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MODELING SOIL COMPACTION WITH SOIL ELECTRICAL CONDUCTIVITY AND YIELD FOR COTTON

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Abstract

Cone index (CI) penetration profiles were recorded up to a depth of 45 cm (18 in.) in two cotton fields in the State of Arkansas. In the field in Forrest City profiles at 369 locations along a transect measuring approximately 1600 m (1 mile) in length and 200 m (1/8 mile) in width were collected. In the field in Fayetteville, 48 profiles were collected in 1307.5 cm X 359.6 cm (429 ft. X 118 ft.) area. Electrical Conductivity (ECa) was measured in only Forrest City field. Electrical Conductivity and the maximum soil compaction at depths beyond 4 inches were found highly correlated to each other (R^2>0.90). An average plant yield was measured for each plot based on machine harvest in the first field and hand-harvest in the second field respectively. Average yield was compared to maximum CI beyond 10 cm (4 in.) depth. Maximum CI readings at or above 1.38 MPa (200 psi) resulted in below average yields for 75-percent of the readings exceeding this limit. Yield was not strongly correlated with CI, and correlation coefficients was 0.067 for the Fayetteville field and ranged 0.008 to 0.017 for Forrest City Field, but showed a very significant trend of negative relationship between yield and the mean CI values as expected.

Introduction

Soil compaction is a serious problem for Arkansas farmers. Field machinery is becoming heavier day by day, and there is motivation for farmers to work the soil when it is moist to reduce efforts. Compacted soil has smaller pores and fewer natural channels and hence water infiltration is drastically reduced. It causes increased surface wetness, increased runoff and erosion, and longer drying time. Wet fields delay planting and harvesting and decrease crop yields. Plant roots get more resistance to growth in compacted soils, causing inadequate moisture and nutrients absorption by the plant. Plant growth solely depends on rooting ability, nutrient status and accessibility of roots to nutrient, soil aeration, and water availability.

Soil compaction maps and soil electrical conductivity maps have been investigated to explain within-field yield variation. Perumpral (1987) studied soil compaction caused by wheel traffic and tillage operations and concluded that it can cause yield depression within fields. Clark (1999) investigated the use of cone penetrometer data to develop soil strength maps at several different spatial scales. Bakhsh et al. (2000) showed that low yield was influenced by soil and topography and high yield was influenced by topography and management practices.

Soil compaction is very important factor from the economic considerations of farming practices. Fulton et al. (1996) researched the spatial variability of bulk density and CI and the economic feasibility of variable depth tillage. Both factors are related to soil strength and quantify soil compaction. They concluded that little correlation existed between bulk density and CI at high moisture contents (28-30% dry basis). They selected a CI value of 2 MPa (300 psi) as the root-impeding layer and as an indicator of compacted soil. It was determined that site-specific subsoiling at a critical CI value of 2 MPa (300 psi), compared to field scale subsoiling, could reduce fuel consumption by 50 percent. Doerge et al. (1999) used EC maps to visually correspond the patterns of yield, to explain yield variation. EC data were significantly correlated to yield, elevation, plant population, surface hydrology, and remotely sensed data.

Researchers have attempted to relate soil compaction and yield, soil conductivity and yield for the crops such as corn or soybean, however there has been no attempt to investigate a relationship between soil compaction and electrical conductivity or soil conductivity and yield for cotton fields in Arkansas.

Objectives

Research was initiated investigate the impact of soil compaction on cotton yield, and to identify precision methods to map soil compaction in a field. The specific objectives of this study were to:

1. Map soil compaction and ECa in experimental fields.
2. To test the ability of soil electrical conductivity measures such as VERIS data to map soil compaction in Arkansas Delta Soils.

Material and Methods

Two cotton fields in State of Arkansas, a 160-acre irrigated grower's cotton field in Forrest City and another 1.16-acre, non-irrigated field in Arkansas Agriculture Experiment Station in Fayetteville were chosen for 2003 experiments (Fig. 1 and 2). A 33-acre experimental area within the large field in Forrest City was selected based on discussions with the cooperating producer about yield variability and topography. Seven plots, each 12 rows wide (40 feet) were under observation. Experimental Designs for these fields were as shown in Fig. 3. The 1.16- acre field was an experimental field with 16 plots (each four rows wide). It was treated with four tillage treatments namely Control (no soil disturbance, no-till), Conventional (chisel, disked and bedded), Chisel compacted (by running a tractor or a roller) and compacted with no-till (by running a tractor or a roller) to create different levels of compaction (Fig. 3). These fields were harvested on November 1st and 21st, 2003 respectively. The general elevation and coordinates were measured with a Leica 500 Standard Global Positioning System (GPS) for the Forrest City field whereas Trimble TSC1 Asset Surveyor GPS unit was used for the Fayetteville Field. Electrical Conductivity for the Forrest City field was measured with Veris 2000 XA Soil EC Mapping System.

The soil composition in Forrest City included Loring silt loam with 1-3 % slopes at the North and South ends of the field, and Arkabulta silt loam and Loring silt loam with 3-8 % slope in the middle (Fig. 4). Soil types in Fayetteville were not available at the time of the research. COTMAN data was also collected for the experimental plots in Forrest City.

Cotton yield for each plot in Forrest City field was determined along with other COTMAN data. The yield determination procedure was different for the Fayetteville field. Cotton was hand picked from two distinct locations in each plot, from one square meter area. The cotton bolls were dried at 120^0 F for three days. The closed bolls at the time of harvest opened after drying. The yield for each plot was then determined by averaging the yield at 2 locations. Other measurements in this field included plant population, soil compaction with a digital cone penetrometer (Spectrum Technologies, Field Scout – SC 900), and plant reflectance with a spectroradiometer (Stellar Net - EPP2000 C-50).

Soil compaction was measured in both the experimental fields with a digital cone penetrometer. Spectrum Technologies "Field Scout" Model SC900 soil compaction meter was manually driven at a penetration rate not exceeding 182 cm/min (72 in/min). It had a standard cone with a diameter of 12.83 mm (ASAE S313.3, 2001). Data were automatically recorded with an inbuilt data logger in the compaction meter. Penetration profiles were recorded at center of the crop row at every 30 feet in the center row in each plot for the Forrest City field, In Fayetteville field, the profiles were taken at every 20 feet in each plot.

Spatial data layers were generated in ArcView 3.2 and ArcGIS 8.2 using the location information collected using Leica 500 standard Global Positioning System in Forrest City. Trimble TSC1 Asset Surveyor was used in Fayetteville for obtaining location information in Fayetteville. Linear regression analysis was performed for each field separately to investigate possible statistical links between soil electrical conductivity, cotton yield and soil compaction.

Results and Discussion

Compaction values along each transect showed significant variability. This table does not provide any information on the effect experiment. The maximum average soil resistance in Forrest City field was 1.7 MPa (251.37 psi) at 100 cm (4 inches) of depth, whereas it was 1.74 MPa (253.46 psi) at 15.24 cm (6 inches) in Fayetteville. The yield for each plot in Forrest City field ranged from 1142.68 to 1516.54 kg (2519.2 to 3343.4 lbs per acre) and for the Fayetteville Field it was 1189.04 to 1877.69 kg (2621.4 to 4139.6 lbs per acre). Soil electrical conductivity was measured only in Forrest City cotton field. It ranged from 3.9 to 42.8 siemens/m averaged to 12.7 siemens/m. A typical compaction profile with mean CI recorded at increment at each at all locations in the fields showed that maximum compaction occurred between 4 to 6 inches depths (Fig. 5). The results of an attempt to establish relationship between the parameters observed such as soil compaction, electrical conductivity and yield are presented below.

A) Electrical Conductivity and Soil Compaction

Soil Compaction values were obtained for depths up to 18 inches. Classification of the CI values were done based on one of the most popular type of classification, Natural Brakes as it identifies brake points by looking for groups and patterns inherent in data (Jenks, 1976). An arithmetic average of the values in the range of each of 10 classes is taken for statistical analysis. Similar classification was performed for the soil electrical conductivity data (Table 1). Higher soil compaction areas exhibited higher soil electrical conductivity at depth 4, 5 and six inches (Fig. 6a, 6b and, 6c). A strong linear correlation exists between electrical conductivity and mean CI at the depths where the maximum CI existed (CI> 200 psi) (R^2 = 0.92 at 4 inches depth, 0.99 at 5 inches, and 0.98 at six inches depth, Fig. 7, Table 2). The reason of strong correlation between EC and soil compaction can be supported based on the pore continuity and its effects. Conductivity of electricity in soils takes place through the moisture filled pores that occur between individual soils particles. Therefore the EC of soil can be influenced by interaction between the pore continuity and soil compaction. Soils with water filled pore that are connected directly with the neighboring soil pores tend to conduct electricity more readily. Soil with high clay content have numerous, small water filled pores that are quite continuous and usually conduct electricity better than sandier soils. The soils present in the study area in Forrest City are Loring silt loam and Arkabulta silt loam. These soils contain higher moisture. Logically, the soil compaction should normally increase with soil EC.

B) Yield and Soil Compaction

The yield values for both the fields did not vary significantly. Typical scattergrams of the yield versus average CI at four inches of depth for the two cotton fields showed no trend in the data. (Fig. 8) Yield values varied with soil compaction treatments (Table 3). Yield value was the lowest for one of the chiseled and compacted plots (1226.25 kg/acre) and the average yield for the plots underwent the compaction treatment was also low (1382.27 kg/acre). The plots which, received the conventional soil-treatments (Chiseling, disking and bedding), yielded the highest average value of 1643.58 kg/acre. Yield and soil compaction values were plotted for 11 different incremental depth levels for Fayetteville cotton field. Yield was not strongly correlated with CI, and correlation coefficient was 0.067 for the Fayetteville field and ranged 0.008 to 0.017 (Table 4) for Forrest City Field.

A plausible explanation could be that a good soil for crop production contains about 25 percent water and 25 percent air by volume. This 50 percent is referred to as pore space. The remaining 50 percent consists of soil particles. Anything, for example tillage and wheel traffic that reduces pore space results in a dense soil with poor internal drainage and reduced aeration. In turn more resistance is offered to the downward root growth. The plant will be deprived from nutrients present in deeper soil layers causing reduced physical plant growth and reduced yield.

Conclusion

We found that the CI greater than 1.38 MPa (200 psi) through the depth between 4 to 6 inches profile best explained soil electrical conductivity along the transect in this study. The classified average CI was highly correlated with electrical conductivity, but no relationship could be established between CI and cotton yield. In this work we assessed capabilities of Geographical Positioning Systems (GPS) technology and Geographical Information Systems extensively for mapping the within field parameter variation.

From this study it can be concluded that:

1. Average CI was strongly correlated to soil electrical conductivity and accounted for more than 90 percent of the soil conductivity variation in the experiment.
2. No relationship was determined between the CI and cotton yield.
3. GPS technology and GIS tools are immensely beneficial for mapping within field variation of different soil and crop parameters.

Based on this research, we recommend further investigation on a substantial number of cotton fields and a large data on electrical conductivity, soil compaction for analysis. Locating highly compacted areas using soil electrical conductivity maps may then be for site-specific tillage operation.

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Table 1. Average Values of Classified Soil Electrical Conductivity and Soil Compaction (Forrest City).

ECa Mili-Siemens/m	**CI at 4 inch (psi)**	**CI at 5 inch (psi)**	**CI at 6 inch (psi)**
7.1	211	211	229
9.2	241	243	265
10.9	272	280	310
13	313	333	356
15.3	352	383	417
18	383	418	473
21.5	457	462	529
24.7	509	533	580
26.8	695	598	667
36.8	998	725	784

Table 2. Average Values of Electrical Conductivity and Soil Compaction.

Relation between	**Correlation Coefficient (R^2)**
ECa and Avg. CI at 4 inch depth	0.92
ECa and Avg. CI at 5 inch depth	0.98
ECa and Avg. CI at 6 inch depth	0.99

Table 3. Average Values for Soil Compaction and Yield at Fayetteville Field by treatment.

Plot No.	**Avg. CI at 4 inches of depth**	**Avg. Yield**	**Treatment**
4	78	3684.21	CL
5	222.66	2935.22	CL
11	254.33	3424.42	CL
14	224	2840.75	CL
1	358	2702.43	CC
7	103.66	3279.35	CC
10	195.33	3009.44	CC
16	168	3198.37	CC
2	74.66	4139.68	CDB
8	388.33	3178.13	CDB
9	141	3478.40	CDB
15	219	3697.70	CDB
3	353	3906.88	CNT
6	213.66	2621.46	CNT
12	249.33	4048.58	CNT
13	195	3518.89	CNT

Treatments:
CL : Control (No Treatment)
CC : Chiseled and Compacted
CDB : Chiseled, Disked and Bedded
CNT : Compacted and Not-Tilled

Table 4. Values of Correlation Coefficient between Yield and CI (Forrest City).

Depth (inch)	0	1	2	3	4	5	6	7	8	9	10
R^2	0.0028	0.0008	0.0061	0.0049	0.0046	0.045	0.017	0.0029	0.0061	0.0424	0.0049

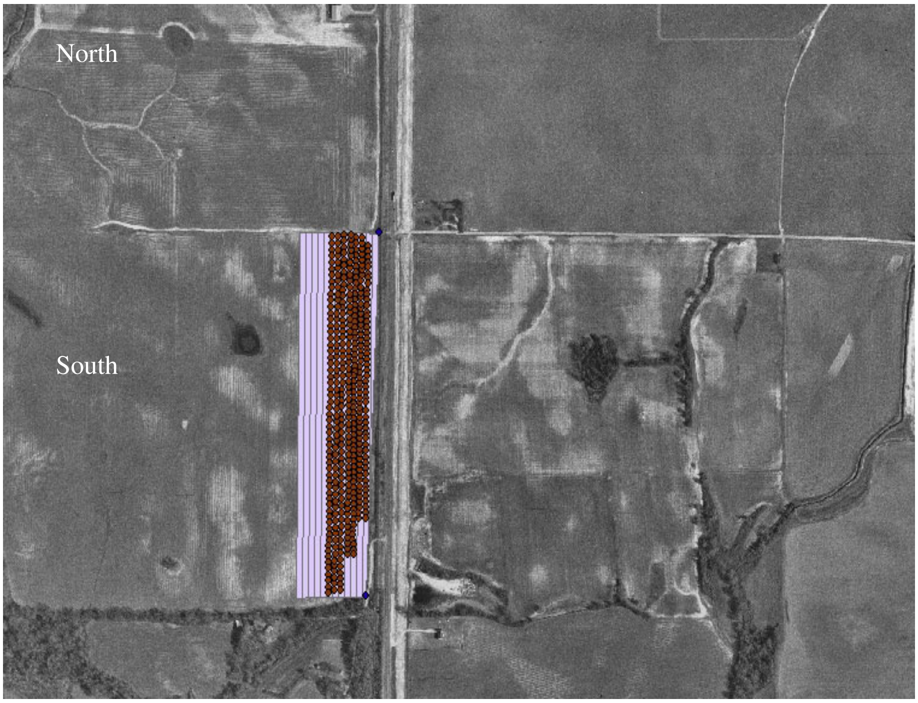


Figure 1. Location of Cotton Field (Forrest City).

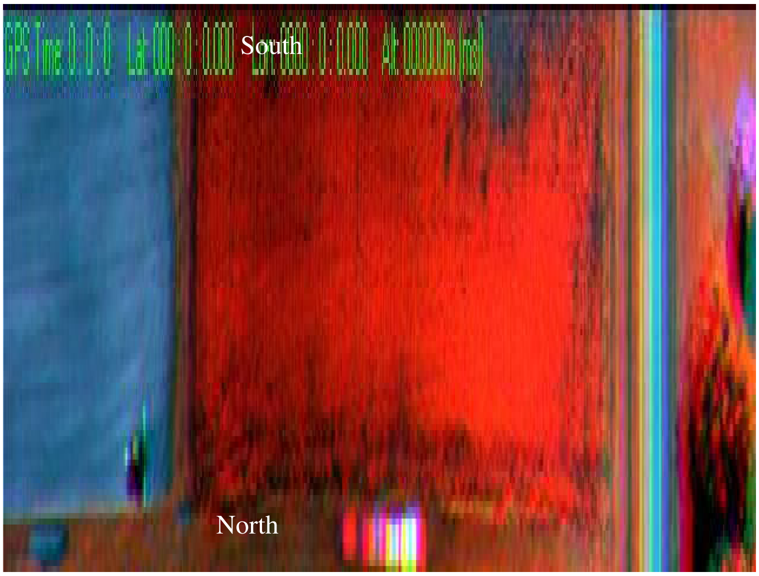
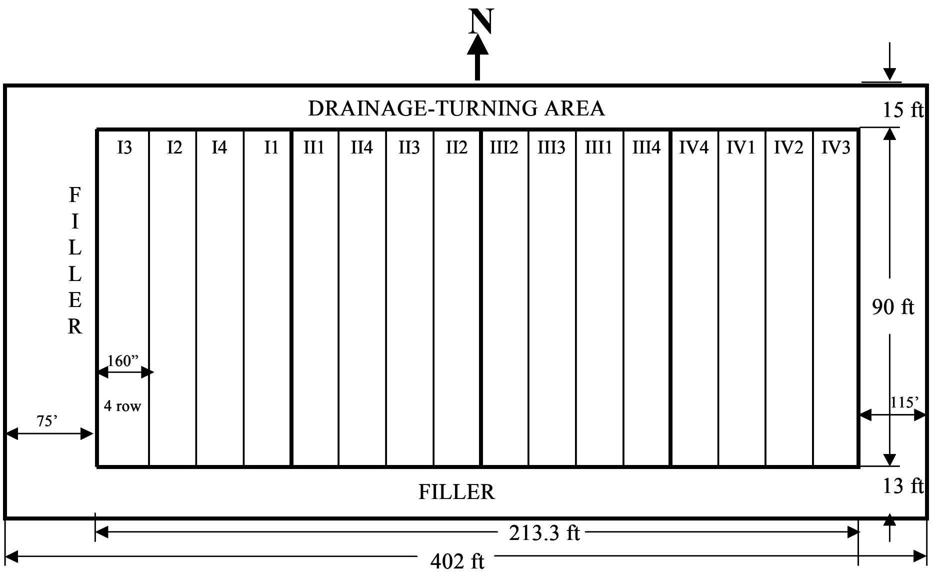


Figure 2. Aerial Photo of Cotton Field (Fayetteville).



Fayetteville

1. Control (no soil disturbance, no-till)
2. Chiseled, disked and bedded (Conventional)
3. Chiseled and compacted (by running tractor or a roller)
4. Compacted and no-till (by running a tractor or a roller)

Plot	7	6	5	4	3	2	1
*	Y	N	Y	Y	N	N	Y

Forrest City

* Subsoiling operation

Figure 3. Experimental Design.

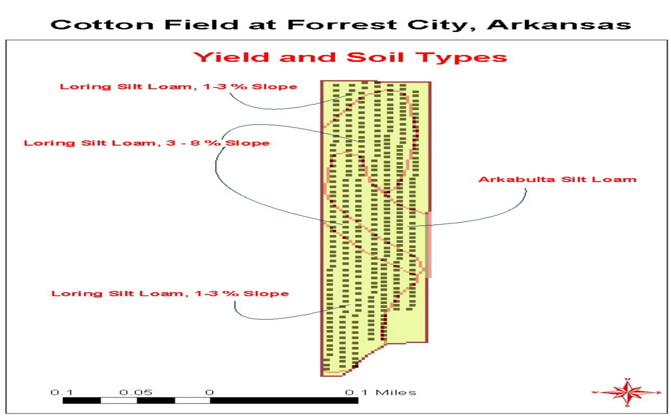
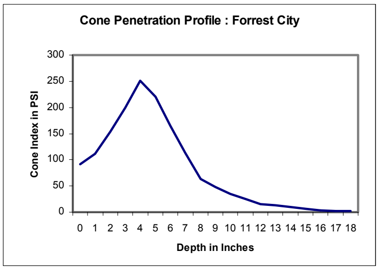


Figure 4. Soil Types in Forrest City Field.



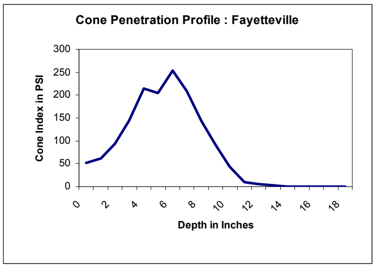


Figure 5. Profiles obtained with Average CI versus depth for all points.

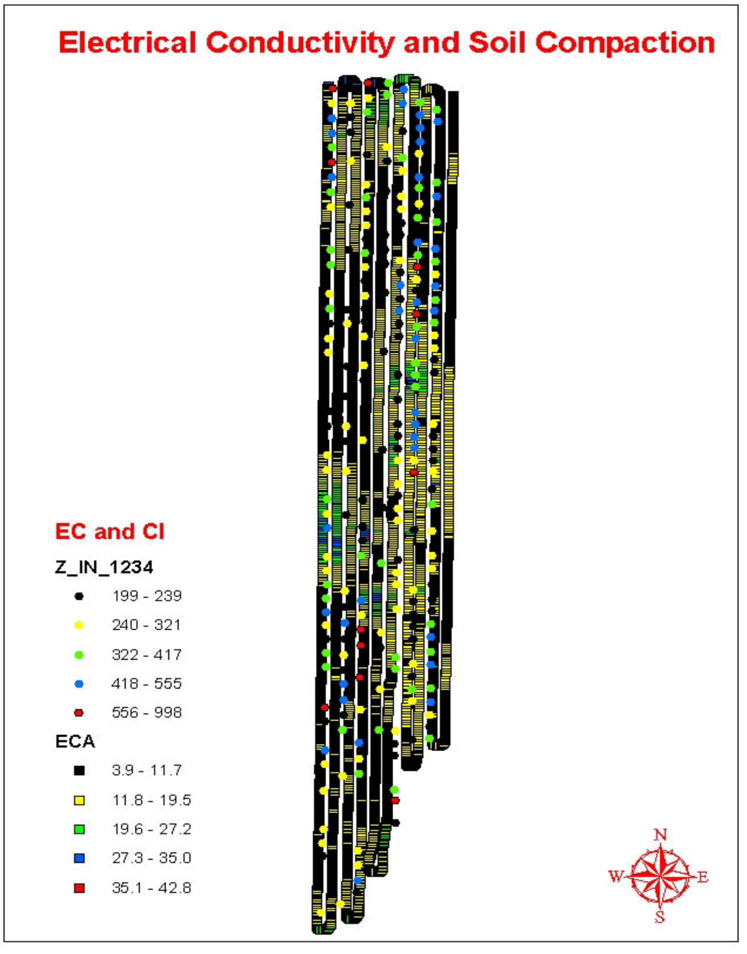


Figure 6a. Soil Electrical Conductivity and Soil Compaction (Depth: Four inches).

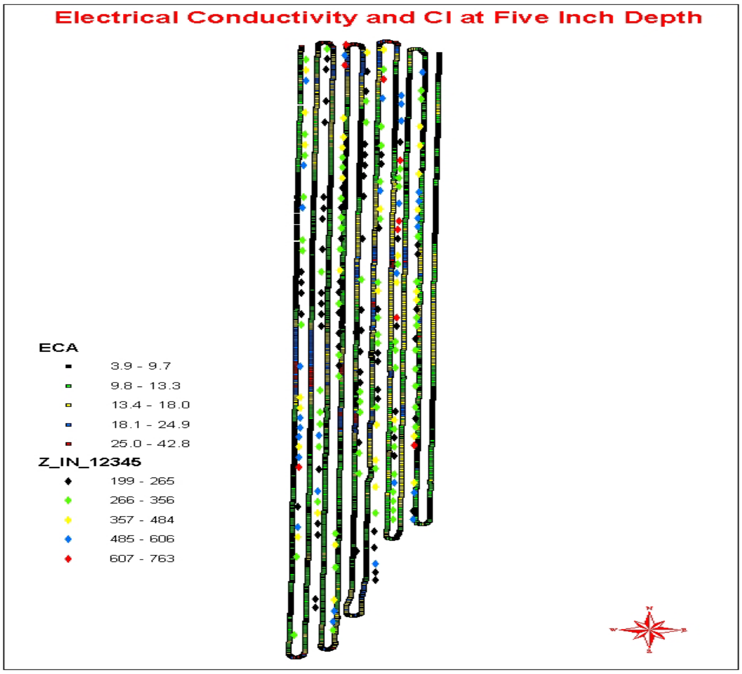


Figure 6b. Soil Electrical Conductivity and Soil Compaction (Depth: Five inches).

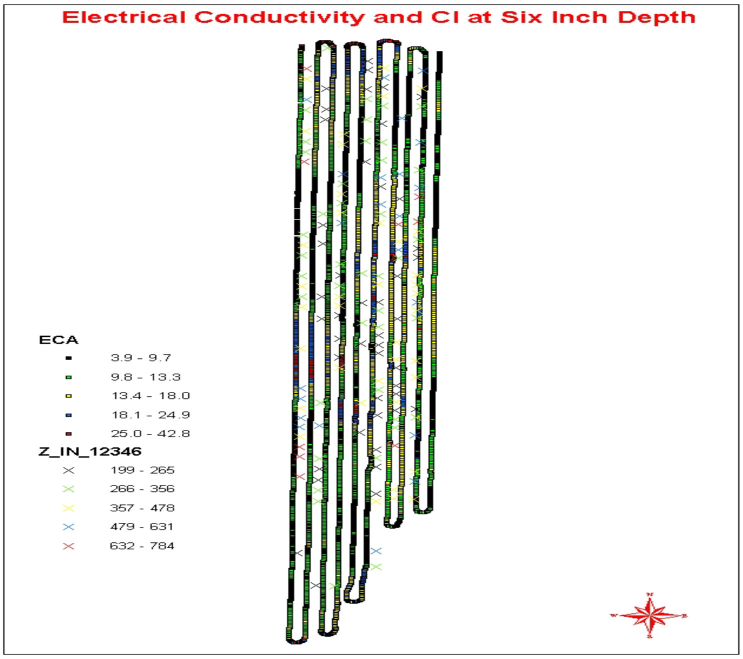


Figure 6c. Soil Electrical Conductivity and Soil Compaction (Depth: Four inches).

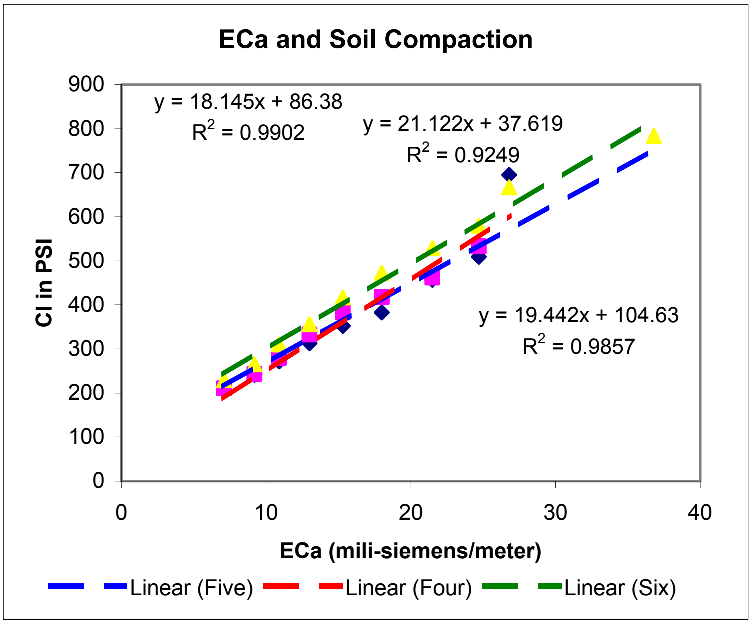


Figure 7. An Average Electrical Conductivity and CI in the Transect (Forrest City).

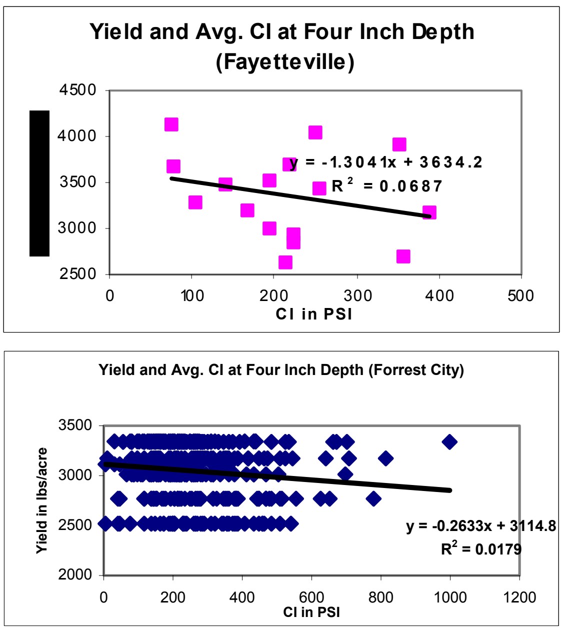


Figure 8. Typical Relation between CI and Yield.