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MECHANIZATION OF SOIL SALINITY ASSESSMENT FOR MAPPING

by

Lyle M. Carter
Agricultural Engineer
USDA, ARS
Shafter, CA

James D. Rhoades
Soil Scientist
USDA, ARS
Riverside, CA

Joseph H. Chesson
Agricultural Engineer
USDA, ARS
Shafter, CA

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Summary:

Two salinity assessment machine systems are described: 1) a mobilized fixed-array four-electrode system for on-the-go measurement of bulk soil conductivity and 2) a combined soil electrical conductance and electro-magnetic induction automated grid sampling system for rapid sampling of multiple field locations at several depths.

Keywords: Electrical conductivity Electromagnetic Instrumentation systems Mapping Measuring systems Salinity Sensors

Mechanization of Soil Salinity Assessment for Mapping

Lyle M. Carter
Member
ASAE

James D. Rhoades

Joseph H. Chesson

ABSTRACT

This paper describes recent developments in equipment for the mechanization of in-situ soil salinity measurements. Two salinity assessment machine systems are described: 1) a mobilized fixed-array four-electrode system for on-the-go measurement of bulk soil conductivity and 2) a combined soil electrical conductance and electro-magnetic induction automated grid sampling system for rapid sampling of multiple field locations at several depths.

INTRODUCTION

Variability among and within agricultural soils is a fact easily observable. Yet many characteristics must be measured by labor and cost intensive methods which require obtaining and transporting a discrete soil sample to a laboratory. For some characteristics affecting plant growth the variability within a defined field may be greater the than average among fields. For some other characteristics the change in the level with time is not only related to production practices but has implications extending beyond agriculture. A good example is soil salinity. It varies in distribution naturally and varies with time depending upon 1) the salt added in irrigation water or groundwater and 2) the net movement of water within the soil. Therefore, a change in soil salinity by depth over time can be used as an indicator for vertical movement of water-mobile pollutants and a change in total soil salinity distribution can be used for evaluation of salt-loading within agricultural landscapes by irrigation and management systems.

Plants have varying tolerance by species, varieties and stage of growth to soil salinity. A periodically updated 3-dimensional salinity map would aid in subdividing fields by crops, in selection of a crop with the appropriate salt-tolerance range and in evaluation of management systems.

The direct and labor costs for obtaining a one time map of salinity distribution using current direct laboratory determination methodology within a field on a 10 meter grid, for example, would be prohibitive; and the single map would provide no information of shift in salinity and the effects of changes in management or weather. This recognition prompted a cooperative research program between ARS groups located at the Riverside and Shafter locations to develop rapid, mobile, on-site, salinity mapping equipment and systems. Progress was enabled by the prior development of: 1) practical instrumentation for measuring bulk soil electrical conductivity (EC_a) using four-electrode (Rhoades 1990a) and electromagnetic-induction (EM) techniques (Corwin 1990, Lesch 1992), 2) appropriate theory and practical methods for inferring soil salinity from EC, for different soil types and moisture conditions (Rhoades 1989 & 1971), and 3) practical instrumentation and methods for locating spatial coordinates of measurement sites using LORAN (Rhoades 1990b) or GPS technology (Long 1991). Most of the research and development involved with items 1 & 2 and some of item 3 was performed at the U.S. Salinity Laboratory in Riverside California. These instruments, methods, techniques and systems of salinity measurement and mapping are reviewed by Rhoades (1993a).

With the advent of the instrumentation described above development began in 1991 on mobilized and automated field equipment for obtaining soil salinity spatial distribution. This paper describes, briefly, two of these systems: 1) a mobilized fixed-array four-electrode system; 2) an automated grid sampling system.

DESCRIPTION OF EQUIPMENT

Mobilized Fixed-Array Four-Electrode System

The goal was to design tractor mounted equipment for continuous measurement of soil conductivity with the electrodes at a constant soil depth and while moving at normal speeds (1.0 to 2.5 m s^{-1}) in planted or fallow fields. A non-equidistant four-probe arrangement was required to allow operation in fields with varying bed spacing from 75 to 100 cm. The outer current electrodes then would be spaced 4 inter-bed distances apart and the inner signal electrodes would be 2 inter-bed distances apart as shown in Figure 1.

The probes were constructed using standard chisels electrically insulated from the supporting shank. A small wedge support bracket was welded to the trailing edge of the chisel. A replaceable hardened tool-steel wedge (or runner) was attached to the bottom of the support to maintain soil contact. The soil beneath the chisel point was compressed by the forward motion of the wedge; the amount of soil compression is dependent upon the depth variation of the chisel. Figure 2. The effective electrode area was the underside of the wedge since: 1) in a normal field condition the soil moisture increases with depth near the surface thus the contact resistance is lowest, 2) the wedge scours thus maintaining a conductive surface and 3) the underside of the wedge is the area of highest sustained soil-contact and pressure. Prior research indicated that a chisel type shank performed poorly as an electrode presumably because the soil contact area was not constant, the interface resistance varied and soil density (and contact pressure) varied within the soil failure cycle, and with equipment vibration. (Carter, 1970).

The shanks were mounted to a folding rectangular section tool bar. Gage wheels were attached to the bar to aid in maintaining constant electrode depth. In practice, the depth of operation for obtaining accurate data was 10 to 15 cm depending upon the soil moisture content. For the research application, the shanks were 91 cm long allowing approximately 1 m crop clearance.

The GPS antenna was positioned above the tractor cab. The electrical generator/conductivity meter, the GPS receiver, data loggers and power supplies were housed in a instrument box attached to the bar. In addition, a remote display for electrical conductivity was placed near the operator for monitoring. The conductivity and GPS signals were sensed at adjustable frequencies with a maximum of once per second and stored in the data loggers for later processing. At a practical tractor speed of 1 m s^{-1} the estimates of salinity and position could be made 1 meter apart providing a nearly continuous bulk soil EC,-distance profile.

Automated Grid Sampling System

The goal of estimating the soil salinity variation with depth was not practical with the fixed-array four probe conductivity instrumentation. With the four probe electrical conductivity system, which estimates the average salinity to a depth approximately equivalent to 1/3rd the outer electrode distance, multiple width arrays would be required. This was deemed impractical for a moving electrode system operating in furrowed fields. With the EM methodology, information of variation by depth must be obtained by either, or both, changing the height of the instrument or the orientation of the magnetic coil configuration. Thus to automate the manual procedures for obtaining depth information, the vehicle must operate in a stop-and-go mode. A major consideration in automation was the confounding affect of nearby metals on electromagnetic induction instrumentation.

A light weight articulated vehicle with front wheel hydrostatic drive originally designed for carrying personnel for spot chemical weeding was chosen. Figure **3.** This vehicle allowed simple height and width adjustment without complications of steering geometry and mechanical power trains. The mass of the vehicle was found to have negligible impact upon the EM reading if the distance between the nearest end of the instrument to the front of the vehicle was greater than 1.8 meters.

The EM survey instrument (described by Rhoades, 1992) was suspended in front of the vehicle enclosed in a vinylester pipe with an inside diameter of 15.9 cm and a wall thickness of 0.45 cm. The tube was fastened to the vehicle by sliding over a short section of steel tubing. At the far end a slot was milled into the tube to receive the EM instrument. Figure 4. The instrument was secured in slotted hardwood bulkheads and fastened with straps. All hardware beyond the vehicle was non-metallic. With this design static deflection at the end of the tube was less than .7 cm with half the mass as compared to a design based upon commonly available PVC pipe exceeding 1.5 cm. For travel the tube was removed and placed in a cradle at the back of the vehicle. The EM tube was rotated by a small gearhead DC motor and belt operating on a non-slip strip applied to the vinylester tube. Limit switches and stops were placed inside the steel support tube for the vertical and horizontal EM positions. Removing the EM support tube for travel requires unplugging the instrument cable and loosening the belt and the pipe clamp.

A carriage was designed to provide

vertical and horizontal translation of the EM support tube. The elevator portion of the carriage was fabricated of two rails using cam followers for linear bearings. Lift was provided by a small hydraulic motor through a chain with an idler at the top of the elevator. A limit switch was placed under the EM tube to stop the downward movement when the center line of the EM instrument was 10 cm above ground surface. A electromagnet, slider and limit switch mechanism was designed to allow the EM support tube to raise 40 cm. Figure 5. At time of engagement for upward movement, the magnet grasps the slider which has travel limited to 40 cm by the upper limit switch. For travel within the field, the magnet releases the slider which then falls to a stop on the elevator. The elevator then continues upward until the slider again activates the switch. During downward travel the slider is also released and it follows the elevator for 40 cm at which time it rests on a stop on the elevator rail while the elevator continues until the foot switch is activated by the soil surface. Therefore, the two limit switch mechanisms allow 10 and 50 cm positions. above the soil for the EM independent of the bed topography. Four salinity depth samples of 0 to 30, 30 to 60, 60 to 90 and 90 to 120 cm can be estimated by the succession of EM measurements.

Horizontal translation of the carriage was accomplished with sliding door hardware (track and trolleys) mounted on a cross beam in the front of the vehicle and a single cam follower in a channel mounted near but in front of the vehicle articulation bearing assembly. Translation was provided through a small wire rope attached at the ends of the cross beam with one wrap around a hydraulically rotated drum attached to the carriage. One end of the wire rope was attached through a spring, thus the carriage acceleration and shock could be controlled with regulated slippage on the drum. Adjustable limit switches were attached to the track to allow selected right and left carriage positions. Thus EM measurements could be obtained at two lateral locations and 4 soil depths at any given stop. The lateral positions allowed measurements in bed and/or furrow, or in two beds or furrows or two specified locations in unfurrowed fields.

The soil electrical conductivity system was attached to the carriage under the vehicle. Figure 6. Thus the range of lateral motion was coincident with the EM system. Both 2-meter and l-meter 4-probe arrays were attached to a common beam. The distance between the inner signal electrodes was 80% of the outer current electrodes. The probes were machined from 1.27 cm (0.5”) stainless steel rod. The diameter of the lower 3 inches of the probe was machined to 1 cm diameter so the total force required for insertion of the 8 probes would be less than the combined weight of the driver and front section of the vehicle. Insulating step washers were used to attach the probes to the common beam. The common beam was part of a parallel ‘scissor-action’ mechanism with a maximum travel of 78 cm allowing 58 cm travel clearance and a maximum insertion of 20 cm. The actuator was a hydraulic cylinder imbedded within the upper ‘scissor-action’ beam. A linear cam with a heavy foot pad was installed in the lower beam to sense depth of penetration. Two roller-plunger snap-action switches sensed notches in the linear cam: a narrow notch was interpreted as a depth to obtain a measurement and a wide notch indicated the last measurement.

Control System

A sequence of 52 operator actions would be required to obtain the full range of potential measurements at a single location (more with multiple depth conductivity measurements). This was deemed essentially impossible without automation for the desired rate of 20 or more sample sites per hour. A control system was designed based upon switches and relay logic with auxiliary electronic timing. The operator interface control consisted of a system enable button and a system defeat or panic/safety button, two sample initiation buttons for EM and 4-probe and a 6-position selector switch. Figure 7. This switch had one position for each of the basic four Y-Z positions for the EM system and two for each of the basic Y positions for the conductivity system. A one-way interlocked sequence (ladder) was imposed upon the first four selector switch positions to prevent damage to the EM instrument and mast and to maintain simple data logger management and synchronization. Figure 8. The data initiation buttons were grouped with the respective carriage control switch positions in a way to create a logical flow of operator responses. All controls and actuators were disabled each time the engine was started and selectively by depressing the panic button to prevent personnel injuries and equipment damage. Depression of a system enable button was required before any automation was activated.

After the system is enabled the EM tube rotates to the vertical attitude, the carriage moves to the right limit and the 4-probe moves to the travel position. The start button for the EM data sequence is activated when the selector is turned to position '1'. The EM 'START' button then initiates the following sequence: 1) delay for data acquisition, 2) rotate EM instrument to horizontal, 3) delay for data acquisition and 4) rotate back to vertical. This sequence is repeated for each Y-Z position. Figure 9. The start button for the 4-probe is enabled in switch positions 5 and 6. Depressing the 4-probe 'START' initiates the following sequence: probe movement down to first soil depth limit, a delay for instrument initiation, a delay for data acquisition, and probe movement down to next soil depth. On reaching the last soil depth, the 4-probe system moves upward to the travel position. Figure 10. A small printed circuit board provides the time delay functions.

A distance counter, belt driven from the un-powered rear wheel of the vehicle, was installed to: 1) define a sample location with accuracy greater than the GPS and 2) permit the conductivity measurement to be made in the same location as the EM. The display was incorporated into the operators control panel. Figure 7.

PERFORMANCE

Graphical presentation of the data obtained with the mobilized fixed-array four-electrode soil conductance system provides direct visual information of the average bulk EC, distribution within a field. Example output data obtained with this system are shown in Figure 11 in terms of EC, versus distance along one pass made through a tile-drained field in the Coachella Valley of California. The cyclic response suggested twice a many tile drains as was recorded in the farmer's records. Excavation verified that the instrument system's response of the salinity pattern correlated closely with the

pattern of the tile-drainage system.
Such data can be used to infer drainage design efficiency. This impressive information never would have been practical to obtain by conventional salinity measuring techniques. (Rhoades 1993b) Yet the data set was obtained with about 5 minutes of effort using the mobile fixed-array system. In a field in the San Joaquin valley of California a single pass with this system illuminated a four-fold increase in EC, related to the distance along the flow path of the furrow irrigated field. This type of data can be used to infer differences in water infiltration, distribution and leaching efficiency as a function of irrigation systems and methods. A map of a field showing salinity patterns can easily be constructed by processing the data from multiple passes.

The bulk soil electrical conductivity can be measured at speeds of 1.0 to 2.5 m s^{-1}. With 50 meter distance between passes, greater than 1 section of land can be surveyed for EC, distribution in one day.

The automated grid sampling system provides additional depth information of variation EC, within a field using two independent methods. The sampled data can be averaged and compared to the fixed-array data as shown by the discrete points in Figure 11 or plotted to form a multiple map by soil depth as shown in Figure 12. Table 1 gives example salinity distributions for the latter field in term of percentages. These data can be used in turn to determine the yield losses that would result for a given crop from salinity present in this field. The data set of salinity by depth and location can be used to assess the adequacy of past leaching or drainage practices. The methodology for converting the recorded data laboratory-equivalent expressions of salinity and other inferences are discussed by Rhoades (1993b). The purpose of this discussion of performance is to show that meaningful data can be quickly obtained with the two salinity survey instruments that can be evaluated in many ways to provide needed information not otherwise obtainable.

The data at one stop for the grid sampling system requires less than **60** seconds after the operator becomes familiar with the procedure. During this time EM readings at 4 soil depths and 2 lateral positions, electrical conductivity readings at two depths and two lateral positions, and the GPS determined location are recorded. Depending upon the distance selected between stops, up to 30 field locations can be sampled per hour.

CONCLUSIONS

Mechanization of instrumentation for rapid mobilized in-situ measurement of EC, in field soils has been demonstrated. This mechanization opens new opportunities for assessing: 1) the dynamic nature, distribution, management and extent of soil salinity, 2) salinity related crop production systems, 3) water management efficiency and 4) adequacy of leaching and drainage systems and practices. Projected uses of the mechanized instrumentation include large area surveys for water and soil management, field surveys for crop and irrigation management and diagnosis of crop production problems. The projected users would be private and governmental organizations, regulatory agencies, consultants, and farmers. The two systems, mobilized fixed-array and automatic grid sampling, provide complimentary types of assessment of EC, within fields and agricultural landscapes.

The mobilized fixed-array systems offer for the first time high speed area survey of bulk soil salinity. Dependent upon the detail required, one section of land, or more, could be surveyed in a single working day. The resultant line graphs and maps allow rapid and visual appraisal of salinity distribution and determination of areas within the survey deserving more detailed study. The operational advantages of mobilized fixed-array system are equipment simplicity and speed of operation.

The automated grid sampling system offers for the first time a rapid method of assessing 3-dimensional location and movement of salt and water within the soil profile. Locations within a field can be measured at a rate of 30 per hour. With the addition of a portable or field van computer the information can be evaluated the same day as sampling.

Table 1. Area-Percentages of 9 furrow-irrigated fields within various ranges of soil salinity (EC, basis) Rhoades (1993)

Range in	Soil Salinity dS/m				
Soil Depth, m	O-2	2-4	4-8	8-16	> 16
o-o.3	14	41	36	9	0
0.3-0.6	44	32	17	6	1
0.6-0.9	17	34	22	16	10
0.9-1.2	15	31	25	17	11
o-1.2	3	49	29	16	2

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Figure 1. Mobilized fixed-array four-electrode salinity sampling system.

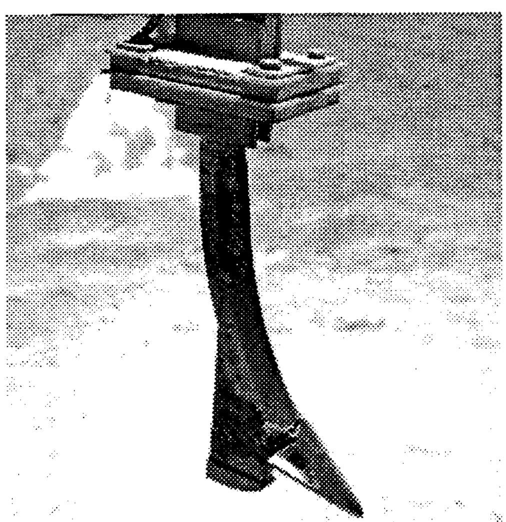


Figure 2. Closeup showing one of four fixed-array probes.

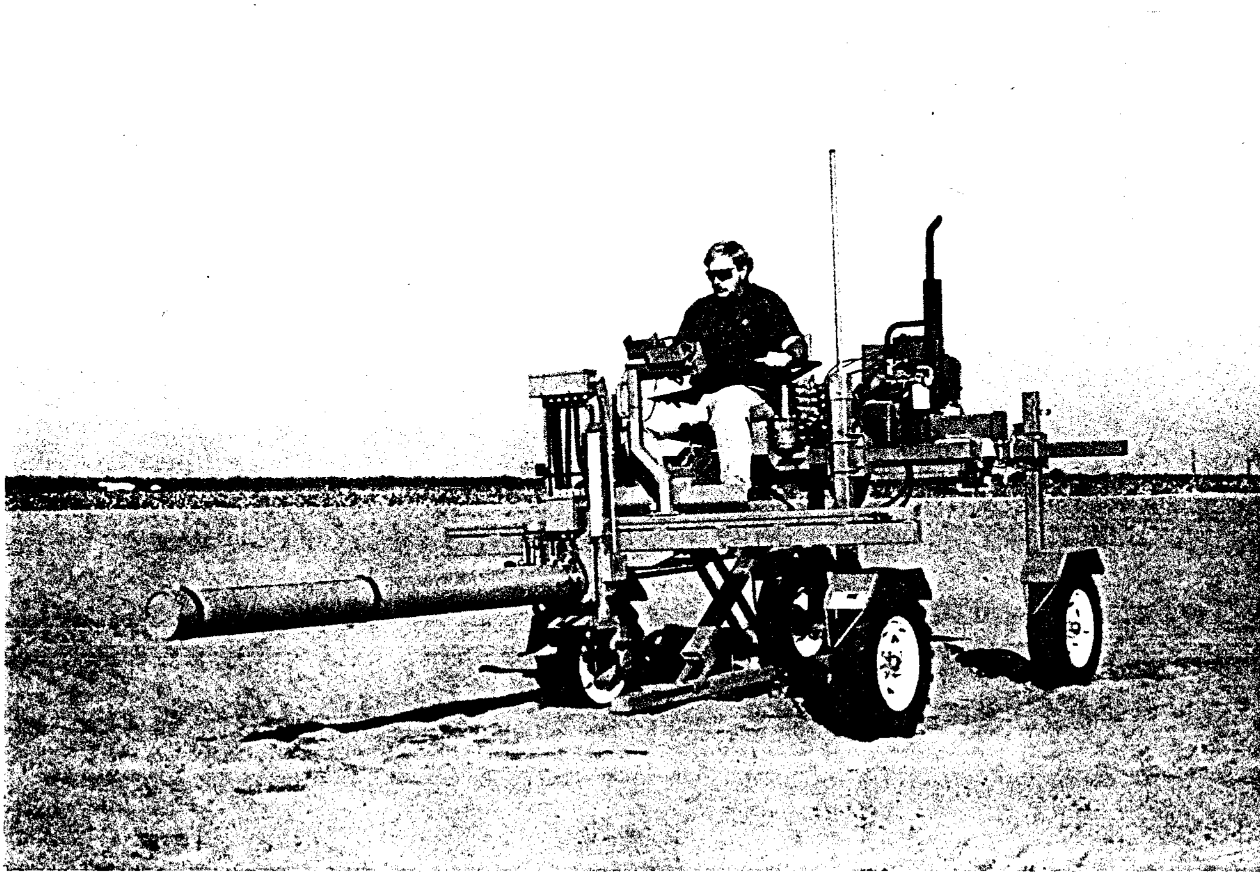


Figure 3. Salinity Assessment vehicle with combined soil electrical conductance and electro-magnetic induction sampling.

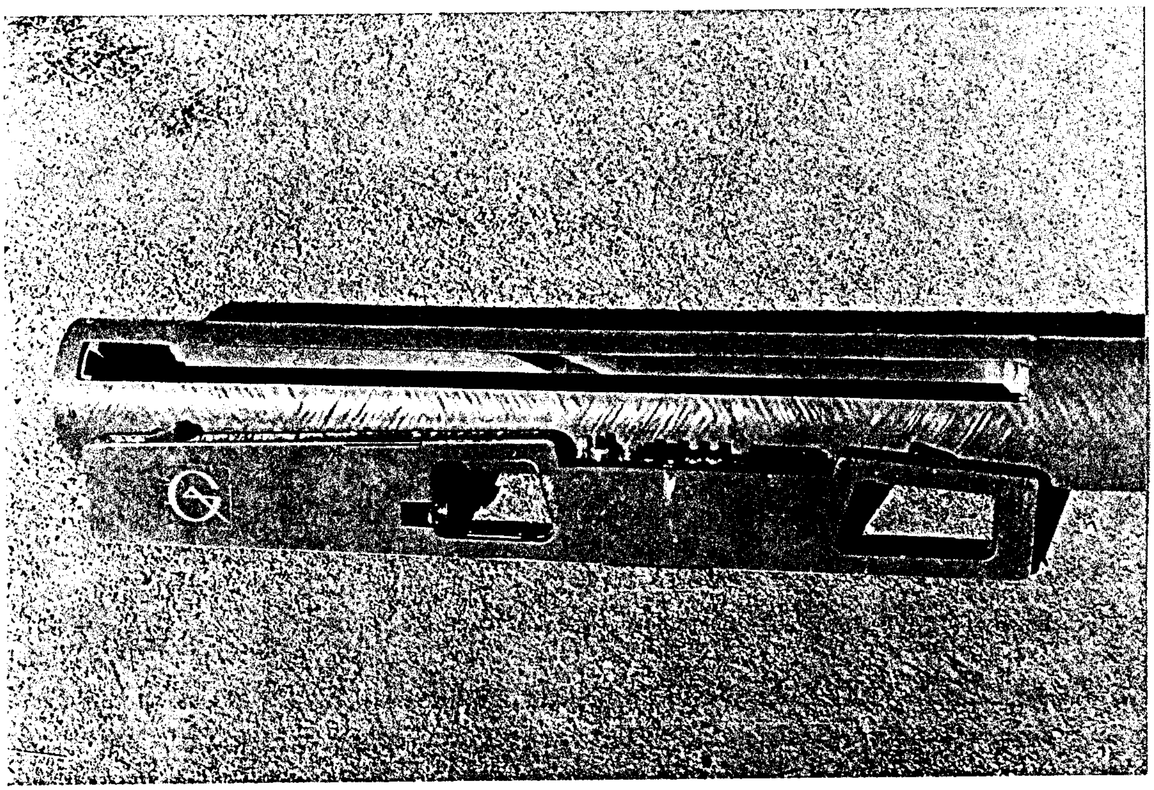


Figure 4. Electro-magnetic support tube and EM instrument.

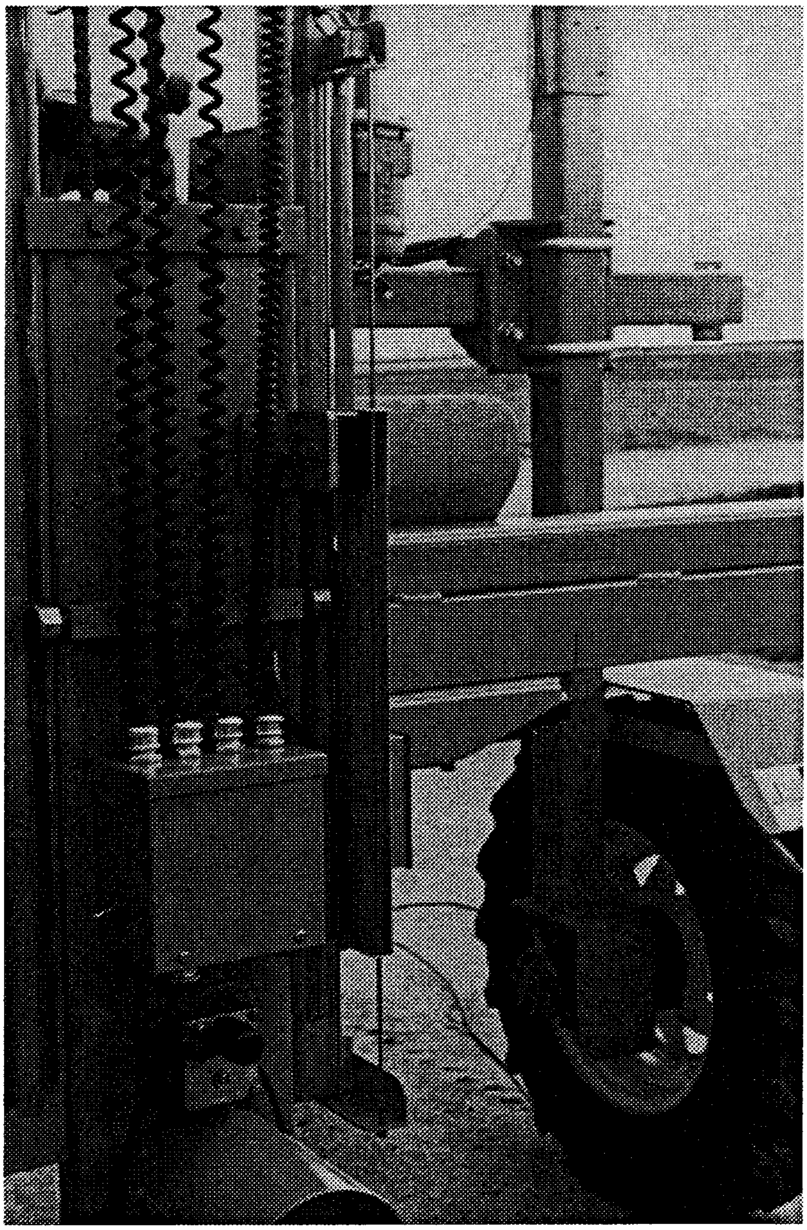


Figure 5. Automatic height control (Electro-magnet and slider)

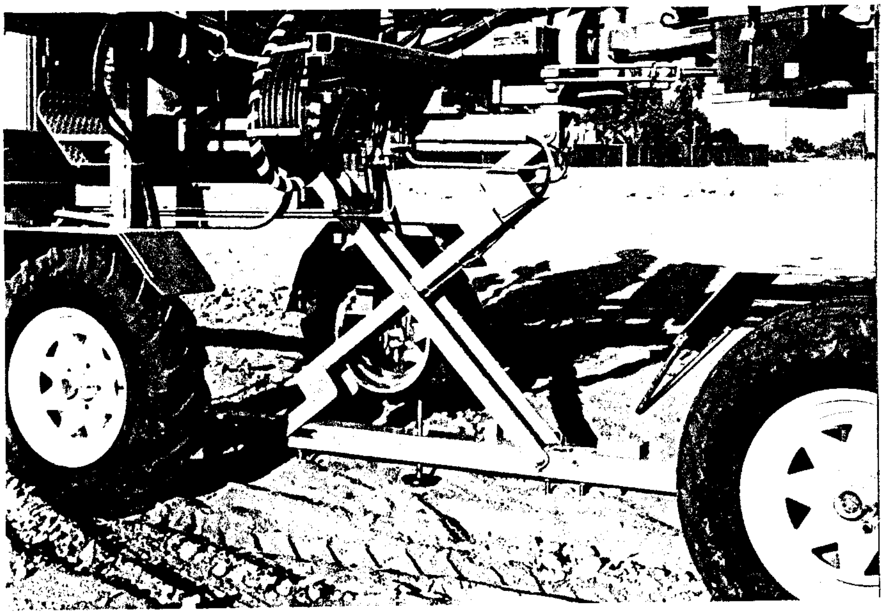


Figure 6. Fixed-array four-electrode sampling unit.

Figure 7. Operator control panel.

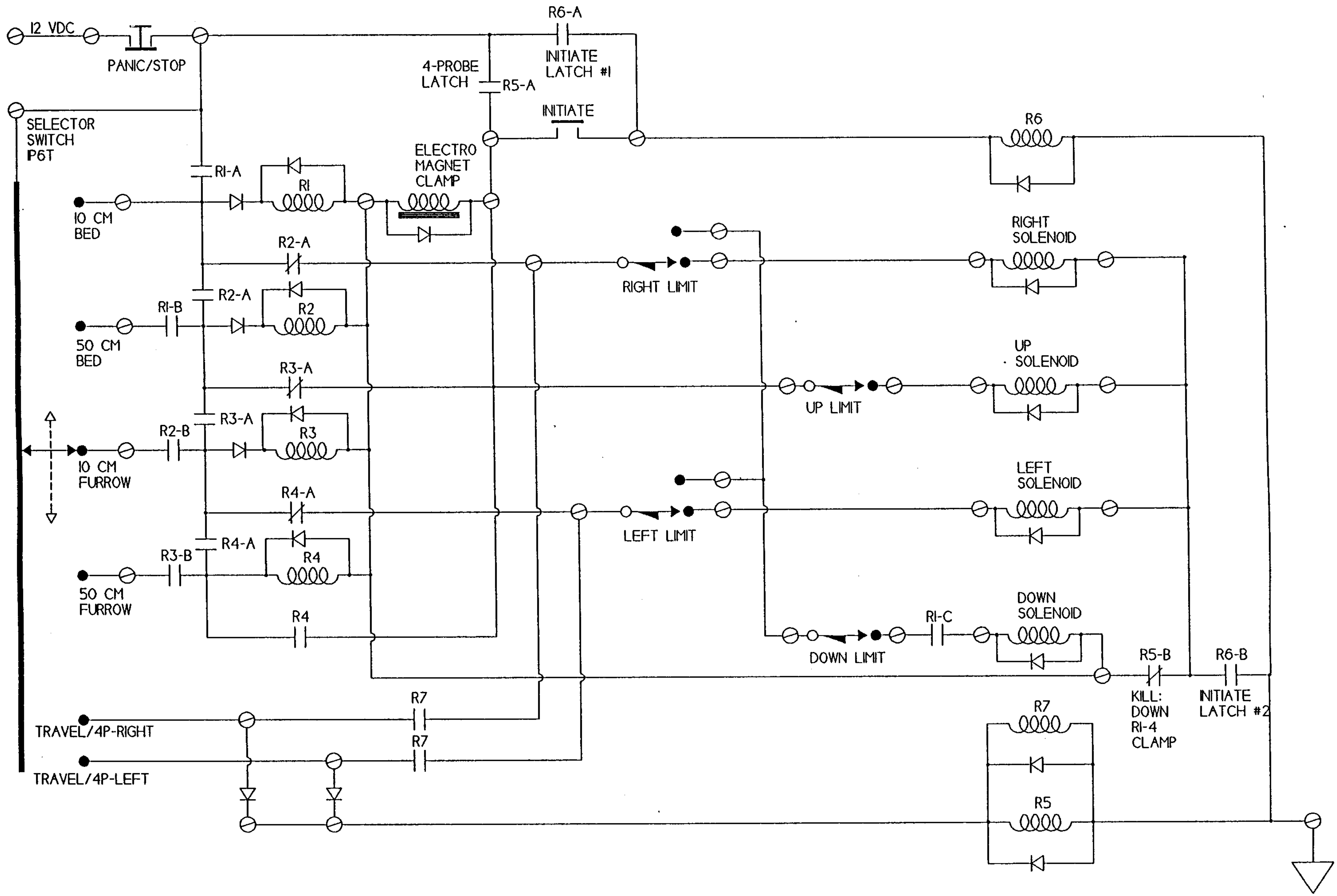


FIGURE 8. ELECTRICAL CIRCUIT FOR CARRIAGE CONTROL

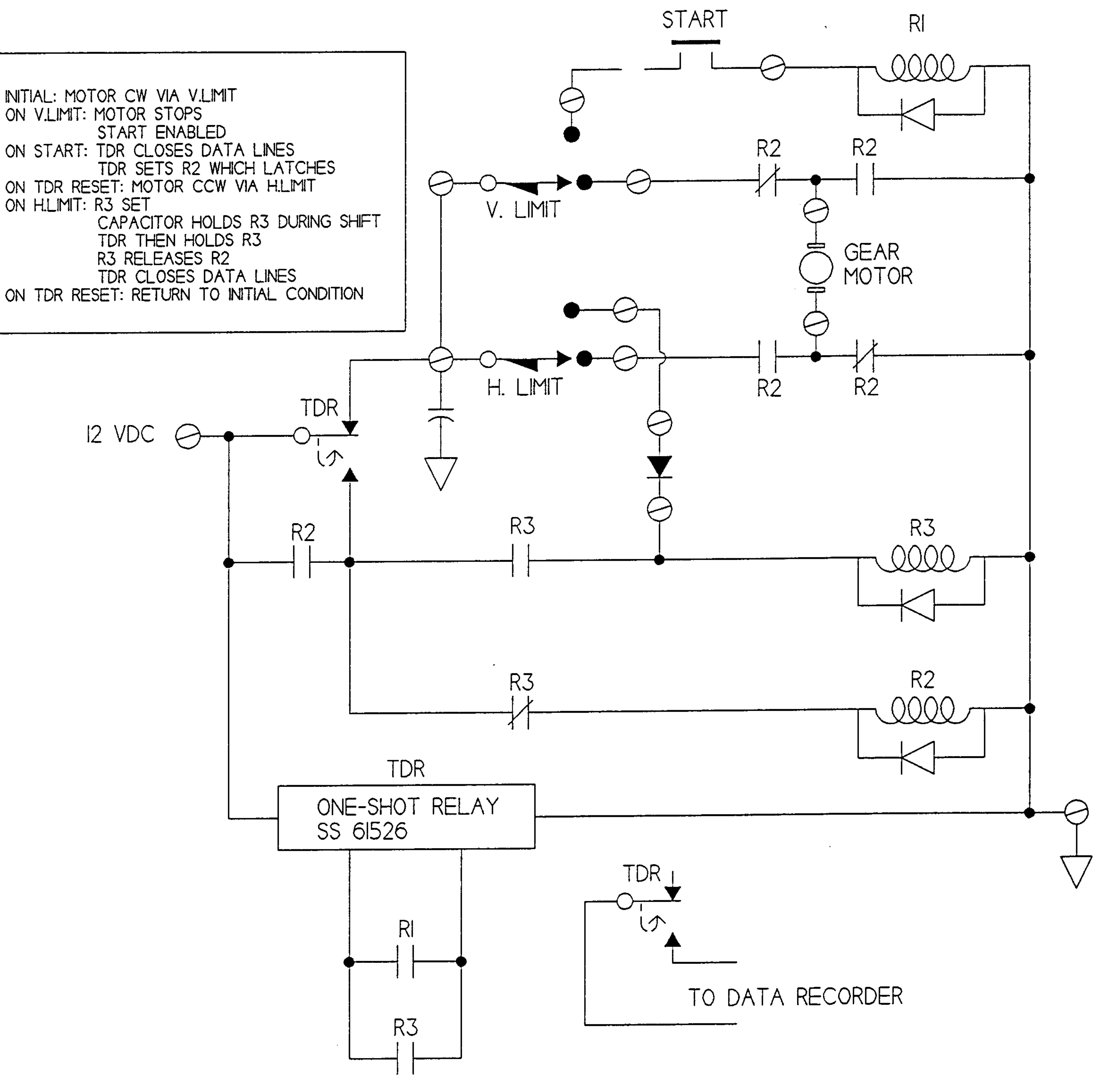
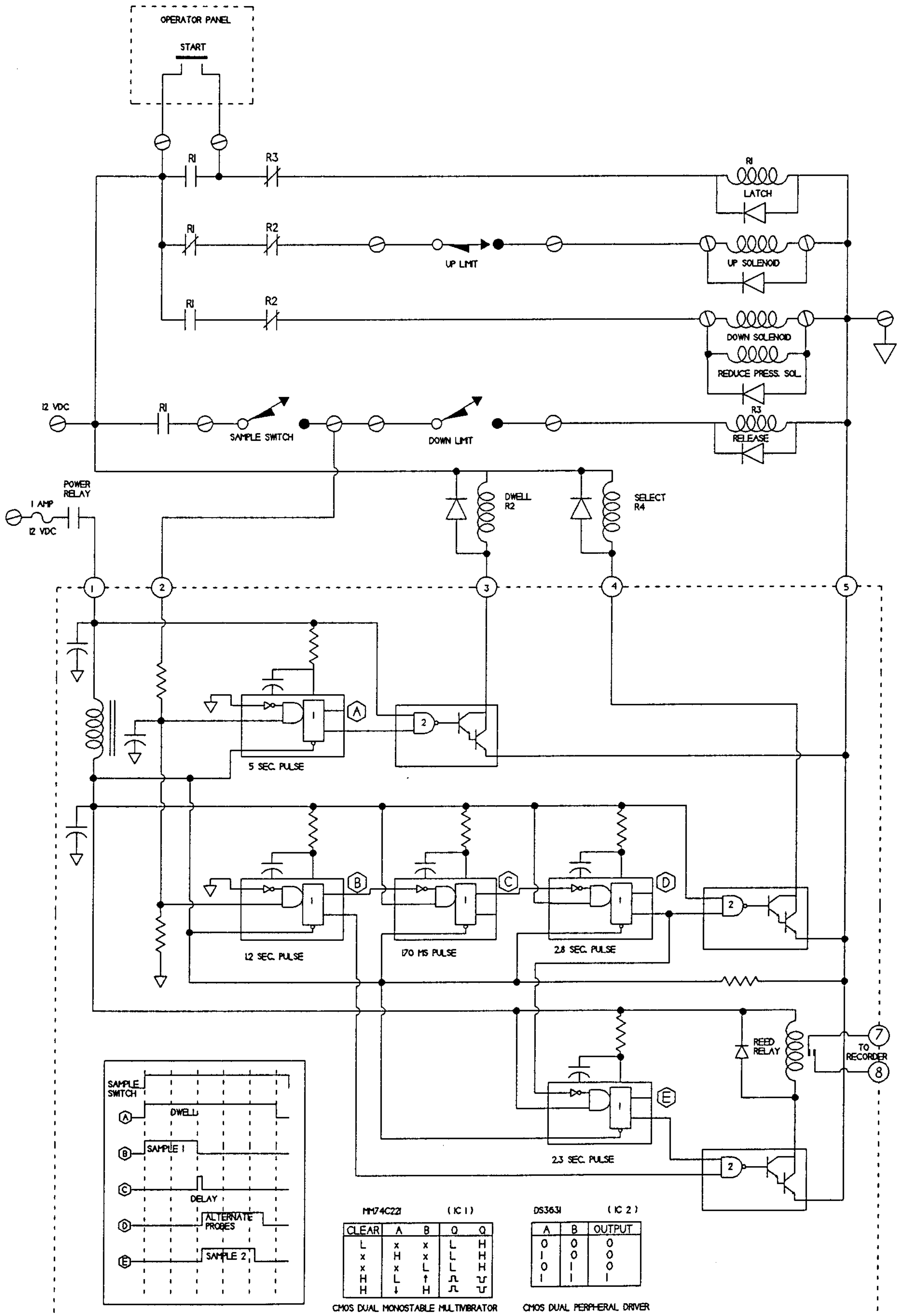


FIGURE 9. ELECTRICAL CIRCUIT FOR EM CONTROL AND DATA ACQUISITION



CLEAR	A	B	Q	Q
L	x	x	L	H
x	H	x	L	H
x	x	L	L	H
H	L	↑	⎍	⊔
H	↓	H	⎍	⊔

A	B	OUTPUT
0	0	0
1	0	0
0	1	0
1	1	1

FIGURE 10. ELECTRICAL CIRCUIT FOR 4 - PROBE CONTROL AND DATA ACQUISITION

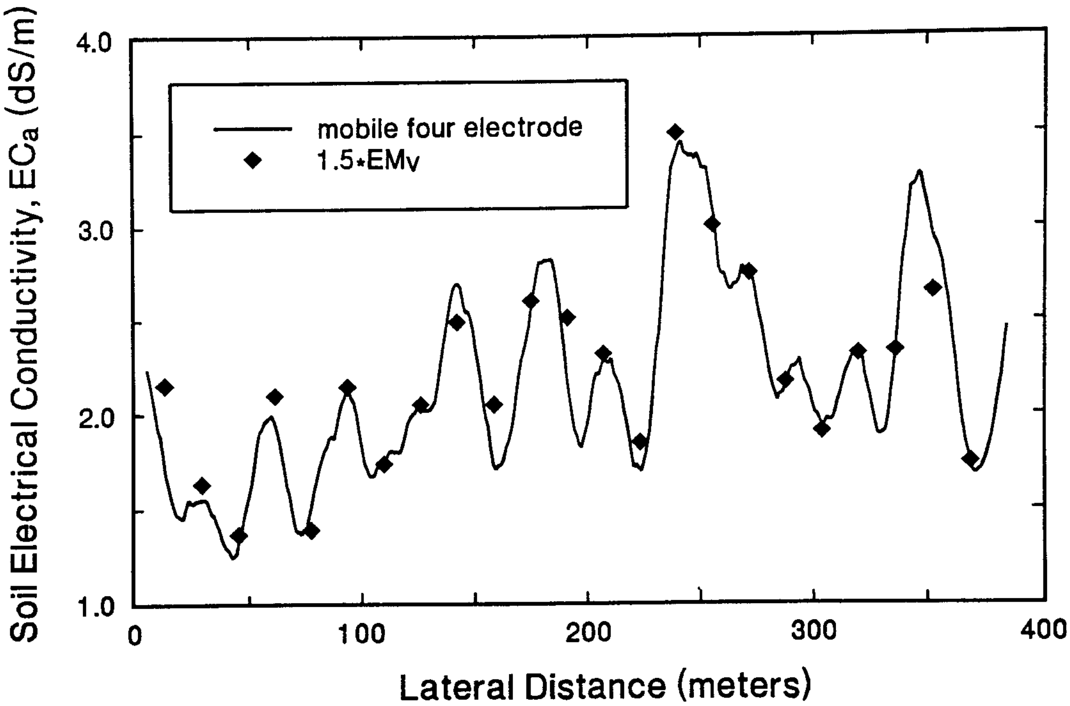


Figure 11. Cyclic relation between log of bulk soil electrical conductivity and distance across an irrigated, tiled drained field in the Coachella Valley of California.

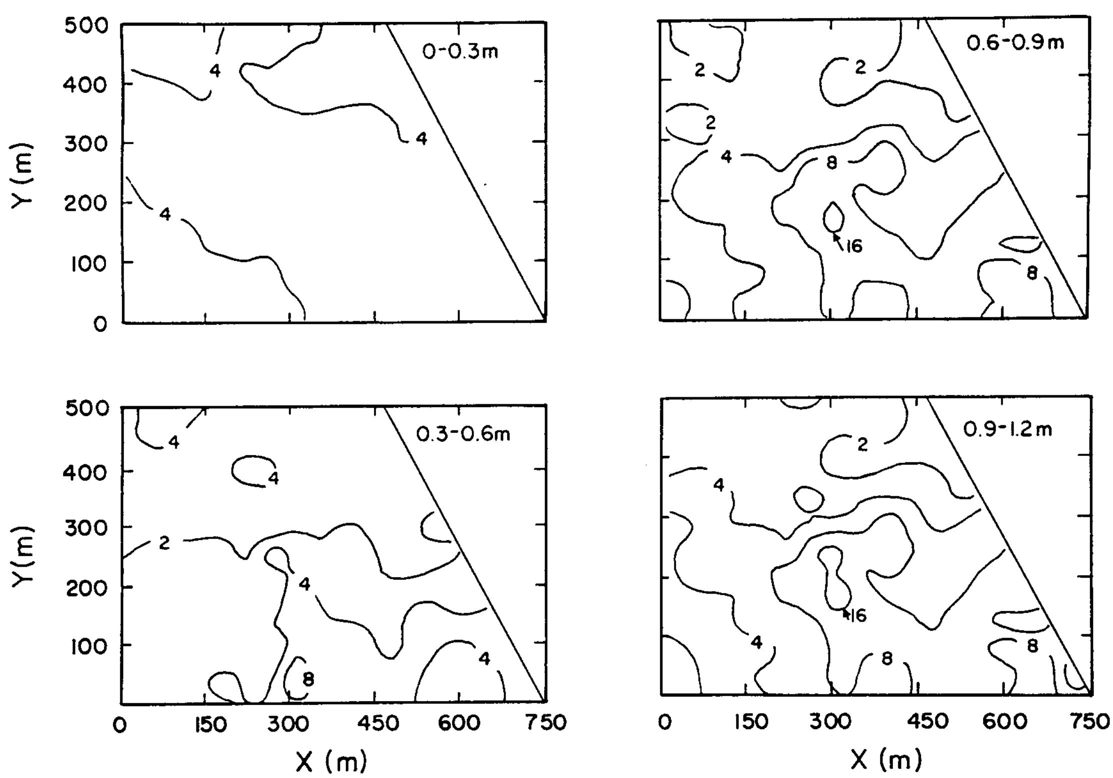


Figure 12. Map of soil salinity (EC_e basis in dS/m) within four depths in a furrow-irrigated, cotton-field in the San Joaquin Valley of California.