding capacity. This would then collectively affect the soil's ability to transmit water at the soil surface. These innate soil properties are important possible sources of variation to explain potential differences in surface infiltration among landuses and how those differences may be related to specific management practices. For example, soil aggregation is highly affected by tillage practices and could influence the intercept parameter associated with a particular landuse. These hypothetical differences would then point towards surface disturbance by tillage as a possible cause for the differences between initial infiltration rates.

In contrast to the slope parameter, the intercept parameter differed somewhat among landuses ($P < 0.05$). The intercept parameter was greatest for the two forest ecosystems, which did not differ, and smallest for the grassland and two agroecosystems, which did not differ (Table 2). Differences in the intercept parameter characterizing the linear relationship between the LN of the infiltration rate and the mid-point of time among landuses demonstrates that, despite no effect of landuse on the slope parameter, landuse clearly affects the process of surface infiltration. The minimally disturbed, forested ecosystems appear to have inherent soil surface properties that are more conducive to promoting infiltration than are the inherent properties of present and former agroecosystems, which have experienced more surface disturbance over time.

Grassland History Effects on Infiltration

In addition to evaluating the general effect of landuse on infiltration, a specific analysis was also conducted to evaluate potential differences in infiltration between undisturbed native prairie and CRP landuses, which were combined as grassland in the general analysis. In contrast to the results of the main objective of this study, there were no differences in initial VWC, overall infiltration rate, or slope and intercept parameters characterizing the linear relationship between the LN of the infiltration rate and the mid-point of time between native prairie and CRP sites (Table 3). These results indicate that the CRP program is effective in returning cultivated land to its natural equilibrium, as judged by the similarities in infiltration characteristics between CRP and native prairie. It is important to point out, however, that the sample size of this analysis was limited and no substantive conclusions can be inferred from these results. Consequently, further research on this topic is warranted.

Measurement Position Effects on Infiltration in the Coniferous Forest

Similar to the specific evaluation of infiltration into CRP and native prairie landuses, an additional specific analysis was conducted to evaluate infiltration among in-row and between-row measurement positions in the coniferous forest landuse. This analysis was conducted to determine whether infiltration rates measured in the coniferous forest plantations may have been influenced by the fact that the trees had been planted in rows and also that the inter-row area had been partially disturbed by periodic management.

Similar to the results for the native prairie and CRP comparison, there were no differences in initial VWC, overall infiltration rate, or slope or intercept parameters characterizing the linear relationship between the LN of the infiltration rate and the mid-point of time among in-row and between-row measurement positions (Table 4). However, the overall infiltration rate was more than three times numerically greater in the row (0.34 cm hr^{-1}) than between the rows (0.11 cm hr^{-1}; Table 4). If these numeric differences in overall infiltration were an indication of actual effects, had more data been able to be gathered, these results might be attributed to differences in density, which may have been greater in the row than between rows. It is also possible that there was greater soil compaction between rows than within rows due to periodic mowing that occurred within the pine plantations. Once again, it is important to point out that the sample size associated with this analysis was limited and no substantive conclusions can be inferred from these results. Consequently, further research on this topic is warranted.

Discussion

To further understand the meaning behind the results quantified in this study, it is helpful to compare them to results reported in similar studies. For instance, in the study by Cao et al. (2012), who investigated the effects of straw amendments on existing landuses, results showed significant differences in infiltration rates across different methods of straw amendment. However, organic matter and surface residue did not appear to be significant factors among sites evaluated in this study. In fact, the only significant difference in infiltration that was shown to exist among the landuses in this study existed between the deciduous forest ecosystem and all other landuses. Given that organic matter and surface residue varied widely across all sites, it would stand to reason that if organic matter and surface residue were significant drivers for surface water infiltration, then greater and/or more differences might have resulted. Not only do the results of this study this stand in contrast to the results of Cao et al. (2012), but results of this study also appear to contradict results of Verkler et al. (2008) and Harper et al. (2008).

Verkler et al. (2008), for instance, evaluated two landuses: conventionally tilled and no-tillage agriculture. While the results from Verkler et al. (2008) included several variations to those landuse categories (i.e., burned or non-burned residue, irrigated and non-irrigated soybean production, and high and low surface residue), greater soil water contents were reported where surface residue was maintained compared to where there was less surface residue. Verkler et al. (2008), however, did not have to contend with the wide variation in landuse characteristics present between, for instance, an established forested system versus a regularly tilled agroecosystem. It is possible, therefore, that the range of soil water contents measured by Verkler et al. (2008) was smaller, thereby allowing treatment means to be better separated than those in this study. Furthermore, since Verkler et al. (2008) evaluated soil water content and water residence time, rather than specifically focusing on the causal factors surrounding surface water infiltration, the mechanisms which led to the observed increase in soil water content can most likely not be attributed to infiltration alone.

Likewise, Harper et al. (2008) reported similar runoff coefficients between a ridge-tilled agroecosystem and a native prairie. While it was hypothesized that similar runoff coefficients between ridge-tilled agriculture and native prairie may be linked to an increased water residence time, due to surface residue and the ridge-planted soybean crop, the current study did not observe similar differences, thus it appears that surface water infiltration may not be the primary driver associated with the observed reduction in runoff. Although Harper et al. (2008) observed significant differences in infiltration into the native prairie and agroecosystems, with native prairie infiltration rates three to four times greater than those in the agroecosystem (Harper et al., 2008), it is likely that greater soil water contents in the native prairie prior to rainfall simulations created a soil surface that was more conductive than that in the agroecosystems. In addition, the VWC did not increase significantly in the prairie system during rainfall simulations. However, since runoff was reduced in the prairie compared to the agroecosystem, indicating a longer on-site residence time, it is possible that the surface residue itself absorbed a portion of the potential runoff.

An additional observation can be made when comparing the results for surface water infiltration across the deciduous and coniferous forest systems. A significant difference in surface infiltration rate existed between deciduous and coniferous forest landuses and, much like Wang et al. (2012), could possibly be attributed to the manner by which these systems are maintained. Wang et al. (2012) reported that agricultural fields planted as a monoculture exhibited a greater surface infiltration rate than did walnut monocultures. Annual tillage was implemented between the rows of the walnut monoculture and could possibly have been a cause for the reduced infiltration (Wang et al., 2012). Likewise, in this study, the coniferous forest systems that were selected had been planted in rows and were subject to regular maintenance in the form of mowing. The deciduous forests, on the other hand, appeared to have been largely undisturbed for decades. This could have led to factors such as reduced soil compaction, increased root growth, increased surface residue and soil organic matter, as well as increased macro- and micro-invertebrate activity, all of which could have affected surface water infiltration rates. One further interpretation that could be made is that the species of the trees themselves could have affected infiltration, primarily with regards to the degree of root growth. Larger expanses of root development would have the ability to create a more prolific network of micro- and macropores, thus increasing the rate by which water is able to infiltrate the soil.

Additional factors that could have affected the results of this study include the presence of burn management, as well as differences in soil water contents. Burn management has been shown to significantly reduce the rate of surface water infiltration, as reported by both Mallik et al. (1984) and Verkler et al. (2008). Mallik et al. (1984) demonstrated that burning heather (*Calluna vulgaris*) reduced surface water infiltration by as much as 29 to 90%. Similarly, the coniferous forest sites evaluated in this study all showed evidence of burning at some point in the past, as did the Gray Prairie system, which had been burned as recently as two weeks prior to conducting infiltration measurements. This is an especially important point to make given that infiltration rates into the grasslands included in this study did not differ from the infiltration rate into the conventionally tilled agroecosystems. In short, burning could be an explanation for the lower-than-expected infiltration rate, or at least is a factor that should be more extensively analyzed when comparing infiltration rates across burned and non-burned sites.

It is also essential to point out, for grasslands especially, that the CRP and native prairie sites had greater mean volumetric water contents than any other landuse. This factor alone may likely be the cause for the reduced infiltration rates exhibited by the grassland landuse. Additional studies should attempt to maintain a uniform VWC across all landuse combinations.

As for the lack of differences between the conventional and no-tillage agroecosystems, this is most likely a result of a small sample size. As with all of the other landuses, only four sites were selected for each, resulting in an analysis of 12 measurements per landuse. While the overall number of measurements among all landuses (i.e., 60) is a respectable start, when comparing between only two landuses, 24 data points may have been too insufficient to draw a conclusion with any degree of confidence. It may well be that no difference exists between the infiltration rates of conventional and no-tillage agroecosystems, but further analysis with a greater sample size is suggested before a solid conclusion can be reached.

Summary, Conclusions, and Implications

The primary hypothesis for this study was that the more naturally maintained the soil system, the greater the rate of surface water infiltration. It was also specifically hypothesized that conventionally tilled agriculture would exhibit the lowest rate of surface water infiltration, followed by no-tillage agriculture, grassland, and then the forested systems, coniferous and deciduous, respectively. Although the results of this study did not support the primary hypothesis with statistical significance, the numeric ranking of overall infiltration rates among landuses followed the hypothesized ranking exactly. Inclusion of more sites and more replicate measurements may have provided more statistically significant support of the primary hypothesis. Nonetheless, results of this study clearly showed that landuse significantly affects surface infiltration in loessial and alluvial soils in the Delta region of eastern Arkansas.

The design of this study could easily be utilized as a template for further investigations involving surface water infiltration. Given the incredible rate at which groundwater is being consumed, it is vital that steps are taken to better manage the remaining groundwater in the Alluvial Aquifer in the Delta region of eastern Arkansas. A better understanding of how surface water infiltrates into the soil is a piece of that puzzle and could help streamline irrigation and groundwater recharge efficiency.

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Table 1. Summary of landuses and site information included in this infiltration study.

Landuse	Specific Site	Location	Soil Parent Material	Mapped Soil Series (Taxonomic Description)
Grassland	CRP[a] 1	PTBS[b]	Loess	Henry (Coarse-silty, mixed, active, thermic typic fragiaqualfs)
	CRP 2	PTBS	Loess	Calloway (Fine-silty, mixed, active, thermic aquic fraglossudalfs)
	Gray Prairie	Monroe County	Alluvium	Stuttgart (Fine, smectitic, thermic albaquultic hapludalfs)
	Seidenstricker Prairie	Prairie County	Alluvium	Dewitt (Fine, smectitic, thermic typic albaqualfs)
Deciduous Forest	Pecan Grove	CBES[c]	Loess	Calloway (Fine-silty, mixed, active, thermic aquic fraglossudalfs)
	Forest 1	PTBS	Loess	Calloway (Fine-silty, mixed, active, thermic aquic fraglossudalfs)
	Forest 2	PTBS	Loess	Calhoun (Fine-silty, mixed, active, thermic typic glossaqualfs)
	Forest 3	CBES	Loess	Memphis (Fine-silty, mixed, active, thermic typic hapludalfs)
Coniferous Forest	Forest 1	PTBS	Loess	Loring (fine-silty, mixed, active, thermic oxyaquic fragiudalfs)
	Forest 2	PTBS	Loess	Calloway (Fine-silty, mixed, active, thermic aquic fraglossudalfs)
	Forest 3	PTBS	Loess	Calloway (Fine-silty, mixed, active, thermic aquic fraglossudalfs)
	Forest 4	PTBS	Loess	Calloway (Fine-silty, mixed, active, thermic aquic fraglossudalfs)
Cultivated Agriculture	CT[d] 1	CBES	Loess	Calloway (Fine-silty, mixed, active, thermic aquic fraglossudalfs)
	CT 2	PTBS	Loess	Calloway (Fine-silty, mixed, active, thermic aquic fraglossudalfs)
	CT 3	PTBS	Loess	Calhoun (Fine-silty, mixed, active, thermic typic glossaqualfs)
	CT 4	CBES	Loess	Memphis (Fine-silty, mixed, active, thermic typic hapludalfs)
No-tillage Agriculture	NT[e] 1	CBES	Loess	Calloway (Fine-silty, mixed, active, thermic aquic fraglossudalfs)
	NT 2	CBES	Loess	Calloway (Fine-silty, mixed, active, thermic aquic fraglossudalfs)
	NT 3	CBES	Loess	Calloway (Fine-silty, mixed, active, thermic aquic fraglossudalfs)
	NT 4	CBES	Loess	Calloway (Fine-silty, mixed, active, thermic aquic fraglossudalfs)

[a] CRP, Conservation Reserve Program
[b] PTBS, Pine Tree Branch Station, near Colt, AR
[c] CBES, Cotton Branch Experiment Station, near Marianna, AR
[d] CT, conventional tillage (CT 1: No-Burn, High Residue, Irrigated; CT 2: Burned, Low Residue, Irrigated; CT 3: No-Burn, Low Residue, Irrigated; CT 4: No-Burn, Low Residue, Irrigated)
[e] NT, no-tillage (NT 1: No-Burn, High Residue, Irrigated; NT 2: No-Burn, Low Residue, Irrigated; NT 3: No-Burn, High Residue, Non-Irrigated; NT 4: No-Burn, Low Residue, Non-Irrigated)

Table 2. Summary of effects of landuse on soil volumetric water content (VWC) in the top 6 cm, overall infiltration rate, and the slope and intercept parameters characterizing the linear relationship between the natural logarithm of the infiltration rate and the mid-point of time.

Landuse	**VWC (m^3 m^{-3})**	**Overall Infiltration Rate (cm hr^{-1})**	**Slope**	**Intercept**
Grassland	0.41 A[a]	0.08 B	-0.05 A	0.08 C
Deciduous Forest	0.32 B	1.2 A	-0.15 A	1.65 A
Coniferous Forest	0.17 C	0.23 B	-0.04 A	0.94 AB
Cultivated Agriculture	0.18 C	0.05 B	-0.13 A	0.20 CB
No-tillage Agriculture	0.20 C	0.07 B	-0.14 A	0.50 CB

[a] Means in a column with the same letter are not significantly different ($P > 0.05$).

Table 3. Summary of effects of grassland management history on soil volumetric water content (VWC) in the top 6 cm, overall infiltration rate, and the slope and intercept parameters characterizing the linear relationship between the natural logarithm of the infiltration rate and the mid-point of time for the grassland landuse only.

Management History	**VWC (m^3 m^{-3})**	**Overall Infiltration Rate (cm hr^{-1})**	**Slope**	**Intercept**
CRP[a]	0.39 A[b]	0.06 A	-0.06 A	0.01 A
Native Prairie	0.42 A	0.10 A	-0.03 A	0.15 A

[a] CRP, Conservation Reserve Program
[b] Means in a column with the same letter are not significantly different ($P > 0.05$).

Table 4. Summary of effects of measurement position on soil volumetric water content (VWC) in the top 6 cm, overall infiltration rate, and the slope and intercept parameters characterizing the linear relationship between the natural logarithm of the infiltration rate and the mid-point of time for the coniferous forest landuse only.

Measurement Position	**VWC (m^3 m^{-3})**	**Overall Infiltration Rate (cm hr^{-1})**	**Slope**	**Intercept**
In-row	0.17 A[a]	0.34 A	-0.04 A	1.06 A
Between-row	0.17 A	0.11 A	-0.04 A	0.82 A

[a] Means in a column with the same letter are not significantly different ($P > 0.05$).

Figure 1. Infiltration measurements were conducted at four locations at the Lon Mann Cotton Branch Experiment Station (CBES) near Marianna, AR representing three different landuses (i.e., cultivated agriculture, no-tillage agriculture, and deciduous forest).

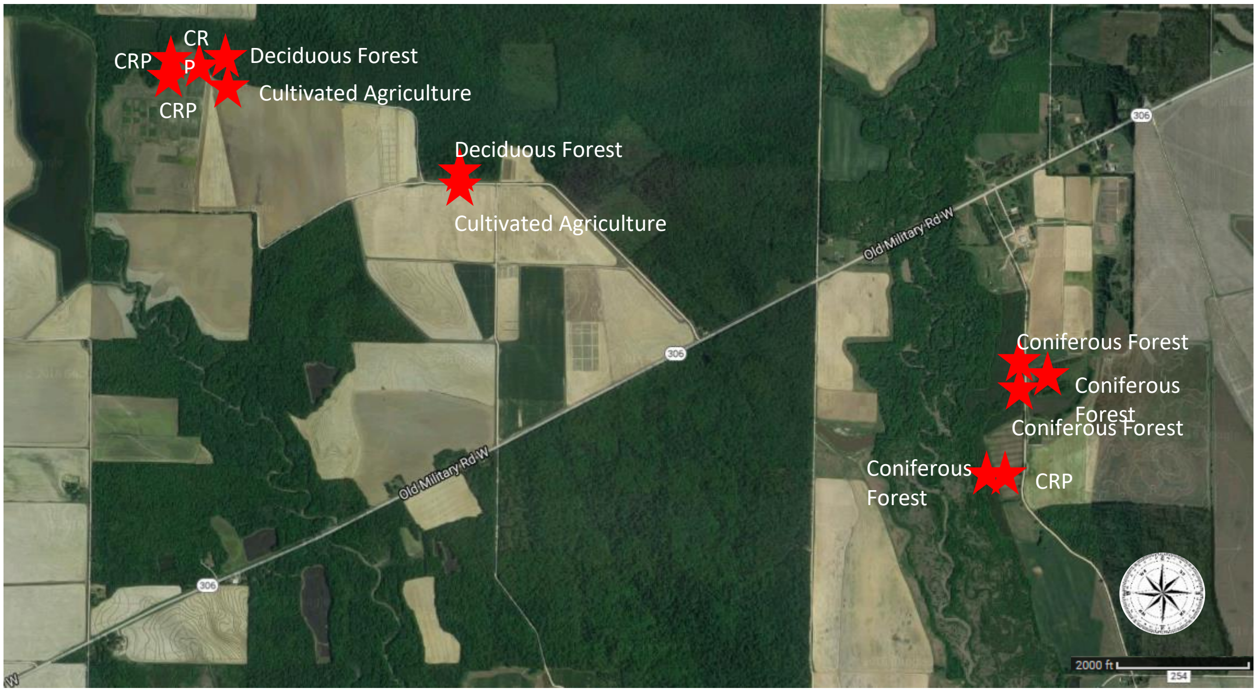

Figure 2. Infiltration measurements were conducted at 12 locations at the Pine Tree Branch Station (PTBS) near Colt, AR representing four different landuses (i.e., cultivated agriculture, Conservation Reserve Program (CRP) grassland, coniferous forest, and deciduous forest).

Figure 3. Infiltration measurements were conducted at the two native tallgrass prairie sites located north to northeast of Stuttgart, AR.