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CHANGES IN SOIL DENSITY, MOISTURE, STRENGTH, AND RESIDUE COVER INDUCED BY TILLAGE AND TIME

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Changes in soil density, moisture, strength, and residue cover induced by tillage and time

by

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LIST OF ABBREVIATIONS

C	Celsius
cm	centimeter
DB	dry basis
hr	hour
Km	kilometer
m	meter
Mg	megagram
mm	millimeter
N	newton
V	volt

GENERAL INTRODUCTION

The art of crop production developed from the observations of early man in the Fertile Crescent. Crop residue was removed from the field for feeding animals, cooking, heating, and building houses. The bare soil was then tilled with a chisel-like plow called the ard. As the ard was adopted westward beyond the Dardanella, Europeans modified the ard by attaching a moldboard on one side of the implement to aid the covering of residue. This implement, the moldboard plow, was carried by Europeans to North America in 1617. The objective of tillage at that time was to provide a bare surface for planting and controlling weeds, insects, and rodents (Rush, 1960).

During the mechanization era (1920-1940) and the scientific era (post-World War II), tillage was well-defined, and its objectives were clearly established. Tillage was defined as mechanical, soil-stirring operations performed for the purpose of nurturing crops. The goal of tillage was to provide a suitable environment for seed germination, root growth, weed control, soil erosion control, and moisture control (avoiding moisture excesses and reducing moisture shortages) (Buckingham, 1976; Buchele, 1979).

Traditionally, row crops were produced under clean cultivation, i.e., moldboard plowing (fall or spring), one or more diskings in the spring for seedbed preparation and several cultivations after planting. Farmers in Iowa, until very recently, continued to carry out these operations and regarded soil loss by wind and water as a normal part of farming.

The dust storm on May 12, 1934, darkened the skies from the Great Plains to New York City and focused attention to the need for soil conservation. The Soil Conservation Service was quickly established and research programs in wind and water erosion were initiated in the semiarid and humid areas of the country (Wittmuss et al., 1973). Conservation tillage research expanded rapidly after the introduction of herbicides for weed control and insecticides for insect control solved two main problems associated with conservation tillage.

In the 1950s, researchers questioned the need for extensive secondary tillage in row crop production (Sprague, 1952). Later, in 1980, a USDA report showed that erosion rates in the United States exceed 11.2 ton/hectare/year on about 23% of the cropland, 11% of the rangeland, 7% of the pastureland, 15% of the grazed forest land, and 2% of the non-grazed forest land. Iowa has the largest acreage of erosive soil and the highest percentage of land in intensive cultivation. Almost 5 million hectares in Iowa have more than 11.2 ton/hectare/year annual soil loss (USDA, 1980).

Conservation tillage was a far-off goal when Faulkner called for a change in tillage practices in 1943. There is now strong evidence that farmers want to practice conservation tillage.

The purpose of this research is to evaluate the effect of three tillage systems upon physical properties of the soil. These systems are chisel plow, paraplow, and no-till.

The choice of the chisel plow system was based on the growing popularity and use of the chisel plow as a substitute for the moldboard plow (Dulley and Russel, 1942; Faulkner, 1943; Buchele, 1979). Furthermore, the chisel plow is considered a conservation tool when compared with the moldboard plow.

The paraplow, still an experimental implement in the United States, has been developed in England by Howard Rotovator Company and the Plant Protection Division of the Imperial Chemical Industries. Long (1982) described the paraplow as one of the best machines ever developed for use in heavy soils where arable crops are to be direct drilled. Long claims that the paraplow breaks the plow pan, that may form at a depth of 7 to 8 inches, increases the infiltration capacity of the soil and improves aeration while causing little disturbance of the soil surface.

No-till (zero tillage) leaves maximum plant residue on the soil surface for soil conservation and requires minimum costs for labor, fuel, and equipment.

Soil failure due to forces applied by a tillage implement may affect the properties of the soil. Evidence has been found that bulk density, moisture content, and penetration resistance are important soil physical properties.

Soil bulk density was related to the suitability of soils for no-till direct drilling (Pidgeon, 1980), rate of corn seedling elongation (Phillips and Kirkham, 1962), rate of corn root growth (Grable and Siemer, 1968), infiltration rate (Gumbs and Warkentin, 1972), and leaf water potential (Morris and Daynard, 1978).

Moisture content measurements are needed in practically every type of soil study. In the field, knowledge of water available for plant growth requires a direct measure of moisture content, or a measure of some indicator of moisture content. In the laboratory, determining and reporting of many physical and chemical properties of the soil necessitates knowledge of moisture content.

Despite the limitations of cone index measurements (Carter, 1967; Freitag, 1968; Mulqueen et al., 1977), penetrometer measurements are the only easy, quick, and available method for evaluating soil strength (Anderson et al., 1980). The penetrometer has been used to measure and relate soil compaction to plant growth (Bilbro and Wanjura, 1982), to compare tillage implements (Dumas et al., 1975; Soane et al., 1976; Voorhees et al., 1978) and to predict vehicle mobility (Wismer and Luth, 1973).

The advantages of leaving crop residue on the surface of the soil were recognized more than 50 years ago. Residue cover was found to reduce run-off, water and wind erosion and surface evaporation and to increase soil capacity to absorb water (Dulley and Russel, 1942; Bennett, 1977; Buchele and Marley, 1978).

Therefore, it was concluded that soil bulk density, moisture content, cone index, and percent crop residue cover are important for evaluating tillage systems.

During the course of this study, it became clear that taking cone index measurements with a hand-operated penetrometer is a back-breaking, labor-intensive job demanding a high degree of coordination between the penetrometer operator and the recorder. To solve this problem, a study was undertaken to design, develop, and fabricate an easy-to-use and accurate recording penetrometer.

This dissertation presents two papers, "Changes in Soil Density, Moisture, Strength, and Residue Cover as Induced by Tillage and Time," and "A Microcomputer-based Penetrometer."

PART I. CHANGES IN SOIL DENSITY, MOISTURE, STRENGTH, AND RESIDUE COVER AS INDUCED BY TILLAGE AND TIME

INTRODUCTION

Adopting a certain tillage system has been and is still largely governed by estimates based on previous experience. Traditionally, crops were produced under clean cultivation, whereby a smooth seedbed was prepared and insects, weeds, diseases, and rodents were controlled. Many farmers are still practicing bareland agriculture, regarding soil loss by wind and water as a natural part of farming. Wind and water erosion in the United States exceeds 11.2 ton/hectare/year on about 23% of the cropland, 11% of the rangeland, 7% of the pastureland, 15% of the grazed forest land, and 2% of the nongrazed forest land. Iowa has the largest acreage of erosive soils and the highest percentage of land under intensive cultivation. Almost 5 million hectares in Iowa have erosion in excess of 11.2 ton/hectare/year; of these, 2 million have more than 31.4 ton/hectare/year (USDA, 1980).

The importance of leaving crop residue on the soil surface to reduce wind and water erosion, surface evaporation and run-off, to increase soil capacity to absorb water, and to provide a source of plant nutrients, has been reported by many researchers (Dulley and Russel, 1942; Bennett, 1977; Buchele and Marley, 1978). The disadvantages of leaving crop residue on the surface includes reducing soil temperature, increasing insect, weed, disease, and rodent risks, and reducing the mobility of nutrients (Amemiya, 1977).

Many approaches and techniques were developed to strike the delicate balance between minimum soil loss and profitable farming. Among those solutions was ridge farming (Buchele et al., 1955), mulch farming

(Mannering and Meyer, 1963; Wittmuss et al., 1973), strip till-planting (Wittmuss et al., 1971), and controlled residue harvest (Colvin et al., 1981a).

Several methods and equations for predicting soil loss in the field (Wischmeier and Smith, 1978; Laflen and Colvin, 1981; Laflen et al., 1981) and for predicting percent of residue reduction by implements (Sloneker and Moldenhauer, 1977; Hartwig and Laflen, 1978; Siemens and Oschwald, 1978; Colvin et al., 1980; Colvin et al., 1981b) were employed.

Soil failure due to forces applied by a tillage implement may affect the physical properties of the soil. Evidence has been found that soil density, moisture, and strength are important properties affecting plant growth. Bulk density was related to the suitability of the soil for no-till drilling (Pidgeon, 1980), rate of corn seedling elongation (Phillips and Kirkham, 1962), rate of corn root growth (Grable and Siemer, 1968), infiltration rate (Gumbs and Warkentin, 1972), and leaf water potential (Morris and Daynard, 1978). Soil moisture was found to be an important factor promoting innumerable chemical, physical, and biological activities in the soil, and to act as a solvent and a carrier of nutrients (Lyon and Buckman, 1947). Cone index, as a measure of soil compaction, was related to plant growth (Bilbro and Wanjura, 1982), and was used to compare tillage implements (Dumas et al., 1975; Soane et al., 1976; and Voorhees et al., 1978).

Many machines have been designed and developed for the purpose of managing residue, reducing erosion, and increasing the productivity of marginal land. Among these machines is the paraplow, recently introduced by Howard Rotovator Company of England. The paraplow breaks the plow pan, increases the infiltration capacity of the soil, and improves aeration with little disturbance of the soil surface (Long, 1982; Pidgeon, 1983). The chisel plow, when compared to the moldboard plow, was considered by many researchers as a conservation tool (Faulkner, 1943; Buchele, 1979). No-till leaves maximum residue on the soil surface and requires minimum cost for labor, fuel, and equipment.

The objective of this paper was to compare the paraplow, the chisel plow, and the no-till tillage systems based on their effect on soil bulk density, moisture content, penetration resistance, and residue cover and also to calculate the number of replications required to detect a preselected density, moisture, or penetrator resistance difference.

MATERIALS AND METHODS

The area of study was located in central Iowa at the Agricultural Engineering Research Center, 11 km west of Ames, in Boone County. The soil in the experimental field was from the Clarion-Nicollet-Webster soil ssociation. The experimental field has been cropped since the late 1800s with the last three years under corn. The plots (76.2 m x 6.1 m) were laid east-west, with a landscape having a gentle slope (approximately 1%) to the north. Three tillage treatments were selected for this study: (a) fall paraplowing; (b) fall chiseling and spring disking; and (c) no-till. These treatments, where corn was grown, were replicated six times in a randomized split plot design. The 76.2 m x 6.1 m plot was divided into 25 subplots per treatment; each was approximately 6.1 m x 3 m. Sampling dates were assigned randomly for each subplot. This assured that each subplot, within the treatment, would be sampled only once during the course of this study. Soil bulk density, moisture content, penetration resistance, and percentage residue cover were monitored throughout the year, whenever the weather permitted.

The powered sampler, developed by Buchele (1961), was used to obtain an undisturbed soil sample from the interrow away from the wheel track. The sample was encased into liners supported by the inner tube. The internal diameter of the liners (7.62 cm) is slightly larger than the internal diameter of the cutting and trimming edge of the inner tube (7.50 cm), which is equal to the outer diameter of the soil column.

The soil column is then sectioned using the edge of the 5.0 cm long liners as a guide. Seven samples (sampled 35 cm deep)/treatment/replicate were taken. The oven method (105 C for 24 hr) was used to obtain the dry weight of the sample.

The hand-held penetrometer (Weight and Test System, Model FD 127) was used to estimate the penetration force on the 30 degree, 12.83 mm base diameter, stainless steel cone. Depth was estimated from notches, 5.0 cm apart on the shaft (9.5 mm diameter) of the penetrometer.

The percent residue cover was estimated by the photographic method suggested by Williams (1979). Slides of the soil surface are projected onto a gridded screen. Residue cover is the percentage of intersections on the grid that are over residue.

Two samples were taken in November, 1982 (before and after tillage for 1982/83 cropping season), one sample each month starting from April through September of 1983, and two samples in November 1983 (before and after tillage for 1983/84 cropping season). Percentage residue cover was estimated each time soil samples and penetrometer readings were taken.

The procedure suggested by Cochran and Cox (1957) was used to estimate the minimum number of replications required to detect a preselected moisture, density, cone index, or residue cover difference.

The data for each sampling date were analyzed separately to determine if differences between treatments and/or depths exist. Then, the pooled data were analyzed to determine how soil conditions changed with time. The least significant difference (LSD) was used to compare means.

RESULTS AND DISCUSSION

Soil moisture, bulk density, and penetration resistance (cone index), for ten sampling dates (Tables 1-10) were determined for each tillage system at seven depths. The effects of tillage system and sampling date on soil conditions, for the 1982/83 season, are summarized in Table 11. Table 12 presents the effect of tillage on soil conditions before and after tillage for 1982/83 and 1983/84 seasons. The number of replications required to detect a preselected moisture, density, cone index, or residue cover difference are presented in Tables 13-15 and 17, respectively. The residue cover and the yield data are presented in Tables 16 and 18, respectively.

Soil Moisture Content

The analysis of variance showed that there was no significant difference in moisture content between treatment means (averaged across depths) for any date except November 16, 1983 (Table 9). The maximum moisture difference between any two means was less than 3%. Differences of this magnitude will not be expected to cause any variations in plant growth. This similarity can be attributed to the abundance of moisture (rain or thawing snow) at the experiment site. The similarity in moisture between different tillage systems in this region was also reported by Luttrell (1963). The drought that occurred in the summer of 1983 was expected to cause significant variation between treatment means. It was thought that the no-till treatment would have less moisture. The similarity in moisture content during that period may indicate that

Table 1. Effect of tillage on soil density, moisture, and penetration resistance (first sampling date, before tillage, November 16, 1982)

Depth	Moisture content			Depth mean	Bulk density			Depth mean	Cone index[a]			Depth mean
	No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow	
cm	% DB				Mg/m^3				N/cm^2			
2.5	32.4	30.3	33.8	31.2	0.77	0.57	0.56	0.64	66	43	22	44
7.5	31.3	33.5	30.1	31.6	1.21	1.05	1.15	1.14	94	61	41	66
12.5	31.5	31.3	30.7	31.2	1.35	1.29	1.25	1.29	102	68	69	80
17.5	31.6	30.2	28.4	30.1	1.30	1.31	1.40	1.34	103	75	93	90
22.5	31.5	31.6	27.7	30.3	1.28	1.25	1.34	1.29	97	67	101	88
27.5	30.1	33.9	27.7	30.6	1.35	1.16	1.39	1.30	76	63	101	80
32.5	28.8	32.1	27.7	29.5	1.38	1.30	1.43	1.37	78	66	95	80
Tillage mean	31.0	31.8	29.4	30.7	1.23	1.13	1.21	1.19	88	63	75	75

LSD (0.05) for comparing:
1) Tillage means a) moisture content = NS b) bulk density = 0.07 Mg/m^3 c) cone index = 7 N/cm^2
2) Depth means a) moisture content = NS b) bulk density = 0.09 Mg/m^3 c) cone index = 8 N/cm^2
3) Tillage by depth interaction a) moisture content = 3.4% b) bulk density = NS c) cone index = 14 N/cm^2

[a]Depths for cone index values are 5, 10, 15, 20, 25, 30, and 35 cm.

Table 2. Effect of tillage on soil density, moisture, and penetration resistance (second sampling date, after tillage, November 19, 1982)

Depth	Moisture content			Depth mean	Bulk density			Depth mean	Cone index			Depth mean
	No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow	
cm	% DB				Mg/m^3				N/cm^2			
2.5	30.4	24.8	25.4	26.8	1.03	1.05	0.87	0.98	63	34	41	46
7.5	29.0	29.8	29.9	29.6	1.30	1.11	1.15	1.19	80	34	81	65
12.5	27.8	30.7	29.2	29.2	1.32	1.15	1.30	1.26	90	55	100	82
17.5	28.5	31.9	29.9	30.1	1.30	1.14	1.28	1.24	98	59	113	90
22.5	28.0	33.1	29.7	30.3	1.33	1.18	1.27	1.26	101	63	107	90
27.5	26.4	32.2	29.4	29.3	1.34	1.21	1.33	1.29	106	70	111	96
32.5	23.6	30.4	27.7	27.2	1.37	1.28	1.32	1.33	109	74	109	97
Tillage mean	27.6	30.4	28.7	28.9	1.28	1.16	1.21	1.22	92	56	95	81

LSD (0.05) for comparing:
1) Tillage means a) moisture content = NS b) bulk density = 0.08 Mg/m^3 c) cone index = 8 N/cm^2
2) Depth means a) moisture content = 1.5% b) bulk density = 0.06 Mg/m^3 c) cone index = 9 N/cm^2
3) Tillage by depth interaction a) moisture content = 2.7% b) bulk density = 0.10 Mg/m^3 c) cone index = 15 N/cm^2

Table 3. Effect of tillage on soil density, moisture, and penetration resistance (third sampling date, after winter, April 24, 1983)

Depth	Moisture content			Depth mean	Bulk density			Depth mean	Cone index			Depth mean
	No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow	
cm	% DB				Mg/m^3				N/cm^2			
2.5	33.8	31.3	34.9	33.3	1.05	0.88	1.03	1.00	61	43	56	53
7.5	33.1	31.9	31.6	32.2	1.20	1.11	1.25	1.18	87	49	76	71
12.5	32.1	30.2	29.3	30.6	1.30	1.18	1.34	1.27	90	51	80	74
17.5	31.6	32.3	29.2	31.0	1.29	1.21	1.35	1.28	84	56	93	77
22.5	30.2	27.8	29.3	29.1	1.31	1.18	1.32	1.27	81	57	84	74
27.5	29.5	30.0	29.4	29.6	1.25	1.33	1.33	1.30	79	57	83	73
32.5	28.7	28.8	28.0	28.5	1.36	1.36	1.35	1.35	72	45	75	64
Tillage mean	31.3	30.3	30.2	30.6	1.25	1.18	1.28	1.24	79	51	78	70

LSD (0.05) for comparing:
1) Tillage means a) moisture content = NS b) bulk density = 0.08 Mg/m^3 c) cone index = 9 N/cm^2
2) Depth means a) moisture content = 1.8% b) bulk density = 0.07 Mg/m^3 c) cone index = 8 N/cm^2
3) Tillage by depth interaction a) moisture content = NS b) bulk density = NS c) cone index = 15 N/cm^2

Table 4. Effect of tillage on soil density, moisture, and penetration resistance (fourth sampling date, May 20, 1983)

Depth	Moisture content			Depth mean	Bulk density			Depth mean	Cone index			Depth mean
	No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow	
cm	% DB				Mg/m^3				N/cm^2			
2.5	30.2	26.7	26.6	27.8	1.04	1.11	1.02	1.05	48	39	38	42
7.5	29.8	31.6	32.12	31.2	1.33	1.17	1.32	1.27	55	44	47	49
12.5	28.0	31.5	30.2	29.9	1.45	1.34	1.37	1.39	77	50	77	68
17.5	28.5	31.5	30.7	30.2	1.46	1.32	1.38	1.39	74	41	83	66
22.5	29.0	31.5	30.4	30.3	1.41	1.29	1.30	1.36	72	55	80	69
27.5	28.3	30.8	28.8	29.3	1.35	1.35	1.40	1.37	70	47	69	62
32.5	27.6	29.9	27.6	28.4	1.37	1.27	1.40	1.35	63	53	71	62
Tillage mean	28.8	30.5	29.5	29.6	1.35	1.26	1.32	1.31	65	50	66	60

LSD (0.05) for comparing:

1) Tillage means a) moisture content = NS b) bulk density = 0.05 Mg/m^3 c) cone index = 6 N/cm^2
2) Depth means a) moisture content = 1.4% b) bulk density = 0.06 Mg/m^3 c) cone index = 6 N/cm^2
3) Tillage by depth interaction a) moisture content = 2.3% b) bulk density = NS c) cone index = 10 N/cm^2

Table 5. Effect of tillage on soil density, moisture, and penetration resistance (fifth sampling date, June 21, 1983)

Depth	Moisture content			Depth mean	Bulk density			Depth mean	Cone index			Depth mean
	No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow	
cm	% DB				Mg/m^3				N/cm^2			
2.5	23.7	20.2	20.2	21.3	1.20	1.05	1.09	1.11	94	59	61	71
7.5	25.9	24.8	24.9	25.2	1.32	1.15	1.23	1.24	122	95	109	109
12.5	26.0	24.6	25.3	25.3	1.38	1.22	1.36	1.32	157	75	161	131
17.5	27.7	28.9	26.6	27.7	1.31	1.22	1.33	1.29	164	86	145	132
22.5	27.7	23.1	25.5	25.4	1.29	1.26	1.38	1.31	156	86	150	131
27.5	27.6	24.1	24.1	25.3	1.32	1.25	1.39	1.32	150	83	140	125
32.5	27.0	24.7	24.5	25.4	1.37	1.32	1.37	1.35	145	110	144	133
Tillage mean	26.5	24.3	24.4	25.1	1.31	1.21	1.31	1.28	141	85	130	119

LSD (0.05) for comparing:
1) Tillage means a) moisture content = NS b) bulk density = 0.08 Mg/m^3 c) cone index = 17 N/cm^2
2) Depth means a) moisture content = 2.5% b) bulk density = 0.07 Mg/m^3 c) cone index = 14 N/cm^2
3) Tillage by depth interaction a) moisture content = NS b) bulk density = NS c) cone index = 24 N/cm^2

Table 6. Effect of tillage on soil density, moisture, and penetration resistance (sixth sampling date, July 13, 1983)

Depth	Moisture content			Depth mean	Bulk density			Depth mean	Cone index			Depth mean
	No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow	
cm	% DB				Mg/m^3				N/cm^2			
2.5	24.2	23.9	23.1	23.7	1.05	1.02	0.99	1.02	50	49	59	52
7.5	24.2	26.5	27.0	25.9	1.33	1.16	1.02	1.17	83	74	70	75
12.5	23.8	26.3	26.2	25.4	1.34	1.19	1.18	1.23	109	53	93	85
17.5	24.0	26.3	24.8	25.0	1.33	1.23	1.29	1.28	109	74	83	89
22.5	23.8	26.2	23.6	24.5	1.38	1.25	1.37	1.33	99	70	85	84
27.5	22.8	27.0	22.3	24.0	1.38	1.28	1.39	1.35	93	74	92	86
32.5	21.0	25.3	21.6	22.7	1.43	1.33	1.37	1.38	86	87	85	86
Tillage mean	23.4	25.9	24.1	24.3	1.32	1.20	1.23	1.25	90	69	81	80

LSD (0.05) for comparing:
1) Tillage means a) moisture content = NS b) bulk density = 0.07 Mg/m^3 c) cone index = 12 N/cm^2
2) Depth means a) moisture content = 1.1% b) bulk density = 0.05 Mg/m^3 c) cone index = 8 N/cm^2
3) Tillage by depth interaction a) moisture content = 1.9% b) bulk density = 0.09 Mg/m^3 c) cone index = 14 N/cm^2

Table 7. Effect of tillage on soil density, moisture, and penetration resistance (seventh sampling date, August 19, 1983)

Depth	Moisture content			Depth mean	Bulk density			Depth mean	Cone index			Depth mean
	No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow	
cm	% DB				Mg/m^3				N/cm^2			
2.5	31.2	28.7	29.9	29.9	1.05	1.13	0.98	1.05	63	32	52	49
7.5	26.6	25.2	26.9	26.2	1.27	1.14	1.13	1.18	107	49	84	80
12.5	25.1	23.7	23.4	24.1	1.29	1.16	1.37	1.27	106	70	124	100
17.5	24.2	23.6	23.0	23.6	1.29	1.21	1.35	1.28	109	88	137	111
22.5	23.8	24.1	22.4	23.5	1.29	1.27	1.33	1.30	115	89	137	114
27.5	21.5	24.8	20.4	22.3	1.35	1.26	1.40	1.33	124	87	127	113
32.5	21.0	23.7	20.6	21.7	1.34	1.33	1.36	1.34	118	82	132	110
Tillage mean	24.8	24.8	24.0	24.5	1.27	1.21	1.26	1.25	106	71	113	97

LSD (0.05) for comparing:
1) Tillage means a) moisture content = NS b) bulk density = NS c) cone index = 14 N/cm^2
2) Depth means a) moisture content = 1.1% b) bulk density = 0.07 Mg/m^3 c) cone index = 9 N/cm^2
3) Tillage by depth interaction a) moisture content = 2.0% b) bulk density = 0.12 Mg/m^3 c) cone index = 16 N/cm^2

Table 8. Effect of tillage on soil density, moisture, and penetration resistance (eighth sampling date, September 12, 1983)

Depth	Moisture content			Depth mean	Bulk density			Depth mean	Cone index			Depth mean
	No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow	
cm	% DB				Mg/m^3				N/cm^2			
2.5	28.8	28.4	27.8	28.3	1.11	0.95	1.06	1.04	71	52	52	59
7.5	29.3	30.5	29.8	30.0	1.28	1.23	1.13	1.22	98	99	87	92
12.5	28.6	29.0	28.1	28.6	1.37	1.31	1.36	1.35	110	106	132	116
17.5	28.9	29.2	27.9	28.6	1.30	1.32	1.36	1.33	107	103	136	116
22.5	29.2	29.3	28.7	29.1	1.33	1.29	1.35	1.32	105	86	118	103
27.5	28.0	28.7	27.8	28.2	1.32	1.32	1.34	1.32	110	70	114	98
32.5	26.3	27.3	26.8	26.8	1.35	1.37	1.38	1.37	103	64	121	96
Tillage mean	28.0	28.9	28.1	28.5	1.29	1.25	1.28	1.27	101	82	109	97

LSD (0.05) for comparing:
1) Tillage means a) moisture content = NS b) bulk density = NS c) cone index = 12 N/cm^2
2) Depth means a) moisture content = 1.5% b) bulk density = 0.06 Mg/m^3 c) cone index = 10 N/cm^2
3) Tillage by depth interaction a) moisture content = NS b) bulk density = NS c) cone index = 17 N/cm^2

Table 9. Effect of tillage on soil density, moisture, and penetration resistance (ninth sampling date, before tillage, November 16, 1983)

Depth	Moisture content			Depth mean	Bulk density			Depth mean	Cone index			Depth mean
	No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow	
cm	% DB				Mg/m^3				N/cm^2			
2.5	32.4	34.0	28.3	31.6	1.10	1.05	1.20	1.12	29	22	20	24
7.5	24.0	29.2	23.6	25.6	1.37	1.29	1.43	1.36	61	56	57	58
12.5	24.1	24.1	20.5	22.9	1.43	1.30	1.51	1.41	75	76	79	77
17.5	25.5	26.2	22.8	24.8	1.46	1.33	1.46	1.42	84	68	93	82
22.5	23.9	24.3	23.3	23.8	1.41	1.34	1.48	1.41	84	65	95	81
27.5	27.5	23.7	22.6	24.6	1.38	1.36	1.47	1.40	82	68	81	77
32.5	24.5	23.5	22.6	23.5	1.40	1.40	1.44	1.41	79	68	79	75
Tillage means	26.0	26.4	23.4	25.3	1.36	1.30	1.43	1.36	71	60	72	68

LSD (0.05) for comparing:
1) Tillage means a) moisture content = 2.0% b) bulk density = 0.07 Mg/m^3 c) cone index = 9 N/cm^2
2) Depth means a) moisture content = 2.7% b) bulk density = 0.007 Mg/m^3 c) cone index = 11 N/cm^2
3) Tillage by depth interaction a) moisture content = NS b) bulk density = NS c) cone index = 19 N/cm^2

Table 10. Effect of tillage on soil density, moisture, and penetration resistance (tenth sampling date after tillage, November 17, 1983)

Depth	Moisture content			Depth mean	Bulk density			Depth mean	Cone index			Depth mean
	No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow	
cm	% DB				Mg/m^3				N/cm^2			
2.5	32.4	32.3	31.3	32.0	1.10	0.57	1.05	0.91	29	8	9	15
7.5	30.0	29.9	29.5	27.8	1.37	0.97	1.22	1.19	61	13	20	32
12.5	24.1	28.8	32.4	28.4	1.43	1.07	1.32	1.27	75	21	49	48
17.5	25.5	29.0	25.6	26.7	1.46	1.22	1.43	1.37	84	25	83	64
22.5	23.9	29.5	25.8	26.4	1.41	1.26	1.42	1.36	84	24	97	68
27.5	27.5	29.4	27.0	28.0	1.38	1.28	1.39	1.35	82	48	86	72
32.5	24.5	24.4	25.1	25.7	1.40	1.36	1.42	1.39	79	50	90	76
Tillage means	26.0	29.5	28.1	27.9	1.36	1.10	1.32	1.26	71	28	62	54

LSD (0.05) for comparing:

1) Tillage means a) moisture content = NS b) bulk density = 0.12 Mg/m^3 c) cone index = 13 N/cm^2
2) Depth means a) moisture content = 2.5% b) bulk density = 0.08 Mg/m^3 c) cone index = 11 N/cm^2
3) Tillage by depth interaction a) moisture content = NS b) bulk density = 0.14 Mg/m^3 c) cone index = 20 N/cm^2

Table 11. Effect of tillage and sampling date on soil bulk density, moisture content, and penetration resistance (1982/83 cropping season)

Sampling date	Moisture content			Date mean	Bulk density			Date mean	Cone index			Date Mean
	No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow		No-till	Para-plow	Chisel plow	
mo/da/yr	% DB				Mg/m^3				N/cm^2			
First 11/16/82	31.0	31.8	29.4	30.8	1.23	1.13	1.21	1.19	88	63	75	75
Second 11/19/82	27.6	30.4	28.7	28.9	1.28	1.16	1.21	1.22	92	56	95	81
Third 4/24/83	31.3	30.3	30.2	30.6	1.25	1.18	1.28	1.24	79	51	78	70
Fourth 5/20/83	28.8	30.5	29.5	29.6	1.35	1.26	1.32	1.31	66	50	66	60
Fifth 6/21/83	26.5	24.3	24.4	25.1	1.31	1.21	1.31	1.28	141	85	130	119
Sixth 7/13/83	23.4	25.9	24.1	24.5	1.32	1.20	1.23	1.25	90	68	81	80
Seventh 8/19/83	24.8	24.8	24.0	24.5	1.27	1.21	1.26	1.25	106	71	113	97
Eighth 9/12/83	28.5	28.9	28.1	28.5	1.29	1.25	1.28	1.27	101	82	109	97
Tillage means	27.7	28.4	27.3	27.8	1.29	1.20	1.26	1.25	95	66	93	85

LSD (0.05) for comparing:
1) Tillage means a) moisture content = NS b) bulk density = 0.03 Mg/m^3 c) cone index = 5 N/cm^2
2) Date means a) moisture content = 1.3% b) bulk density = 0.04 Mg/m^3 c) cone index = 6 N/cm^2
3) Tillage by date interaction a) moisture content = NS b) bulk density = NS c) cone index = 10 N/cm^2

Table 12. Effect of tillage on soil moisture, density, and penetration resistance (before and after tillage)

Sampling date	Moisture content: No-till	Moisture content: Para-plow	Moisture content: Chisel plow	Date mean	Bulk density: No. till	Bulk density: Para-plow	Bulk density: Chisel plow	Date mean	Cone index: No-till	Cone index: Para-plow	Cone index: Chisel plow	Date mean
	% DB				Mg/m^3				N/cm^2			
Before tillage, 1982	31.0	31.8	29.4	30.7	1.23	1.13	1.21	1.19	88	63	75	75
Before tillage, 1983	26.0	26.4	23.4	25.3	1.36	1.30	1.43	1.36	71	60	72	68
Before tillage, mean	28.5	29.1	26.4	28.0	1.30	1.22	1.32	1.28	80	62	74	72
After tillage, 1982	27.6	30.4	28.7	28.9	1.28	1.16	1.21	1.22	92	56	95	81
After tillage, 1983	26.0	29.5	28.1	27.9	1.36	1.10	1.32	1.26	71	28	62	54
After tillage, mean	26.8	30.0	28.4	28.4	1.32	1.13	1.27	1.24	82	42	79	68
Tillage mean	27.7	29.5	27.4	28.2	1.31	1.17	1.21	1.26	81	52	76	61

LSD (0.05) for comparing means:

1) Before tillage:
A) Tillage a) moisture content = 2.0% b) bulk density = 0.05 Mg/m^3 c) cone index = 6 N/cm^2
B) Date a) moisture content = 1.4% b) bulk density = 0.04 Mg/m^3 c) cone index = 4 N/cm^2
C) Tillage by date a) moisture content = NS b) bulk density = NS c) cone index = 7 N/cm^2

2) After tillage:
A) Tillage a) moisture content = 2.3% b) bulk density = 0.09 Mg/m^3 c) cone index = 8 N/cm^2
B) Date a) moisture content = NS b) bulk density = NS c) cone index = 5 N/cm^2
C) Tillage by date a) moisture content = NS b) bulk density = 0.08 Mg/m^3 c) cone index = NS

3) Before and after:
A) Tillage a) moisture content = 1.3% b) bulk density = 0.04 Mg/m^3 c) cone index = 6 N/cm^2
B) Date a) moisture content = 1.2% b) bulk density = 0.05 Mg/m^3 c) cone index = 4 N/cm^2
C) Tillage by date a) moisture content = NS b) bulk density = 0.08 Mg/m^3 c) cone index = 7 N/cm^2

Table 13. Number of replications required for 95% probability of obtaining a significant result for a preselected soil moisture difference

Desired difference (%)	Number of replications required to achieve desired difference		
	Treatment means (averaged across depths)	Depth means (averaged across treatments)	Treatment by depth interaction
1	101	57	171
2	27	14	40
3	13	6	18
4	8	4	11
5	6	3	7
6	5	3	6
7	4	2	4
8	2	2	3
9	2	2	3
10	2	2	2

Table 14. Number of replications required for 95% probability of obtaining a significant result for a preselected soil density difference

Desired difference (Mg/m^3)	Number of replications required to achieve desired difference		
	Treatment means (averaged across depths)	Depth means (averaged across treatments)	Treatment by depth interaction
0.01	1009	946	2838
0.05	42	38	114
0.1	12	10	30
0.2	4	3	8
0.3	2	2	4
0.4	2	2	3
0.5	2	2	2

Table 15. Number of replications required for 95% probability of obtaining a significant result for a preselected soil penetration resistance difference

Desired difference (N/cm^2)	Number of replications required to achieve desired difference		
	Treatment means (Averaged across depths)	Depth means (averaged across treatments)	Treatment by depth interaction
1	2033	1666	4996
5	82	67	200
10	44	17	50
15	10	8	23
20	6	5	13
25	4	3	9
30	4	2	6
35	2	2	4
40	2	2	4
45	2	2	3
50	2	2	3
55	2	2	2

Table 16. Percent residue cover and residue reduction for no-till, paraplow, and chisel plow tillage systems at different dates

Date	Residue cover			LSD (0.05)	Date mean	Residue reduction			Date mean	Note
	No-till	Para-plow	Chisel plow			No-till	Para-plow	Chisel plow		
11/16/1982	99	99	98	NS	99	0	0	0	0	Before tillage (1982)
11/19/1982	99	96	81	2	92	0	3	17	7	After tillage (1982)
4/24/1983	94	86	74	4	85	5	10	9	8	After winter (1983)
5/20/1983	91	77	26	8	65	3	10	65	24	After disking (1983)
6/21/1983	87	72	24	9	61	4	7	8	6	During
7/13/1983	84	55	19	6	53	3	24	21	13	the
8/19/1983	76	53	17	6	49	10	4	11	8	1983
9/12/1983	77	45	3	5	42	-1	15	82	14	season
Tillage mean (1982/83 season)	88	73	43	2	68					
LSD (0.05) for comparing: 1) Date means = 1.5%; and 2) Tillage by date interaction = 3.1%.										
11/16/1983	100	100	100	NS	100	0	0	0	0	Before tillage (1983)
11/17/1983	100	80	76	7	85	0	20	24	15	After tillage (1983)
Before tillage mean (1982/83 & 1983/84)	100	100	99	NS	100					
After tillage mean (1982/83 & 1983/84)	100	88	79	3	89					
LSD (0.05) for comparing: 1) Date means = 8%; and 2) Tillage by date interaction = 12%.										

Table 17. Number of replications required for 95% probability of obtaining a significant result for a preselected residue cover difference

Desired difference (%)	Number of replications required to achieve desired difference
	Treatment means
1	95
2	25
3	12
4	8
5	6
6	5
7	4
8	2

Table 18. Corn yield for no-till, paraplow, and chisel plow tillage systems

Tillage system	Corn yield	C.V.
	ton/ha	%
No-till	7.1	20
Paraplow	8.5	12
Chisel plow	8.5	9
LSD (0.05)	0.7	

residue was more important in preserving soil moisture (Dulley and Russel, 1942; Bennett, 1977; Buchele and Marley, 1978) than was low compaction.

Depth means for moisture (averaged across treatments) were significantly different for each date except November 16, 1982 (Tables 1-10). Generally, no specific pattern was deduced; however, moisture differences were more pronounced between the 2.5 cm depth and the other depths, and between the 32.5 cm depth and the other depths, while the 7.5, 12.5, 17.5, 22.5, and 27.5 cm depths were similar. These moisture differences can be attributed to the degree of exposure of a certain depth to the weather and the within-treatment moisture distribution caused by the tillage system. It seemed that the effect of these tillage treatments, which were carried out in the same plots in the spring of 1982, did not affect moisture distribution with depth in the fall of 1982 (first sampling date, November 16, 1982).

Tillage by depth interaction for soil moisture was found to be significant on November 16, 1982, November 19, 1982, May 20, 1983, July 13, 1983, and August 19, 1983 (Tables 1, 2, 4, 6, and 7). On these dates, moisture content of the upper 25 cm of no-till was statistically similar and higher than the lower 10 cm. High bulk density, which facilitates the unsaturated upward movement of water, and the presence of residue over the no-till plots, may be the reason for this moisture gradient. On these dates, with the exception of the 2.5 cm and the 32.5 cm depths, the paraplow showed a uniform moisture distribution with depth. This means that the paraplow might have created a low density profile which increased infiltration and reduced unsaturated loss of moisture to the surface. On November 16, 1982, the chisel plow moisture profile was similar to the no-till moisture profile. On the rest of the dates, chisel plow moisture profile was similar to the paraplow profile with the exception of an increase at the 17.5 cm depth. This increase in moisture may be due to a high density zone created by the disk which enabled moisture to move up to that depth but not further due to the low density above that zone. This phenomenon can be also caused by residue buried at that depth. A barer and looser surface may be the reason for low moisture on the top 5 cm of the chisel plow treatment. Generally, moisture distribution within the treatment may be due to the state of soil loosening or compaction, and the degree of residue coverage caused by the tillage system. No moisture treatment by depth interaction in April 24, 1983, June 21, 1983, and September 12, 1983, sampling dates implies that tillage did not materially change the soil physical condition to the degree that could affect moisture movement in the profile. Water use by the plant may also be important.

Table 11 presents treatment means at different dates and the date means for 1982/83 cropping season. The analysis showed no significant moisture differences between treatment means (averaged across dates), and no treatment by date interaction. However, a highly significant difference in moisture between date means (averaged across treatments) was found. The differences in moisture between date means can be attributed to rainfall and to water use by the crop.

Significant moisture differences between treatment means (averaged across dates before and after tillage) were found (Table 12). Before tillage, the paraplow and no-till treatment had statistically similar moisture means which were significantly higher than the chisel plow treatment mean (29.1, 28.5, and 26.4%, respectively, with an LSD of 2.0%). After tillage, the paraplow and the chisel plow treatment were similar in their moisture content and both were significantly higher than the no-till (30.0, 28.4, and 26.8%, with an LSD of 2.3%). Treatment by date interactions was not significant before or after tillage. Abundant moisture, cool weather, and short sampling interval masked the effect of tillage on soil moisture. When the pooled data (before and after tillage) were analyzed, significant moisture differences between treatment and date means were found. Moisture content of the paraplow treatment (29.5%) was significantly higher than the chisel plow and no-till treatment means (27.4 and 27.7%, respectively). Date means suggest that tillage in 1982 was carried out at a significantly higher moisture (30.7%) than in 1983 (25.3%) and resulted in higher moisture after tillage in 1982 (28.9%) than it did in 1983 (27.9%).

Table 13 shows the minimum number of replications required to detect a preselected moisture difference. The table suggests that, with the six replications used in this study, a minimum moisture difference of 5% can be detected at a 95% probability level.

Soil Bulk Density

There were significant density differences between tillage treatment means (averaged across depths) in all sampling dates except for August 19, 1983, and September 12, 1983 (Tables 1-10). On November 16, 1982 (before tillage), the paraplow mean bulk density (1.17 Mg/m^3) was significantly lower than the chisel plow and no-till systems (1.25 Mg/m^3 for each). Because these tillage operations were carried out in the same plots in the spring of 1982, this difference in bulk density may be caused by a long-lasting soil disturbance by the paraplow. On November 19, 1982 (after tillage), there was no significant difference in bulk density between the paraplow and the chisel plow treatment means (the difference was 0.04 Mg/m^3 compared with an LSD of 0.08 Mg/m^3). This means that both systems caused a similar average soil loosening. However, on November 17, 1983 (after tillage for 1983/84 season), the difference in density between the paraplow and the chisel plow was significant (Table 10). This difference may be explained by the tillage depth. After disking (April 24, 1983), the difference (0.10 Mg/m^3 compared to an LSD of 0.08 Mg/m^3) between the paraplow and the chisel plow was also significant. On this date, identical treatment means for no-till and chisel plow were measured (1.31 Mg/m^3). This means that fall chiseling followed by disking will increase the soil bulk density in the spring (Chesness et al., 1972) more than the fall paraplowing and the density will be equivalent to that with no-till. This pattern continued through July 13, 1983. Adequate moisture and sufficient residue during this period masked a possible density effect on moisture by influencing water movement in the profile. On August 19, 1983, it seemed that the loosening effect of the paraplow was diminished. Surprisingly, this happened as a result of a reduction in density of the no-till and the chisel plow treatment means rather than an increase in the paraplow treatment means. These differences cannot be attributed to the performance of the sampler at different moisture levels because comparable moisture situations for each tillage system were encountered (e.g., July 13, 1983).

Depth means for bulk density (averaged across treatments) were found to be significantly different in all dates. A gradual increase in bulk density with depth was observed on November 16, 1982, November 19, 1982, April 24, 1983, and November 17, 1983. A sizable density increase at the 12.5 cm depth was the general pattern in the rest of the dates. Disking of the chisel plow plots in May 20, 1983, may be the reason for this phenomenon.

Generally, soil bulk density (averaged across replicates) increased with depth. However, this increase was only significant on November 19, 1982, and November 17, 1983 (after tillage), July 13, 1983, and August 19, 1983. On these dates, the no-till system showed a difference in density between the 2.5 cm depth mean (1.05 Mg/m^3) and the others, and between the 32.5 cm depth mean (1.34-1.43 Mg/m^3) and the others, with the remaining depths being similar and different from the others. However, with the exception of the 2.5 cm depth, this density pattern is the same as the moisture distribution observed in no-till. Bulk density for the paraplow treatment increased with depth with the 32.5 cm depth always having the highest mean bulk density. This means that the paraplow changed the soil bulk density up to 30 cm. This confirms the reason mentioned before for the uniform moisture distribution found with the paraplow treatment. For the chisel plow, on November 19, 1982, and November 17, 1983, the upper 20 cm had lower bulk density than did the remainder of the profile. This suggests that the chisel plow affected soil density up to 20 cm. However, due to disking, the 15 cm depth had the lowest density means in June 21, 1983, and July 13, 1983. This favorably agrees and supports the previous assumption that bulk density affected moisture distribution within the profile. Therefore, whenever depth by tillage system interactions in bulk density occurred, they can be explained by the effective depth of the tillage performed but, when they did not, unknown factor(s) might have masked the tillage effect.

A highly significant difference between tillage treatment means (averaged across dates) and date means (averaged across treatments) for bulk density were found (Table 11). The paraplow created the lowest bulk density mean (1.20 Mg/m^3), followed by the chisel plow (1.26 Mg/m^3) which was statistically similar to no-till (1.29 Mg/m^3). This shows that the density changes caused by the paraplow lasted longer than those caused by the chisel plow. Date means increased and decreased inconsistently. The May 20, 1983, sampling date (after disking) had the highest density (1.31 Mg/m^3). A rain after tillage and before the

November 19, 1982, sampling masked the effect of tillage on bulk density.

Before tillage, the paraplow treatment caused a significantly lower density mean (1.22 Mg/m^3) than the chisel plow (1.32 Mg/m^3) and no-till (1.30 Mg/m^3) treatments (Table 12). Because this tillage was carried out in the same plots in the spring of 1982, this difference might have been caused by a longer-lasting soil disturbance by the paraplow. After tillage, the density of the paraplow treatment was significantly lower than the chisel plow and no-till treatment means (1.13, 1.27, and 1.32 Mg/m^3 respectively with an LSD of 0.09 Mg/m^3). This means that the paraplow loosened the soil more than did the chisel plow. Similar to moisture content, differences in bulk density between date means were found to be significant only before tillage. This implies that bulk density has an effect on soil moisture movement. Date by treatment interaction effects on bulk density were found to be significant after tillage. Bulk density, residue cover, and other environmental factors may be the reason for these moisture similarities and differences. The analysis of the pooled data (Table 12) suggests that lower bulk densities, not necessarily similar, were created after paraplowing and chiseling. The table shows that the paraplow treatment caused a significantly lower density (1.17 Mg/m^3) than the chisel plow (1.29 Mg/m^3) which created an average density similar to that with no-till (1.31 Mg/m^3).

Table 14 shows the minimum number of replications required to detect a preselected difference in bulk density at a 95% probability level.

With the six replications used in this study, a minimum density difference of 0.3 Mg/m^3 can be detected.

Penetration Resistance

There were significant soil penetration resistance differences, as indicated by cone index, between treatment means (averaged across depths), and between depths means (averaged across treatments) for each date (Tables 1-10). There was also a cone index treatment by depth interaction for all dates except April 24, 1983. The paraplow treatment caused a lower penetration resistance for all dates compared with the chisel plow and the no-till treatments (e.g., on November 19, 1982, the treatment mean was 56 N/cm^2 for the paraplow, 95 N/cm^2 for the chisel plow, and 92 N/cm^2 for no-till). Because there was no difference in moisture between treatment means, low bulk density caused by the paraplow will be assumed to be the reason for this difference in soil strength. A significant difference in soil strength between the chisel plow and no-till treatment means was found on all dates except on November 16, 1982 (75 N/cm^2 for the chisel plow and 88 N/cm^2 for no-till). This means that the chisel plow did not loosen the soil as much as did the paraplow.

Generally, cone index (averaged across treatments) increased with depth with an occasional decrease at the 22.5 cm and/or the 27.5 cm depths. Because soil moisture and bulk density also showed significant differences on all dates, this suggests that cone index differences can be related to moisture content as well as to bulk density.

The differences between cone index depth means within treatments were significant in all sampling dates except on April 24, 1983. On this date, both bulk density and moisture content interactions were insignificant. However, moisture and density interactions were also insignificant for July, September, and November 16, 1983, sampling dates. In turn, this suggests that factors other than bulk density and moisture might have caused these cone index differences.

Cone index treatment means (averaged across dates), date means (averaged across treatments) and the treatment by date interaction were found to be significantly different (Table 11). The paraplow treatment mean (66 N/cm^2) was lower than the chisel plow and no-till treatment means (93 and 95 N/cm^2, respectively). Because no moisture differences between the treatment means were detected at this level, density was again assumed to be the reason for these differences. Date means of cone index showed no specific trend with soil moisture and/or bulk density.

Significant differences in cone index between treatment means, date means, and treatment by date interaction (except before tillage) were found before and after tillage (Table 12). Tillage with the paraplow was carried out at a significantly lower soil strength than the chisel plowing (62 N/cm^2, 74 N/cm^2, respectively). The tillage in the spring of 1982 might have caused this difference in soil strength. After tillage, the paraplow treatment caused a significantly lower soil strength compared with the chisel plow and no-till treatment means. After the 1983 tillage, the mean cone indexes were 28

N/cm^2, 71 N/cm^2, and 62 N/cm^2 for the paraplow, the chisel plow, and the no-till, respectively (the LSD was 8 N/cm^2).

These differences in cone index were believed to be related to bulk density (treatment means within the date), to both bulk density and moisture content (depth means), or to other factors (treatment by depth interaction and date means). It is apparent that the parameters of bulk density and moisture content are insufficient for predicting penetration resistance. The same difficulties were encountered by Chesness et al. (1972) when they tried to relate density and moisture to soil strength.

Table 15 was constructed to estimate the minimum number of replications required to detect a known cone index difference. In this study, a minimum difference of 20 N/cm^2 can be detected.

Residue Cover

Table 16 shows the percentage residue cover and residue reduction for no-till, paraplow, and chisel plow at different dates. On November 19, 1982, the paraplow essentially left the percent residue cover unchanged (3% reduction) compared to November 16, 1982 (99% surface cover). However, on November 17, 1983, the paraplow reduced the percent residue cover by 20% from that of November 16, 1983 (100% surface cover). On November 19, 1982, and November 16, 1983, the chisel plow reduced the residue cover by 17% and 24%, respectively. This implies that the paraplow managed the residue better than the chisel plow.

On April 24, 1983 (after winter), significant reduction in the percent residue cover was observed under all systems. The no-till resulted in a 5% reduction which was less than the paraplow and the chisel plow with 10% and 9%, respectively. This means that, even with minimum residue disturbance, fall tillage rendered the residue more susceptible to weathering and decomposition.

On May 20, 1983, the no-till residue cover remained unchanged and the paraplow lost 10% from April 24, 1983, disking reduced the percent residue cover by 65%. These results agree favorably with the results reported by Colvin et al. (1981a).

The analysis showed that the mean percent residue cover of the no-till treatment was significantly higher than the paraplow treatment mean on all dates except on November 16 and 19, 1982, and November 16, 1983. This suggests that, although the paraplow did not result in a significant change immediately after tillage (November 19, 1982), it rendered the residue more susceptible to weathering compared to no-till. On the other hand, paraplow treatment means were higher than the chisel plow treatment means on all dates except on November 16, 1982, and November 16, 1983 (before tillage). The residue, which was known to reduce evaporation (Dulley and Russel, 1942; Bennett, 1977; Buchele and Marley, 1978), explains the high moisture in the 2.5 cm depth of no-till. Residue was also found to reduce the soil temperature, crop emergence rate, and to increase insects, disease, and rodent risks (Amemiya, 1977).

Treatment means (averaged across dates for 1982/83 season), unsurprisingly, showed that no-till with higher percent residue cover (88%) than paraplow (73%) which in turn was better than the chisel plow (43%).

This indicates that the overall effect of the paraplow in managing residue was much better than the chisel plow.

When averaged across the treatments, residue cover significantly decreased with time. These reductions were caused by burying the residue with tillage and by decomposition.

When the data were pooled (before and after tillage), the analysis showed that the paraplow managed the residue better in 1982 (3% reduction) than it did in 1983 (20% reduction). However, the chisel plow managed the residue essentially the same in both years (17% in 1982 and 24% in 1983).

Table 17 suggests that a 5% residue difference can be declared significant with the six slides taken per replicate. This result agrees with Williams' (1979) recommendation that six slides per replicate are required to detect a 5% difference.

Yield

Table 18 shows the corn yield, ton/ha, for the no-till, the paraplow, and the chisel plow tillage systems. The data indicate that the paraplow and the chisel plow yielded the same amount of corn (8.5 ton/ha) and significantly more than no-till (7.1 ton/ha). Since no differences in moisture between treatments were found, and high density and cone index existed in the no-till as well as the chisel plow, this difference in corn yield may be caused by these factors combined with the presence of the residue on the no-till plots (Amemiya, 1977). Low density and penetration resistance in the paraplow system might have reduced the effect of the residue on corn yield.

SUMMARY AND CONCLUSIONS

A field experiment was conducted to evaluate the effect induced by tillage and time on soil density, moisture, penetration resistance, and residue cover. No-till, chisel plow, and the newly-introduced paraplow were selected because they are potential soil and water conservation methods. Treatment means within and between dates, depth means, and treatment by depth and by date interactions were evaluated.

No moisture differences between treatment means within and between dates were found due to adequate precipitation during the season. However, the highly significant difference between date means was attributed to the relationship between rainfall and the use of water by the crop.

The paraplow treatment had a significantly lower mean bulk density for most of the season. Before tillage, the difference in density between the paraplow treatment mean (1.17 Mg/m^3) and the chisel plow treatment mean (1.25 Mg/m^3) was found to be significant. This difference was not significant after tillage. This means that both tools caused a similar soil loosening. On April 14, 1983, the difference was again significant. Also, from April through July, the treatment means of the chisel plow and that of no-till were found to be statistically similar. However, in August and September, no significant density differences between treatment means were observed. The tillage depth and the efficiency of the tool in disturbing the soil were believed to be the reasons. The differences between depths means, within the treatment, were found insignificant in most dates. The pooled data showed that the paraplow resulted in the lowest treatment mean (1.20 Mg/m^3) over the sampling period compared to the chisel plow and no-till (1.25 Mg/m^3 and 1.29 Mg/m^3, respectively). Time effect on bulk density between date means was found to be significant.

The paraplow produced the lowest cone index in all dates. On April 24, 1983, the treatment mean was 51 N/cm^2 for the paraplow, 78 N/cm^2 for the chisel plow, and 79 N/cm^2 for the no-till. High cone index in the chisel plow treatment was thought to be caused by disking and buried residue and corn cobs. On May 20, 1983, the mean cone index was 50 N/cm^2 for the paraplow, and 66 N/cm^2 for the chisel plow and no-till. Because no moisture differences were detected between treatments throughout the sampling period, bulk density was assumed to be the cause for these variations. Depth differences, which were found to be significant in all dates, were caused by the significant differences in moisture, density, and other unknown factors.

When the cone index data were pooled and analyzed, the paraplow was found to have the lowest cone index mean (66 N/cm^2) compared to the chisel plow and no-till (93 N/cm^2 and 95 N/cm^2, respectively). Generally, moisture content and bulk density were found insufficient to describe soil strength.

No-till resulted in the lowest percentage of residue reduction throughout the sampling period. Over the winter, the no-till lost 5% of the residue cover, where the paraplow and the chisel plow lost 10% and 9%, respectively. High residue cover in the no-till treatment increased infiltration, reduced evaporation, and was believed to reduce the yield due to its effect on soil temperature. Disking of the chisel plow treatment reduced the residue by 65% and increased the penetration resistance of the 12.5 cm depth. No-till left the highest average percentage residue (88%) during the season compared to paraplow (73%) which managed residue better than the chisel plow (43%).

High bulk density, cone index, and residue cover were combined to cause a significant decrease in the yield of the no-till (7.1/ton/ha) compared to the identical yield produced by the paraplow and the chisel plow (8.5 ton/ha).

From this study, the following conclusions can be drawn:

(1) The tillage treatments did not affect the soil moisture within or between the sampling dates.

(2) Paraplowing created lower and longer-lasting bulk density and cone index changes than did the chisel plow system.

(3) No-till left the highest percentage of surface residue throughout the year compared to paraplow which left more residue than the chisel plow system.

(4) The paraplow and the chisel plow systems had the same corn grain yield which was significantly greater than the no-till system.

RECOMMENDATION FOR FURTHER RESEARCH

It is difficult to draw decisive conclusions from a one-year study about the advantages demonstrated by the paraplow as an efficient soil and residue manager; however, it is important to further explore the potential of this tool. Therefore, this study should be continued for four years. Crop-related measurements like emergence rate and root growth should be made in addition to soil condition measurements.

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PART II. A MICROCOMPUTER-BASED PENETROMETER

INTRODUCTION

Information was desired on soil strength resulting from various crop production systems. The cone index, defined as the ratio of the force required to press a 30 degree cone into the soil, to the projected area of the base, provides a relative indication of the soil strength (ASAE, 1982).

Penetrometers have been widely used as a quick and easy method to provide test data that are suitable for analytical interpretation of soil strength. However, the limitations of the penetrometer for measuring soil strength have been widely acknowledged. The relationship between the force used to push a probe into the soil and the physical properties of the soil is complicated and only partially understood (Carter, 1967; Mulqueen et al., 1977). Cone penetration tests did not differentiate between cohesion and adhesion in Coulomb's equation (Freitag, 1968). However, useful empirical correlations were obtained between cone index and bulk density (Carter and Tavernetti, 1968) and between cone resistance and crop root growth (Morton and Buchele, 1960; Phillips and Kirkham, 1962; Taylor and Bruce, 1968; Taylor and Ratliff, 1969; Taylor, 1971). Specific relationships between soil crust strength, seedling emergence, and seedling size were also reported (Bilbro and Wanjura, 1982). Cone index, with other soil properties, was also used to compare the compactive or loosening effects of wheels or tillage tools (Dumas et al., 1975; Soane et al., 1976; Voorhees et al., 1978) and to predict vehicle mobility (Turnage, 1972; Wismer and

Luth, 1973). Thus, until new methods for measuring soil strength are developed, it appears that penetrometer measurements are the best, easy way to measure soil strength.

Many types of penetrometers have been constructed and used. These range from simple hand-held devices (Howson, 1977) through X-Y plotter data recording equipment (Smith and Dumas, 1978) to sophisticated electronic devices (Anderson et al., 1980; Riethmuller et al., 1983).

Despite improvement in the design and operation, the penetrometers are expensive (The Push Recording Soil Penetrometer cost 1930 Sterling pounds in 1981), unreliable, and there is still need for improvement in penetrometer hardware and software.

The objective of this paper was to design, develop, and fabricate a penetrometer that was easy to use and could accurately measure, display, and store penetration force at any predetermined depth.

The Penetrometer System

The general design requirement was for an instrument that one person can use in the laboratory or the field, to easily, rapidly, and accurately measure penetration force and depth. Thus, instantaneous digital data output and storage within the system are considered important. To meet these requirements, a force transducer, a depth transducer, and a signal conditioner were needed. The components of the system are illustrated in Figure 1.

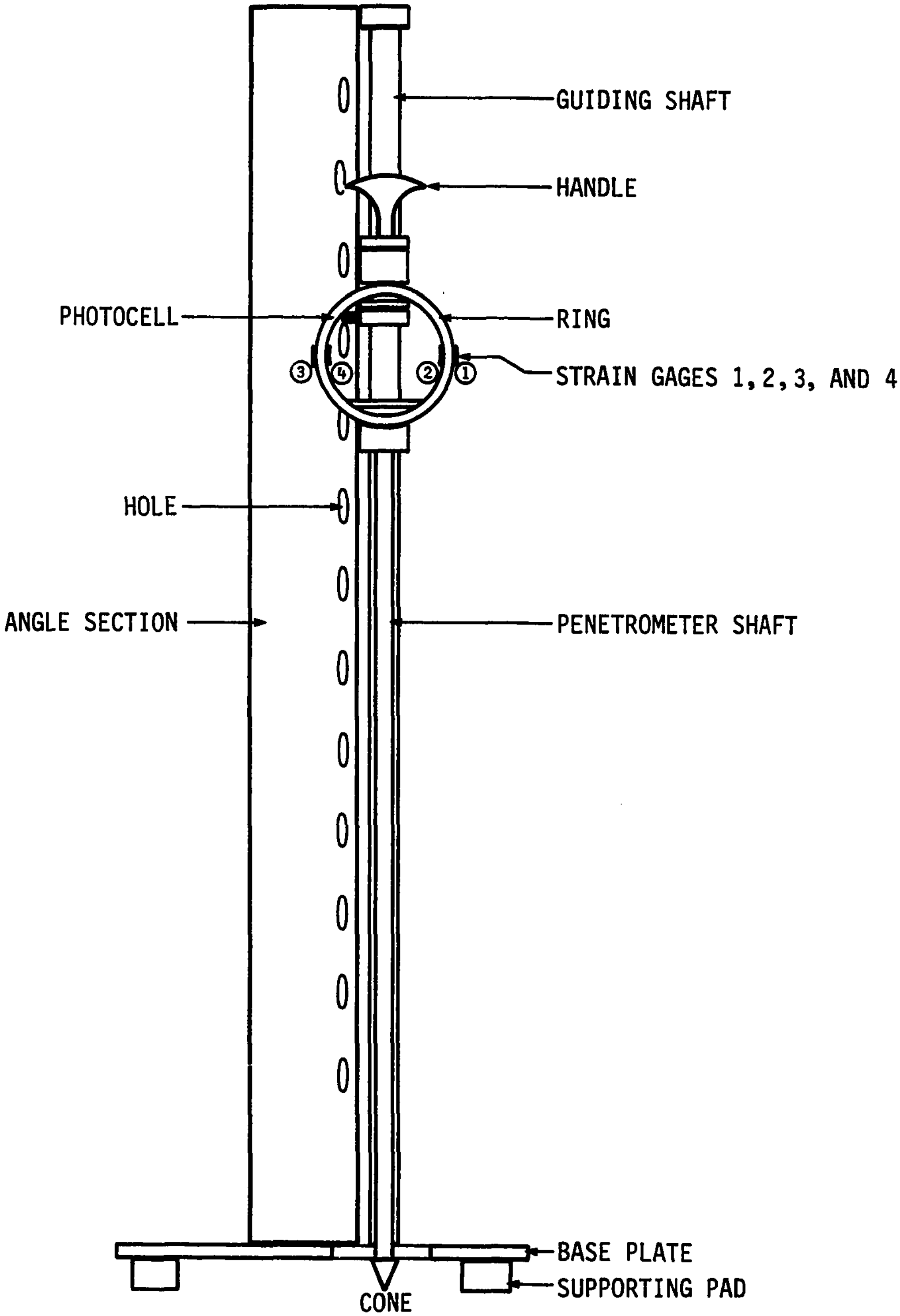

Figure 1. General arrangement drawing of the penetrometer system

The force transducer

The force on the penetrometer ring was measured using a four-arm, temperature-compensated strain gage bridge load cell (Measurement Group Inc., Type EA-13-250AF-120). The 5.0 V input to the bridge was supplied from the AIM 65 microcomputer through the signal conditioner. The amplified output of the load cell is fed to the computer through an analog to digital converter (ADC 0817).

The depth transducer

In this instrument, the depth was measured relative to the position of the cone base. An infrared emitting diode and detector unit (General Electric, Type H13A1), attached to the penetrometer handle which slides up and down a metal plate that has holes drilled at preselected intervals (5.0 cm), was used to obtain a zero to 5.0 V square wave signal. This signal was connected to the start pin on the ADC.

The signal conditioner

The purpose of the signal conditioner was to supply low current, constant voltage input to the load cell and to amplify and filter the output of the bridge. The circuit, adopted from McConnell and Park (1981), uses four 741 operational amplifiers contained in a single package designed as LM324.

For detailed information on the force and the depth transducers, and the signal conditioner, see the Appendix.

Calibration

The purpose of the calibration was to calculate the calibration constant (the slope of the curve of the amplifier voltage output versus the applied force). This constant can be used to calculate the calibration factor. This factor will be used to convert the equivalent voltage reading by ADC to the actual force value.

The penetrometer load cell was calibrated in the laboratory. Weights, ranging from 20 N to 300 N, were applied five times each on the penetrometer handle. The linear relationship between the applied force and the voltage output of the amplifier is shown in Figure 2. The slope of plot is 0.015 V/N.

The calibration factor (f) is equal to: f = maximum voltage input to the computer (4.8 V)/255 count x 0.015 V/N) = 1.254 N/count.

The Microcomputer

A microcomputer was needed to reduce the time for reading, recording, printing, displaying, and storing penetration force and depth values. The ROCKWELL AIM 65 microcomputer was chosen for its keyboard, printer, input/output tape control, and high data manipulation speed. A Radio Shack audio cassette recorder (Model 26-1206) was used to develop and store the program. The overall instrumentation scheme is presented in Figure 3. The two output variables shown in the figure are from the penetrometer force and depth transducers. The penetrometer force is an analog signal from the four-arm, temperature-compensated bridge on the penetrometer ring. The AIM 65 microcomputer was programmed to read the force only when a falling-edge depth signal is recognized.

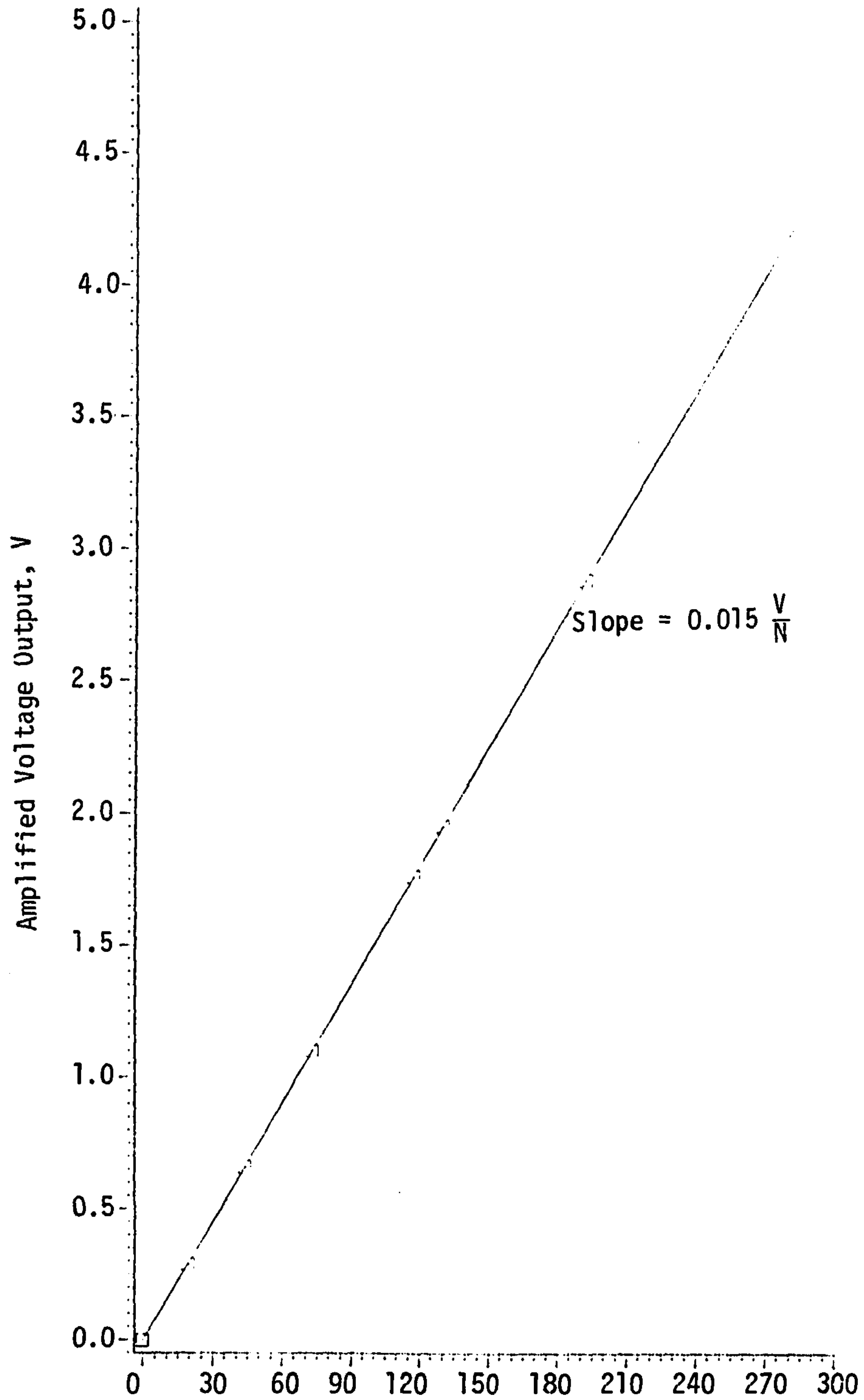

Figure 2. Calibration curve of the amplified voltage output versus the applied force

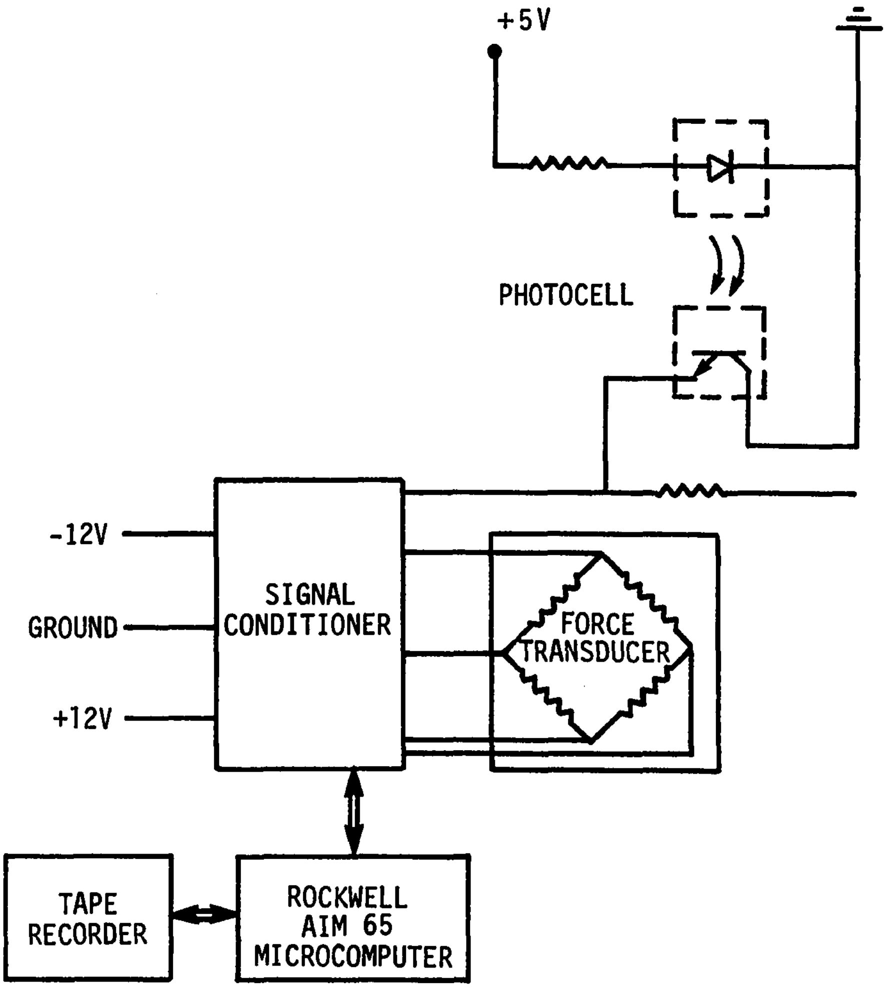

Figure 3. Overall instrumentation scheme for the penetrometer system

Figure 4 shows a flow chart of the system program. Whenever the computer receives the depth signal, the depth will be increased by one and the force will be read, converted to actual units through calibration subroutines, stored in the memory, and displayed. When the required depth is reached, number of depths as well as the corresponding force can be displayed and printed out.

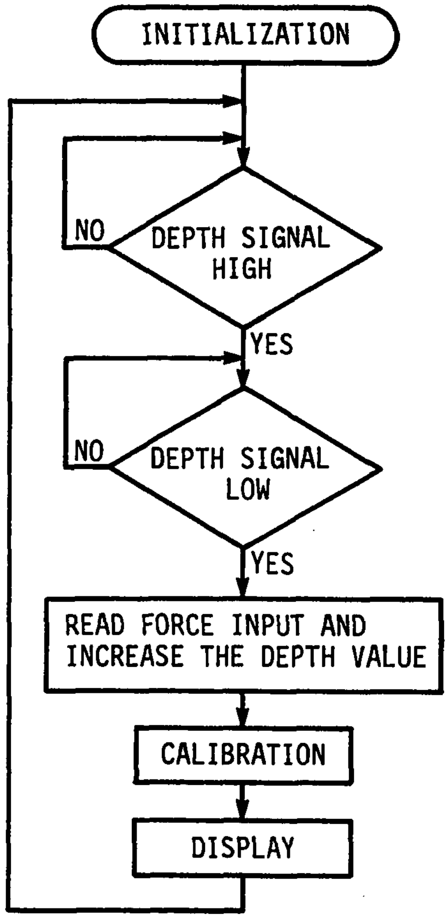

Figure 4. Flow chart of the program

EVALUATION OF THE PENETROMETER

This test was carried out to evaluate the performance of the penetrometer by comparing profiles of cone index against depth obtained from this penetrometer with profiles obtained from another penetrometer. Two trials were carried out in the soil tank at the Agricultural Engineering Department, Iowa State University. Two profiles of cone index versus depth, each at different moisture content, were obtained by compacting the soil as required.

The microcomputer-based penetrometer was compared with a hand-held penetrometer (Weight and Test System, Model FD 127). The penetration force of the hand-held penetrometer was read from a dial gage that measured the deflection of a spring. Depth is estimated from notches on the shaft of the penetrometer. This measuring system can measure force from 0 N to 265 N.

The soil tank used in the two trials was 244 cm long, 122 cm wide, and 91 cm deep and the soil used was a Webster silty clay loam. In the first trial, the soil in the tank was prepared so that constant cone index versus depth can be assumed. In the second trial, the soil was packed so that different cone index with trial can be obtained. This arrangement enabled monitoring the penetrometers under a variety of situations which can occur in the field. In these trials, one stroke was made with each penetrometer randomly across the soil tank. This process was repeated 10 times, 25 cm away from each other, for a total of 10 strokes for each penetrometer. The outer stroke was kept at least

15 cm away from the edge of the tank to eliminate the edge effect. Force readings were recorded each 5.0 cm to a depth of 40 cm.

The analysis of variance was used to test if there are any significant differences between penetrometers, depths, or penetrometer by depth interaction. The least significant difference (LSD), at 0.05 probability, was used to compare penetrometer means, depths means, and penetrometer by depth interactions.

RESULTS AND DISCUSSION

The profiles of cone index versus depth from the two trials are shown in Figures 5 and 6. The points plotted are the mean values of the cone index obtained at the specified depth. Visual inspection of the plots reveals the similarity of the penetrometers in estimating soil strength.

Tables 1 and 2 present the mean cone index and the coefficient of variation estimated by the microcomputer-based penetrometer and the hand-held penetrometer at different depths, moisture, and bulk density for the first and the second trial, respectively. The analysis of variance showed no significant difference between treatment means (averaged across depths or across replicates at the same depth). The cone index values measured by the two were similar, differing by a maximum of 11 N/cm^2. The tables also show the high coefficient of variability (C.V.) associated with the hand-held penetrometer. The C.V. for the hand-held penetrometer ranged from a minimum of 14% at the 2.5 cm depth in the first trial, to a maximum of 36% at the 17.5 cm depth in the second trial. On the other hand, the C.V. for the cone index means measured by the microcomputer-based penetrometer ranged from a minimum of 8% at the 37.5 cm depth in the second trial to a maximum of 16% at the 22.5 cm depth in the first trial. This variability may be introduced by human error in reading the force in the hand-held penetrometer.

This study and others (Anderson et al., 1980; Riethmuller et al., 1983) proved that microcomputers can be easily used to measure soil

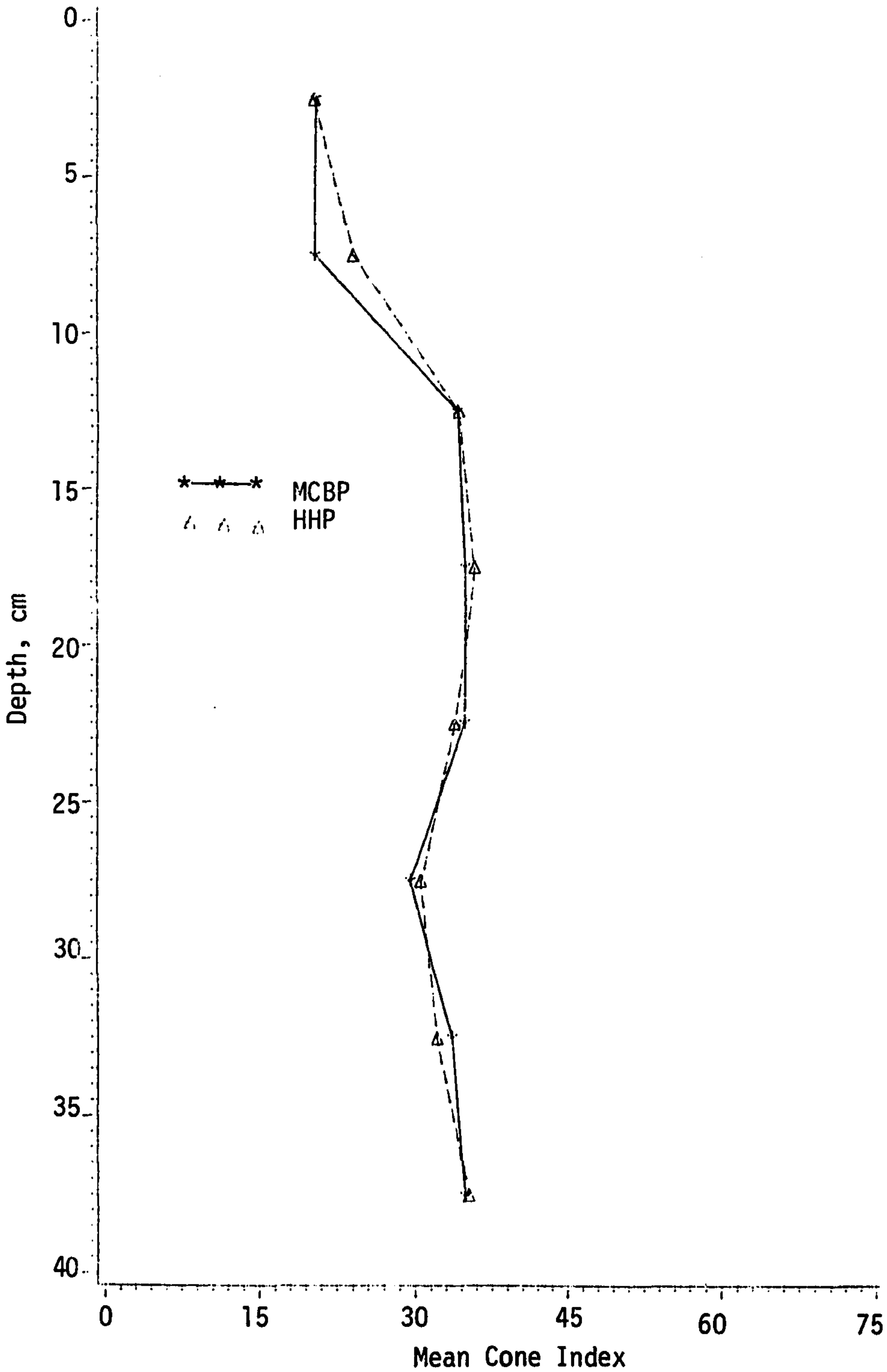

Figure 5. Plot of depth versus mean cone index obtained by the micro-computer-based penetrometer (MCBP) and the hand-held penetrometer (HHP) for the first trial

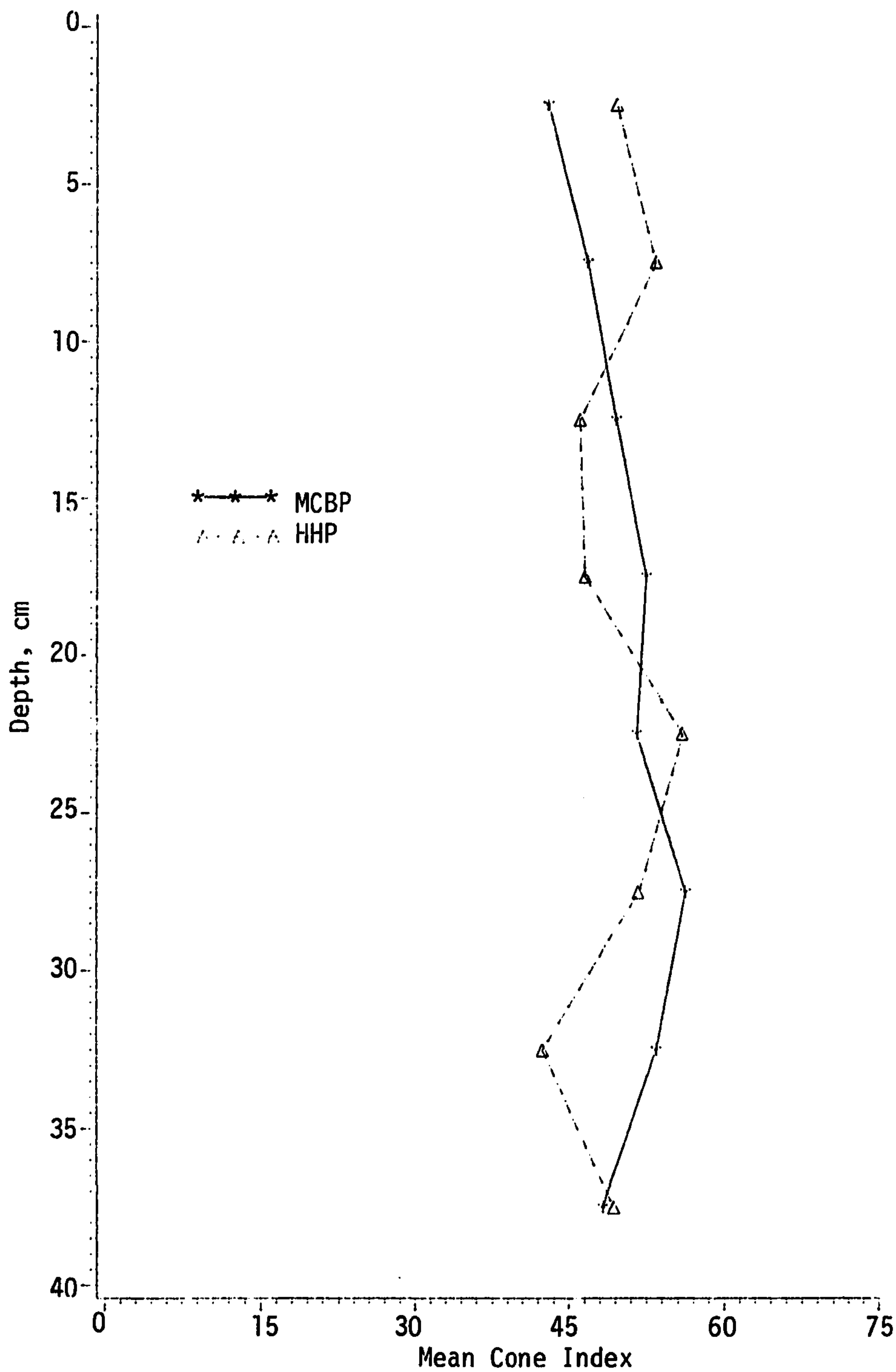

Figure 6. Plot of depth versus mean cone index obtained by the micro-computer-based penetrometer (MCBP) and the hand-held penetrometer (HHP) for the second trial

Table 1. The mean cone index and the coefficient of variability obtained by the microcomputer-based penetrometer (MCBP) and the hand-held penetrometer (HHP) for the first trial

Depth	Mean moisture content	Mean bulk density	Mean cone index MCBP	C.V.	Mean cone index HHP	C.V.
cm	%	Mg/m^3	N/cm^2	%	N/cm^2	%
2.5	22	0.90	21	10	20	14
7.5	23	1.13	20	16	26	21
12.5	25	1.20	34	11	34	29
17.5	23	1.26	35	14	40	18
22.5	23	1.25	35	13	34	31
27.5	25	1.31	29	16	30	29
32.5	22	1.38	34	10	32	32
37.5	28	1.41	35	11	35	31
Penetrometer mean			38	13	31	26

LSD (0.05) for comparing:
1) Penetrometer means = NS; and
2) The two penetrometers at the same depth = NS.

Table 2. The mean cone index and the coefficient of variability obtained by the microcomputer-based penetrometer (MCBP) and the hand-held penetrometer (HHP) for the second trial

Depth	Mean moisture content	Mean bulk density	Mean cone index MCBP	C.V.	Mean cone index HHP	C.V.
cm	%	Mg/m^3	N/cm^2	%	N/cm^2	%
2.5	18	0.91	43	13	50	17
7.5	19	1.18	47	15	53	23
12.5	17	1.29	50	11	46	27
17.5	18	1.31	52	12	47	36
22.5	17	1.33	52	10	49	30
27.5	15	1.32	56	14	49	16
32.5	17	1.41	53	11	42	27
37.5	16	1.40	48	8	49	37
Penetrometer mean			50	12	48	27

LSD (0.05) for comparing:
1) Penetrometer means = NS; and
2) The two penetrometers at the same depth = NS.

strength in a manner that can save time, effort, and assure accuracy. However, in order to more completely describe the soil physical conditions and to utilize the capability of the microcomputer, a device to quickly measure soil moisture content and bulk density may be incorporated at the base of the penetrometer cone.

SUMMARY AND CONCLUSIONS

A Rockwell AIM 65 microcomputer was used to record, store, and display depth and force values of a hand-operated cone penetrometer. Analog data inputs from strain gages mounted on penetrometer ring were amplified, filtered, and converted to digital inputs to the microcomputer. The computer was programmed to read, store, and display the force value only when activated by a signal from the depth transducer.

When this penetrometer was compared to a hand-held penetrometer, no significant difference was detected between treatment means (averaged across depths or across replicates at the same depth). However, high variability was observed in the mean cone index measured by the hand-held penetrometer.

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APPENDIX

The Force Transducer

The free body diagram of the penetrometer ring shown in Figure 7 is statically indeterminate with respect to internal bending moment. Before the stress or deflection can be calculated, it is instructive to determine the bending moment at some point, after which the bending moments at any point can be calculated. Because of symmetry, only one-half of the ring needs to be analyzed; and for the same reason, it is further reduced to one-quarter (Figure 8). From Figures 7 and 8,

$$F1 = F2 = F \tag{1}$$

$$ds = R d\alpha \tag{2}$$

$$M' = Fy/2 = (FR/2)\sin\alpha \tag{3}$$

where M' is the moment at the cut (ds).

From the bending theory, the slope at A, ϕ_A', created by the moment M', is,

$$\phi_A' = \int_0^{\frac{\pi}{2}} (M'/EI)\, ds \quad . \tag{4}$$

Substituting the value of ds from equation 2 and M' from equation 3 into equation 4 yields

$$\phi_A' = \int_0^{\frac{\pi}{2}} (FR^2 \sin\alpha/2EI) d\alpha = FR^2/2EI \quad . \tag{5}$$

For continuity, this slope must be eliminated, because it can be seen, from symmetry, that the slope at A will remain zero under loading, and both halves will deflect the same amount in the direction of loading.

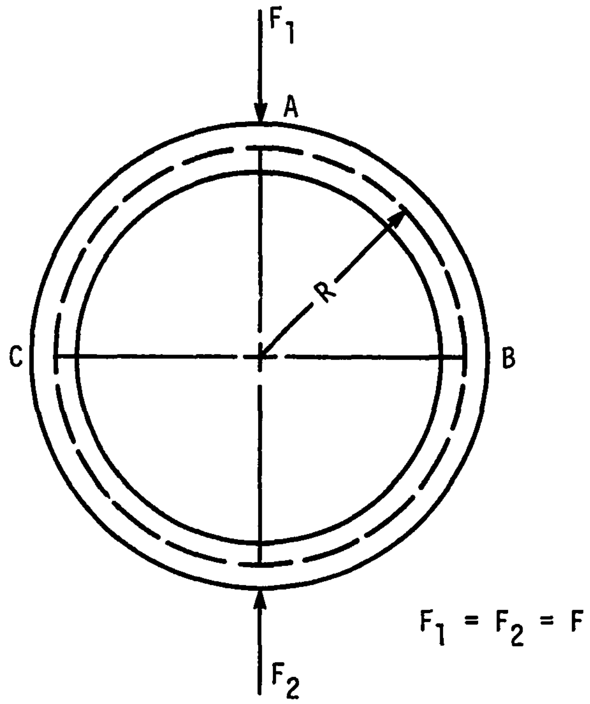

Figure 7. Free body diagram of the penetrometer ring

To restore the slope at A to zero, a moment M" will be applied there (Figure 9). This moment will act, at constant value, over the entire quarter section. The slope (ϕ_A'') produced at A will be

$$\phi_A'' = \int_0^{\frac{\pi}{2}} (M''/EI(ds = \int_0^{\frac{\pi}{2}} (M''R/EI)d\alpha$$

$$\phi_A'' = \frac{\pi}{2} M''R/EI \quad . \qquad (6)$$

Therefore, the total slope at A, ϕ_A, will be,

$$\phi_A = \phi_A' + \phi_A'' = FR^2/2EI + \frac{\pi}{2} M''R/EI = 0 \qquad (7)$$

$$M'' = - FR/\pi \quad . \qquad (8)$$

From equations 3 and 8, the net moment at any point is

$$M = M' + M'' = (FR/2) \sin\alpha - FR/\pi$$

$$M = (FR/2)(\sin\alpha - 2/\pi) \quad . \qquad (9)$$

Therefore, the maximum moment occurs at $\sin\alpha = 1$ or at point B or C where $\alpha = 90^0$,

$$M = 0.1817\ FR \quad . \qquad (10)$$

R for the penetrometer ring is 4.76 cm,

$$M = 0.8653\ F \quad . \qquad (11)$$

Now, the deflection (δ) can be determined from equation 9 and the use of equation 12 (from Higdon et al., 1976).

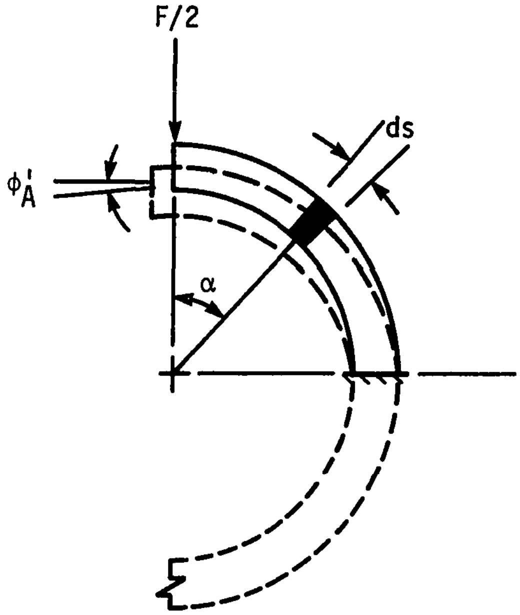

Figure 8. Free body diagram of one-quarter of the ring showing the slope ϕ_A' created at point A by the moment M' at the cut section

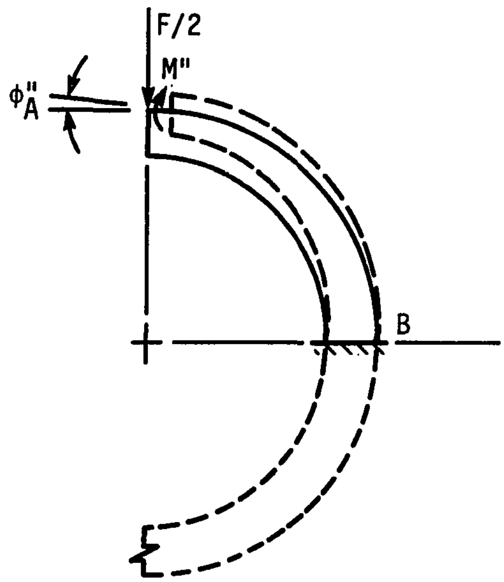

Figure 9. Free body diagram of one-quarter of the ring showing the slope ϕ_A'', required to restore the net slope to zero at point A, created by the applied moment M"

$$\delta_i = \int^{\alpha} \frac{M}{EI} \frac{\delta M}{\delta F_i} ds \tag{12}$$

where δ_i, F_i, and M are the deflection, the force, and the moment at the point in question, respectively. Substituting equation 9 for M, equation 1 for F_i, and equation 2 for ds yields

$$\delta = \int_0^{\alpha} \frac{FR}{2EI} (\sin^2\alpha - \frac{4\sin\alpha}{\pi} + \frac{4}{\pi^2})\, d\alpha = \frac{FR^3}{2EI} (\frac{\pi}{2} - \frac{\sin 2\alpha}{4} + \frac{4\cos\alpha}{\pi} + \frac{4\alpha}{\pi^2})\Big|_0^{\alpha} \tag{13}$$

The maximum value of the quantity between the brackets in equation 13 occurs where $\alpha = \frac{\pi}{2} = 90^o$ at point B or C in Figure 1.

$$\delta_{B,C} = \frac{FR^3}{2EI} (\frac{\pi}{4} + \frac{2}{\pi} - \frac{4}{\pi})$$

$$\delta_{B,C} = \frac{FR^3}{2EI} (\frac{\pi}{4} - \frac{2}{\pi}) = 0.0744 \frac{FR^3}{EI} \quad . \tag{14}$$

From this analysis, it is clear that the maximum bending moment and the maximum deflection occurs 90^o away from where the force is applied. Therefore, four strain gages were installed, two at each location to measure the tension as well as the compression. The four gages were wired to form a wheatstone bridge.

The Wheatstone Bridge

The wheatstone bridge is used to measure resistance changes in strain gages. The bridge is powered by a constant voltage, 5.0 V, power supply. Figure 10 shows a current (I) delivered by the power supply divided at point A into currents (I1) and (I2) where I = I1 + I2. The current drop between point A and B is,

$$I_1 = \frac{V}{R_1+R_2} \qquad \therefore V_{AB} = I_1R_1 = \frac{VR_1}{R_1+R_2} \tag{15}$$

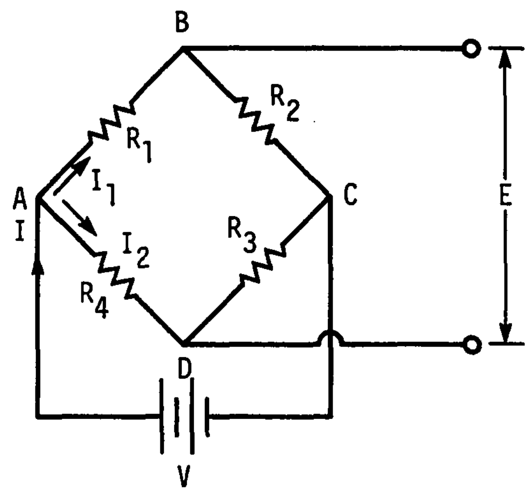

Figure 10. Constant volt wheatstone bridge

and the current drop between point A and D is,

$$I_2 = \frac{V}{R_3+R_4} \qquad \therefore \quad V_{AD} = I_2R_4 = \frac{VR_4}{R_3+R_4} \tag{16}$$

Thus, the output voltage from the bridge can be expressed as,

$$E = V_{BD} = V_{AB} - V_{AD} = V\left(\frac{R_1}{(R_1+R_2)} - \frac{R_4}{(R_3+R_4)}\right) = V\left\{\frac{(R_1R_3 - R_2R_4)}{(R_1+R_2)(R_3+R_4)}\right\} \tag{17}$$

Under load condition, the resistor R_1, R_2, R_3, and R_4 will change by ΔR_1, ΔR_2, ΔR_3, and ΔR_4, respectively, and the voltage output, $E + \Delta E$, is,

$$E + \Delta E = \left[\frac{(R_1+ R_1)(R_3+ R_3) - (R_2+ R_2)(R_4+ R_4)}{(R_1+ R_1+R_2+ R_2)(R_3+ R_3+R_4+ R_4)}\right] V \tag{18}$$

$$\therefore \Delta E = \text{equation 18 - equation 17}$$

$$=\left[\frac{R_1R_2}{(R_1+R_2)^2}\left(\frac{(R_1+R_2)}{(R_1+\Delta R_1)(R_2+\Delta R_2)}\right)\left(\frac{\Delta R_1}{R} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right)\right]V \tag{19}$$

The gage factor (S_g) for the gages used in this penetrometer, was provided by the manufacturer and is equal to 2.00. Therefore, experimentally the term

$$\frac{R_1 + R_2}{(R_1+\Delta R_1)(R_2+\Delta R_2)} = 0.9907$$

can be assumed equal to 1; and

$$R_1 = R_2 = R_3 = R_4 = 120 \text{ ohm}$$

$$\Delta E = \frac{V}{4}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right) \tag{20}$$

The gage factor (S_g) relates the resistance change to the axial and the tangential strain by,

$$\Delta R/R = S_g \varepsilon$$

$$\frac{\Delta R_1}{R_1} = \frac{\Delta R_3}{R_3} = S_g \varepsilon_a = \frac{S_g F}{AE} \quad (21)$$

$$\frac{\Delta R_2}{R_2} = \frac{\Delta R_4}{R_4} = S_g \varepsilon_t = \frac{-S_g \nu F}{AE} \quad (22)$$

where:

ε_a = normal strain along axial direction of gage = F/AE;

ε_t = normal strain along transverse direction of gage = $-\nu F/AE$;

E = modulus of elasticity, FL^{-2};

A = area of the specimen, L^2; and

ν = Poisson's ratio.

Substituting equations 21 and 22 into equation 20 yields

$$\Delta E = \frac{V}{4} \left(\frac{2S_g F}{AE} + \frac{2S_g \nu F}{AE}\right) = \frac{VS_g F}{2AE} (1 + \nu) \quad (23)$$

For S_g = 2.00,

$$\Delta E = KF \quad (24)$$

where:

$$K = \frac{V}{AE} (1 + \nu) \quad .$$

For a known F, ΔE can be measured and K can be calculated.

The Circuit Conditioner

The circuit conditioner, shown in Figure 11, was adopted from McConnell and Park (1981). It consists of two circuits, the amplifier

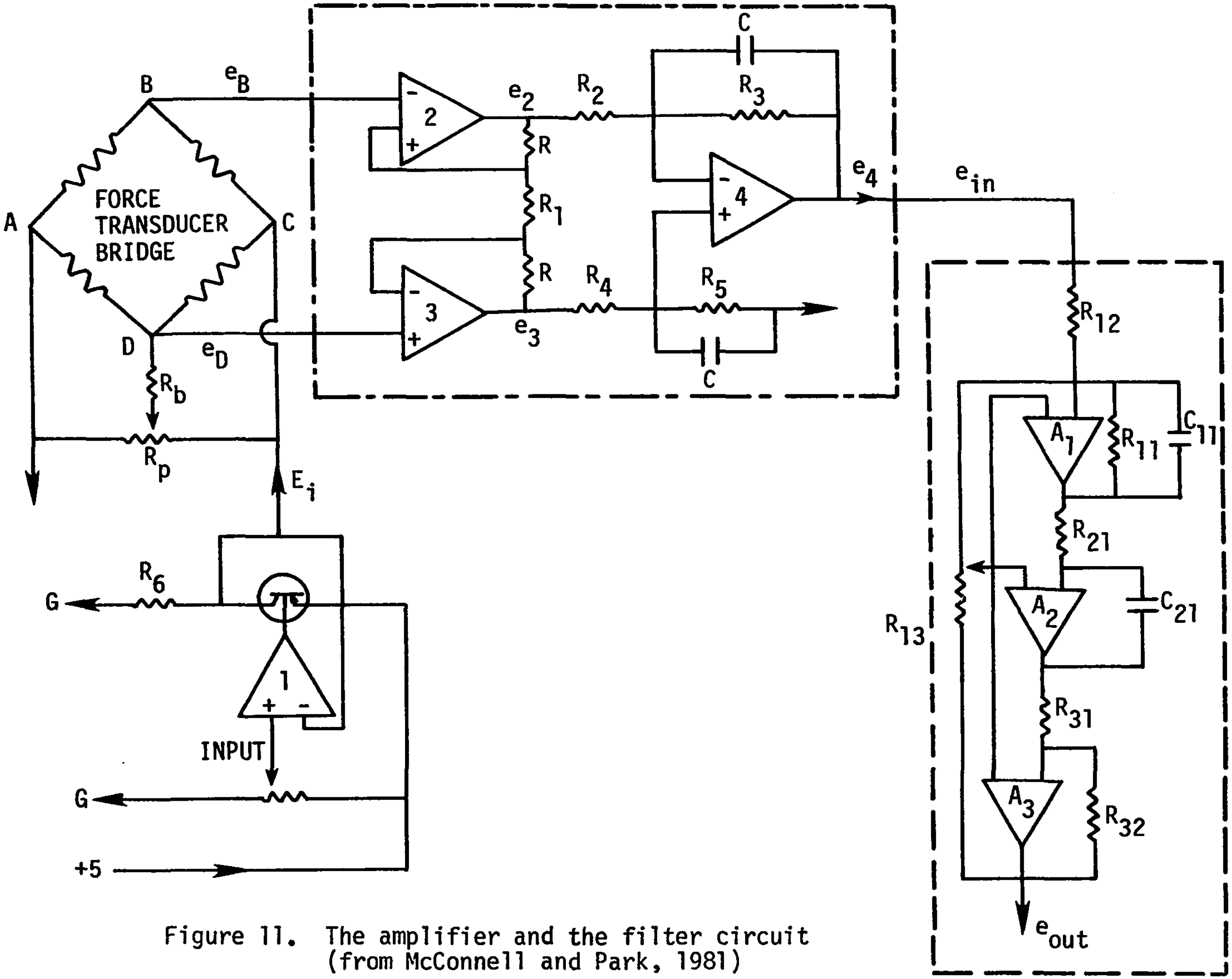

Figure 11. The amplifier and the filter circuit
(from McConnell and Park, 1981)

and the filter circuit.

The amplifier circuit

The amplifier circuit shown in Figure 11 uses four 741 operational amplifiers (op-amp) contained in a single package designed as an LM348. The op-amp No. 1 is used to provide low current constant voltage bridge excitation. The negative feedback of op-amp No. 1 is connected to the transistor (2N3904) output (E_i). The op-amp output drives the transistor on or off an appropriate proportional amount so that E_i is equal to the positive input signal (+5.0 V).

The output of the bridge (e_B and e_D) is connected to the positive input of op-amp No. 2 and 3, respectively. The output voltages e_2 and e_3 are dependent on the input voltage from the bridge, e_B and e_D, as well as resistors R and R_1. When R_5 is adjusted so that $R_3/R_2 = R_5/R_4$, maximum noise rejection is obtained.

The output (e_4) of op-amp No. 4 is,

$$e_4 = (1 + 2R_1/R)(R_3/R_2)(e_D - e_B) = G(e_D - e_B) \qquad (25)$$

So that the system gain, G, is given by,

$$G = (1 + 2R_1/R)(R_3/R_2) \quad . \qquad (26)$$

Substituting the values of R, R_1, R_2, and R_3, a maximum gain of

$$G = (1 + 2*200/5)(100/10) = 810$$

is obtained.

The filter circuit

In order to achieve the desired voltage signal with unwanted high frequency noise suppressed, a low-pass filter is required. The filter circuit shown in Figure 11 has the transfer function H(jw) of

$$H(jw) = e_{out}/e_{in} = -K/\{(1 - (w/w_n)^2 + 2j\zeta(w/w_n)\} \quad (27)$$

where:

w = frequency of one of the inputs, Hz;

w_n = the filter natural frequency, Hz;

ζ = the filter damping ratio;

K = the filter grain; and

$j = \sqrt{-1}$.

The parameter can be related to the system resistances and capacitances by,

$$w_n^2 = (R_{32}/R_{31})(1/R_{13}C_{11}R_{21}C_{21}) \quad . \quad (28)$$

Substituting the values of the resistors and the capacitors in equation 28,

$$w_n = \sqrt{(77k\ /100k\Omega)\{(1/(200k\Omega)(0.1\ f)(200)(0.1)(10)6\}} = \sqrt{1925} = 43.87 \text{ Hz}$$

$$\zeta = w_n/2\ (R_{13}/R_{11})(R_{31}/R_{32})(R_{21}C_{21})$$

$$\zeta = (43.87/2)(200k\Omega/175k\Omega)(100k\Omega/77k\Omega)(200)(0.1)(10^{-3}) = 0.65.$$

Therefore, the optimum response of this filter occurs at $\zeta = 0.65$.

The Depth Transducer

The General Electric H13A1 is an infrared emitting diode coupled with a photo-transistor enclosed in a plastic housing. The gap in the housing provides a means of interrupting the signal with an opaque material (e.g., metal sheet with holes drilled on it). This switches the output transistor from an "ON" state to an "OFF" state (Figure 12).

Figure 12 shows the diode pins, 1 and 2, the transistor pins, 3 and 4, and the gap, between them. Figure 13 shows the electrical diagram of the transducer, and the maximum rating for the diode and the transistor. From Figure 13,

$I_{F_{max}}$ = 60 mA continuous;

$V_{F_{max}}$ - 1.7 V;

$I_{C_{max}}$ = 100 mA continuous; and

V_{CE} = 1.0 V.

From the specification

$R_F = (V_{in} - V_{F_{max}})/I_{F_{max}}$

R_F = (5.0 V - 1.7 V)/60 mA = 55 ohm

R_F = 68Ω was used.

$I_{F_{max}}$ = (5.0 V - 1.7 V)/68 = 48 mA < 60 mA.

For the transistor:

$R_C = (V_{in} - V_{CE})/I_{C_{max}}$

$I_{C_{max}}$ = 1.8 mA was chosen

R_C = (5.0 V - 1.0 V)/1.8 mA = 2.22 K ohm.

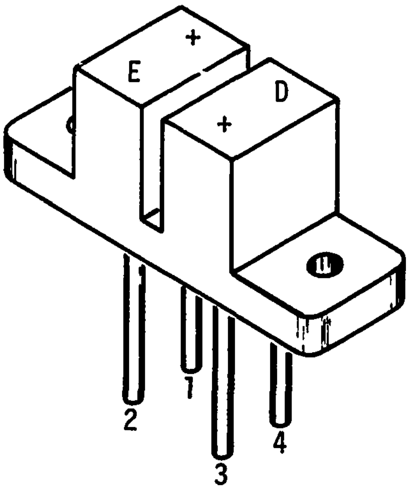

Figure 12. Drawing of the depth transducer (General Electric Model H13A1)

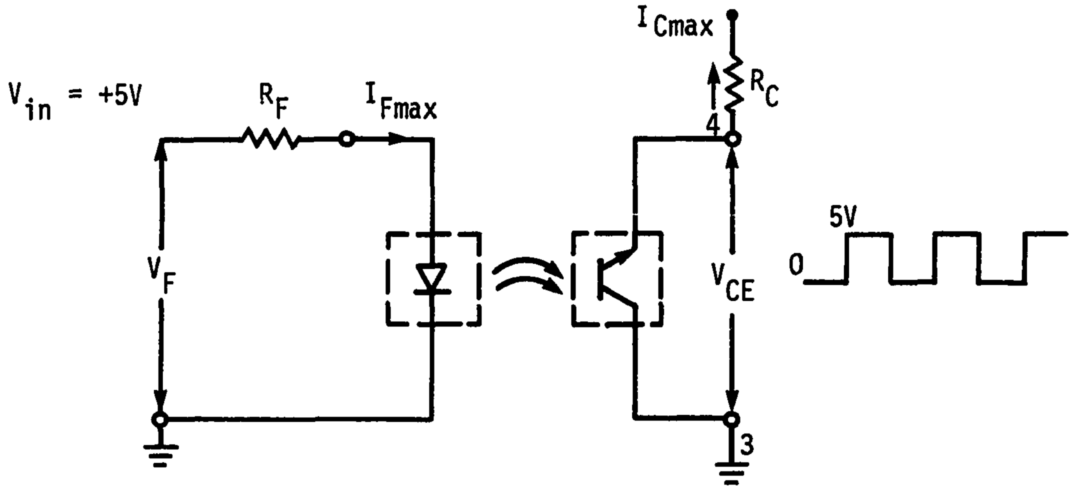

Figure 13. Circuit diagram of GE H13A1 showing the input, the output, and the resistors used to reduce the current

SUMMARY

Soil erosion by wind and water placed an emphasis on introducing new machinery that can either work efficiently through residue or work the soil with minimum residue disturbance. No-till, paraplow, and chisel plow were selected because they are considered as potential soil and water conservation methods. Sufficient evidence was found that soil moisture, density, penetration resistance, and residue cover are important for evaluating these systems. These properties were monitored before and after tillage, after winter, at planting, and four times during the season.

Due to adequate precipitation in the region, no moisture differences between treatment means within or between dates were found. Differences in moisture between date means were attributed to the relationship between rainfall and water use by the crop.

After tillage, the paraplow and the chisel plow treatment had similar density means. However, for most of the season, the no-till and the chisel plow treatment means were statistically similar and lower than the paraplow. The pooled data showed that the paraplow resulted in the lowest treatment means during the sampling period. Tillage depth and efficiency of the tool in disturbing the soil were the reasons for these density differences.

The paraplow treatment produced the lowest cone index mean within and between the dates. High cone index in the chisel plow was caused by disking and buried residue and corn cobs. Generally, moisture and

density were found insufficient to explain these differences.

No-till left the highest percentage of residue throughout the year compared to paraplow which managed the residue better than the chisel plow.

High bulk density, penetration resistance, and residue cover combined to significantly reduce the yield of no-till compared to the identical yields produced by paraplow and chisel plow systems.

Also, this research contributed to the state of the art of soil strength measurement. A microcomputer-based penetrometer was developed, constructed, and used to record, store, and display penetration force and depth values. When compared to the standard hand-held penetrometer, this penetrometer was found to be fast and more precise.

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