# GIS Mapping of Soil Compaction and Moisture Distribution for Precision Tillage and Irrigation Management

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## Abstract:

Soil compaction is one of the forms of physical change of soil structure which has positive and negative effects, in agriculture considered to make soil degradation. The undisciplined use of heavy load traffic or machinery in modern agriculture causes substantial soil compaction, counteracted by soil tillage that loosens the soil. Higher soil bulk densities affect resistance to root penetration, soil pore volume and permeability to air, and thus, finally the pore space habitable for soil organisms. In contrarily for some soils, controlled soil compaction can improve the water holding capacity. Through a combination of these factors, soil compaction will affect crop growth. Soil compaction reduces total pore space of a soil and makes water and air flow through soil more difficult. Low soil oxygen levels caused by soil compaction are the primary factor limiting plant growth. Rectifying compacted soil is very costly process and involves again the use of machinery. Precision agriculture is a farming management concept based on observing and responding to intra-field variations. Precision agriculture is proven to be successful and very cost effective in fertilizer and planting/seeding application rates and, another promising area could be in the primary tillage operations leading to irrigation management.

In this research conducted under arid-zone crop cultivation in Oman, a penetrologger was used to measure soil penetration resistance and moisture contents in a selected farm field plots grown with Rhoades Grass and Sweet Corn. The main objective of this study was to investigate the effects of soil compaction level due to vehicle traffic indicated in the cone penetration resistance and irrigation patterns on the growth of grass and corn grown. The selected field plot area was approximately 1.8 ha. Based on the layout of the sprinkle irrigation system used, the field was subdivided into 84 subplots (each 12×12 m). One control condition and six compaction treatments were given to filed strips (24×12 m) having three replications from each arranged under randomized block design. The penetrologger device utilized in the experiments recorded GPS and moisture content readings simultaneously. The experiments were conducted for more than two years, completing three corn crops and seven grass crops. The results were analyzed and used for planning irrigation applications and tillage management.

The mapping of soil compaction levels and moisture status were successfully done through integrating data obtained into GIS maps. Result indicated that there was a trend for significant reduction in the growth of Rhoades grass in areas of higher soil compaction level due to traffic. In part of the field a hard pan (penetration resistance higher than 5 MPa) was clearly visible at 6-10 cm depth soil layer. Water logging observed on the fields was correlated with high soil compaction at the soil surface layer (1-5 cm deep). However, significant correlation could not be obtained for corn due to the fact that deeper root zone, soil type and other climatic factors specific to the country. Based on the result of this study, operational costs, schedules for tillage management practices could be optimized.

**Keywords:** penetration resistance, soil compaction, precision agriculture, moisture content, plant growth, tillage.

## 1. Introduction

### 1.1. Soil Compaction Effect on Plant Growth

Land preparation is one of the most important and critical processes among various field operations involved in the crop production process. Land preparation with machines provides a greater relief to the farmer to achieve his targets. Optimizing tillage is one of the major objectives in mechanized farming to achieve economically viable crop production system. When considering the different conditions, mechanisms and variables involved in the soil-tool interaction system, this becomes a difficult task. More and more complex situations need to be handled during the process as the behavior of soil could be varied even with a slight change in moisture content, compaction level, type of soil minerals or texture as well as the implement parameters and its manner of motion.

Soil compaction by vehicular traffic can be a severe problem in mechanized row crop farming. Compaction is caused by the harvesting, tillage and sowing operations, and others form of traffic used in crop cultivations. It can directly reduce crop growth and yield. Indirectly, compaction can result in higher fuel costs for tillage, and less efficient use of fertilizer and water (Raghavan et al., 1990), whereas compaction of the soil surface may be alleviated through shallow tillage. Deep soil compaction can lead to slow drainage and accelerated runoff, poor root growth and reduced efficiency of water and nutrient uptake (Figgure1.1). Furthermore, the severity of compaction effects on crop yields depends on soil properties, axle load, crop and cropping systems, tillage methods and the prevalent climate. Raper (2005) recommended vehicle traffic could be better when the soil moisture level is less than 60%, and suggested methods with which the wheel contact pressure on soil can be minimized.


Figure 1.1: In-row subsoiling to depths sufficient to disrupt the hardpan benefits the crop while leaving the areas between the rows relatively undisturbed (Raper, 2005).

The trend in modern agriculture shows increase in both the size and power of equipment, which allows more economical crop production by reducing labor costs and increasing farm size (Oskoui and Voorhees, 1991). Several studies have confirmed that heavy machinery can lead to compaction in the subsoil to a depth of at least 50 cm (Soane, 1970; Soane and Van Ouwerkerk, 1994; Etana and Håkansson, 1994; Ai-Adawi and Reeder. 1996; Arvidsson, 1998; Arvidsson, 2001, Jayasuriya et al., 2013; Sornpoon and Jayasuriya, 2013).

### 1.2 Compaction Effect and Moisture Retention

Water holding capacity of the soil is important for irrigation efficiency. Soils having high infiltration may have poor water use efficiencies due to high percolation. In sandy and sandy loamy soils, keeping proper compaction levels when the soil bed preparation may help improving moisture retention as well as minimizing the nutrient leaching (Abu-Hamdeh, 2004). However, high compaction may creates poor drainage conditions which could adversely affect the plant growth (Nolte and Fausey, online). Therefore, it is important to maintain proper soil compaction levels particularly in areas where soil porosity is common and the water scarcity is a problem.

### 1.3 Use of GIS and Map Interpretations on Soil Compaction

Tillage management plan will be done based on GIS map interpretations prepared using soil properties in the field. In addition to the experimental area, field blocks and plots, the farming area of the AES will be used for map interpretation. During the two years of experiments, seasonal based monitoring and recording of data will be done and entered in GIS data base. All data attributes will be used with GPS data on location and time. The map interpretations will be of spatial and temporal means; which will be helpful to understand the seasonal variation of soil properties in the field. Figures 1.2 (a) and (b) show examples of such GIS map interpretations on soil properties, similar techniques will be utilized in this project.

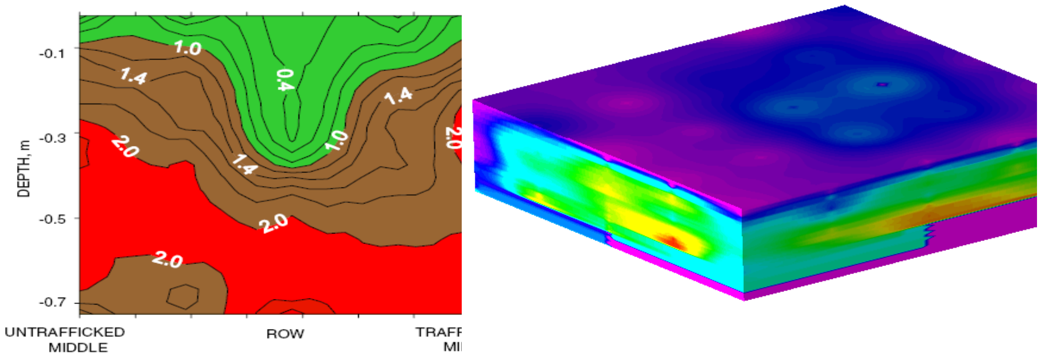



Figure 1.2. Mapping of compaction profiles; (a) Cone index profile across the row in sandy loam soils (Raper, 2005); (b) Interpolated 3-D soil compaction model generated based on cone resistance data (Rooney et al., 2005).

A systematic approach to investigating the compaction patterns and how they correlates with the machinery traffic in the field is intended in this research. In addition, changes taken place on soil properties and root development were to be investigated. In order to obtain accurate results and make conclusions, the research was continued for few crop seasons. GIS techniques was used in which GIS database was created with map interpretations for seasonal changes in soil layers within the topsoil layer due to disturbances by machinery with irrigation, natural and machinery made soil consolidation.

## 2. Materials and Methods

### 2.1 Experimental Arrangement and Procedure

A series of field experiments were carried out in seasonal manner for nearly two years to determine the compaction effect on two selected crops by machinery use. The field was arranged as number of strips and soil compaction was induced by different level of tractor passes with a roller compactor attached to it, which was applied uniformly to cover the entire surface of each experimental plot. Compaction treatments were done immediately before planting when moisture content was uniform and below the field capacity. The number of passes was selected as the main variable, without roller passes was selected as the control.

Field strips were prepared for 6 compaction treatments with the control, each having three replications and arranged in randomized complete block design (RCBD) manner. Two crops selected were Rhoades grass and Sweet corn which are commonly grown in Oman.

Different type of machinery had to be used, compatible with the procedures use in Oman and at SQU-AES as shown in Figure 2.1. For Rhoades grass, land preparation, seeding, fertilizer application, harvesting, raking and baling activities were practiced, while for corn all such activities were done manually. In addition to the initially set compaction levels, accumulation of compaction of machinery traffic was measured during the cropping activities. For the corn crop, tillage practices as well as compaction treatments were applied before the each season (3 seasons) while Rhoades grass had the treatments only at the beginning.


Figure 2.1. Machinery used in the field for different farm activities; (a) Land preparation; (b) Grain seeder; (c) Mower; (d) Rake; (e) Baler; (f) Trailer for transportation (Jayasuriya, et al., 2013).

Figure 2.2 shows the preparation of filed strips, compaction treatments applied and how the applications were interpreted using GIS maps. Figure also shows the crops grown.

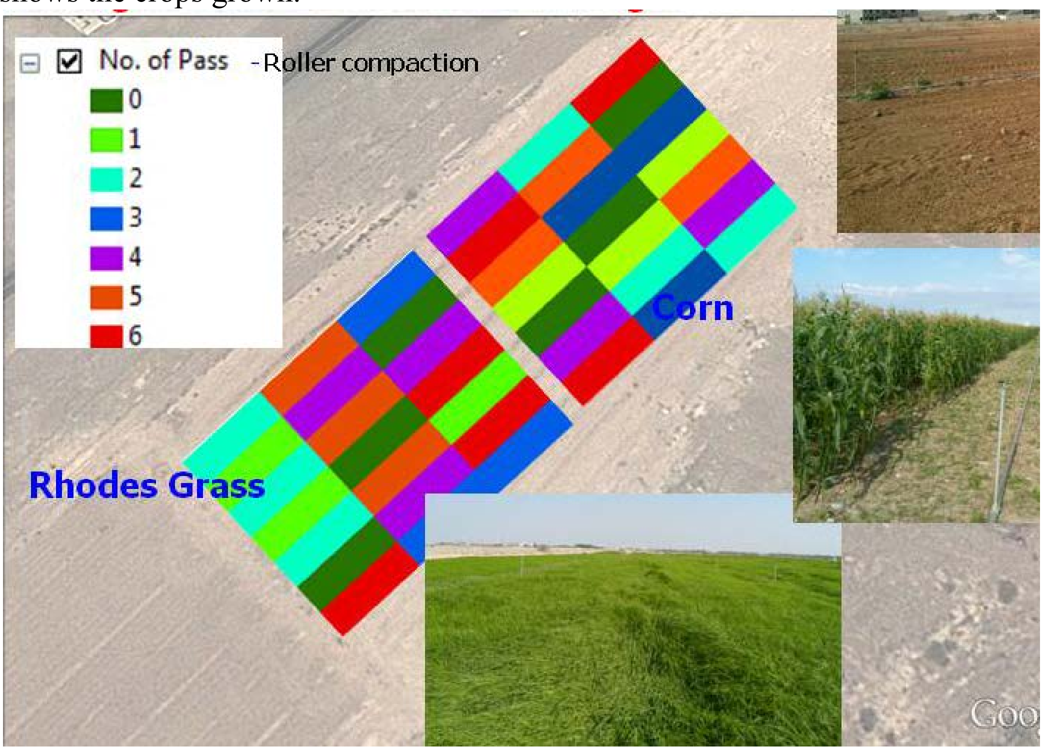



Figure 2.2. Land preparation; compaction treatments and GIS mapping of land strips for Corn and Rhoads grass (Jayasuriya, et al., 2013).

### 3. Results and Discussion

Figure 3.1 shows a soil profile and a graph showing soil moisture content variation with depth. The soil profile is the typical soil characteristics for the selected field at AES of SQU. The topsoil layer is transported soils of silty sand (around 40 cm) and below 40 cm horizon shows the residual soil. Water holding characteristics is also visible in the graph.

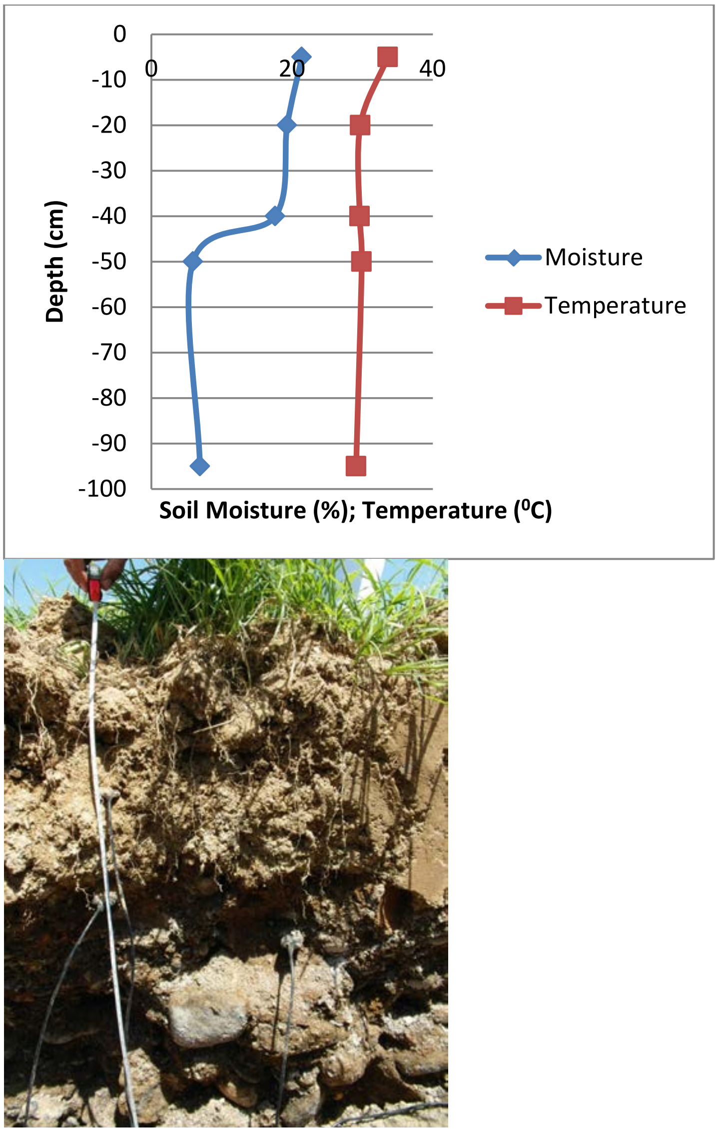



Figure 3.1. Soil profile showing the moisture holding characteristics; topsoil of 40 cm is silty sand and below the boundary soil is residual course sandy and rockey soil typical to Oman soil conditions (Jayasuriya, et al., 2013).

Figure 3.2 shows the GIS maps of soil compaction levels and the moisture contents of the field strips taken at the time of compaction measurements. Figure 3.3 shows the root development characteristics of the field strips. The root development in grass was in the depth range of 5-10 cm while in corn, the range varied from 10 to 25 cm. There was a correlation of root development with compaction levels for corn while a poor correlation found for Rhoades grass. The compaction and moisture content levels in GIS maps can be used for the tillage management in the subsequent seasons to maintain appropriate tillage with optimums soil compaction and water holding capacities.

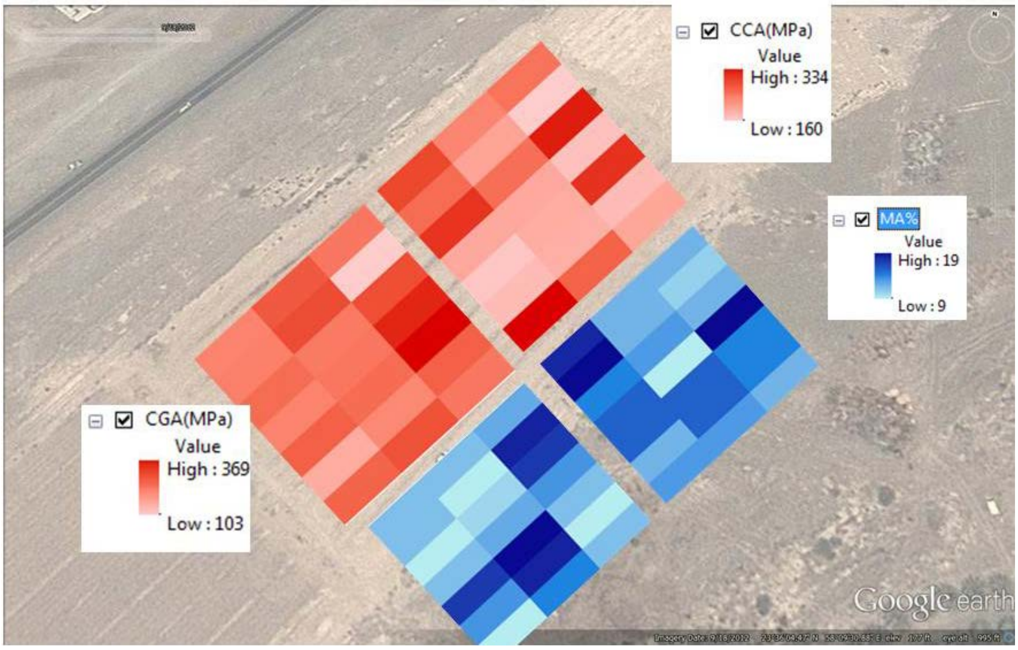
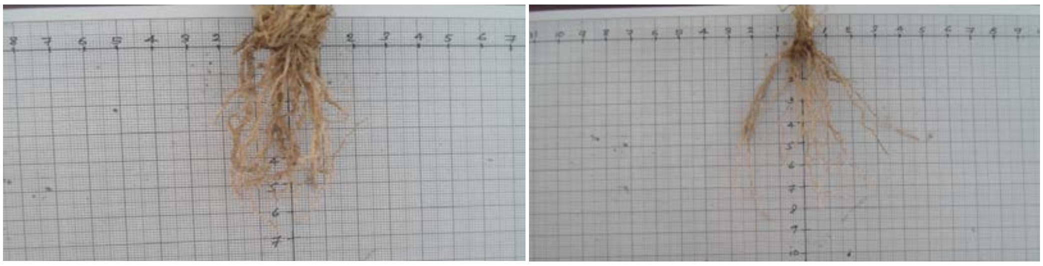



Figure 3.2. A GIS map showing soil compaction levels in field strips randomly arranged and the corresponding moisture contents at the time of compaction measurements pasted on it (Jayasuriya, et al., 2013).



(a) Rhodes grass roots - low compacted soils

(b) Rhodes grass roots - high compacted soils

(a) Corn roots - low compacted soils

(a) Corn roots - low compacted soils

Figure 3.3. Root development characteristics of Corn and Rhodes grass under different compaction levels (Jayasuriya, et al., 2013).

Figure 3.3 shows the GIS map of yield characteristics of the two crops Rhoades grass and Corn after the first season. Due to the some inherent soil characteristics in some filed strips due to the varying topsoil layer thickness, high correlation could not be obtained. In some field strips in the corn field, the topsoil layer varied between 20 and 40 cm. It was recommended that in future compaction studies at AES of SQU or elsewhere, the uniformity in topsoil layer should be an important factor to be taken care.

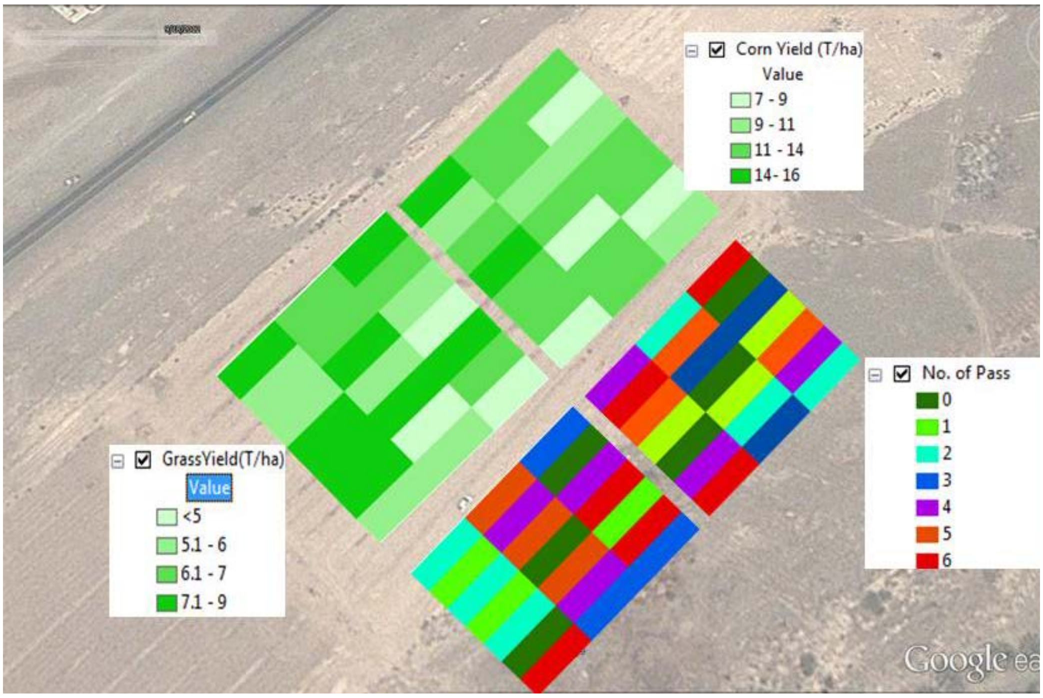



Figure 3.4. A GIS map showing the yields of Corn and Rhoads grass (Jayasuriya, et al., 2013).

**4. Conclusive Remarks**

- It was observed that the increase in compaction levels due to machinery use with the seasons progressed in Rhodes grass due to ratooning was practiced for multiple seasons without land preparations or replanting.  or
- Conclusions cannot be drawn without repeating the experiments for multiple crop seasons. General trends could be found supporting the hypotheses.
- Based on previous research – Machinery use in filed should be only when moisture is less than 60% of field capacity.
- Previous studies show 10-20% yield reduction in 4 years under heavy machinery use.
- Machinery selection (size and weight) should be as per the soil type (smaller machines in compressible soils).
- Precision Tillage techniques would be important for tillage management, optimizing the compaction level maintaining appropriate water holding capacities. This will help saving irrigation water, fertilizer and farm energy. GIS mapping of compaction levels, moisture status, tillage management can be optimized.
- Depth of tillage can be optimized for different crops, and can be scheduled for cycles of crop rotations.
- Compaction effect for Rhodes Grass seems to be insignificant (root depth was less that 10 cm)

- Compaction effect has significant effect on corn (Root depth not exceeded 25 cm).

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