Potential impact of conservation tillage on conserving water resources in Georgia

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Abstract: Reduced tillage and surface residue increases infiltration, soil water content, and plant available water, while at the same time decreasing runoff and sedimentation. However, there is a general lack of knowledge and appreciation regarding the impact conservation tillage has on sustainable water resources. The objective of this study was to estimate water savings as a result of conservation tillage adoption in Georgia. Total acreages by crop (cotton, corn, and peanut) and tillage (conventional and conservation) were obtained via the Conservation Technology Information Center for the 2004 growing season. Rainfall simulation studies conducted over row-cropped lands in conventional and conservation tillage were obtained for soils in the Coastal Plain and Piedmont physiographies. Data were integrated within a geographical information system. In 2004, cotton, corn, and peanuts represented 85% of row crop production in Georgia, with nearly 90% of the acreage in the Coastal Plain. Conservation tillage systems are currently in place on approximately 30% of those acreages, primarily in the form of strip tillage. Results from rainfall simulation studies indicate that conservation tillage can reduce runoff and increase infiltration in these systems by 29% to 46%. Extrapolating these results to the state, conservation tillage reduced estimated statewide, irrigated water requirements from 4% to 14%. Increasing conservation tillage to 40% in intensively row-cropped counties where conservation tillage adoption rates were less than the national average (40%) increased estimated water savings by an additional 1% to 6%.

Key words: conservation tillage—geographical information systems—sustainable water use

Georgia agriculture represents a $5.8 billion dollar industry and currently ranks in the top 10% of the nation's peanut, cotton, vegetable, and poultry production (National Agricultural Statistics Service 2004). Crop production accounts for $1.8 billion, or 31% of the state's agricultural revenues. However, intense agricultural production demands more efficient use of water resources. The amount of irrigated land has increased steadily from 81,000 ha (200,155 ac) in 1970 to 606,000 ha (1,497,459 ac) in 2004 (Harrison 2005). In response to anticipated water resource concerns, Georgia has enacted a Joint Comprehensive Water Plan Study Committee and Water Planning Advisory Committee to establish a statewide water conservation plan by 2007. The Flint River Basin has also initiated a Flint River Regional Development and Conservation Plan in response to impacted flow associated with urbanization and agricultural water use. Thus, accurate assessments of agricultural water needs and the impact of the best management practices are necessary to ensure agricultural water needs are met. Adoption of conservation tillage (CsT) shows promise as a management practice for more efficient use of water resources (Reeves 1997; Truman et al. 2003), yet very little has been done to evaluate the impact of CsT on sustainable water use in Georgia.

Long-term tillage and residue management increases soil water holding capacity and infiltration, while reducing runoff and erosion (Franzeubblers 2001; Truman et al. 2003; Truman and Rowland 2005). The United States Department of Agriculture (USDA) National Resources Conservation Service (NRCS) defines residue and tillage management as a reduction in soil disturbance while actively managing the distribution of plant residues year-round. Two of the most commonly used CsT practices include strip-tillage (ST) and no-tillage (NT). Strip-tillage consists of tilling a 15 to 20 cm (6 to 9 in) strip in preparation for planting, while in NT the crop is planted directly into the killed cover crop.

The impact of tillage on infiltration and runoff was demonstrated by Truman et al. (2003) on a Rhodic Paleudult cropped to cotton using rainfall simulation. Results showed that after a two hour rainfall event (50 mm hr^{-1} [2 in hr^{-1}]) NT with fall paratilling reduced runoff by greater than 34% compared to conventional tillage (CT) treatments. More recently, Truman and Rowland (2005) reported findings from a long-term field study conducted on two Coastal Plain soils. In their study, ST systems significantly reduced runoff and increased infiltration compared to CT treatments. During peak runoff events, maximum runoff rates from CT treatments were five times greater compared to CsT treatments. Truman and Rowland (2005) demonstrated the impact of tillage regime on rainfall partitioning was nonexistent in year one of the study. However, in years two to six, ST treatments increased infiltration, soil water content and estimated plant available water content by 30%, 40% to 50%, and 50%, respectively.

Maintaining plant available soil water is particularly important in the humid, southeastern United States, where long and sometimes drought-prone growing seasons necessitate supplemental irrigation. Truman and Rowland (2005) showed that measured plant water use for cotton and peanut in a ST system was 20% to 50% less compared to CT treatments with similar yields. In their study, actual plant water use was measured directly and compared to estimated plant available water obtained via rainfall simulation data. Estimated plant available water content compared well with measured plant water use.

To date, reduced tillage with residue management is one of the most well-known conservation practices. Recent estimates

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Table 1
Site descriptions for rainfall simulation studies.

Site	Map unit name	Family	Tillage treatments	Time in tillage (years)
Gibbs Farm	Tifton loamy sand, 2%	Fine, loamy, siliceous, thermic, Plinthic Kandiudult	ST	6
			CT	6
E.V. Smith	Compass loamy sand, 1%	Coarse-loamy, siliceous, thermic, Plinthic Paleudult-Typic Hapludult	NT+PT	10
			NT	10
			CT+PT	10
			CT	10
J.P. Campbell	Cecil sandy loam, <1%	Clayey, kaolinitic, thermic, Typic Kanhapludult	NT	15
			CT	15
Belle Mina	Decatur silt loam, <1%	Fine, kaolinitic, thermic, Rhodic Paleudult	NT+PT	10
			NT	10
			CT	10

Notes: Treatments include conventional tillage (CT), strip tillage (ST), and no tillage (NT). Tillage treatments receiving paratillage are denoted (+PT).

of CsT practices indicate 41% of row crop producers have adopted CsT practices nationwide (CTIC 2004). Reeves et al. (2005) estimate that CsT in Georgia currently saves enough water to sustain 2.8 million people per year. Furthermore, their data suggest that annual soil and water quality savings can be as high as $245 million. These findings have established the need for a comprehensive analysis of water savings associated with the adoption of CsT.

The underlying hypothesis of this study is that CsT systems can be used to conserve water resources in two predominant physiographic regions in Georgia. This hypothesis was evaluated by integrating measurable differences in infiltration under variable tillage and residue management regimes with county level estimates of crop acreage, soil distributions, irrigation and CsT using a geographic information system (GIS). Our goal was to estimate potential water savings under current and increasing CsT adoption in Georgia.

Methods and Materials

Rainfall Simulation Data. Rainfall simulation data were archived from two extensive and previously published datasets (Truman et al. 2005, 2003), as well as data collected from two unpublished studies. Sites were located in the Southern Coastal Plain (E.V. Smith and Gibbs farm), Southern Piedmont (J.P. Campbell) and Limestone Valley (Belle Mina). Sites were selected to be most representative of production systems in each physiographic region. In the Coastal Plain, study sites were located on gently sloping, well-drained soils (USDA 2005c). Compared to the Coastal Plain, study sites in the Piedmont and Limestone Valley physiographic regions were more highly eroded (USDA 1994). Due to limited availability of rainfall simulation datasets, the fourth site was located in the Limestone Valley region of Alabama, having a similar crop rotation and surface soil properties to those at the Piedmont location. Site descriptions are provided in table 1.

Rainfall simulation was conducted proximate to planting to evaluate tillage and residue management impacts on infiltration. The following text describes the rainfall simulation procedure. For a more detailed description the reader is referred to Truman et al. (2005, 2003).

Triplicate 6 m^2 (2 m wide and 3 m long [6.5 ft wide and 10 ft long]) rainfall simulation plots were established on each tillage treatment for each site. A rainfall simulation plot consisted of a flume and metal borders to prevent water from running into or out of the plot area. An area surrounding each 6 m^2 (65 ft^2) plot was treated like the test area to allow soil material to be splashed in all directions and to sample soil. Simulated rainfall was applied to each 6 m^2 plot at a target, constant intensity of 50 mm h^{-1} (2 in hr^{-1}) for one hour. The target intensity is representative of the average amount of rainfall expected to occur over one hour during a typical spring rainfall event in the Coastal Plain or Piedmont.

The average, minimum, and maximum infiltration for each physiographic region and tillage regime (CT vs. CsT) were used to generate a range in expected water savings using the Conservation Tillage Effects Assessment (CTEA). It should be noted that seasonal rainfall patterns may vary in duration and intensity. Thus, the amount of infiltrated rainfall may be greater or less than what was observed during a simulated event.

Conservation Tillage Effects Assessment. For the purpose of this paper, we are evaluating differences in irrigated water requirements in conventional and CsT systems to estimate the potential for CsT to conserve water. Estimates of agricultural water use developed in this paper are not absolute and do not represent actual plant water use. In much of the Coastal Plain, irrigation water comes from ground water resources. This may not be entirely true for the Piedmont. However, the Piedmont represents less than 10% of the row cropped area discussed in this manuscript (USGS 2005b; CTIC 2004).

Three GIS coverages were used to provide a foundation for the CTEA. The coverages included Georgia major land resource areas (MLRAs) (USGS 2005b), Georgia county boundaries, and Georgia State Soil Geographical (STATSGO) database (USDA 1991). Based on the Georgia MLRA coverage, the Southern Coastal Plain and Southern Piedmont account for 67% of the total land area (figure 1). The CTEA was used to evaluate water savings in counties having greater than 75% of the total land area within the Coastal Plain and Piedmont. This was done to maintain the integrity of county level information along the boundary of each physiographic region.

The Georgia STATSGO database is a broad assessment of state soil and nonsoil areas that occur in repeatable patterns across the state (USDA 1991). Based on the STATSGO coverage, a soil textural class designation was assigned to each county. Textural class designations indicate a specific textural class can be found in greater than 75% of the total land area within a county. Loamy sand (54%) and sandy loam (40%) epipedons accounted for a majority of surface soils mapped in the Coastal Plain and Piedmont MLRAs.

Next, tillage and crop information were added to the GIS. The Conservation Technology Information Center (CTIC) provided a current (2004) estimate of row crop acreages and tillage practices at the county level (CTIC 2004). The CTIC uses a roadside survey and may over-estimate crop residue cover in the 25% to 35% cover range compared to in-field line-transect estimates (Thoma et al. 2004). However, CTIC is currently the only known, national estimate of CsT adoption. Tillage data were aggregated into two groups: CT (<30% residue cover) and CsT (>30% residue cover) for each crop. ST accounted for greater than 90% of CsT practices in the Coastal Plain and Piedmont (CTIC 2004). These data did not include peanuts, which are traditionally grown in CT systems. Although it is recognized that the adoption of CsT among peanut producers is increasing (Wright 2002), for this study, we assumed that all peanuts were CT, and peanut acreages were obtained via the 2002 USDA National Agricultural Statistics Service (NASS) dataset (USDA NASS 2002).

We have assumed all systems observe USDA Natural Resource Conservation Service (NRCS) recommended management of crop residue cover, cover crop, and tillage (USDA 2005a). Current NRCS recommendations for Georgia require a minimum of 30% crop residue cover at planting, suggest paratillage every 18 months, and suggest an annual cover crop be planted in late October to early November. Because hydrologic benefits may be seen only in the second and third years of continuous CsT (Truman and Rowland 2005; Truman et al. 2003; Franzuebblers 2001; Terra et al. forthcoming), we assumed all CsT fields have been in practice for a minimum of two years.

Precipitation data were acquired via the National Weather Service Forecast Center (NWSFC, Peachtree City, Georgia) from several weather stations in the state and represent the minimum, average, and maximum monthly rainfall observed over a 30-year period (1971 to 2000). Since water is generally not limiting during maximum rainfall years, these data were not included in the analysis. Rainfall data were assimilated first by physiographic region and then by growing season for cotton (May to September), corn (March to July) and peanuts (May to September) (table 2).

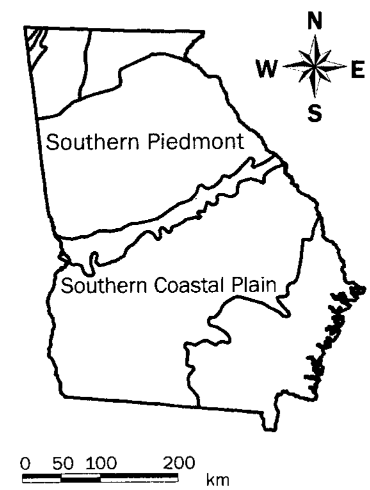
Baseline water requirements for each crop were obtained via University of Georgia Cooperative Extension Service recommendations. Water requirements reflect the minimum amount of water (rainfall and irrigation) necessary to achieve adequate yields for cotton, corn, and peanuts. Recommended water requirements ranged from 0.23 to 0.26 ha-m (22 to 25 ac-in) for 8 to 10 Mg ha^{-1} (8,960 to 11,200 lb ac^{-1}) yields for corn (Rhoads et al. 1991), 0.22 to 0.24 ha-m (21 to 23 ac-in) for 1350 to 1680 kg ha^{-1} (1,500 to 1,880 lb ac^{-1}) yields for cotton (University of Georgia 2003), and 0.23 to 0.26 ha-m (21 to 24 ac-in) for a 4500 kg ha^{-1} (5,000 lbs ac^{-1}) yields for peanuts (Stansell and Pallas 1985).

To account for the inherent variability in soil conditions, site location, and management, the minimum, average, and maximum observed infiltration were incorporated into the CTEA. Infiltration was expressed as a percentage of rainfall (obtained via rainfall simulation) (table 3). Infiltration was assigned based on soil textural class designations for each county and tillage regime.

Irrigated land area (statewide) for each crop was expressed as a percentage based on the 2004 University of Georgia Cooperative Extension Service irrigation surveys. It was estimated that 55% of corn, 49% of cotton, and 56% of peanuts were irrigated in 2004 (Harrision 2005; CTIC 2004; USGA NASS 2002). Total irrigated acreages at the county level were calculated by multiplying the percent irrigated by cropped acres for cotton, corn, and peanuts. Irrigated acreages were further divided into irrigated CT and irrigated CsT using the percentage of CT or CsT within the county (CTIC 2004).

Based on the inputs described above (precipitation, crop water requirements, measured infiltration data, cropped area, tillage regime, and irrigated area), irrigated water demand was calculated for minimum and average precipitation years under four tillage scenarios: 0% CsT, 100% CsT, observed CsT, and the impact of a 10% increase in observed CsT. Conservation tillage effects assessment calculations assumed that infiltration was equivalent to plant available water. To demonstrate this assumption, two earlier studies evaluated hydraulic conductivity in a Piedmont and Coastal Plain soil and showed that in these systems water infiltrates much more rapidly compared to losses associated with lateral flow or ground water recharge (Bruce et al. 1983; Rasmussen et al. 2000; Washington et. al 2004). These findings were supported by West et al. (n.d.) and Schoeneberger et al. (1995), indicating a well-structured Bt horizon in these systems can lead to a perched water table. This explains the strong correlation between estimated plant available water content, calculated from rainfall simulation studies, and measured crop water use data in the Coastal Plain (Truman and Rowland 2005).

Figure 1
Georgia major land resource areas (USGS 2005b).



The CTEA was accomplished in two parts. First, irrigated crop water requirements were adjusted for in-season precipitation and tillage effects as shown in the following equation:

$$(WR) - (PPT \times INF) = AdjWR ,$$

where WR (ac-in) refers to water requirement, PPT (in) refers to in-season precipitation, INF (%) refers to the percent of infiltrated rainfall calculated via rainfall simulation for specific soil and tillage regimes, and AdjWR (adjusted water requirement [ac-in]) refers to the amount of water needed to meet crop water demand after taking precipitation into account.

Next, county level crop water use was estimated by multiplying the total acreage in each tillage group (irrigated CT or irrigated CsT) by the AdjWR and converting to megaliters (ML) of water. Total water use was determined by summing water use for irrigated CT and CsT across counties.

Table 2
Long-term (30 year) precipitation record for cotton, peanut, and corn growing seasons in the Coastal Plain and Piedmont physiographies (USGS 2000).

Physiography	Crop	Average (cm)	Minimum (cm)
Coastal Plain	Corn	63.39 (1.71)	24.90 (1.51)
	Cotton-peanut	41.51 (1.3)	20.60 (1.31)
Piedmont	Corn	68.42 (2.44)	20.67 (3.26)
	Cotton-peanut	43.77 (1.74)	13.82 (2.38)

Notes: Average and minimum rainfall during the 30-year period are reported. Standard errors calculated from precipitation records at individual weather stations within each physiography are given in parentheses.

Accuracy Assessment. To evaluate the validity of our assumptions under the CTEA, estimated water use was compared with University of Georgia Cooperative Extension Service irrigation surveys (Harrison 2005). The University of Georgia surveys are estimates of actual irrigated water use provided via county extension agents. Surveyed irrigated water use for each crop was multiplied by total irrigated area in each county. Next, linear regression analyses were used to compare the relationship between water use estimates obtained via the CTEA and extension survey data for cotton, corn and peanuts.

Impact Assessment. Water savings represent the total amount of water saved by increasing CsT adoption from zero to 100%. Based on the amount of water saved, years of water use were calculated by dividing the estimated water savings (ML) by the amount of water used per year in Fulton (237,200 ML yr^{-1} [62×10^9 gal]), Chatham (63,300 ML yr^{-1} [16×10^9 gal]), Muscogee (62,900 ML yr^{-1} [16×10^9 gal]), Bibb (213,500 ML yr^{-1} [56×10^9 gal]), Dougherty (307,300 ML yr^{-1} [81×10^9 gal]), Lowndes (46,100 ML yr^{-1} [12×10^9 gal]), Tift (38,600 ML yr^{-1} [10×10^9 gal]), and Colquitt (296,600 ML yr^{-1} [78×10^9 gal]) counties in 2000 (USGS 2000). Water use included public, domestic, irrigated, industrial, thermo-electric power, mining, livestock, commercial, and aquaculture.

Results and Discussion

Land Use Characterization. Cotton, corn, and peanuts represent nearly 85% of row crop production in Georgia, primarily in the Coastal Plain and Piedmont physiographic regions (figure 1). In 2004, nearly 797,000 ha (2 million ac) were planted with cotton, corn for grain, or peanuts in the Coastal Plain and Piedmont (CTIC 2004; USGA NASS 2002). Corn for grain accounted for 12.6%, peanuts accounted for 23.7%, and cotton accounted for 63.7%. Greater than 90% of the total row crop land area was planted in the Coastal Plain physiographic region. Because this region of the state is prone to long and often droughty growing seasons, growers rely on supplemental irrigation to achieve expected yield potential. These production systems typically rely upon center pivot or lateral move irrigation systems (Evans et al. 1998).

About 30% of row crop producers in Georgia utilize CsT, primarily in the form of ST (CTIC 2004). This is slightly less than the national CsT adoption rate of 41% (CTIC 2004). In Georgia, CsT adoption rates vary by crop and physiographic region. Although a higher CsT adoption rate was observed in the Piedmont (47%), a relatively small percentage of the land area was planted with row crops (3,700 ha [9,000 ac]) compared to the Coastal Plain (722,000 ha [1.8 million ac]) with a CsT adoption rate of 30%. When expressed by crop, CsT practices accounted for 41% of cotton and 32% of corn acreages planted in 2004. At the county level, adop-

Table 3
Rainfall simulation results for the Tifton loamy sand and Cecil sandy loam.

				Infiltration		Runoff			
Physiography	Soil	Tillage	Time in tillage regime (years)	mm h^{-1}	Percent of rainfall	mm h^{-1}	Percent of rainfall	ET assigned (mm d^{-1})	PAW_{est} (days)
Coastal Plain	Tifton	CT	6	26.0 (1.8)	51%	25.0 (1.5)	49%	7	3.7
		ST	6	44.0 (3.1)	80%	11.0 (0.6)	20%	7	6.3
	Dothan	NT–R–P	10	45.8 (1.4)	81%	10.9 (1.2)	19%		
		NT–R+P	10	45.1 (0.0)	91%	4.7 (0.5)	9%		
		NT+R–P	10	47.3 (0.0)	97%	1.6 (0.2)	3%		
		NT+R+P	10	53.6 (0.0)	97%	2.0 (0.1)	4%		
		CT–R–P	10	17.0 (1.5)	39%	26.5 (1.6)	61%		
		CT–R+P	10	48.8 (1.0)	89%	6.0 (1.1)	11%		
Piedmont	Cecil	CT	15	25.0 (9.3)	44%	31.0 (9.6)	56%	6	4.2
		ST	15	51.0 (3.6)	90%	6.0 (2.4)	10%	6	8.5
	Decatur	NT+R+P	11	47.4 (1.4)	95%	2.6 (0.7)	5%		
		NT+R–P	11	41.9 (5.0)	81%	9.4 (13.0)	19%		
		NT–R–P	11	40.6 (2.4)	83%	8.2 (2.4)	17%		
		CT–R–P	11	31.7 (1.9)	64%	18.1 (0.4)	37%		

Notes: CT = conventional tillage, ST = strip tillage, NT = no tillage, –R = residue removed, +R = residue on, +P = with paratillage, and –P = without paratillage. Standard deviations are given in parentheses. PAW_{est} = estimated plant available water content.

tion rates were more variable, ranging from 0% to nearly 100% adoption. Specifically, cotton and corn exceeded 50% adoption in 22 and 28 counties, respectively.

Rainfall Simulation and Plant Available Water Content. Data collected at the University of Georgia Gibbs farm and the J.P. Campbell research facilities demonstrate that CsT reduces runoff, increases infiltration and increases estimated plant available water content (table 3). Under the conditions evaluated here, infiltration rates for CsT treatments ranged from 44 ± 3.1 mm hr^{-1} (1.7 ± 0.1 in hr^{-1}) for ST treatments at the Gibbs farm, to 51 ± 3.6 mm hr^{-1} (2.0 ± 0.1 in hr^{-1}) for NT treatments at the J.P. Campbell research facilities. Compared to CsT, infiltration rates for conventionally managed plots ranged from 25 ± 9.3 to 26 ± 1.8 mm hr^{-1} (0.9 ± 0.4 in hr^{-1} to 1.0 ± 0.1 in hr^{-1}), regardless of physiographic region. All CsT treatments resulted in significantly higher infiltration rates compared to CT treatments. Because actual rainfall events can vary in duration and intensity, values reported here may be greater than or less than actual infiltration.

CsT treatments reduced runoff (calculated as a percentage of rainfall) by 29% and 46% at the Gibbs farm and J.P. Campbell study sites, respectively. This translates to a 29% to 46% increase in total infiltrated rainfall. To demonstrate the impact of increased infiltration, days of plant available water content were estimated using an estimated evapotranspiration rate for each soil (table 3). Plant available water estimates were based on the assumption that all infiltrating water was plant available and that evapotranspiration rates may vary according to soil specific changes and management. Based on the assumption that lateral flow and ground water recharge is minimal, it was estimated that compared to CT treatments, CsT provided an additional 2.6 days of water at the Gibbs farm and 4.3 days at the J.P. Campbell study sites (table 3). Differences in estimated plant available water between tillage systems were at least 70%, an extremely important finding for the relatively low water holding capacity soils of Georgia during drought conditions. Furthermore, literature sources suggest that CsT decreases soil evaporative losses, which were not accounted for in our estimates, and may lead to increased days of plant available water in these systems (Christensen et al. 1994; Hatfield et al. 2001).

Figure 2

Comparison between water use estimates (ML) obtained via the Conservation Tillage Effects Assessment (CTEA) and 2004 University of Georgia Cooperative Extension Service irrigation survey (Harrison 2005). Observations correspond to counties growing cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), or peanuts (*Arachis hypogaea*) within the Coastal Plain and Piedmont physiographic region.

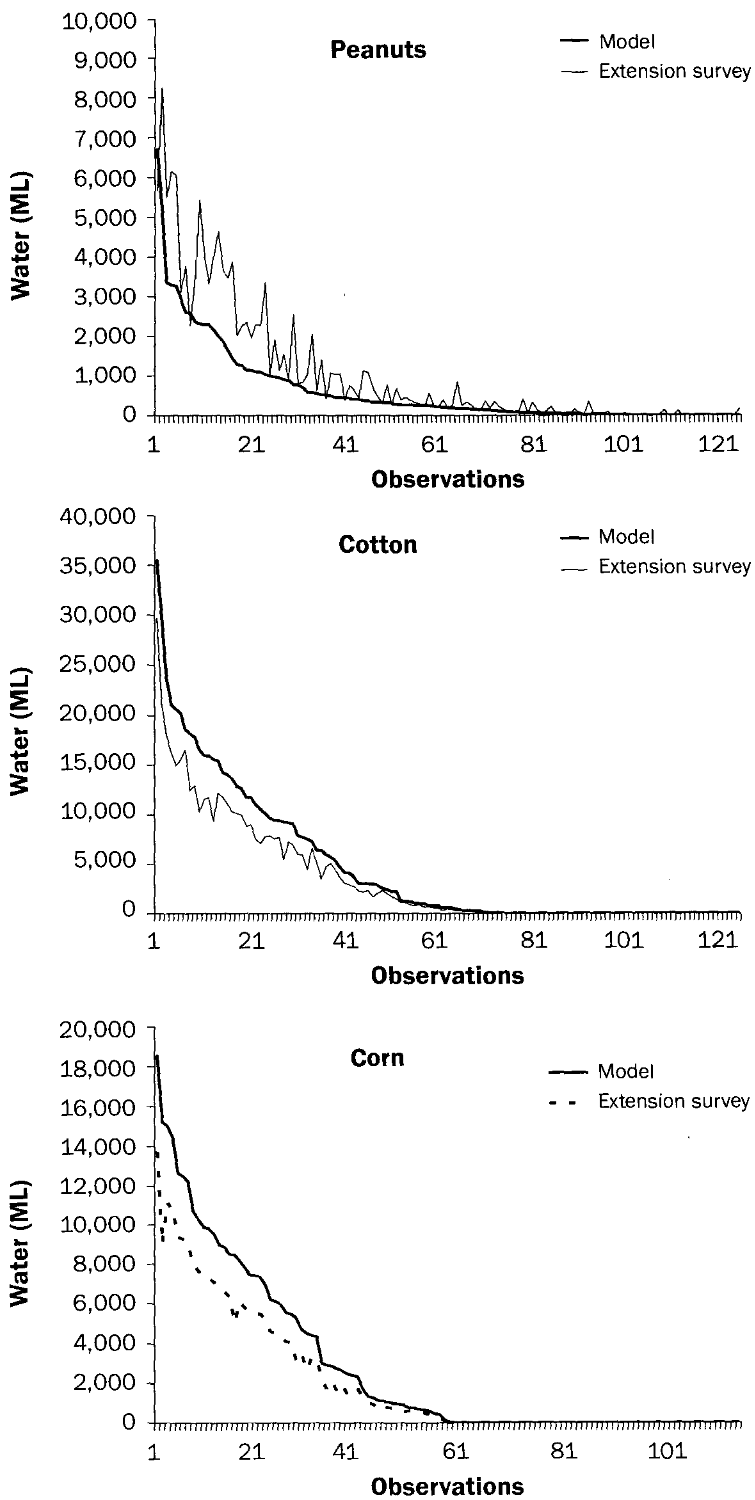


Table 4
Conservation tillage affects assessment results.

Precipitation	Conservation tillage	Total irrigated water use (ML) Min.	Average	Max.	Water savings (ML) Min.	Average	Max.
Minimum	Observed	1,921,201	1,716,352	1,599,331	103,675 (5%)	49,482 (2%)	27,308 (1%)
	+10%	1,847,986	1,666,269	1,566,370	176,890 (9%)	99,565 (5%)	60,269 (3%)
	100%	1,654,512	1,580,543	1,517,342	370,364 (18%)	185,291 (9%)	109,297 (5%)
	0%	2,024,876	1,765,834	1,626,639			
Average	Observed	1,408,790	975,030	726,503	222,126 (14%)	106,601 (7%)	58,739 (4%)
	+10%	1,311,937	929,504	703,770	318,979 (20%)	152,127 (9%)	81,472 (5%)
	100%	878,502	721,488	587,660	752,414 (46%)	360,143 (22%)	197,582 (12%)
	0%	1,630,916	1,081,631	785,242			

Note: Results are given based on the minimum, average, and maximum infiltration rates observed during rainfall simulation.

Similar observations were made at the E.V. Smith and Belle Mina Research Centers in Alabama. At the Limestone Valley site (Belle Mina Research Center), Truman et al. (2003) showed that NT with paratillage and residue management significantly increased infiltration (31% absolute) compared to CT systems. At the Coastal Plain site (E.V. Smith), Truman et al. (2005) demonstrated similar results showing NT with para-tillage and residue management increased infiltration by 58% compared to CT treatments with cover removed and no paratillage. Paratillage was a major influencing factor on infiltration in this region and increased infiltration by 10% and 50% in NT and CT treatments, respectively.

Accuracy Assessment. An accuracy assessment was conducted to evaluate the validity of the following three assumptions:

1. Infiltrating rainfall is equal to plant available water.
2. Rainfall simulation represents average observed infiltration rates for a typical spring/summer storm in the Coastal Plain and Piedmont of Georgia.
3. Conservation tillage fields observe recommended NRCS best management practices for CsT.

To do this, water use estimates obtained via the CTEA were compared with the 2004 University of Georgia Cooperative Extension Service irrigation survey data. Based on this analysis, a strong linear relationship between the University of Georgia irrigation survey (Harrision 2005) for irrigated water use and the CTEA existed ($r^2 > 0.96$, $P < 0.05$) for all crops. However, the CTEA had a tendency to overestimate seasonal water usage for cotton and peanuts by 33% to 38% (figure 2). Comparatively, the CTEA underestimated corn water usage by 40%. These data indicate that estimated water use reported here can be used to describe relative trends in agricultural water use as a function of CsT adoption and crop type. However, quantitative estimates are subject to the errors described above.

The discrepancy between the CTEA and survey data is not surprising. Differences in estimated water use are likely associated with temporal variations in precipitation patterns, not accounted for in the CTEA. Bosch et al. (1999) studied 30 years of precipitation data from a dense rain gage network in a 334 km^2 (129 mi^2) watershed in Tifton, Georgia, to evaluate the spatio-temporal variability of precipitation patterns in the Southern Coastal Plain. Bosch et al. (1999) found precipitation frequency was greatest during midsummer months; however, spatial variability in rainfall patterns was high during this time. In our study, during periods of extreme wetness or drought the CTEA may over or underestimate actual water use. Comparatively, results from the University of Georgia Cooperative Extension Service survey reflect water use as a function of 2004 growing season conditions. In 2004, growing conditions were affected by drought in late spring, followed by above average rainfall in late summer (Harrison 2005). Thus, for cotton and peanuts, which require water through August and September, it is reasonable to expect that the extension survey data would more accurately represent water use compared to the CTEA.

Conservation Tillage Effects Assessment. In an average rainfall year, CsT systems may have a substantial impact on water savings. Under the current CsT adoption rate, it is estimated that CsT currently reduces irrigated water requirements by 4% to 14% or 58,739 to 222,126 ML (15.5 to 58.7 × 10^9 gal). Using the average infiltration rate, the average expected water savings was 7% or an estimated 106,601 ML (58.7 × 10^9 gal) (table 4). Increasing the adoption of CsT by 10% resulted in estimated water savings of 5% to 20%, a 1% to 6% increase over water savings at the current CsT adoption rate. Moreover, if all irrigated row cropped lands (cotton, corn, and peanuts) in the Coastal Plain and Piedmont adopted CsT, estimated statewide water savings would peak between 12% to 46%, with an average estimated water savings of 22% or 360,143 ML (95 × 10^9 gal).

Results are a function of the variability in infiltration rates observed during rainfall simulation studies. Using the minimum observed infiltration rates, estimated water savings increased steadily with increasing adoption of CsT, ranging from 14% to 46% (table 4). Using the maximum observed infiltration rate for both tillage systems, estimated water savings ranged from 4% to 12%. The observed differences in water savings is likely due to the fact that paratillage in some Coastal Plain systems can lead to infiltration rates as high as 89%, in some cases approaching or exceeding infiltration rates observed for NT systems (table 3) (Truman et al 2005). Data demonstrate that although variability in soil, landscape position, and management practice can impact infiltration, relative water savings associated with CsT adoption can be observed.

During drought years, at the observed CsT adoption rate, estimated water savings ranged from 1% to 5% (table 4). Increasing the adoption rate of CsT by 10% brought total estimated water savings to 3% to 9% with a maximum savings of 5% to 18% if all row cropped lands adopted CsT. Using the average infiltration rate to estimate savings,

Table 5
Urban water use savings (expressed in years) as a function of water saved under the observed conservation tillage adoption rate (University of Georgia survey) and an overall increase in conservation tillage by 10%.

		Minimum PPT (years)			Average PPT (years)		
County	Tillage	Min.	Average	Max.	Min.	Average	Max.
Bibb	Survey	0.49	0.23	0.13	1.04	0.50	0.28
	+10%	0.83	0.47	0.28	1.49	0.71	0.38
Chatham	Survey	1.64	0.78	0.43	3.51	1.68	0.93
	+10%	2.79	1.57	0.95	5.04	2.40	1.29
Colquitt	Survey	0.35	0.17	0.09	0.75	0.36	0.20
	+10%	0.60	0.34	0.20	1.08	0.51	0.27
Dougherty	Survey	0.34	0.16	0.09	0.72	0.35	0.19
	+10%	0.58	0.32	0.20	1.04	0.50	0.27
Fulton	Survey	0.44	0.21	0.12	0.94	0.45	0.25
	+10%	0.75	0.42	0.25	1.34	0.64	0.34
Lowndes	Survey	2.25	1.07	0.59	4.82	2.31	1.27
	+10%	3.84	2.16	1.31	6.92	3.30	1.77
Muscogee	Survey	1.65	0.79	0.43	4.82	1.69	0.93
	+10%	2.81	1.58	0.96	5.07	2.42	1.29
Tift	Survey	2.68	1.28	0.71	5.75	2.76	1.52
	+10%	4.58	2.58	1.56	8.25	3.94	2.11

Notes: PPT = precipitation. Data are reported for average precipitation and drought years and calculated based on the minimum, average, and maximum infiltration rates observed during rainfall simulation. Calculations were made by comparing the amount of water saved via conservation tillage to water demand in eight Georgia counties in 2000 (USGS 2000).

this amounts to 49,482, 99,565, and 185,291 ML (13×10^9, 26×10^9, and 49×10^9 gal) of water under the observed, 10% increase and 100% CsT adoption scenarios, respectively.

Comparing water savings between average and minimum precipitation years illustrates the potential of CsT to conserve water resources statewide. During an average year estimated water savings were 31,431 to 118,451 ML (8 to 31×10^9 gal) greater compared to savings in a drought year. In drought years, water savings decrease as a majority of crop water is supplied via irrigation in both tillage systems. However, it is important to note that relative water savings associated with the adoption of CsT were observed under drought conditions.

Impact Assessment. Expanding urban water needs are currently being met through increasing surface water withdrawals from the Chatahoochee, Coosa, and Altamaha river basins (USGS 2005a). This has resulted in a statewide initiative to improve water use efficiency and sustainability (Cummings et al. 2005). State mandated water conservation plans necessitate an accurate understanding of the impact that best management practices have on conserving water.

Using the observed CsT adoption rate, precipitation in an average year, and estimated water use in 2000, it is estimated that CsT saves the equivalent of 0.20 to 0.75 years (Colquitt and Dougherty Counties-urban) or 1.5 to 5.8 years (Tift County-rural) of water use (table 5). Increasing CsT adoption by 10% increases estimated water savings to 0.27 to 1.1 years in Colquitt and Dougherty Counties and 2.1 to 8.3 years in Tift County. In drought years, estimated water savings under the current CsT adoption rate range from 0.09 to 0.35 years (Colquitt and Dougherty Counties) or 0.71 to 2.7 years (Tift County) (table 5). These estimates are promising, considering the impact CsT systems may have on water resources during water scarcity.

In addition to efforts at the state level to improve water use efficiency, the U.S. federal government has spent $1.9 billion in 2004 and 2005 on the Environmental Quality Incentives Program (EQIP) (USDA NRCS 2005b). The EQIP program facilitates the adoption of best management practices, one of which is CsT. Thus, a more relevant question to ask is, where does CsT have the greatest impact on sustainable water use? Currently, counties having the greatest impact on water savings are nearly all located in the Southern Coastal Plain. These counties represent areas of intensive row crop production (>1% of the state's cotton and corn), and currently exhibit CsT adoption rates in excess of 40%. This area corresponds to 24,702 ha (61,040 ac) of corn and 183,308 ha (452,964 ac) of cotton.

Counties with the potential to influence water savings were also located primarily in the Coastal Plain. Greater than 50% of corn and cotton, and nearly 90% of peanuts are planted in row crop intensive counties that exhibit CsT adoption rates less than 40%. Thus, if CsT adoption rates in these counties were increased to 40%, estimated water savings would increase by 5% to 20%, with an average estimated savings of 10% (157,482 ML [41.6×10^9 gal]). Based on estimates of water use in 2000, this is equivalent to an additional 0.66 years of water supply in Fulton and Bibb Counties (urban) or four years in Tift County (rural). Water savings were calculated for an average precipitation year.

Summary and Conclusions

Our study integrated rainfall simulation results from conventional and CsT studies in predominant soils of the Coastal Plain and Piedmont, with currently available crop, tillage, and soil surveys. Data were used to estimate potential water savings associated with increasing CsT adoption. Estimated savings were based on three primary assumptions: (1) infiltrating rainfall is equal to plant available water, (2) rainfall simulation represents average observed infiltration rates for a typical spring/summer storm in the Piedmont or Coastal Plain of Georgia, and (3) CsT fields observe recommended NRCS best management practices for CsT. Results indicate that CsT currently reduces estimated irrigation water requirements by 4% to 14% compared to estimated water use under 100% CT. Water savings were greatest in an average precipitation year. During drought years, a majority of crop water requirements were supplied via irrigation. Variability in water savings was a function of the range in infiltration rates observed during experimental rainfall simulation studies. Data suggest that although soil, landscape position, and management practices are variable throughout the state, estimated water savings increase with increasing adoption of CsT practices.

The impact of CsT was also expressed in terms of days of water use. Using estimated water savings from the CTEA and water use in 2000 (USGS 2005a), CsT may save the equivalent of 0.2 to 6.0 years of water use as a function of county water demands in average precipitation years. Because of the potential for conservation systems to conserve water, a GIS was used to select intensively cropped counties with CsT adoption rates below the national average (40%). By increasing CsT to 40% in targeted counties, estimated water savings increased an additional 1% to 6%.

References

Bosch, D.D., J.M. Sheridan, and F.M. Davis. 1999. Rainfall characteristics and spatial correlation for the Georgia Coastal Plain. Transactions of the American Society of Agricultural Engineers 42:1637-1644.

Bruce R.R., J.H. Dane, V.L. Quisenberry, N.L. Powell, and A.W. Thomas. 1983. Physical Characterization of Soils in the Southern Region: Cecil. Southern Coop. Series Bulletin No. 267. Athens, GA: University of Georgia.

Christensen, N.B., T.L. Jones, and G.J. Kauta. 1994. Infiltration characteristics under no-till and clean-till furrow irrigation. Soil Science Society of America Journal 58:1495-1500.

CTIC (Conservation Technology Information Center). 2004. National Crop Residue Management Survey. West Lafayette, IN: Conservation Technology Information Center.

Cummings, R.G., M.B. Walker, and K. Ackaramongkolrotn. 2005. Georgia's agricultural water use metering program: Using results to benefit farmers and the state. Water Policy Working Paper no. 2005-006. Albany, GA: Georgia Water Policy and Planning Center.

Evans, R.O., K.A. Harrison, J.E. Hook, C.V. Privette, W.I. Segars, W.B. Smith, D.L. Thomas, and A.W. Tyson. 1998. Irrigation Conservation Practices Appropriate for the Southeastern United States. Project Report 32. Atlanta: Georgia Geologic Survey, Environmental Protection Division, Georgia Department of Natural Resources.

Foster, G.R., W.H. Neibling, and R.A. Natterman. 1982. A programmable rainfall simulation. Transactions of the American Society of Agricultural Engineers Paper No. 82-2570.

Frauenfeld, B. and C.C. Truman. 2004. Variable rainfall intensity efforts on runoff and interrill erosion from two Coastal Plain Ultisols in Georgia. Soil Science 169:143-154.

Franzuebblers, A.J. 2001. Water infiltration and soil structure related to organic matter and its stratification depth. Soil and Tillage Research 66:197-205.

Gardner, W.H. 1986. Water content. *In* Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods, Agronomy Monograph No. 9, 2nd ed., ed. A. Klute, 493-594 Madison, WI: American Society of Agronomy-Soil Science Society of America.

Harrison, K.A. 2005. Irrigation Survey for Georgia, *In* Proceedings of the 2005 Georgia Water Resources Conference, April 25-27, 2005, ed. K.J Hatcher. Athens, GA: University of Georgia Institute of Ecology.

Hatfield, J.L., T.J. Sauer, and J.H. Preuger. 2001. Managing soils to achieve greater water use efficiency: A review. Soil Science Society of America Journal 93:271-280.

Perkins, H.F., J.E. Hook, and N.W. Barbour. 1986. Soil Characteristics of Selected Areas of the Coastal Plain Experiment Station and ABAC Research Farms. Research Bulletin No. 346. Georgia Agricultural Experiment Station, College of Agriculture, University of Georgia.

Rasmussen T.C., R.H. Baldwin Jr., J.F. Dowd, and A.G. Williams. 2000. Tracer vs. pressure wave velocities through unsaturated saprolite. Soil Science Society of America Journal 64:75-85.

Reeves, D.W. 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil and Tillage Research 43:131-167.

Reeves, D.W., M.L. Norfleet, D.A. Abrahamson, H.H. Schomberg, H. Causarano, and G.L Hawkins. 2005. Conservation tillage in Georgia economics and water resources, *In* Proceedings of the 2005 Georgia Water Resources Conference, April 25-27, 2005, ed. K.J Hatcher. Athens, GA: University of Georgia Institute of Ecology.

Rhoads, F.M., and C.D. Yonks. 1991. National Corn Handbook. NCH 20. Ames, IA: Iowa State University Extension.

Schoeneberger P.J., A. Ammozegar, and S.W. Buol. 1995. Physical property variation of a soil and saprolite continuum at three geomorphic positions. Soil Science Society of America Journal 59:1389-1397.

Stansell, J.R. and J.E. Pallas. 1985. Yield and quality response of Florunner peanut to applied drought at several growth stages. Peanut Science 12:64-70.

Terra, J.A., J.N. Shaw, D.W. Reeves, R.L. Raper, E. van Santen, E.B. Schwab, and P.L. Mask. Forthcoming. Soil management and landscape variability affects field-scale cotton productivity. Soil Science Society of America Journal.

Thoma, D.P., S.C. Gupta, and M.E. Bauer. 2004. Evaluation of optical remote sensing models for crop residue cover assessment. Journal of Soil and Water Conservation 59:1-9.

Truman, C.C., J.N. Shaw, and D.W. Reeves. 2005. Tillage effects on rainfall partitioning and sediment yield from an ultisol in central Alabama. Journal of Soil and Water Conservation 60:89-98.

Truman, C.C., D.W. Reeves, J.N. Shaw, A.C. Motta, C.H. Burmester, R.L. Raper, and E.B. Schwab. 2003. Tillage impacts on soil property, runoff, and soil loss variations from a Rhodic Paleudult under simulated rainfall. Journal of Soil and Water Conservation 58: 258-267.

Truman, C.C. and D.L. Rowland. 2005. Conservation tillage to manage water and supplemental irrigation in Georgia, *In* Proceedings of the 2005 Georgia Water Resources Conference, April 25-27, 2005, ed. K.J Hatcher. Athens, GA: University of Georgia Institute of Ecology.

University of Georgia. 2003. UGA 2003 Cotton Production Guide. Athens, GA: University of Georgia Cooperative Extension Service.

Washington, J.W., D.M. Endale, L.P. Samarkina, K.E. Chappell. 2004. Kinetic control of oxidation state at thermodynamically buffered potentials in subsurface waters. Geochemica et Cosmochimica Acta 68(23):4831-4842.

USDA (United States Department of Agriculture). 1991. State Soil Geographic (STATSGO) Database. Publication Number 1492. Washington, DC: US Government Printing Office.

USDA. 1994. National Cooperative Soil Survey. Washington, DC: US Government Printing Office.

USDA NASS (United States Department of Agriculture National Agricultural Statistics Service). 2002. Crops county data. USDA NASS. http://151.121.3.33:8080/Census/Create_Census_US_CNTY.jsp.

USDA NASS. 2004. Georgia ag facts. USDA National Agricultural Statistics Service. http://www.nass.usda.gov/Statistics_by_State/Georgia/index.asp.

USDA NRCS (United States Department of Agriculture Natural Resources Conservation Service). 2005a. Electronic Field Office Technical Guide. Tift County GA: USDA NRCS. http://www.nrcs.usda.gov/technical/efotg.

USDA NRCS. 2005b. Environmental Quality Incentives Program. Washington, DC: USDA NRCS. http://www.nrcs.usda.gov/programs/eqip/.

USDA NRCS. 2005c. Web Soil Survey. Washington, DC: USDA NRCS. http://websoilsurvey.nrcs.usda.gov/app/.

USGS (United States Geological Survey). 2000. Georgia Water Information Network (GWIN). Washington, DC: USGS. http://ga2.er.usgs.gov/gawater/waterusega.cfm.

USGS. 2005a. Atlanta area water supply and use. Washington, DC: USGS. http://ga.water.usgs.gov/olympics/atlanta.wu.html.

USGS. 2005b. Download major land resource areas of the conterminous U.S. Washington, DC: USGS. http://sobo.cr.usgs.gov/QM/DLMRLA.htm.

West, L.T. Professor; Crop and Soil Sciences Dept. University Of Georgia, Athens, GA.

Wright, D.L., J.J. Marois, J.R. Rich, R.K. Sprenkel, and E.B. Whitty. 2002. Conservation Tillage Peanut Production. SS-AGR-185. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.