PROCEEDINGS

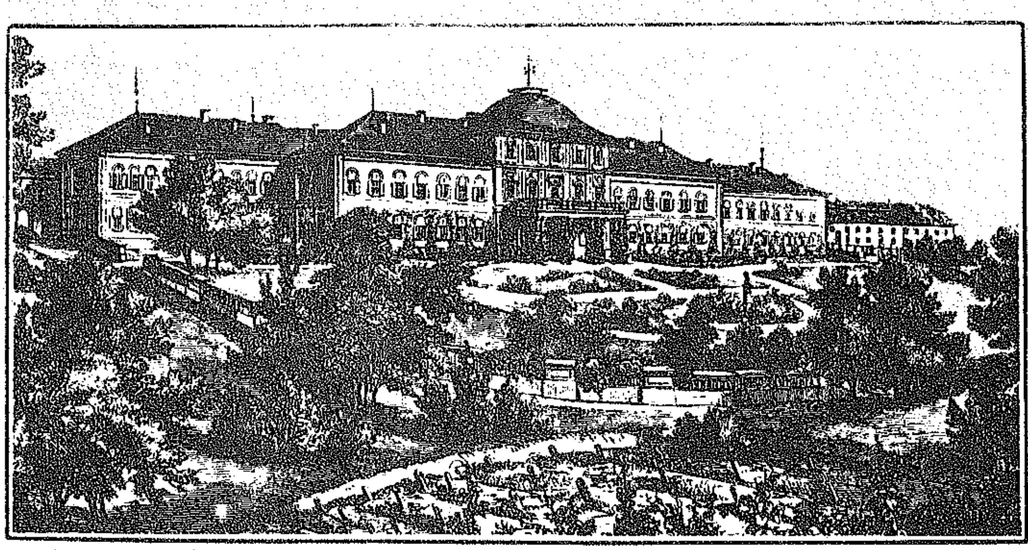
Volume 1

of the International Soil Tillage Research Organization, ISTRO

(8th Conference)

1979

UNIVERSITY OF HOHENHEIM



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Preface

We wish all participants a pleasant and informative stay at the University of Hohenheim and in the country Baden-Württemberg.

Within 14 sessions of alltogether 68 lectures problems of soil tillage and results of soil tillage experiments in different climate zones of the world are presented. The aimes of soil tillage are not only to optimize the growing factors for the development of plants, but also to improve other cultural measures such as fertilization and plant protection as well as to avoid damages of the soil.

The aimes of the conference are:

a) to set up priorities for a future soil tillage research in different parts of the world. These priorities will be worked on scientifically until the following conference.

b) to concentrate on points of emphasis for a conforming to the aim soil tillage depending on climate, soil and the species of fruit beeing cultivated.

c) to develop new procedures of the technical-mechanical soil tillage in consideration of the interaction between the aimes of soil tillage and the kind and amount of fertilizers, the plant protection measures and the crop rotation.

d) to integrate chemical and biological measures in cultivation systems in order to facilitate, to improve, to accelerate and to lower the costs of technical-mechanical soil tillage.

The print of the proceedings and the arrangement of the conference has been kindly supported by the Universitätsbund Hohenheim e.V., the Deutsche Forschungsgemeinschaft, the Deutscher Akademischer Austauschdienst and the Ministerium für Ernährung, Landwirtschaft und Umwelt Baden Württemberg. We thank these institutions here for the received financial and organizational aid.

Prof. Dr. G. Kahnt

President of the ISTRO

CONTENTS

The 8th Conference of the International Soil Tillage Research Organization, ISTRO, Bundesrepublik Deutschland, 1979.

EVALUATION OF TILLAGE SYSTEMS AND CROP ROTATIONS IN THE STATE OF PARANÁ, BRAZIL.

Preliminary findings prepared by OSMAR MUZILLI
IAPAR - Fundação Instituto Agronômico do Paraná
Caixa Postal, 1331 - 86100/LONDRINA, PARANÁ, BRASIL.

ABSTRACT

Direct drilling was introduced to the State of Paraná in 1971, following pioneer work by farmers and researchers who were interested in finding a means to reduce soil erosion losses under the conventional soybean/wheat rotation.Still today, there is no detailed information on the agronomic aspects of the system, changes in soil properties and on options for different crop rotations.

In view of this, IAPAR stablished in 1976 a joint multidisciplinary research project with Imperial Chemical Industries Ltd. in order to compare the direct drilling system with the conventional system. The principle points under consideration are as follows: a) crop development and yields under various soil and climatic conditions; b) changes in the chemical and physical properties of the soil; c) incidence of insect pests, deseases and weeds; d) inputs of labour and fuel consumption for the soil preparation and planting operations.

The first trial was installed at Londrina (North of Paraná) in a red distrophic Latosol (Typical Acrortrox) of 70% clay content. The summer crops include soybean, maize and cotton with wheat as the winter crop. Results here are partial and include the first two years starting with the 1976/77 summer crops. In the previous winter, the whole area was subsoiled, soil acidity corrected and wheat planted conventionally.

CROP DEVELOPMENT AND YIELDS

Average crop yields under the two systems are presented in Table 1.

In the first summer crop (1976/77) when climatic conditions were regular and adequate, average yields were satisfatory and similar for both systems. The lower yield in direct drilled maize was due to damage caused by excess residual herbicide. The subsequent crops were affected by irregular occurrence and distribution of rainfall, the effects of wich influenced the development and yield of crops. The higher yields obtained under direct drilling were due to two factors: a) the higher soil moisture content which allowed for better germination and a more uniform and vigorous plant development; b) better soil moisture retention due to the covering crop residues and dissecated weeds which reduced the effects of drought during crop development. With regard to crop rotations, the longer cotton cycle and the need to pull out and burn crop residues caused a delay in the wheat planting and a reduction in soil moisture retention, to the detriment of wheat yield. By comparison, when preceded by maize, wheat development and yield were enhanced by the high volume of crop residue remaining on the soil surface.

TABLE 1. Yields of crop rotations under the two tillage systems from 1976 to 1978. Average of 3 replications per treatment.

Tillage systems	Yields (Kg/ha) of crop rotations			
	Summer 1976/77	Winter 1977	Summer 1977/78	Winter 1978
	SOYBEAN	WHEAT	SOYBEAN	WHEAT
Direct drilling	3280	967	1448	2036
Conventional	3230	609	530	708
	MAIZE	WHEAT	MAIZE	WHEAT
Direct drilling	4868*	1169	6489	2341
Conventional	5606	523	5678	891
	COTTON	WHEAT	COTTON	WHEAT
Direct drilling	1423	385	1749	1813
Conventional	1414	132	1491	682
	SOYBEAN	WHEAT	MAIZE	WHEAT
Direct drilling	3247	1094	6981	2446
Conventional	2939	642	5548	969
	COTTON	WHEAT	MAIZE	WHEAT
Direct drilling	1557	451	6670	2308
Conventional	1435	102	5706	965
	SOYBEAN	WHEAT	COTTON	WHEAT
Direct drilling	3179	1055	1633	2078
Conventional	3111	732	1549	879
	MAIZE	WHEAT	SOYBEAN	WHEAT
Direct drilling	4680*	1173	1301	2140
Conventional	5324	448	577	641

*:- Damaged by residual herbicide applied in excess.

THE OCCURRENCE OF INSECT PESTS

The low level of soil moisture favoured the attack of soil caterpillar (*A. ipisilon* and *E. lignosellus*) in the 1977 wheat crop. Although from an agronomic point of view, levels of attack were not significant, the incidence was more intense in conventional plots, where 56 to 68% more plants were affected than in direct drilled plots. Levels of attack were higher in the soybean/wheat rotation than in the maize/wheat rotation (Table 2). In the cotton/wheat rotation, the wheat crop was not yet established.

TABLE 2. Evaluation of wheat plants killed by soil catterpillars (*A. ipisilon* and *E. lignosellus*), 1977 crop. Average of 3 replications per treatment.

Crop rotations	Number of dead plants		% increase of attack in conventional
	Conventional system	D. Drilling system	
Soybean/wheat	139	61	56
Maize/wheat	68	22	68
% increase of attack in soybean/wheat	51	64	

There was a similar occurrence in the 1977/78 maize crop where the combined effects of drought and soil catterpillars caused a reduction in stand around 38% more in the conventional plots than in the direct drilled plots (Table 3).

TABLE 3. Total number of young maize plants under different tillage systems and crop rotations, during a period of drought combined with an attack of soil catterpillars (*A. ipisilon* and *E. lignosellus*), 1977/78. Average of 3 replications per treatment.

Previous crop rotations	Total number of plants in		% less of plants in conventional
	D. drilling	Conventional	
Maize/wheat	1316	814	38
Soybean/wheat	1285	822	36
Cotton/wheat	1293	797	38

In the cotton crop, for both years, the occurrence of aphid attack (*A. gossypii, Glover*) was higher in direct drilled plots than in the conventional plots (Figure 1).

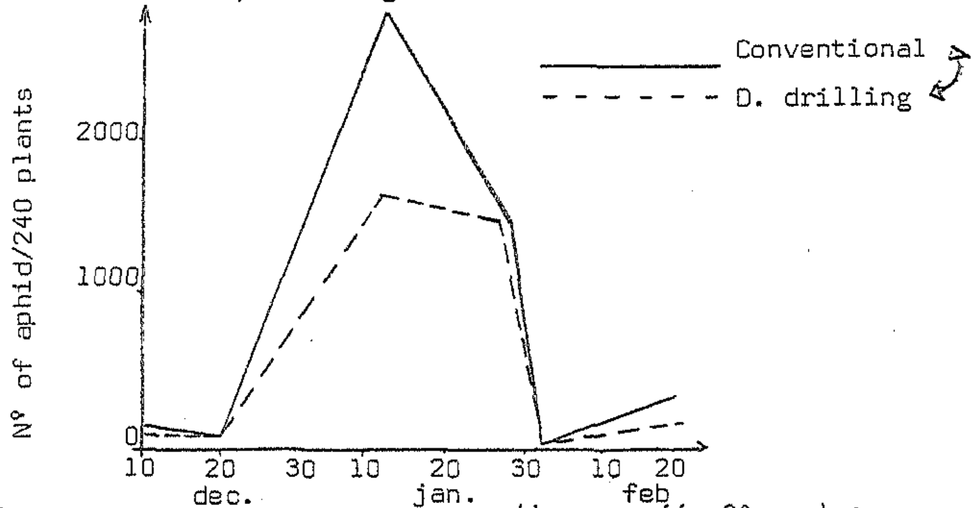

Fig. 1. Occurrence of aphid attack (*A. gossypii, Glover*) in conventional and direct drilled cotton 1976/77 and 1977/78crops.

In soybean, monthly evaluations of attack by insect pests did not show significant differences in species, population levels and crop defoliation between the two tillage systems (Table 4).

TABLE 4. Occurrence of insect attack and degree of defoliation in conventional and direct drilling soybeans. 1976/77 crop.

Tillage system	Number of insects/sample		% of defoliation
	Catterpillars	Bugs	
Conventional	31.0	3.2	29
Direct drilling	34.3	3.6	27

OCCURRENCE AND CONTROL OF DISEASES

In the 1977 wheat crop, assessments were made to determine the levels of leaf rust (*Puccinia recondita*) before and after the application of fungicides. The level of infection was two times higher in conventional wheat even after the chemical control measures (Table 5).

TABLE 5. Incidence of leaf rust (*P. recondita*) in wheat, 1977 crop. Average of 6 replications per system.

Tillage systems	% of leaf affected by rust	
	1st. assessment	2nd. assessment*
Direct drilling	12.0	10.7
Conventional	27.5	20.3

*:- Disease level after chemical control.

CHANGES IN SOIL FERTILITY

After the wheat harvest in 1977, soil samples were collected at every 5 cm depth up to 30 cm and analysed to determine the distribution of nutrients in the soil (Figure 2).

Even in the first year, the direct drilled plots showed an increase in organic matter content (evaluated by carbon content), especially after the maize/wheat rotation where the volume of crop residue was high; after the cotton/wheat rotation where the summer crop residues are pulled out and burned, this increase in organic matter was much less marked.

For both tillage systems there were high concentrations of phosphorus in the first 5 cm of soil and at the lower depths there was a marked decrease in concentration. Surface concentration was higher in direct drilling especially after the cotton/wheat rotation whereas the lowest concentrations were found after the maize/wheat rotation in both tillage systems. The main reason for these high surface concentrations is the high phosphorus retention capacity of the soil, associated with the fact that in the case of direct drilling, with the machinery at present used, fertilizer is localized on the surface of the soil.

Concentrations of calcium, magnesium and potassium decreased gradually with depth. Surface concentrations were higher in direct drilling and there was little difference between rotations.

With regard to nutrient availability to the crops, maize plants at flowering showed signs of N deficiency in the direct drilled plots. A leaf analysis confirmed this fact. Differences were more evident after a maize/wheat rotation (Table 6).

TABLE 6. N, P and K contents in maize leaves under two tillage systems and following different crop rotations, 1977/78 crop. Average of 3 replications per treatment.

Previous crop rotation		Nutrient content (%)					
Summer 1976/77	Winter 1977	D. Drilling system			Conventional system		
		N	P	K	N	P	K
Maize	Wheat	4.18	0.29	2.33	3.75	0.29	2.47
Soybean	Wheat	4.19	0.29	2.40	3.91	0.31	2.65
Cotton	Wheat	4.09	0.31	2.48	3.95	0.28	2.48

The lower leaf N content in maize under direct drilling can be explained by the higher microbiological activity in the soil wich is in turn related to the high soil organic matter content. Leaf P content did not differ between tillage systems or crop rotations, while for K content, lower levels were detected in the direct drilled maize especially after the soybean/wheat sequence.

Observations are also being made of soil physical changes under the two systems and effects upon root development.

This work is being carried on at two other sites in the State of Paraná where soil and climatic conditions differ somewhat. After 5 years, a complete analysis of results will be made and from this, soil management techniques and crop rotational sequences for different regions in the State of Paraná will be recommended.

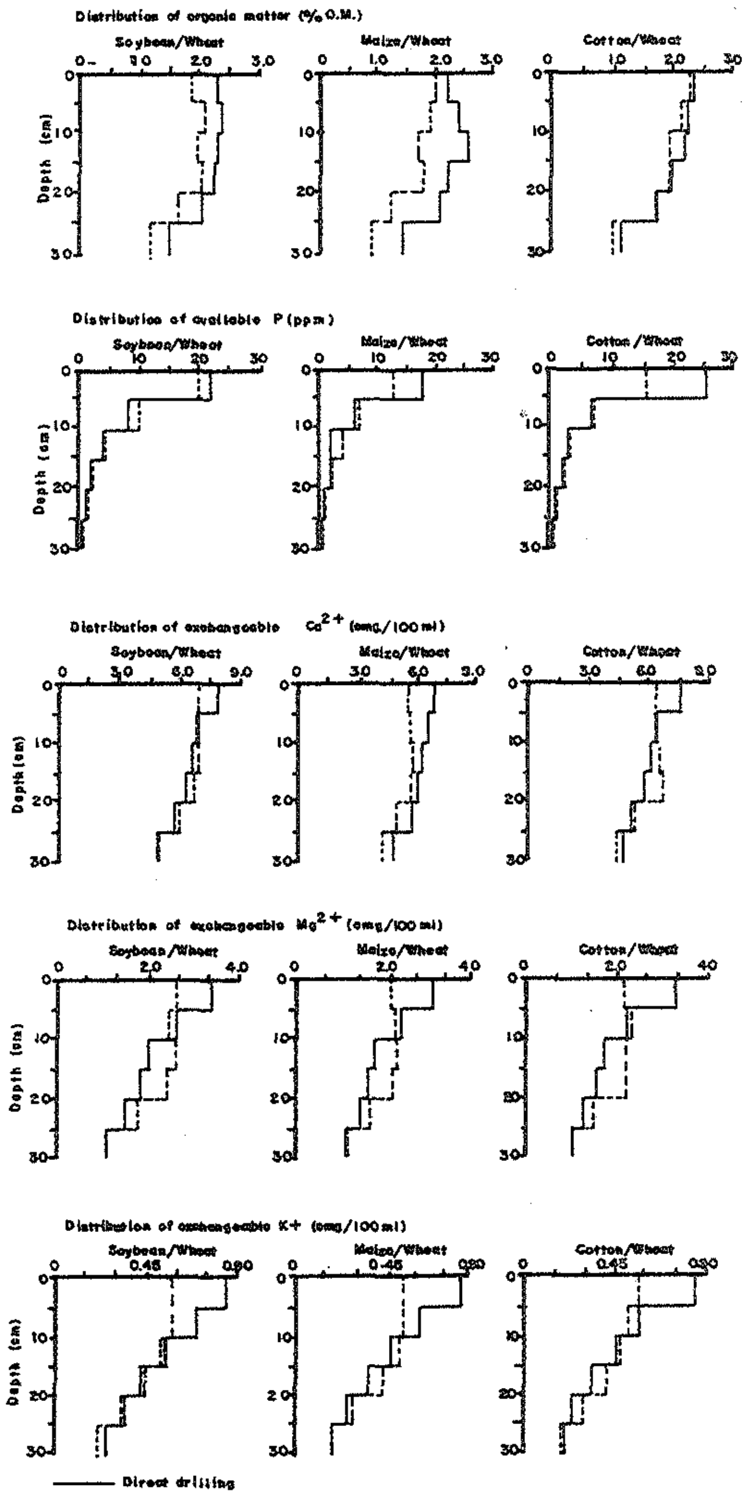

Fig. 2 Distribution of nutrients in arable layer of soil, after Wheat harvest in sequence to summe crops (1st year). Londrina, 1.977.

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SOIL CONDITIONS AND TILLAGE SYSTEMS IN THE TROPICS

M. Armon and R. Lal
International Institute of Tropical Agriculture, Ibadan, Nigeria.

ABSTRACT
Effects of continuous no-tillage and conventional plowing on soil physical and chemical properties of an Alfisol was investigated 8 years after initiating this tillage experiment immediately after forest removal. There was no erosion on no-tillage plots. Soil bulk density, penetrometer resistance, saturated hydraulic conductivity, moisture retention at low suctions, and available water holding capacity of the surface layer were more favourable for crop production in no-till compared with plowed plots. Similarly affected was soil chemical fertility. Soil productive potential can be maintained indefinitely, with proper management, by adopting no-tillage system with crop residue mulch.

Introduction

No-tillage farming is a soil conserving system. Being an effective erosion control measure, it helps maintain soil fertility and soil physical properties at a favourable level compared with the conventional tillage that involves soil disturbance through plowing and harrowing. Crop yield is sustained with no-tillage system because it maintains a status-quo in soil properties.

There exists a controversy in the literature concerning the yield response to tillage systems. Yield, being a function of multitude of factors, is affected by soil characteristics, agro-ecological environments, and management. In addition to the effects of initial level of soil physical and chemical properties, variation in climatic factors during the crop period have a significant effect on yield. A short-term yield record is not a good parameter to evaluate the relative performance of tillage systems. In the long run however, tillage methods must have a decisive effect on trends in crop yields.

The controversy can be resolved by either evaluating the long term effects of tillage systems on soil properties, crop production, or both. Soil, being a non-renewable natural resource, must be protected against the climatic elements. Maintenance of its properties at a lwvel favourable for crop production is the objective underlying the choice of an appropriate tillage system. The objective of this report is to describe the effects of 8 years of no-tillage and conventional plowing on the chemical and physical properties of a tropical Alfisol.

Materials And Methods

The experiments, were conducted during 1977 and 1978 at IITA near Ibadan, Nigeria. Tillage plots have been maintained since 1970 and earlier results have been reported elsewhere (Lal, 1974; 1976). Since 1977, different levels of fertilizer were superimposed over the tillage treatments as main plots. Nitrogen was applied at four levels: 0 (N_0), 40 (N_1), 80 (N_2), and 120 (N_3) kg/ha of N, and phosphorus at 0 (P_0), 13 (P_1), and 26 (P_2) kg/ha of P. A uniform application of KCl was made to all plots at 30 kg/ha of K. Physical and chemical analyses of soil properties were made during 1977 and 1978 after growing 17 consecutive crops with the same tillage method.

Results And Discussion

A. Soil Physical Properties:

1. Bulk density and penetrometric resistance: Soil bulk density and penetrometric resistance were generally low for no-tillage compared with the conventionally plowed plots (Table 1). A layer of crop residue mulch prevented crust formation on no-tillage plots, and, by maintaining favourable soil moisture and temperature regimes, enhanced activity of earthworms that lowered soil bulk density and penetrometric resistance.

2. Moisture retention and transmission: Low bulk density, and high total porosity, of no-tillage plots is reflected in relatively high saturated hydraulic conductivity of the surface layer (Table 2). However, conductivity of the sub-soil horizons was generally more for the plowed compared with unplowed plots. Moisture retention curves determined on undisturbed soil cores indicated higher moisture retention in soil from no-tillage compared with conventionally plowed plots (Table 3). High total porosity in no-tillage plots, indicated by moisture retention at zero suction, consists of relatively large proportion of macro-pores.

Table 1. Bulk density and penetrometer resistance.

(a) Bulk density (gcm^{-3}

Depth (cm)	Before planting		Four weeks after planting		Eight weeks after planting		Twelve weeks after planting	
	NT	CT	NT	CT	NT	CT	NT	CT
0-5	1.33	1.60	1.35	1.50	1.27	1.50	1.30	1.58
5-10	1.44	1.70	1.50	1.67	1.50	1.66	1.31	1.31
10-20	1.55	1.73	1.54	1.66	1.55	1.72	1.55	1.77
20-30	1.67	1.81	1.63	1.78	1.60	1.80	1.59	1.82
LSD(.05)	0.12		0.09		0.04		0.07	

(b) Penetrometer resistance ($kgcm^{-2}$

Depth (cm)	Before planting NT	Before planting CT	Four weeks NT	Four weeks CT	Eight weeks NT	Eight weeks CT	Twelve weeks NT	Twelve weeks CT
0-5	0.98	1.97	0.70	1.02	0.90	1.80	1.56	4.50
5-10	1.56	2.52	1.30	1.59	1.43	2.4	4.50	4.50
10-20	1.98	2.68	1.57	1.95	2.10	2.74	4.50	4.50
20-30	2.24	3.60	2.10	3.3	2.50	3.70	4.50	4.50
LSD(.05)	0.45		0.42		0.45		-	

NT No-tillage
CT Conventional tillage

Table 2: Saturated hydraulic conductivity (cm/hr) determined on undisturbed soil cores.

Depth cm	Before planting NT	CT	Four weeks after planting NT	CT	Eight weeks after planting NT	CT	Twelve weeks after planting NT	CT
0-5	148.3	87.5	39.9	125.5	132.9	91.1	137.3	61.1
5-10	61.2	80.9	62.1	94.7	63.3	84.3	60.6	75.0
10-20	46.2	65.5	41.7	71.2	47.9	62.3	44.2	50.7
20-30	35.6	39.4	38.6	41.6	36.2	39.5	37.0	41.4
LSD(.05)	23.5		24.2		16.3		13.2	

NT No-tillage
CT Conventional tillage

B. Soil Chemical Properties:
Soil chemical properties and nutrient status of different layers, as affected by tillage systems and level of fertilizer application, are shown in Table 4, a to d. In the 0 to 5 and 5 to 10cm layer, soil from the no-tillage plots had more organic carbon, total nitrogen, Bray-1 psophocarpus and total concentration of bivalent cations. Soil pH (1:1 in soil-water suspension) was not significantly different among two tillage systems. In the sub-soil horizons of 10 to 20 and 30cm depths, however, the soil from conventinally plowed plots had slightly more organic carbon, total nitrogen,pH, and cation concentration compared with that from no-tillage plots.

Chemical composition of worm casts: Activity of earthworms, as observed by number of worm casts on the soil surface, was several folds less in tilled compared with untilled plots. In addition, the chemical composition of worm casts obtained from plots receiving differential fertilizer and tillage treatments, reflects the fertility status of soils from those plots. Whereas there were no definite trends in chemical composition of worm casts in relation to different rates of fertilizer applications, tillage system had a significant effect on these properties (Table 5). Worm casts sampled from no-tillage plots had more organic carbon, total nitrogen, available P, and cation concentration compared with those from conventionally tilled plots.

GENERAL DISCUSSION

With an adequate quantity of crop residue on the soil surface of no-tillage plots, physical and chemical properties are maintained at favourable level compared with plowed plots. These trends are established over a long period of time, and are also reflected in crop yields. In general, maize grain yields with no-tillage were equivalent or better than those from conventional tillage. Fertility status of those tropical soils that are prone to accelerated soil erosion can be maintained for sustained crop production with proper adaptation of no-tillage system with crop residue mulch.

Table 3: Moisture retention (% by weight) at different suctions.

Soil Depth (cm)	Tillage treatment	MOISTURE POTENTIAL (BARS) 0	0.015	0.05	0.1	1	3	5	15
0-5,	NT	44.6±6.6	34.2±1.2	33.0±1.9	25.0±1.4	11.5±1.8	10.3±1.6	8.9±1.0	7.8±0.6
	CT	27.8±1.5	25.5±1.5	23.6±1.2	21.9±1.8	8.8±1.8	7.0±0.7	6.2±0.9	5.4±0.9
5-10	NT	39.1±1.5	30.2±2.3	24.0±1.4	20.3±0.7	7.7±1.7	7.1±0.4	6.6±0.3	5.7±0.6
	CT	26.8±0.8	23.4±0.4	22.1±0.6	20.3±0.7	8.2±1.0	7.2±1.1	6.2±0.9	5.1±0.6
10-20	NT	33.0±0.4	25.4±1.5	21.8±0.9	18.3±0.2	7.2±-.9	6.7±0.7	5.8±0.1	5.0±0.0
	CT	23.2±2.4	21.±1.9	18.3±1.6	15.4±2.0	7.5±1.6	6.2±1.2	5.9±0.9	5.4±0.6
20-30	NT	29.4±0.6	20.8±1.5	18.1±1.4	14.6±1.0	6.8±1.2	5.8±1.3	4.7±0.5	4.1±0.2
	CT	18.2±2.0	17.4±2.0	14.2±0.7	11.0±0.5	5.8±1.6	5.6±1.3	4.0±0.3	3.5±0.2

Determined on undisturbed soil cores. NT = No-tillage CT = Conventional tillage

TABLE 4a. Soil chemical properties in relation to tillage and fertilizer treatmen.

0 - 5cm (depth)

TREAT-MENT	Organic Carbon		Total Nitrogen		pH		Available P		Ca		Mg		Mn				Na	
	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT
	%		%				ppm				(meq/100gm)							
N_oP_o	1.85	0.90	0.33	0.14	5.90	6.20	31	39	3.60	1.58	0.70	0.24	0.01	0.01	0.16	0.46	0.08	0.07
N_oP_1	1.68	1.10	0.32	0.16	6.50	5.40	89	77	4.92	4.18	1.10	0.44	0.03	0.03	0.5[illegible]	0.35	0.06	0.07
N_oP_2	1.58	1.15	0.35	0.18	6.20	5.90	111	122	3.94	3.83	0.50	0.44	0.05	0.05	0.[illegible]	0.50	0.06	0.07
N_1P_o	2.10	0.85	0.34	0.13	5.80	6.20	36	46	4.81	2.53	0.86	0.30	0.01	0.02	0.85	0.50	0.06	0.06
N_1P_1	1.35	1.23	0.26	0.18	6.10	5.70	127	31	4.07	1.95	0.67	0.25	0.67	0.25	0.19	0.10	0.07	0.04
N_1P_2	1.85	1.13	0.32	0.17	5.70	5.40	21	120	4.50	2.89	0.67	0.15	0.03	0.004	0.19	0.16	0.09	0.04
P_2P_o	1.65	1.15	0.30	0.17	5.40	5.40	102	33	4.00	2.06	0.56	0.24	0.01	0.76	0.35	0.31	0.09	0.06
P_2P_1	1.53	1.08	0.23	0.15	5.90	5.50	75	36	3.45	1.94	0.39	0.16	0.03	0.004	0.12	0.31	0.08	0.05
P_2P_2	1.65	1.10	0.23	0.11	5.90	5.50	50	72	2.60	3.41	0.35	0.40	0.04	0.02	0.14	0.23	0.43	0.004
N_2P_o	1.48	1.03	0.32	0.16	5.90	5.20	127	44	3.30	2.29	0.69	0.28	0.04	0.01	0.42	0.27	0.05	0.06
N_3P_1	1.40	1.25	0.36	0.18	5.50	5.40	216	64	4.88	3.3	0.77	0.33	0.07	u.d	0.34	0.23	0.08	0.06
N_3P_2	1.83	1.03	0.30	0.12	5.90	6.40	94	7	5.19	2.1	0.47	0.35	0.06	0.06	0.23	0.19	0.05	0.03
MEAN	1.70	1.08	0.30	0.20	5.90	5.70	90	57	4.11	2.67	0.67	0.30	0.09	0.10	0.30	0.30	0.10	0.05
SE	0.06	0.04	0.10	0.01	0.08	0.10	15	10	0.23	0.24	0.06	0.03	0.05	0.06	0.03	0.04	0.03	0.006

TABLE 4b. Chemical properties in relation to tillage and fertilizer treatment. (5-10cm)

TREAT-MENT	Organic Carbon		Total Nitrogen		pH		Avail. P		Ca		Mg		Mn		K		Na	
	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT
	%		%				ppm		Me/100gm)									
N_oP_o	1.85	0.98	0.33	0.14	5.90	6.0	30	35	2.40	1.81	0.40	0.33	0.01	0.004	0.16	0.19	0.04	0.06
N_oP_1	1.15	1.10	0.26	0.15	6.50	5.60	67	53	3.25	3.09	0.64	0.40	0.04	0.004	0.54	0.23	0.05	0.06
N_oP_2	1.13	1.23	0.23	0.16	5.90	6.00	91	56	3.11	3.83	0.46	0.54	0.05	0.01	0.23	0.46	0.07	0.07
N_1P_o	1.50	0.93	0.22	0.13	5.90	6.00	21	40	4.22	2.40	0.73	0.32	0.004	0.004	0.31	0.27	0.06	0.06
N_1P_1	0.98	1.13	0.20	0.15	6.20	5.80	53	30	2.77	1.95	0.37	0.29	0.06	u.d	0.19	0.09	0.06	0.03
N_1P_2	1.96	1.28	0.20	0.17	5.80	5.20	103	72	3.11	2.55	0.55	0.22	0.01	0.15	0.19	0.14	0.09	0.04
N_2P_o	1.45	1.15	0.30	0.16	6.20	5.40	18	36	3.40	1.91	0.92	0.27	0.004	0.05	0.40	0.31	0.09	0.06
N_2P_1	1.08	1.08	0.16	0.16	5.50	5.20	69	50	2.21	2.59	0.29	0.28	0.05	0.03	0.14	0.27	0.07	0.07
N_2P_2	1.65	1.08	0.23	0.17	5.90	5.60	72	44	2.00	3.44	0.30	0.47	0.004	0.004	0.13	0.47	0.43	0.004
N_3P_o	1.13	1.10	0.18	0.14	6.00	5.20	25	40	2.98	2.00	0.65	0.24	0.03	0.004	0.42	0.31	0.06	0.07
N_3P_1	1.40	1.30	0.27	0.19	5.80	5.30	39	59	2.56	2.42	0.31	0.29	0.08	0.02	0.19	0.14	0.05	0.05
N_3P_2	1.13	0.98	0.22	0.13	5.60	6.40	130	7	3.08	1.78	0.40	0.34	0.09	0.004	0.19	0.004	0.05	0.03
MEAN	1.40	1.10	0.23	0.20	5.90	5.70	76.70	43.80	2.92	2.48	0.50	0.33	0.04	0.02	0.30	0.24	0.09	0.05
SE	0.10	0.03	0.01	0.03	0.10	0.12	21.1	4.70	0.17	0.19	0.05	0.03	0.01	0.01	0.03	0.04	0.03	0.02

Table 4_c. Soil chemical properties in relatio to tillage and fertilizer treatment. 10-20cm (depth).

TREATMENT	Organic Carbon		Total Nitrogen		pH		Avail. P		Ca		Mg		Mn		K		Na	
	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT
	%		%				ppm		me/100gm									
N_oP_o	0.80	0.85	0.11	0.13	5.40	6.10	23	38	1.50	1.81	0.20	0.26	0.004	0.004	0.12	0.31	0.05	0.10
N_oP_1	0.68	1.15	0.10	0.14	6.10	6.00	7	51	3.03	3.18	0.53	0.40	0.02	0.004	0.50	0.50	0.05	0.06
N_oP_2	0.75	1.13	0.14	0.19	5.80	5.60	40	29	2.02	3.70	0.25	0.55	0.09	u.d	0.19	0.31	0.06	0.06
N_1P_o	0.78	0.98	0.16	0.13	5.80	6.00	5	35	4.31	2.40	0.57	0.30	0.004	u.d	0.23	0.27	0.04	0.05
NN_1P_1	0.60	1.03	0.14	0.15	5.70	5.80	25	22	2.06	2.23	0.35	0.33	0.07	0.13	0.07	0.13	0.06	0.02
N_1P_2	0.73	1.23	0.17	0.16	5.20	5.10	40	61	2.06	2.12	0.22	0.19	0.004	0.01	0.19	0.11	0.06	0.09
N_2P_o	1.03	1.98	0.19	0.14	6.10	5.30	8	28	2.54	2.49	0.72	0.45	u.d	0.004	0.31	0.15	0.07	0.06
N_2P_1	0.78	1.08	0.13	0.14	5.70	5.40	35	30	1.59	2.43	0.23	0.35	0.47	0.004	0.15	0.27	0.06	0.08
N_2P_2	0.78	1.00	0.11	0.17	5.80	5.50	26	29	1.40	3.49	0.16	0.43	0.05	u.d	0.12	0.19	0.03	0.04
N_3P_o	0.83	1.03	0.13	0.13	6.00	5.10	13	35	1.69	1.92	0.30	0.23	0.05	0.01	0.35	0.12	0.04	0.04
N_3P_1	1.08	1.20	0.20	0.20	5.90	5.30	19	36	2.22	2.03	0.22	0.23	0.06	0.02	0.15	0.16	0.04	0.05
N_3P_2	0.83	0.93	0.17	0.13	5.50	6.00	59	63	2.51	1.64	0.21	0.27	0.06	0.004	0.23	0.19	0.06	0.03
MEAN	0.18	1.10	0.15	0.17	5.30	5.60	25	34	2.24	2.45	0.33	0.33	0.07	0.02	0.22	0.23	0.05	0.04
SE	0.03	0.03	0.01	0.02	0.40	0.10	4	3	0.23	0.20	0.05	0.03	0.03	0.01	0.03	0.03	0.03	0.08

Table 4d. Soil chemical properties in relation to tillage and fertilizer treatment. 20-30cm depth.

TREAT-MENT	Organic Carbon NT (%)	Organic Carbon CT (%)	Total Nitrogen NT (%)	Total Nitrogen CT (%)	pH NT	pH CT	Avail.P NT (ppm)	Avail.P CT (ppm)	Ca NT	Ca CT	Mg NT	Mg CT	Mn NT	Mn CT	K NT	K CT	Na NT	Na CT
									me/100gm									
N_oP_o	0.70	0.83	0.12	0.10	5.30	6.10	2	24	2.2	1.75	0.40	0.26	0.004	u.d	0.16	0.19	0.04	0.67
N_oP_1	0.75	0.90	0.10	0.10	6.00	5.90	2	23	1.67	2.90	0.26	0.35	0.04	0.004	0.31	0.23	0.05	0.01
N_oP_2	0.55	0.75	0.11	0.15	5.60	5.30	12	9	1.36	4.1	0.15	0.55	0.09	u.d	0.11	0.27	0.04	0.06
N_1P_o	0.70	0.70	0.13	0.10	5.80	6.10	4	18	3.40	2.50	0.47	0.34	0.004	0.01	0.23	0.20	0.05	0.06
N_1P_1	0.63	0.85	0.13	0.14	6.00	6.10	11	8	1.77	2.40	0.31	0.31	0.06	u.d	0.14	0.15	0.05	0.03
N_1P_2	0.65	1.03	0.13	0.14	5.20	5.60	2	33	1.22	2.28	0.25	0.27	0.05	0.15	0.19	0.14	0.04	0.04
N_2P_o	0.70	0.90	0.14	0.13	6.10	5.30	3	11	3.30	2.29	0.45	0.38	u.d	0.004	0.16	0.19	0.05	0.06
N_2P_1	0.50	1.00	0.09	0.12	5.30	4.90	9	18	1.16	2.06	0.14	0.30	0.004	0.03	0.06	0.19	0.04	0.07
N_2P_2	0.68	0.90	0.01	0.14	5.40	5.50	6	15	2.66	3.4	0.35	0.40	0.04	0.02	0.14	0.23	0.43	0.004
N_3P_o	0.58	0.80	0.09	0.13	5.90	5.50	9	21	2.26	2.08	0.32	0.33	0.04	0.03	0.23	0.19	0.05	0.07
N_3P_1	0.78	0.98	0.11	0.13	5.80	5.40	9	15	1.77	2.06	0.18	0.29	0.06	0.004	0.13	0.13	0.04	0.06
N_3P_2	0.70	0.70	0.14	0.11	5.90	6.00	15	4	2.68	1.68	0.30	0.29	0.03	0.01	0.23	0.15	0.05	0.03
MEAN	0.70	0.80	0.11	0.12	5.70	5.64	7	17	2.12	2.28	0.30	0.33	0.04	0.02	0.17	0.19	0.08	0.10
SE	0.20	0.10	0.01	0.01	0.1	0.11	1	2	0.22	0.21	0.03	0.02	0.01	0.01	0.02	0.05	0.03	0.05

Table 5. Chemical composition of worm casts

TREAT-MENT	Organic Carbon NT	Organic Carbon CT	Total Nitrogen NT	Total Nitrogen CT	Avail.P NT	Avail.P CT	Ca NT	Ca CT	Mg NT	Mg CT	Mn NT	Mn CT	K NT	K CT	Na NT	Na CT
	%		%		ppm		me/100gm									
N_oP_o	2.97	1.83	0.62	0.27	303	59	13.5	6.34	2.93	1.35	0.05	0.18	1.30	0.75	0.08	0.04
N_oP_1	2.93	2.04	0.64	0.32	224	103	13.75	8.30	2.94	1.41	0.09	0.13	1.45	0.75	0.09	0.05
N_oP_2	3.04	2.29	0.60	0.30	219	98	15.01	5.56	2.54	1.34	0.05	0.14	1.18	0.74	0.10	0.04
N_1P_o	3.09	2.12	0.64	0.44	134	40	13.70	5.07	3.02	1.45	0.07	0.18	1.34	0.92	0.09	0.05
N_1P_1	2.96	2.05	0.63	0.29	199	116	14.15	7.01	2.17	1.14	0.07	0.16	0.98	1.00	0.09	0.05
N_1P_2	2.97	2.64	0.60	0.48	117	113	11.86	6.71	3.18	1.33	0.08	0.22	1.37	0.94	0.09	0.04
N_2P_o	2.99	2.18	0.70	0.33	182	63	12.51	5.97	2.70	1.09	0.08	0.15	1.30	0.82	0,08	0.05
N_2P_1	3.03	2.53	0.60	0.28	225	138	14.00	6.82	1.88	0.88	0.08	0.13	0.92	0.56	0.08	0.05
N_2P_2	3.10	2.21	0.77	0.32	255	118	14.86	7.22	2.58	1.72	0.06	0.13	1.01	1.09	0.09	0.05
N_3P_o	3.08	2.59	0.79	0.37	128	117	14.65	8.36	3.52	1.60	0.09	0.17	1.34	1.18	0.09	0.05
N_3P_1	3.04	2.55	0.63	0.37	162	108	13.63	7.23	2.59	1.27	0.08	0.13	1.11	1.11	0.09	0.05
N_3P_2	3.02	2.38	0.75	0.38	2.90	93	14.59	7.24	3.05	0.95	0.09	0.12	1.57	1.111	0.11	0.05 +
MEAN	3.00	2.30	0.70	0.35	192	95	18.86	6.82	2.78	1.29	0.07	1.15	0.24	0.91	0.09	0.05
SE	0.02	0.07	0.02	0.02	14	8	0.26	0.29	0.13	0.07	0.004	0.01	0.06	0.05	0.002	0.001

REFERENCES

1. Lal, R. 1974. No-tillage effects on soil properties and maize production in western Nigeria. Plant and Soil 40:589-606.

2. Lal, R. 1976. No-tillage effects on soil properties under different crops in western Nigeria. Soil Sci. Soc. Amer. J.40:762-768.

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EFFECTS OF VARYING TILLAGE PROCEDURES ON CROP GROWTH FACTORS IN SOUTHERN AUSTRALIA.

Iain T. Grierson

Roseworthy Agricultural College, Roseworthy, South Australia, Australia, 5371

Abstract

A factorial experiment involving three types of cultivation techniques with two types of seeding methods was conducted on a solonized brown soil in southern Australia.

Highest wheat yields were obtained by methods giving maximum soil disturbance, for peas highest yields were obtained by tillage procedures resulting in minimum soil disturbance. It is suggested the larger roots of the pea plants are better able to exploit the soil conditions produced by minimum tillage and perhaps there is a need to breed new wheat varieties for minimum tillage techniques.

The preparation of the seedbed for a wheat crop in Southern Australia is influenced by 2 main factors, first the length of time during which the soil is kept bare and secondly the methods used in tilling the soil.

In general the term fallowing is used when the soil is cultivated in the winter or the early spring (August-September) kept bare over the summer and then sown in the autumn (May-June).

Early in Australian agriculture it was shown that fallowing gave higher yields (Perkins and Bristow 1926, Richardson and Fricke 1931). The yield increases were attributed to better water storage, weed control and a better seedbed. Later it was shown that yield increases could also be due to the higher amounts of nitrate nitrogen accumulating in fallows (Richardson and Gurney 1935). These findings encouraged the widespread use of fallowing on all soils. However the fallowing together with narrow rotations without productive pasture, led to widespread erosion, and by 1940, yields were declining in many of the wheat districts (Cornish 1949).

After 1945 the increased use of legume pastures improved soil fertility and laid down the basis for the leyland farming system as currently used. The length of the fallow period has now been generally restricted to initial cultivation two to three months prior to sowing.

However farmers are continually looking for ways of reducing tillage costs and are interested in the effect on crop growth factors of alternative techniques such as minimum tillage. In southern Australia the most commonly used minimum cultivation technique involves directly seeding wheat through an existing stand of herbage. A chemical spray is used to check the growth of the herbage until the canopy of the grain crop can do this for itself.

During 1978 a tillage trial to investigate the merits of the minimum cultivation technique in comparison with traditional farming practice was carried out at Roseworthy Agricultural College.

Materials and Methods

The experiment was carried out on a solonized brown soil (Gn 1.46) Northcote (1965). The mean annual rainfall for the past ten years is 489mm while for 1978 it was 530mm.

The trial consisted of a factorial design with three cultivation treatments, two seeding methods and two crops. These were laid out in a randomized block design with each plot being 25m x 3.2m.

The cultivation treatments consisted of minimum cultivation, cultivation by tyne implements and cultivation by rotary implements. Each cultivation treatment was seeded by either used seeding equipment mounted on tyne equipment or on rotary implements.

The two crops were wheat and peas and all plots were sown on the 8th June 1978.

The peas were harvested on the 6th December 1978 from plots 1m x 10m, the wheat harvested on the 11th December, 1978 from strips 1.25m x 40m. Grain samples were taken from all plots ground, using a Casella Wholemeal Mill and protein analyses carried out using the Udy (1971) method.

Results and Discussion

The results for the yield and protein percentages for both wheat and peas under the different treatments are given in Table I.

Table I Effect of Presowing Cultivation Treatment and Seeding method on Yield and Protein Percentage for Peas and Wheat

Presowing Cultivation Treatment	Seeding Method	Peas		Wheat	
		Yield t/ha^{-1}	Protein %	Yield t/ha^{-1}	Protein %
Minimum Cultivation	Tyne	1.99	28.2	1.55	11.2
	Rotary	1.95	28.9	1.89	10.9
Tyne Implement	Tyne	1.87	28.2	1.70	12.3
	Rotary	1.81	28.8	2.15	11.1
Rotary Implement	Tyne	1.62	28.4	2.48	12.5
	Rotary	1.68	29.1	2.40	11.9
LSD $P = 0.05$		.22	NS	.49	NS

The minimum cultivation resulted in significantly increased pea yields and decreased wheat yields. The latter appeared caused by poor weed kill under the chemical application which in conjunction with the apparent slower crop growth resulted in strong weed competition. The reduction in yield may in fact have been much greater had the rainfall in 1978 been lower creating greater moisture stress.

The peas however showed strong early growth and were not troubled by weeds the shallower seeding depths afforded by the minimum cultivation helped to make full advantage of the growing period.

The seeding technique involving the rotary implement gave slightly higher yields (at $P = 0.10$) for all wheat cultivation treatments.

Protein results showed no significant difference.

Conclusion

A number of investigators have found that minimum cultivation results in a denser soil seed bed (Stibble and Ariel 1970, Soane et al 1975). Hence crops with larger diameter roots may respond better to the minimum cultivation technique.

This may also suggest that wheat varieties bred for conventional tillage procedures may not be as well adapted to the minimum cultivation soil environment.

The current Australian seeding method relies on a tyne implement, it appears there is a need for improvement in this area with these new conditions.

References

Cornish, E.A. (1949) Yield trends in the wheat belt of South Australia 1896-1941 Aust.J.Sci.Res.B.Biol.Sci. 2 : 83-137.

Northcote, K.H. (1965) A factual key for the recognition of Australian Soils Rellim Publ., Glenside, S.A.

Perkins, A.J. and Bristow, E.A. (1962) Booborowie Expt. Farm. Rpts. J.Dept.Agric. South Aust. 26 : 766-80.

Richardson, A.E.V. and Fricke, E.F. (1931) The effect of nitrogenous fertilizers on the growth and yields of wheat and barley J.Dept.Agric. South Australia 35 : 57-86.

Richardson, A.E.V. and Gurney, E.F. (1935) Nitrogen in relation to cereal culture. J.Dept.Agric. South Australia 38 : 854-871.

Soane, B.D. et al (1975) Soil/machine interactions in zero tillage for cereals and rasberries in Scotland. Outlook on Agric. 8 : 220-226.

Stibbe, E. and Ariel, D. (1970) No tillage as compared to tillage practices in dryland farming of a semi-arid climate Neth. J.Agric. Sci. 18 : 293-307.

Udy, D.C. (1971) Improved dye method for estimating protein. J.Am.Oil Chemists Soc. 48 : 29-33.

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SOIL TILLAGE IN DRY TROPICAL REGIONS

Willem Hoogmoed, Tillage Laboratory,
Agricultural University Wageningen, The Netherlands

Ernest Rawitz, Department of Soil and Water Science, The Hebrew University of Jerusalem, Faculty of Agriculture, Rehovot, Israel.

ABSTRACT: Soil and climatic conditions of the semi-arid tropics, as well as constraints of economics and energy, require a shift in emphasis among the traditional aims of soil tillage in the direction of improving seedbed moisture regime, seasonal water conservation, weed control, and improving the friability of the root zone. Results of laboratory and field experiments simulating conditions in the Sahel indicate that sorghum yield is strongly dependent on stand density and on soil water supply. While water conservation and plant development are favored by coarsely-structured soil, initial crop establishment is best with shallow sowing in a fine seedbed except when crusting impedes emergence, or when moisture supply is inadequate. Impeded emergence due to crusting can be corrected by control of soil moisture or by mechanical crust breaking. Zone tillage featuring fine-structured seed-row and coarse inter-row soil appears to be a promising solution.

INTRODUCTION: Traditionally, soil tillage has been carried out in temperate climates in the western world with the following objectives:
- Improvement of soil structure (preparation of a proper seedbed and creation of an optimal rooting environment for the plant).
- Weed control before, during and after the crop growing period.
- Incorporation of organic matter into the soil.

However, the conditions prevailing in semi-arid climates are entirely different. In the Sahel region of West Africa, which is the primary area of interest of this project, the farmer faces specific problems of the following nature.

Climate: In the so-called "sedentary Sahel", where rainfed farming is marginally possible, the total annual rainfall of 400 - 650 mm comes in one short rainy period approximately between June and September (Cocheme and Franquin, 1967). Characteristics of this rainy season are:
a) The beginning of the season is uncertain, four-week advance or delay from the long-term average being quite common.
b) Precipitation during the wet season is often extremely variable, not only from year to year, but also within one single season.
c) The rainfall pattern shows intensive rainfalls interspersed with unpredicable drought. During the dry spells, evapotranspiration rates are high.

An analysis of rainfall intensities of 3 years in Niamey (Niger) showed that 38% of the total rainfall came with an intensity of 50 mm/hr or more. For a semi-arid region in India, near Hyderabad, this value was only 15%, while for mediterranean semi-arid climates this value was even lower.

Soils: Due to the climatic conditions, organic matter content of soil is low (<1%). Soils often have a very low infiltrability, so there is a great runoff and erosion potential. Many of the soils in those areas where agriculture depends solely on rainfall are of a sandy or sandy-loam texture. These soils tend to become very hard during the dry season (Charreau and Nicou, 1971; Charreau, 1977). Dry bulk density values of 1.6 g/cm^3 are not uncommon.

Energy and capital: Since most of the agricultural production (mainly millets and sorghum) is essentially subsistence agriculture, capital usually is unavailable or very limited. Power sources in the area are mainly limited to manual labor or draft animals. As a consequence, farm operations are carried out with very simple implements and hand tools. The crop growing period starts at the onset of the rains and the farmer is forced to wait until the rains have wetted a soil layer of 10-15 cm before he is able to start preparing the seedbed and to sow. As a result, there is a peak demand on labor as soon as the rains start. In many areas, agricultural production is more limited by shortage of labor in the peak periods than by shortage of land (Jones and Wild, 1975). In light of the above conditions, soil tillage operations in the semi-arid tropics should aim at:

a) Improving soil water conditions in the seedbed, to ensure fast and uniform germination and emergence of the seedlings. In this case, in addition to considerations of water conservation for germination and seedling survival during the dry spells in the critical stage of crop development, soil structure is also a factor since water uptake by the seed (particularly with small seeds) is improved by close seed-soil contact. Our laboratory experiments showed that best germination of sorghum was in a seedbed of aggregates approximately of the same diameter as the seeds. A fine tilth is, however, unfavorable under high-intensity rains, since the surface is very susceptible to slaking and crust formation. This means that the farmer has to meet conflicting requirements: rough, cloddy surface for water penetration, and a fine seedbed for better germination. Farmers in the Sahel region generally grow their crops either on ridges, when animal power and equipment are available, or on mounds when work has to be done manually. This enables the farmers to collect all organic matter, e.g. plant residues and animal droppings under the seed row. Ridges and mounds also have better drainage during periods of heavy rainfall, and the effect of slaking may be less on top of the ridges. It is on the other hand a common practice for farmers to cultivate very often between the rows, apparently not only to control weeds, but more with the aim of improving soil infiltrability after the surface has been sealed by rainfall.

b) Water conservation over the cropping period. The treatment should conserve rain water which is often in excess in the middle of the growing season, to overcome dry periods at the end of the season, up to the maturation stage of the crop.

c) Weed control in semi-arid zones is a more important aim of soil tillage than in developed areas, since use of herbicides is hardly feasible due to limited effect and high costs. Thus weed control has to be by hand hoeing and weeding, or sometimes by inter-row cultivation by animal-drawn equipment. Excessive weed growth, especially in years with above-average rainfall, may create even higher labor requirement peaks than during soil preparation and planting. Worst weed infested fields may be abandoned in the course of the season (Kassam et al., 1976).

d) Loosening of the arable layer. As mentioned, many of the sandy soils tend to compact severely during the dry season. This phenomenon may be attributed to cohesive forces resulting from wetting and drying cycles, as well as to the particle size distribution of the soil;

a mixture of well-sorted particles will form a much denser mass than uniformly sized particles. It was found in Senegal that loosening of the soil, decreasing bulk density from 1.6 to 1.4 $g.cm^3$ by plowing or subsoiling considerably improved root development and yields of sorghum and groundnuts (Blondel, 1965).

EXPERIMENTAL WORK: The purpose of the experiments was to identify factors affecting the welfare of the crop and to study the effect of tillage on these factors under farming conditions simulating those of the Sahel region. Criteria for simulation were rainfall frequency and the ratio between monthly rainfall amount and evapotranspiration. While it was not intended to copy current tillage practices exactly, the simplest possible tillage sequences involving minimum energy expenditure were chosen. Rainfall was simulated by sprinkler irrigation at a site in the northern Negev of Israel with a mean annual rainfall of about 200 mm concentrated in the winter. The sandy-loam soil described by Hillel (1971) has physical properties very similar to those of the "Loamy Plains" of Niono, Mali, described by Stroosnijder et al. (1977).

Treatments: A main experiment with sorghum was carried out featuring six primary tillage treatments and four moisture regimes, as well as supplementary experiments to study the effects of rainfall intensity, aggregate size distribution and depth of sowing on sorghum emergence; a short-term experiment to study the effect of crusting on sugar-beet establishment; and laboratory experiments on the relation between aggregate size, rainfall application, crust strength and emergence.

The primary tillage treatments of the main experiment were carried out on dry land with wheat stubble in the fall of 1977 as follows:
- Control: no primary tillage applied.
- Disking: one pass with offset disk harrow, penetrating 12 cm deep.
- Shallow plowing: tractor-mounted moldboard plow, two 12" bottoms, giving poor penetration to about 15 cm.
- Deep plowing: tractor-drawn two-way plow, two 16" bottoms, good penetration to 34 cm.
- Chiseling: shanks 30 cm apart, penetrating to 32 cm.
- Ridging: with 3 furrower bottoms 100 cm apart, vertical distance between ridge top and furrow bottom was 35 cm.

Following the winter with only 86 mm of rain, a 100 mm irrigation was given, followed by fertilization (300 kg/ha of N, 100 kg/ha of P, and 50 kg/ha of K). Fertilizer incorporation, weeding and minimal seedbed preparation was carried out on all plots except the ridges by a single pass with a spring-tooth harrow parallel to the direction of primary tillage. The ridges were renewed with the furrower. The "rainfall" regimes were modeled on Kano, northern Nigeria, with mean annual rainfall of 800 mm between May and October, and on Zinder, southern Niger, with mean annual rainfall of 550 mm between May and September (Cocheme and Franquin, 1967). The latter treatment had a "dry" variant and a "wet" one, with 90 mm of rain in the first month being given in two and three applications, respectively. The "Kano treatment" received weekly 30-mm irrigations in the first month. A fourth, unirrigated treatment followed Israeli practice of growing dryland sorghum following a wet winter, except that only 160 mm of irrigation supplemented the 85 mm of winter rainfall. Total seasonal water applications, including the 100-mm preirrigation, a large part of which evaporated during the preparatory period, were as follows: "Kano" - 860 mm; "Zinder wet" - 690 mm; "Zinder dry" - 690 mm; Dryland - 160 mm.

The supplementary small-plot experiment with sorghum was carried out in three replications using the rainfall simulator described by

Rawitz et al. (1972) testing two rainfall intensities (35 and 80 mm/hr), two aggregate-size distributions (1.0 - 4.5 mm and 4.5 - 12.7 mm), and three sowing depths (2, 6, and 10 cm). In the supplementary experiment on crusting six mechanical crust breaking treatments were tested on commercial sugar beets, in three replications. The treatments are described with the results below. In the laboratory experiment four aggregate size classes were exposed to 16 and 32 mm of rainfall at 40 mm/hr. Emergence of sorghum planted 3 cm deep was observed, and crust strength determined.

Results: Dry matter yield of weeds before secondary tillage in the spring, grain yields, and irrigation water applied are summarized in Table 1. Weed yield consisted of 70 - 90% volunteer wheat.

Table 1: Effect of primary tillage on winter weed yield, and of tillage and rainfall regime on grain sorghum yield, tons/ha.

	Tillage treatments					
	Control	Disk	Shallow plow	Deep plow	Chisel	Ridges
Weed yield:	2.79	1.32	2.24	0	1.64	1.57
Rainfall treatment and amount*	Grain Yield, tons/ha.					
Dryland (60)	0.093	0.270	0.680	0.299	0.820	0.220
Zinder dry (590)	3.43	2.26	1.68	2.87	3.14	2.20
Zinder wet	1.44	3.32	1.42	3.24	2.87	1.98
Kano (760)	6.15	6.04	4.56	4.54	3.12	2.73

* - Irrigation water applied, mm, exclusive of 100-mm pre-irrigation.

Tillage affected penetration resistance strongly in the inter-row space, but the planting operation apparently recompacted the soil, thus wiping out this difference except in the ridges, which remained loose. Tillage also affected aggregate-size distribution, mainly in the <1 mm and the >12.7 mm size classes, with the control having the finest seedbed and the ridges the coarsest. Grain yield was strongly and more or less linearly dependent on water supply (Fig. 1), and on stand density in the irrigated treatments (Fig. 2), with stand density in turn being inversely proportional to percent aggregates >12.7 mm (Fig. 3). Thus yield was also inversely proportional to percent of aggregates <12.7 mm (Fig. 4). It should be noted that Kassam et al. (1976) report sorghum yields in the Sahel of about 0.67 tons/ha, experimental yields with improved practice of 1.5 - 3.0 t/ha, and in their opinion potential yields of early varieties with improved practice would be about 3.5 - 4.0 t/ha. In our experiment some yield was lost due to eating by birds, so that our potential yield should be much higher. Under proper tillage and full irrigation, 10 t/ha have been achieved in Israel. The weed stand does not appear to have affected yields. In the dryland treatment the highest yield of the chiseled treatment reflects the fact that water penetration was deepest in this tillage treatment, which evidently affected yield when water was severely limiting, though not in the wetter treatments. Soil moisture fluctuations due to irrigation were restricted to the upper 50 cm, with gradual accumulation of water in the deeper layers after July 20 in the wetter treatments. Root density showed the same pattern, with 70% of the roots, averaged over all tillage treatments, being in the upper 50 cm. layer. Since sorghum is considered a deep-rooted crop, it is probable that root development was restricted by the depth of water penetration, which in turn is a function of the simulated rainfall pattern.

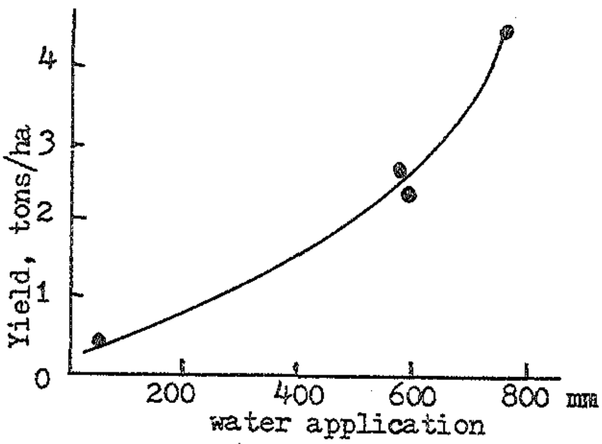

Fig. 1: Grain yield as a function of growing season "rainfall"

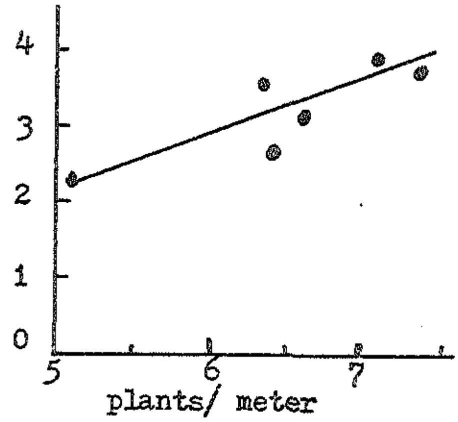

Fig. 2: Grain yield as a function of stand density

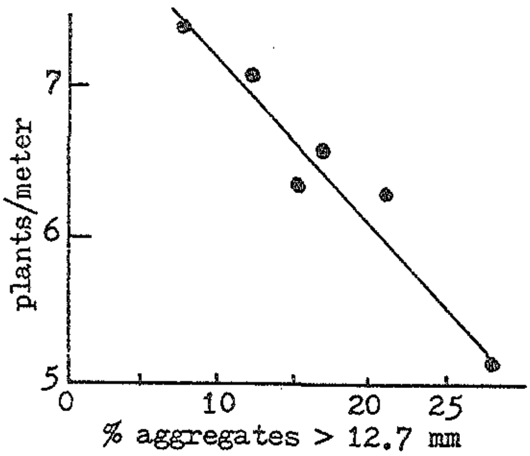

Fig. 3: Stand density as a function of aggregate size

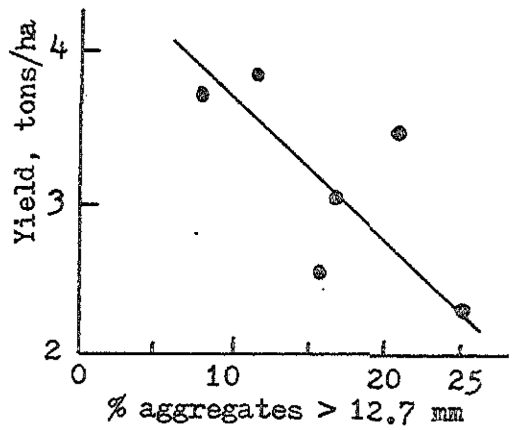

Fig. 4: Grain yield as a function of aggregate size

The supplementary small-plot experiment with the rain simulator showed that emergence was generally better with the 6 cm sowing depth than with 2 or 10 cm depth, except under low rain intensity and large aggregates. Under low rain intensity, where not all aggregates slaked, fine aggregates gave better emergence than coarse ones, confirming the findings of the main experiment. The plant water potential was higher in plants growing in large aggregates, and individual plant growth was likewise better with larger aggregates.

In the supplementary experiment on sugar beet emergence various crust control (by soil conditioners) and crust breaking methods were compared with the usual practice of irrigating to keep the crust moist and soft, and with untreated crust. Heavy and light cultipackers with scalloped disks and, especially, a rotary hoe, were highly successful alternatives to irrigations, saving water and labor and giving better stands. Soil conditioners were less effective than mechanical means. A machine based on rotary hoe wheels has been built to break the crust in the seed row only to a controlled depth. This machine is both more accurate in its work and requires less power than a full rotary hoe.

Laboratory experiments have shown that crust strength increases with amount of rainfall applied and decreases with aggregate size. However, emergence was much better after 32 mm of rain than after 16 mm, in spite of the crust strength being 2-4 times as high after 32 mm. This is due to the fact that at the time of emergence the crust in the soil receiving 32 mm of rain was much wetter, and therefore weaker, than the soil receiving only 16 mm of rain.

References

Blondel, D. Premiers elements sur l'influence de la densite apparrente du sol sur la croissance racinaire de l'arachide et du sorghoses consequences sur les rendements. Symposium on the maintenance and improvement of soil fertility, Proceedings. OAU/STRC, Khartoum, 1965.

Charreau, C. et R. Nicou. L'amelioration du profil cultural dans les sols sableux et sablo-argileux de la zone tropicale seche ouest-africaine et ses incidences agronomiques. L'agronomie Tropicale Vol. 26, 2 (p. 209-255), 5 (p. 531-561), 9 (p. 903-978) and 11 (p. 1183-1248). 1971.

Charreau, C. Controversial points in dryland farming practices in semi-arid West Africa. Proceedings of an international symposium on rain-fed agriculture in semi-arid regions, Riverside, CA. 1977.

Cocheme, J. and P. Franquin. An agrocilmatology survey of a semi-arid area in Africa, south of the Sahara. W.M.O. Tech. Note 86, 1967.

Hillel, D. The application of radiation techniques in water use efficiency studies. Final IAEA Report. The Hebrew University of Jerusalem, Rehovot, Israel, 1971.

Jones, M.J. and A. Wild. Soils of the West-African Savanna - the maintenance and improvement of their fertility. Tech. Comm. 55, Commonwealth Bureau of Soils, Harpenden, U.K. 1975.

Kassam, A.H., M. Dagg, J.M. Kowal and F.H. Khadr. Improving food crop production in the Sudan-Savanna zone of Northern Nigeria. Outlook on Agriculture (ICI), Vol. 8 No. 6, 341-347. 1976.

Rawitz, E., M. Margolin and D. Hillel. An improved variable-intensity sprinkling infiltrometer. Soil Sci. Soc. Amer. Proc. 36: 533-535. 1972.

Stroosnijder, L., S. Diarra and P. Buringh. Production Primaire au Sahel 1: Cartographie des sols et interpretation agronomique d'une region de paturage a Niono, Mali, au Sahel. Miscellaneous Reports, Agricultural University, Wageningen, The Netherlands. 1977.

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RESEARCH EXPERIENCE WITH ZERO TILLAGE IN ONTARIO

T.J. Vyn, T.B. Daynard, and J.W. Ketcheson
Department of Crop Science and Land Resource Science
University of Guelph, Guelph, Ontario N1G 2W1 Canada

ABSTRACT

In results of 15 years of experimentation in Southern Ontario, maize planted without tillage (zero tillage) has averaged about 11% lower in grain yield than with conventional tillage. The yield depression with zero tillage has been less on coarse-textured soils or where maize has followed a perennial sod crop in rotation. The yield reductions could not be attributed to poor weed control, improper planter adjustment, lower soil temperatures, reduced soil fertility, or lower plant densities with zero tillage. Higher soil density and less favourable aggregate size distributions are indicated as possible explanations for the reduction in maize yield. A slower rate of growth and development of maize plants was observed on untilled soil, but not until after the maize seedlings were well established.

INTRODUCTION

Research to assess the potential of zero tillage for maize production under the soil and climatic conditions of Southern Ontario began in the early 1960's. Initial research effort involved study of tillage-fertility and tillage-weed control interactions. Subsequent research concentrated on techniques (including planter adjustments) for planting zero-till maize through crop residues of previous grain maize or perennial forage crops. The research also involved detailed measurements of soil temperature, soil density, certain measurements of rate of plant growth and development, and final grain yield of maize grown with zero tillage versus conventional soil preparation. In recent years, tillage experiments have been expanded to involve several systems of minimum tillage, and five soil textures.

In this paper we describe the response of the maize crop to zero and conventional tillage systems on various soil types and attempt to analyze the possible factors which may have contributed to the responses observed.

For the purposes of this paper zero tillage is assumed to denote the complete lack of primary or secondary tillage with the exception of a 5-cm band of soil prepared within the row by a fluted coulter mounted on the front of the planter. Conventional tillage is understood to denote moldboard plowing in the fall followed by discing and harrowing in the spring.

RESEARCH RESULTS

Grain yield

In research experiments conducted over the past 15 years in Southern Ontario (Table 1) maize planted without tillage (zero tillage) has averaged about 16% lower yield than with conventional tillage on all soils except sandy and gravelly loams where yield differences have been much smaller. Where maize has followed sod crops, yield differences owing to tillage have also been smaller.

Table 1. Grain yields, and percent yield decrease of zero tillage in comparison with conventional tillage, for maize grown on various soil types and following different crops (average of Ontario tests from 1964 to 1978).

	Number of tests or years	Grain yield (dry matter, t/ha) Conventional	Zero tillage	Yield decrease (%)
Soil type				
sandy, gravelly loam	16	5.1	4.9	3
loam, silt-loam	22	5.1	4.4	16
clay, clay-loam	12	5.0	4.3	16
Previous crop				
grass-legume sod	6	5.5	5.3	4
grain maize	44	5.0	4.5	13
Overall mean	50	5.1	4.6	11

Over the years, several reasons have been suggested for the inferior yields which may occur with zero tillage. Common explanations include improper weed control or plant establishment, lower soil temperatures, impaired plant nutrition, and high soil density (eg., Griffith et al., 1977). Each of these factors will be analyzed for their role in relation to the yield decline associated with zero tillage maize in Ontario.

Weed control

Weed control has not been a significant cause of yield depressions with zero tillage. Complete chemical weed control has been achieved in all of the tillage experiments completed. When tillage plots were established on a grass-legume sod the weed control program consisted of an atrazine application in the previous fall followed by a 2,4-D dicamba mixture applied in late April, before planting. An additional application of atrazine and herbicide oil is usually applied soon after planting. When tillage plots are established on maize stover, atrazine and alachlor are normally applied pre-emergence. Similar treatments have been used with good success on farm fields, and weed control has not been an unduly difficult problem with zero-till maize in the Province.

Maize planters

Initially, we suspected that poor design, or maladjustment, of zero-till maize planters could be responsible for the yield inferiority. Research from 1970 to 1972 focused on planter modifications such as operating depth of the fluted coulter, in-line positioning of the fluted coulter relative to the seed double-disc opener, seeding depth (which also affected press wheel pressure), and the optional use of seed covering discs located between the double-disc opener and the press wheel. Yield data presented in Table 2 showed no substantial effect of planter adjustment on maize yields, with the possible exception of slightly lower yields with shallow coulter depth. Thus lower yields with zero tillage cannot be attributed to improper planter adjustment.

Table 2. Maize grain yield on untilled soils as affected by planter modifications (average of 10 experiment-years).

Planter adjustments*				Grain
coulter depth (cm)	coulter position relative to seed opener	planting depth (cm)	use of covering discs	dry-matter yield (kg/ha)
10	centred	2	no	5260
4	centred	2	no	5090
10	4 cm to side	2	no	5340
4	4 cm to side	2	no	5020
10	centred	5	no	5200
4	centred	5	no	4960
10	centred	2	yes	5360
10	centred	5	yes	5310
standard error				194

* Allis Chalmers Series 600 'No-til' planter.

Soil temperatures

Lower soil temperatures are frequently assumed to be a major contributing factor to the depressed yields which occur on soils that are not tilled and where crop residues are not incorporated, particularly in northern locations such as our own (eg., Van Doren and Allmaras, 1978). However, we were unable to observe this association in our own research. Soil temperature measurements were taken, with varying frequencies, on tillage plots from 1964 to 1972. Representative data are shown in Table 3. No consistent difference in soil temperature has been measured, either within or between planting rows, between zero-till or conventionally tilled plots -- regardless of whether the previous crop was grain maize or alfalfa-grass sod.

Logic dictates that soil temperature cannot be a primary cause of lower yields in Ontario with zero tillage. If this were the case greater yield depression would occur with zero-till maize following a previous sod crop, versus grain maize, because of greater surface residue coverage (or mulching) associated with the former. In our research, sizeable yield depressions have only been measured where zero-till maize follows a previous maize crop (continuous maize culture is a standard farm practice in Southern Ontario).

Fertility

Fertility has also been discounted as a possible reason for the yield inferiority of zero tillage. Research results at Guelph over a 4-year period showed that the highest yields of grain maize were obtained consistently with conventional tillage, relative to zero tillage, regardless of the rate of nitrogen, phosphorus or potassium application (Ketcheson, 1977).

Table 3. Effect of tillage treatments on soil temperatures at four experimental sites in May, 1971.

Soil type and previous crop	Measurement period (hours)*	Soil temperature (°C)+					
		conventional tillage			zero tillage		
		min.	max.	mean	min.	max.	mean
Gravelly loam							
grain maize	168	11.1	23.2	16.6	11.0	21.6	16.0
grass-legume sod	120	11.5	20.5	15.5	11.5	20.6	15.4
Clay loam							
grain maize	24	12.2	20.4	15.7	11.7	20.8	15.6
grass-legume sod	48	12.5	17.1	14.5	12.8	18.3	15.1

* Thermocouple temperatures recorded every two hours at a depth of 5 cm below soil surface both within and between the maize rows.

\+ Soil temperatures are presented as daily minimums, maximums and means, and represent averages of between- and within-row measurements for four replications. Comparisons of data in the Table are only valid within each experimental site.

Soil density and strength

Increased soil density may be a partial cause of lower yields with zero tillage. Higher soil bulk density and greater resistance to penetrometer penetration have both been measured when pre-plant tillage has been eliminated (Table 4). Increased soil strength or soil density may inhibit root growth and, consequently, nutrient and/or water uptake.

Table 4. Effect of zero and conventional tillage on dry soil bulk density and resistance to penetration (average of measurements collected within 1 month after planting in 1975 through 1978).

Tillage treatment	Bulk* density (g/cc)	Penetrometer resistance*(bar) depth of measurement	
		5 cm	15 cm
conventional	1.32	4.3	11.9
zero tillage	1.44	14.4	18.5
standard error	0.037	0.72	1.22

* Values are expressed as averages of 12 experiment-years (four soil textures).

Maize establishment and development

In Ontario, zero tillage has not normally affected either the rate of maize plant emergence, or the resulting plant density (Table 5). With either zero or conventional tillage, plant growth and development progress at relatively equivalent rates during early seedling growth and it is not until the young maize plants reach the 4 to 8 leaf stage that differences in plant height and leaf number are observed (Table 6). This development stage coincides approximately with the time of early development of adventitious roots. Final plant heights are usually similar between tillage treatments (Table 6) but reproductive development is delayed with zero tillage. Measurements taken during 16 experiment-years have shown that the date of mid-silking occurred approximately 1 day later in zero tilled plots. Thus it appears that zero tillage does not affect maize development until after initial establishment, after which time plant growth and development proceed at a slower rate.

Table 5. Rate of seedling emergence, and final plant density of maize grown in zero-till and conventionally tilled plots.

Tillage treatment	Number of tests	Days from planting to 50% emergence	Number of tests	Population (plants/ha)
conventional tillage	5	15.8	26	55,700
zero tillage	5	15.9	26	53,400

Table 6. Effect of zero tillage and conventional tillage on the rate of growth and development of maize plots in 1970.

Days after planting	Plant height (cm)*		Leaf number*	
	conventional	zero tillage	conventional	zero tillage
34	16.0	17.5	4.7	4.6
40	23.7	24.8	6.7	6.2
47	42.5	39.0	9.2	8.3
53	58.4	53.0	10.6	9.7
60	79.3	73.0	13.1	12.1
68	117.6	110.2	15.1	14.8
76	171.6	162.2	16.4	16.1
83	196.0	189.5	16.7	16.4
103	230.3	230.2		

* All values represent averages of 2 experiments, one following a grass-legume sod and the other following grain maize.

Recently, strong relationships have been observed in our research between soil aggregate size and maize growth, development and yield. Seedbeds with higher proportions of soil aggregates less than 5 mm in diameter have resulted in higher yields (Vyn et al., 1979). Other Ontario research has shown that the requirement for tillage is confined to a relatively shallow depth (i.e., 10 cm) (Bolton et al., 1976). Size and distribution of aggregates in this zone have a direct relationship to maize yield. The larger proportion of coarse aggregates in seedbeds which are not tilled is thought to be a major limitation to maize yield with zero tillage in Ontario.

BIBLIOGRAPHY

Bolton, E.F., W.I. Findlay, and V.A. Dirks. 1976. Effects of depth and time of plowing Brookston clay on yield of corn and tomatoes. Can. Agr. Eng. 19: 45-47.

Griffith, D.R., J.V. Mannering, and W.C. Moldenhauer. 1977. Conservation tillage in the eastern Corn Belt. J. Soil Water Conserv. 32: 20-28.

Ketcheson, J.W. 1977. Tillage and fertilizer requirement for corn on silty clay loam. Page 160 in Abst. Amer. Soc. Agron. Ann. Meetings. Nov. 13-18, Los Angeles, California.

Van Doren, D.M., and R.R. Allmaras. 1978. Effect of residue management practices on the soil physical environment, microclimate and plant growth. Pages 49-83 in W.R. Oschwald, M. Stelly, D.M. Kral, and J.H. Nauseef, eds. Crop Residue Management Systems, Amer. Soc. Agron. Special Pub. No. 31.

Vyn, T.J., T.B. Daynard, and J.W. Ketcheson. 1979. Tillage practices for field crops in Ontario. Published jointly by University of Guelph, Ontario Ministry of Agriculture and Food, and Ontario Ministry of Energy. 49 pp.

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DEVELOPMENT OF TILLAGE IN CZECHOSLOVAKIA

Č e r n ý , V., Institute for Crop Production, Department of Field Crop Ecology, 161 06 Prague 6 - Ruzyne 507, CSSR

ABSTRACT

The soil tillage takes still its traditionally important role in the farming systems. Social, technical as well as scientific advance has been closely connected with the development of tillage. All problems and new methods have to be investigated by a complex team of research workers from different points of view as soil physics, chemistry, biology, plant growth, yields, weed infestation etc. and also under various soil and climate conditions. This help to understanding all processes which are evoked by the man managing the arable soil.

The soil cultivation which has different functions and involves profound influences on the soil and on plants, has been traditionally an important measure in the farming system. Its role is of extreme significance not only from the point of view of cropping intself, but also from the standpoint of economy, mechanization, energy, and organization of work.

The first problems of soil tillage emerged even at the time when the man started to grow the crops consciousnessly. Since this time he has used more and more adapted implements as well as more efficient animal draught and enigines. The object of all this effort, however, remained unchanged: to prepare the best conditions for seed emergence and crop growth.

For the territory of the CSSR the year 1827 became a very important date in the development of tillage technique: that year, the cousins VEVERKA invented a real plough which was able not only to crush and loosen the soil, but also to turn it over. At the end of XIX^{th} century, the steam plough was firstly used for very deep ploughing in regions with higly fertile soils. At the same time stubble ploughing after cereals was introduced.

Although new cultivation implements and procedures were continually examined by the farmers, the real research in the CSSR started even in 1924, namely under leadership of V. NOVÁK, the Professor of soil science. The first field experiments were to solve problems of optimum stubble ploughing terms after the harvest of cereals. The experiments had three replications and - what is remarkable - their results were analyzed from several points of view: crop yield, weed infestation, soil physics and microbiology, as well. In the following years the research work was concerned to questions of different ploughing depths and different cultivations implements (mouldboard plough, disc tiller, rigid tine cultivator, subsoiler). These experiments were carried out on different soil types. Research work in this branche was then broken by the 2^{nd} world war for many years.

In 1953 a new research started concerning tillage problems on different soils in divergent climate regions of the CSSR. In 4 - 5 years experiments the effect on crop yields, weed infestation, and physical, chemical and microbiological properties of the soil were studied in following projects: three depths of stubble ploughing (2); different depths of ploughing - from 10 cm with disc harrow up to 15, 20, 25 and 30 cm with mouldboard plough - after sugar beet for spring barley (3); the term and way of underploughing the dung for sugar beet and potatoes (2); the term and way of underploughing luzerne, red clover or clover-grass mixture for winter wheat (4). In the long - term experiments (1962 - 1968) on three soil types the effect of tillage system was investigated in two crop rotations. A gradual deepening of the soil profile (every second year) and direct deepening and subsoil loosening to eqaul depth of 40 - 45 cm were compared with a commonly used ploughing depth of 18-28 cm (5, 6, 7). Since 1962 the problem of rotary tillage with different implements (among others Rotawator Howard EMC 70) have been investigated(8).The increased using of heavy implements and machines concerned our interest to the effect of field traffic and its influence on soil properties and crop growth (9). The model experiments (1959-63) with different soil density have shown winter wheat to respond positively on increased soil density (10). The first field experiments did not give good results due to unsuitable for-crop and insuffient effect of herbicides (11). Later, when increased yields after a good technology in winter wheat had been obtained in numerous experiments and also in the practice under relatively dry conditions (about 450 mm) in South Moravia, Czechoslovak industry started to produce machines for direct drilling (triple disc type). As compared with direct drilling winter wheat after traditional ploughing, the yields after direct drilling were higher under studied conditions (12). In 1978, direct drilling was used on 80 000 ha of winter wheat and in some regions under favorable conditions its proportions exceeded nearly 10 % of the total acreage of wheat.

On the basis of all these experiments, of the research work realized during the last 25 years in the Research Institute of Crop Production in Prague and other Czecho - slovak Research Stations, and also experience with farming systems following conslusions may be deduced:

1. The farmer has been always interested in the high crop yield and economic production (work organization, prices, simple as well reliable machines).

2. The research work has to provide the framers with clear conclusions concerning crop yields and their economy, all favourable and unfavourable conditions for any system as well as grounds and causal relations. The research into soil tillage (or zero-tillage) cannot be viewed, however, from the standpoint of yield and economy only. The influence of the soil type, climate, fertilizing level et.c. may lead to quite adverse conslusions. Therefore it is always necessary to know as best the experimental conditions, dynamic changes in the soil physics, chemistry and biology, and also the characteristics of crop growth.

3. Yield increases may be expected if a new method is able to alter the main vegetations factor (light, water supply, temperature, nutrients, air) in so a strong degree that any factor (or factors) is brouth from a low to the optimum (or near to the optimum) level. For this reasons all the complex factors is to be studied (13).

E x a m p l e s :

A very deep ploughing on non-fertilized chernozem or grey brown podzolic soil does increase the crop yields owing to a better mobilization of N, but under higher NPK rates no significant differences are found between the yield levels not only after shallow and deep ploughing(see Tab. 1, lit. 14).

Under conditions of the CSSR, the optimum term of luzerne underploughing or clover-grass mixture for winter wheat has been closely conected with the biological activity, rate of nitrogen release as well as C : N ratio (see Tab. 2, Fig. 1, lit. 15).

The rotary tillage on a heavy soil at Prague-Ruzyne proved better results in the first growth stages of winter wheat than traditional ploughing and seed bed preparation did. On this soil,however, which is characterized by swelling and shrinking (montmorillonit content), deep fissures appeared at the time of wheat anthesis (June),so that water losses and roots breaking followed by yield decrease took place (see Tab. 3, lit. 8).

LITERATURE: 1. ČERNÝ,V.:1960, (Development of tillage in the Czechoslovakia). Rostlinná výroba,Vol.6:1319-1332.- 2. ČERNÝ,V.:1963, Forschung auf dem Gebiet der Agrotechnik in der CSSR.Für soz.Landwirtschaft,Vol.12:25-44.- 3. ČERNÝ, V.:1961, (Study of influence of different depth of ploughing for spring barley after sugar beet).Rostlinná výroba,Vol.7:1571-1584.- 4. POKORNÝ,V.,ČERNÝ, V.-KŘIŠTAN,F.-ET AL.:1962, (The terms and methods of underploughing of forage crops for winter wheat).Vědecké práce VÚRV Ruzyně, Vol.6:119-138.- 5.ČERNÝ,V. -APLTAUER,J.:1970, Bodenvertiefung der Braunerde. Tagungsber. der DAL zu Berlin,Vol.107:77-87.- 6. NOVÁČEK,J.:1970, Bodenvertiefung eines Podsolbodens. - Tagungsber.der DAL zu Berlin,Vol.107:99-113.- TURČÁNY,J.:1970, Bodenvertiefung der Schwarzerde.Tagungsber.der DAL zu Berlin,Vol.107:77-87.- 8.BURDA,V.-ČERNÝ,V.-SNOP,J.:1965,(Rotary tillage on heavy soil for winter wheat)Rostlinná výroba,Vol.11:1021-1030.- 9. ČERNÝ,V.:1968, Influence of pressure on the changes of some physical properties of soil and on plants.Proc.Internat.Smp., June 22-24th 1966,Brno:77-91.- 10. STRAŇÁK,A,:1968, Dependence of growth and yield of cereals on the physical properties of soil.Proc. Internat.Symp.,June 22-24th 1966,Brno:17-29.- 11.STRAŇÁK,A.:1971,(Minimum tillage for winter wheat). Rostlinná výroba,Vol.17:1085-1099.- 12. ŠIMON,J.: 1976, Investigation of some problems of direct drilling in Czechoslovakia. Outlook on Agric., Vol.9: 26-29.- 13. ČERNÝ,V.:1979,Einfluss der Bodenbearbeitung auf Boden und Ertrag unter Standortsbedingungen in der CSSR. Mitteil.d.Österreich. Bodenkundlichen Gesell. (in press).- 14. ČERNÝ,V.:1969,Untergrundlockerung und Vertiefung der Ackerkrume in Verbindung mit Düngung.Symp.über Tiefenbearbeitung des Bodens, Giessen 1969:56-62.- 15. NOVÁČEK,J.-ŘÍDKÝ,K.-TALAFANTOVÁ,A.:1961,(Experiments with luzerne underploughing.) Rostlinná výroba,Vol.7:489-514.-

Table 1. Sugar beet - yields of roots ($t.ha^{-1}$)

Ploughing	0 Fert.	NPK
27 cm	24,7	27,0
41 cm	30,9	29,1

P 0,05 % : Plough. = 3,6 t.ha
Fertil. = 1,6 t.ha

Table 2. Winter wheat after luzerne (L) or clover-grass mixture (CG)

Soil	Crop	Term	t.ha	%
Chernozem	(L)	August September	4,34 3,96	100 91
Grey brown podzolic s.	(L)	August September	4,25 3,89	100 91
Podzol	(CG)	August September	3,18 2,89	100 90

Fig. 1. Microorganism seasonal changes after different underploughing terms of luzerne

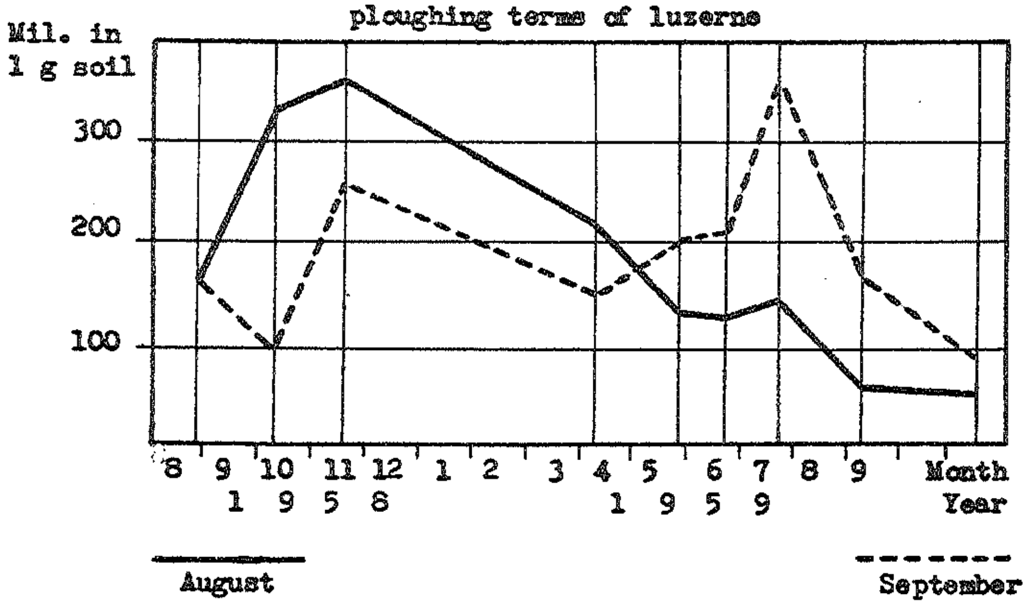

Table 3. Winter wheat ($t.ha^{-1}$, %), average 1962 - 1964

Tillage	$t.ha^{-1}$	%	P=0,05%
Ploughing (20 cm)	5,47	100	-
Rotary tillage (20 cm)	4,78	87	4,06

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SOME ASPECTS CONCERNING SOIL TILLAGE IN ROMANIA

Dr.Gh.Sin, Prof.Dr.C.Pintilie[x)], Dr.H.Nicolae, Dr.C.Nicolae Dr.Gh.Eliade

Research Institute for Cereals and Industrial Crops, 8264 Fundulea, Ilfov, Romania

x) Agronomical Institute "Nicolae Bălcescu", Faculty of Agronomy, 71331 Bd.Mărăşti 59, Bucureşti, Romania

ABSTRACT

The researches pointed out the differentiated requirements of crops on soil tillage under different climatic and soil conditions.

Concerning the minimum tillage more variants were studied. The use of Rotaseeder (strip tillage), Semavator or rotary tiller was more suitable for wheat than for maize. The substitution of ploughing by disking is possible for seedbed preparation at wheat for many years, but at maize only for one year, in alternation with ploughing. By ploughing is achieved a better weed control, especially for perennial weeds. The rationalisation of soil tillage systems must be considered in the framework of alternation of crops with various requirements; it is recommended a deeper soil tillage of 28-3o cm - only once in 3-4 years - and a shallow tillage in the rest of the period.

As concerns heavier and compacted soils, a periodical deep loosening determined an improvement of air and water regime and an increase of wheat (28%) and maize (32%) yields.

The crop land of Romania is characterized by a wide range of soil and climatic conditions. There are different types of chernozems, reddish brown forest soils, brown soils, podsolized soils, vertisols, humic gley soils, sandy soils, alluvial soils, salt-affected soils and others. The yearly rainfall, ununiformly distributed during the year, ranges between 38o-8oo mm.

The arable land of 9,8 million ha is cultivated with maize (34.7%), wheat and barley (29.6%), sunflower (5.2%), sugarbeet (2.6%), potatoes (3.2%), soybean (1.7%), bean (o.8%), flax (1.5%) and other crops.

The necessity of satisfying crop requirements under versatile pedoclimatic conditions determined researches in the experimental fields in order to establish the most suitable soil tillage systems, which have to ensure the soil fertility conservation and the achievement of increased yields.

During the last years a series of aspects of soil tillage were studied and the results obtiined pointed out the necessity of differentiating it depending on soil type, climatic conditions, preceding and following crops.

Establishing the optimum depth of ploughing. Researches were carried out with the main crops under different pedoclimatic conditions. The ploughing depth ranged between 15 and 4o cm. The obtained data pointed out the need to differentiate the ploughing depth especially depending on crop. So the cereals (wheat, barley) and legumes (peas, soybean, bean) need a ploughing depth of up to 18-2o cm., while sugarbeet and potatoes require a ploughing depth of 28-3o cm; maize and sunflower have intermediate needs. A deeper ploughing beyond these limits did not bring yield increases or any other advantages.

In connection with the ploughing, a series of aspects referring to the change of the physical soil properties, to the biological activity in the soil and to the evolution of weed infestation were studied. When the wheat is placed after the early preceding crops (peas, wheat, barley) it was noticed the favourable effect of summer ploughing (immediately after harvesting of preceding crop) on the moisture storage and its conservation, and also on the nitrification during summer, in comparison with the autumn ploughing, before sowing. The differentiation of soil moisture reserves, as a result of ploughing time, influence directly the wheat yield in the following year, as shown in fig. 1.

In a stationary experience with maize crop, it was shown that the deeper ploughing reduces the degree of soil compaction so that the air and water-regime becomes more favourable for intensifying the biological activity, especially that of nitrifying bacteria. The data shown in fig. 2 are evident.

The deeper ploughing contributes more than the superficial one to weed control, especially to the perennial

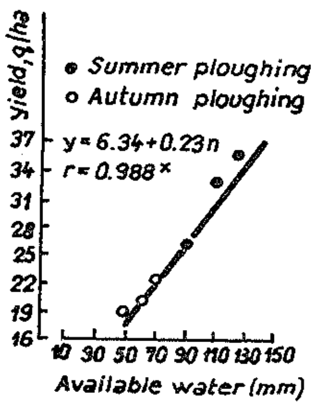

Fig.1 - Relationships between available water storage(0-1oo cm) at sowing time and wheat yield

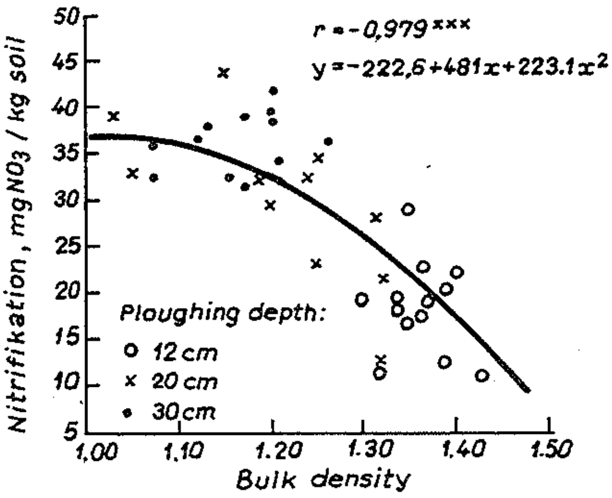

Fig. 2 - Relationships between soil compaction and nitrification

weeds (Sorghum halepense, Cirsium arvense), which are less controlled by herbicides; this is a present role of ploughing, generally of soil tillage, in the framework of the integrate control of weeds.

By continuous ploughing at the same depth,at this limit a compacted layer-hardpan is formed,whose bulk density was 15-2o% higher than of the neighbouring ones.Through the alternation of ploughing to different depths this phenomenon,which limits the normal water flow and the development of the plant roots,is avoided.

Studies on some aspects of fertilization did not point out the interaction between the rate of fertilizers and the ploughing depth.

M i n i m u m t i l l a g e.The working up of the minimum tillage methods is determined by necessity of energy saving,of reducing the passes of tractor and tillage equipment over the land(for avoiding an exaggerate soil compaction)and of performance in a shorter time of more operations.

As ploughing requires a high quantity of energy, ranged between 39-46% from the total need of the seedbed preparation,it was looked for possibilities of its substitution.In this respect it was verified more variants of minimum tillage:

- direct drilling by using Rotaseeder(Strip Tillage).

The success of this method is conditioned by a good levelling of the land and a lack of vegetal residues from preceding crop;these requirements and also the increased energy consumption did not favour the extention of this method.

At wheat crop some satisfying results were obtained while at maize,which is more sensitive to the soil loosening,this method was less suitable.The sowing depth had a great variation and the droughty period which follows after maize sowing caused an ununiform sprout so that the plant density has been affected.The weed control was carried out by means of herbicides.It was remarked,in this case,the contribution of ploughing to weed control,especially to perennial weeds which are not controlled by herbicides;the infestation with weeds was twice lower on the ploughed plots than on the unploughed ones.The maize yields obtained by Rotaseeder and conventional methods were in ratio 1:1.2-3.The studies on the physical soil state indicate a tendency of water stability increase of the structure in the unploughed soil.

- Seedbed preparation by means of rotary tiller.This method is very suitable for wheat which follows maize,especially under certain conditions:the presence on the land of many left residues,a droughty autumn when,if the soil is ploughed,big and tough clods result which require many operations and too much energy for its breaking up.There is no yield differences between using conventional(with ploughing)and the rotary tiller methods. By seedbed preparation and sowing of wheat in one operation using a rotary drill (semavator)good results were obtained,but the machine needs some improvements for achieving a better uniformity both for the loosening depth and the sowing depth.

For the seedbed preparation at maize the using of rotary tiller was not as suitable as for wheat;by this method the maize yield was 3.o-4.2 q/ha lower than by ploughing. Concerning the change of soil state it was ascertained a decrease of water stability of structure and a tendency of soil compaction under tillage depth.Although the use of rotary tiller has some advantages it is not widespread because of its high energy consumption.

- Substitution of ploughing by shallow tillage(diskking).The method has some advantages,especially for winter cereals:

a) it ensures a good seedbed,the surface land is more levelled and the achieved sowing depth is more uniform;
b) it is performed in a shorter period of time,which allows the sowing in optimum time;
c) it needs 24-52% less energy than the seedbed preparation by ploughing.

This method is recommended,like rotary tilling,especially for wheat after maize,sunflower,sugarbeet,potatoes in case of dry autumn when by ploughing there results big clods,for whose breaking are necessary repeated operations with disk and clod crusher,and also for seedbed preparation for second crop under irrigation conditions.There are no differences between wheat yields obtained as an effect of the seedbed preparation by ploughing or only by disking. For maize and sunflower crops the replacement of ploughing by disking can be admitted only for one year in alternation with ploughing.In a stationary experiment of 9 years,in 4 localities,the maize yield, on the plot worked only by disking is 4.2-9.2 q/ha lower as compared with the ploughed plots or to the plots where disking and ploughing alternation is done yearly.If the ploughing is replaced by disking 2-4 years consecutively,the maize and sunflower yields decrease and tend to reach the yields of the plot worked only by disking.

The results obtained in the experiments with alternation of ploughing to different depths with disking allow a rationalisation of soil tillage systems.The optimization of the soil tillage systems must be considered in the framework of crop rotation,of alternation of crops with various requirements.In this way it can be achieved an alternation of different soil loosening depths(10-12 cm by disking 18-20 cm and 28-30 cm by ploughing),so that each year they can have a certain ratio,which allow a deeper soil tillage to 28-30 cm only once in 3-4 years,and a shallow tillage in the rest of period.Thus it is achieved an important energy saving(each centimeter of deepening of soil loosening requires 0.5-1.3 l/ha Diesel oil),ensuring optimum conditions adequate to requirements of each crop.

The reducing of energy at maize, sunflower and sugar-beet is possible and already achieved by the performance of some operations (soil tillage immediately before sowing, fertilizer, herbicides and insecticides application and sowing) in one pass of tractor.

Improving works for heavier and compacted soils. Within the soil profile with fine textured or compacted layer, the ratio air/water is abnormal, the downwards movement of water, due to a reduced permeability, is hampered to pass to subsoil storage; the root penetration is reduced and the plants cannot explore the full depth of the soil for water, air and nutrients. During summer the crops suffer from lack of water, which could not be stored and conserved. Such soils have a low total and air porosity and are alternatively affected by waterlogging and water deficit.

Table 1

Effect of deep loosening upon the soil state and the yield of wheat and maize

Soil tillage	Depth xx) cm	Porosity (%) total	Porosity (%) air	Soil moisture xxx) % Season wet	Soil moisture xxx) % Season dry	Crop roots t/ha	Yields, q/ha (1970-1978) Wheat	Yields, q/ha (1970-1978) Maize
Annual ploughing	0-25 35-50	50.0 45.4	9.3 1.0	37.4 40.6	14.6 15.3	5.0	28.5	44.2
Deep loosening x) and ploughing	0-25 35.50	55.3 53.0	18.7 14.0	28.5 30.4	24.7 25.6	8.9	36.4	58.2

x) Soil loosening to 60 cm depth, at 140 cm intervals (every 3 years)
xx) Clay content: 1st layer: 46%; 2nd layer: 52.4%
xxx) Field capacity: 30%; wilting point: 17%.

For improving the permeability, and the increase of water intake and storage capacity it was studied the effect of deep loosening under conditions of clay soils. The results obtained on a vertisol point out an obvious improvement of air and water regime withint the soil, which favoured the roots development and finally the yields increase (Table 1). The positive effect of deep loosening continues for 3-4 years, being necessary to repeat it after this period.

All experimental data which are obtained during the last 10-15 years allow the optimization of soil tillage systhems by its differential application, depending on the soil and climatic conditions and on the crop requirements, thus being ensured the soil fertility conservation and the achievement of increased yields with less energy consumption.

TILLAGE OR NO-TILLAGE, DEPTH OF PLOUGHING, CONSEQUNECES ON YIELDS

M. FRANKINET, L. RIXHON and A. CROHAIN
with the collaboration of L. GREVY

Station de Phytotechnie de
l'Etat - 5800 Gembloux.

I. TRIAL PRESENTATION

In 1967, the Station of Phytotechnic has settled an important experimental design in view to study the incidence of soil work techniques on the yield of several crops.

The experimental procedure had to allow the study of a maximum crops integrated in a coherent cultural system and closed to the agricultural practice, allowing the expression of different cultural ways.

Choice was carried on the following 4 years rotation:

1. Root plant: sugar beet.
2. Spring cereal: oat or barley
3. Fodder maize (whole plant) or horse bean (vicia faba).
4. Winter cereal: wheat

Experimental design has been settled on the following way: three basic treatments were used:

- normal ploughing - 30 $\pm$ 5 cm depth
- shallow ploughing - 15 $\pm$ 5 cm depth
- no tillage or direct drilling.

These options being defined, two variables were susceptible to be studied:

- on one hand, preliminary experiments having shown the interest of an additional nitrogen manuring when the soil work depth was reduced, this variable has been kept;
- on the other hand, it has been interesting to study one time per rotation the effect of normal ploughing on certain plots treated by shallow ploughing or by direct drilling.

From these elements, seven treatments have beent defined and can be shortly described as follows:

- Treatment 1 - Permanent direct drilling with normal nitrogen manuring (SD).
- Treatment 2 - Permanent direct drilling with a nitrogen manuring supplement (SD N).
- Treatment 3 - Permanent shallow ploughing with normal nitrogen manuring identical to the treatment 1 (D)
- Treatment 4 - Permanent shallow ploughing with a nitrogen manuring supplement (D n), this supplement being generally equal to the half of the one applied to treatment 2 (n = N/2).

TABLE 1

C R O P S	SUGAR BEET		SPRING OAT		SPRING BARLEY		FODDER MAIZE		HORSE BEAN		WINTER WHEAT	
Yields / N° treatments	Sugar kg/ha	kg N /ha	Yield kg/ha	kg N /ha	Yield kg/ha	kg N /ha	Dry mat. kg/ha	kg N /ha	Yield kg/ha	kg N /ha	Yield kg/ha	kg N /ha
1. SD	7.227	156	4.477	69	3.513	44	8.704	155	3.761	15	5.950	109
2. SD N	7.435	183	4.603	93	3.770	71	8.809	187	3.717	20	5.859	142
3. D	9.130	156	4.591	58	3.961	30	9.649	155	3.589	15	6.027	109
4. D n	9.302	173	4.605	70	4.121	44	9.968	171	3.558	20	5.990	127
5. 3 SD N + L	7.444	172	4.594	81	3.917	56	9.410	181	3.691	25	5.953	136
6. 3 Dn + L	9.289	169	4.498	67	4.071	40	9.953	168	3.603	25	5.952	123
7. L	9.005	156	4.577	55	3.982	30	10.142	155	3.558	20	6.014	109
	Roots :	51.797 kg/ha	1000 gr.:	30,32 g	1000 gr.:	37,64 g	G.M. :	38.179 kg/ha			1000 gr.:	40,00 g
	% Sugar : 17,32 %		Hect.: 43,00 kg		Hect.: 64,21 kg		% D.M. : 26,00 %				Hect.: 76,80 kg	

Tests of Newman and Keuls alpha = 0,05

Classification		N° of treatments					
		SUGAR BEET	SPRING OAT	SPRING BARLEY	FODDER MAIZE	HORSE BEAN	WINTER WHEAT
7th	min.	1	1	1	1	4	2
6th		2	6	2	2	7=3	1
5th		5	7	5	5	3=7	6
4th		7	3 Non tested	3	3	6 Non tested	5 Non tested
3th		3	5	7	6	5	4
2th		6	2	6	4	2	7
1st	Max.	4	4	4	7	1	3

kg N/ha : kilogram nitrogen/ha

1000 gr. : wheight of 1000 grains (gram)

Hect. : wheight of one hectolitre of grains (kilogram)

G.M. : green material

% D.M. : dry matter %

- Treatment 5 - Direct drilling with nitrogen supplement during three consecutive years, the fourth year being with normal ploughing and manuring (3 SD N + L).
- Treatment 6 - Shallow ploughing with nitrogen supplement during three consecutive years, normal ploughing and manuring during the fourth year (3 D n + L).
- Treatment 7 - Permanent normal ploughing, normal nitrogen manuring (L).

This trial has been established in a 7,5 ha field which has been devised in four parcels. Each parcel was subdivised in four blocks or replications including each of the seven treatments.
This scheme corresponds to the statistical design of complete random blocks.
These experiments are conducted on a Hesbaye loess soil, which is deep, fresh and fertile.

A more detailed description of the cultural operations and manurings really applied and a complete analysis of results since 1967 to 1977 is reviewed by FRANKINET et al (1978).

II. RESULTS AND DISCUSSION

Table one includes the mean results.

II.1. Sugar beet

After eleven years of trials, the following remarks can be formulated.
Among the six crops being present in this trial, sugar beet appears to be the more sensible to the direct drilling. On an average, indeed, a significant loss of around 20 % is observed in sugar yields.
On the other hand, this crop reacts favourably to a diminution of ploughing depth. To equal nitrogen manuring, a light increase of sugar production is observed with regard to traditional ploughing (+ 1,4 %, N.S. for alpha = 0,05).
Bringing nitrogen manuring supplements increases yield but does not allow the direct drilling to recover the lack of production generated by this technique.
An analysis of annual results shows that this supplementary added nitrogen brings an increase of root production while it slightly diminishes the sugar content; combining the two components meanwhile remains favourable to the sugar production per ha.
The effect of ploughing after three direct drilling or shallow ploughing years expresses itself by getting productions comparable to those of

ploughing; a back-effect of supplemented nitrogen previously spread is also observed. Afterwards, when the direct drilling or shallow ploughing techniques are again used, the yields obtained are comparable to those of the same techniques used in a continued way.

II.2. Spring cereal plants : oat and barley

For those two crops which come after sugar beet, leaves and tops left on the field, we have in hand the results of seven years of observation for oat and four for barley.

From these cultures, barley is the more sensitive to soil preparation. In direct drilling, the barley yield is affected by a decrease of 11 % compared to ploughing, this difference being significant. The effect of the added nitrogen nutrients is of little importance but sufficient to make the difference (5 %) between the other treatments not significant. The practice of continued shallow ploughing slightly decreases the level of yields (less than 1 %).

The nitrogen supplemented beneficial effect is of around 3,5 %.

Let us remark that oat is less sensible than barley to the soil work conditions. In permanent direct drilling, the mean decrease of yield is about 2 %. A supplement of nitrogen gives a production which is comparable to the one of ploughing. The other techniques which have been experimented do not practically affect the production levels.

Oat is compatible to the reduction of ploughing depth; nitrogen supplements increase very slightly the yields per ha.

As for sugar beet, the effect of ploughing after three years of direct drilling or shallow ploughing shows yields/ha comparable to those of the traditional continued ploughing.

II.3.1. Fodder maize whole plant (seven years)

For the sensitivity against conditions of direct drilling, the fodder maize comes immediately after the sugar beet with a significant mean production decrease of 14 %; a nitrogen supplement increases very few the yield level ($\pm$ 1 %).

Let us point out that at the time the experiment was planned, the choice was directed by the simultaneity of sowing and harvest time, which, taking notice of the delay at emergence and initial growth of maize in direct drilling, is unfavourable for this technique.

The practice of permanent shallow ploughing technique affects also but in a less way the production of dry matter/ha. The decrease of yield is 5 %. Supplemented nitrogen allows to recover ± 3 % from this decrease. Ploughing has the same effects as such previously described. In a general way, the nitrogen supplements give slight increases of dry matter level.

II.3.2. Horse bean (four years)

From all the crops present in this trial, the horse bean is the sole which reacts favourably to the direct drilling conditions. Ploughing depth reduction has no effect. Nitrogen supplements have no beneficial effects for this crop.

II.4. Winter wheat

Among eleven years of winter wheat observations, this one comes seven times after maize and four times after horse bean. It goes from itself that appropriate manuring has been given in relation with the preceding crops.

As a general rule, this crop has not suffer very from direct drilling. Compared to ploughing, the yield decrease is about 1 %.

Permanent shallow ploughing practice does not affect yields level.

Looking at the mean results, the opportunity of a nitrogen supplement does not seem favourable to yields, either in direct drilling or in shallow ploughing. The analysis between years does allow a better approach of the problem. It indeed did appear that the reference nitrogen manure level applied to ploughing directly influences the classification of the other techniques according to this manure is lower or higher of the optimum.

If this manure seems to be inferior to the optimum for the encountered climatic conditions, superficial work is disfavoured. If this manure has been overestimated, superficial work is favoured.

This brings us to think that, due allowance being made, it appears that a nitrogen supplement is desirable when the depth of ploughing is diminued below a certain level.

Ploughing after three years of direct drilling or shallow ploughing gives results similar to those of permanent ploughing. Later on, the yields come back comparable to those of these same practices realized in the permanent manner.

III. CONCLUSIONS

Reducing the depth of ploughing up to shallow ploughing does not affect practically the yields level.
On the other hand, permanent direct drilling does appreciably affect yields of sugar beet (- 20 %), fodder maize (whole plant) (- 14 %) and spring barley (- 12 %). Oat and winter wheat are little sensible to the reduction of soil practices whereas horse bean gives a 5 % gain production.
A supplementary nitrogen dose looks generally beneficial when the work depth is reduced below a certain level.
After eleven years of direct drilling or of continued shallow ploughing, no cumulative effect did appear.

IV. BIBLIOGRAPHY

M. FRANKINET, L. RIXHON et A. CROHAIN avec la collaboration de L. GREVY
Labour, demi-labour ou semis direct en continu. Conséquences phytotechniques.
Bull. Rech. Agron. - Vol. 4, 1978.

The 8th Conference of the International Soil Tillage Research Organization, ISTRO, Bundesrepublik Detutschland,1979.

Changes in the Physical Properties of Soils as Affected by Various Management Practices.

A. Canarache
Soil Science and Agrochemistry Research Institute, Bul. Mărăşti 61, 71331 Bucharest, Romania.

ABSTRACT
The physical status of the soil, as shown by various physical properties and by a synthetic " agrophysical index", as well as its relationships to crop yields, are discussed. Results from long term field experiments with various tillage, crop rotation, and fertilization treatments are presented.

Introduction. A research project is in progress in Romania since 1973, with the aim to studying changes in soil physical properties under intensive management practices. This is a cooperative project, involving the Soil Science and Agrochemistry Institute in Bucharest, as well as the Cereals and Technical Crops Institute in Fundulea and a number of research stations throughout the main agricultural areas of the country. Field experiments with a variety of tillage systems, crop rotation, and fertilizers are currently conducted in these research stations, some of them being 10...15years old.

The most significant research stations, field experiments, and treatments are selected to be studied. Field and laboratory analyses are carried out to determine infiltration rate, penetrability, bulk density, hydraulic conductivity, pore-size distribution, structure, dispersion rate, and other physical properties. A synthetic index evaluating the physical status of the soil, called agrophysical index, is also calculated; it represents the artihmetic mean of the standardized values of 10 individual physical properties. 16 ... 32 replicate samples are usually being analyzed for each tratment to achieve statistical significance of the results.

Various soils, ranging in texture from coarse sands to heavy clays, are studied. In this paper result are reported for only three research stations. They are located on deep, loose, permeable soils developed on loess: Brăila (vermic Chernozem with 20...26 percent clay), Mărculeşti(vermic Chernozem with 28 ... 30 percent clay), and Fundulea (typical Leached Chernozem with 32...38 percent clay).

Tillage. The continuous disc system shows a somewhat poorer physical status in the upper soil layer, thus indicating a possible disadvantage for the present time (figure 1). This same tillage system determines a somewhat better physical status of the lower soil layer; as such it represents a reserve of non deteriorated soil and indicates an advantage for the future times.

Generally speaking the differences between the tillage treatments are small as far as physical soil properties are concerned. A practical consequence is that other criteria, such as costs, fuel consumption, or weed control, and not the physical status of the soil, should be used to choose the most suitable tillage system.

Cultivation traffic compaction. More important are the changes in the soil physical properties in the wheel tracks of the tractors used for minor tilage and other crop maintenance operations, although such changes are not permanent and disapear with the next ploughing or discing.

Infiltration rate (figure 2) is lowered, due to traffic compaction, in a relatively higher degree for the Fundulea, less permeable, soil: basic infiltration rate in tracks is only 10 ... 15% as compared to basic infiltration rate out of tracks; for the Mărculeşti soil the figure is 60 ... 65%. An interesting feature is the cross-over of the infiltration curve, a possible explanation being the presence, in the tractor wheel tracks, of cracks enabling an initial high infiltration rate: as soon as the cracks disapear infiltration rate shows a decrease

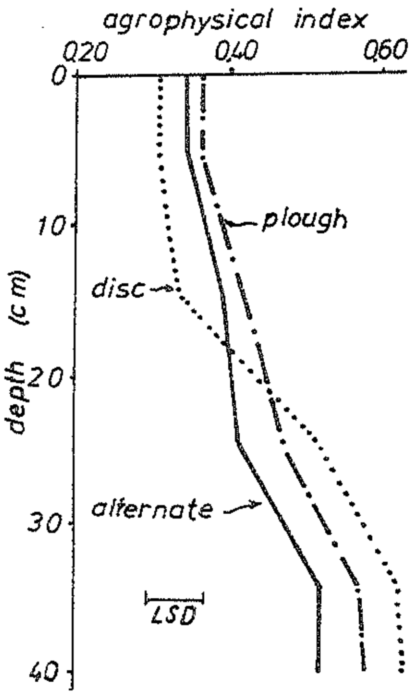

Fig. 1 Depth variations of the agrophysical index as related to different tillage systems (MĂRCULEȘTI, 1978)

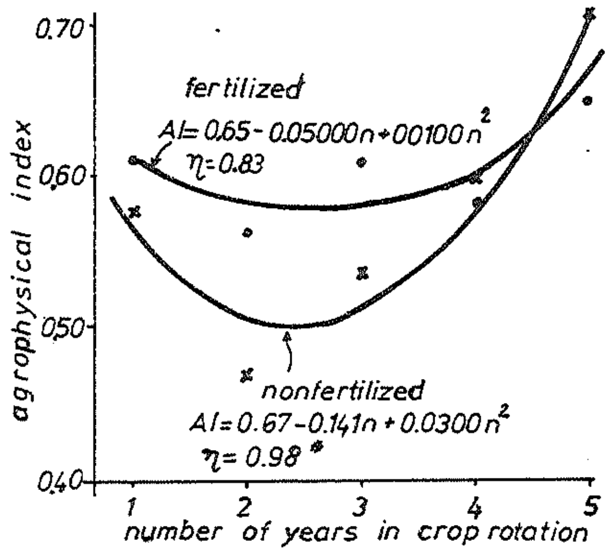

Fig. 3 Variation of the agrophysical index in a field experiment with different crop rotation treatments (BRAILA 1977)

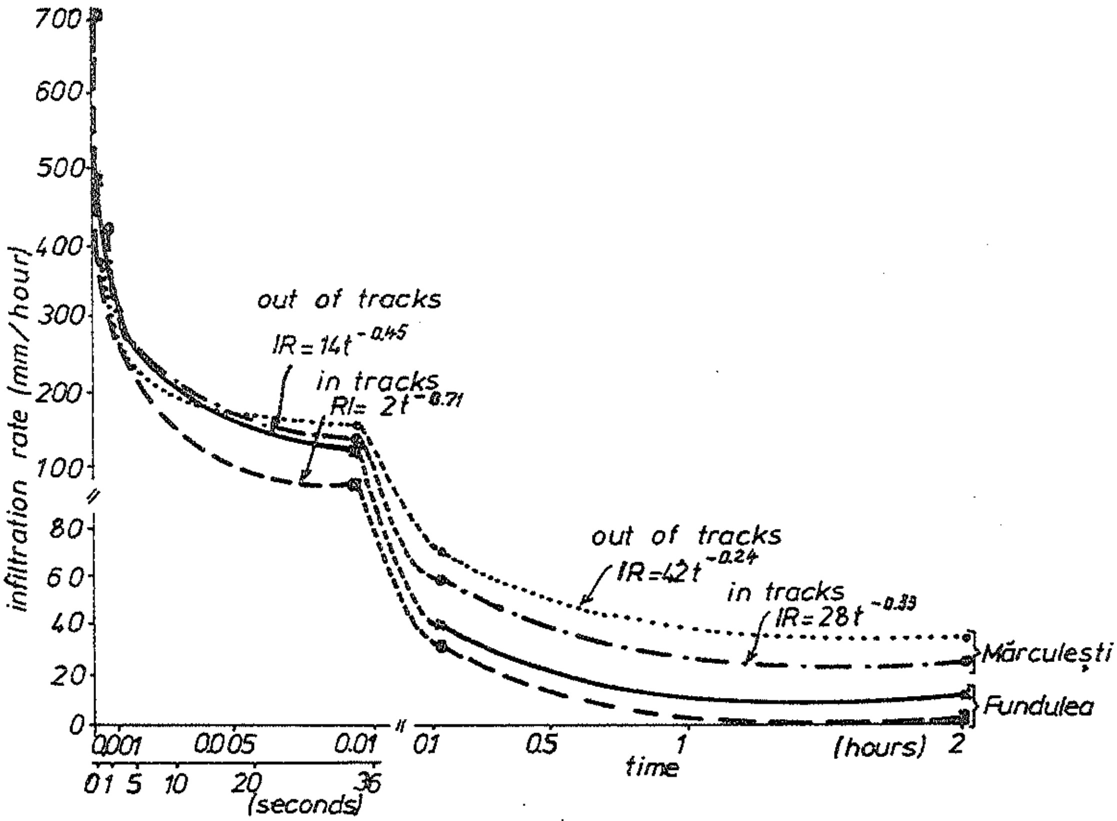

Fig. 2 Infiltration rate as affected by traffic compaction (FUNDULEA, 1977; MĂRCULEȘTI 1978).

Crop rotation. There is a clear trend of improvement of the physical status of the soil with increasing number of years in the crop rotation (figure 3). An exception is the continuous maize treatment, with an unexpected good physical status. Lower yields in this treatment are probably due to other reasons than physical properties of the soil, such as weed control problems.

Improving crops. A very good method to increase the physical status of the soil is to include improving crops in the crop rotation. The five years crop rotation in figure 3, which includes alfalfa, is an example of this effect. Another example is given in figure 4: following a Lolium multiflorum improving crop, infiltration rate increases up to three times when compared to that of the soil where no improving crops have been raised.

Fertilization. The positive effect of adequate fertilization can be seen in figures 3 and 4. It might be explained taking into account the better development of the root system in the fertilized treatments. Data reported in figure 5, where various yields are due to different fertilezer treatment, underlain such an explanation.

Mechanisms of physical deterioration. Data were obtained enabling a look insight the processes leading to a deterioration of the soil physical status. The process starts with a worsening of the soil structure and a decrease in the water stable aggregates percentage. A lowering of infiltration rate follows. Changes in bulk density, macroporosity, and other properties apear at a later stage (figure 6).

The deterioration of soil structure is illustrated, among other features, by a change in the relative importance of the two main mechanisms of water stable aggregates formation (figure 7). In the soil under forest, with its natural structure, porous aggregates predominate, and the percentage of water stable aggregates decreases with increasing bulk densities. On the contrary, in the cultivated soil, physically deteriorated, the main aggregate forming process is mechanical pressure and, as such, the percentage of water stable agre-

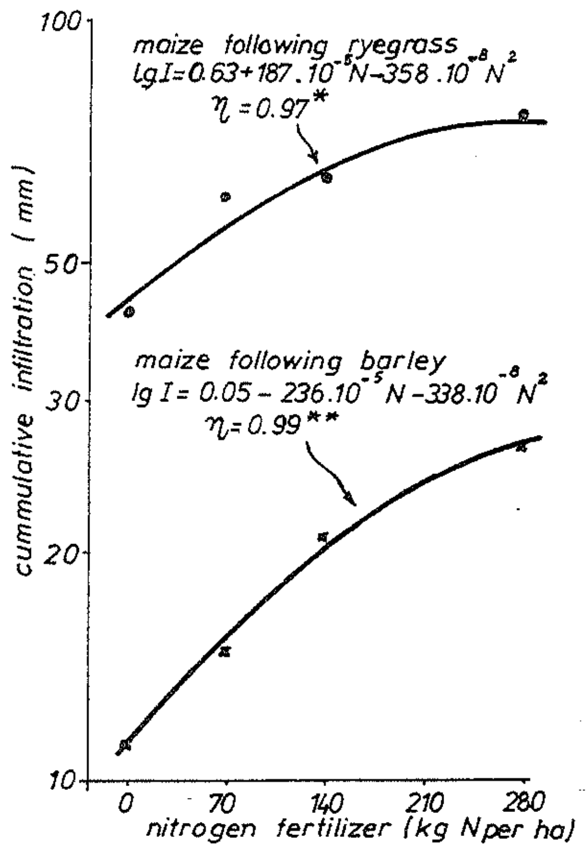

Fig.4 Variation of cummulative infiltration in a field experiment with maize following ryegrass as an improving crop (FUNDULEA, 1976-1978)

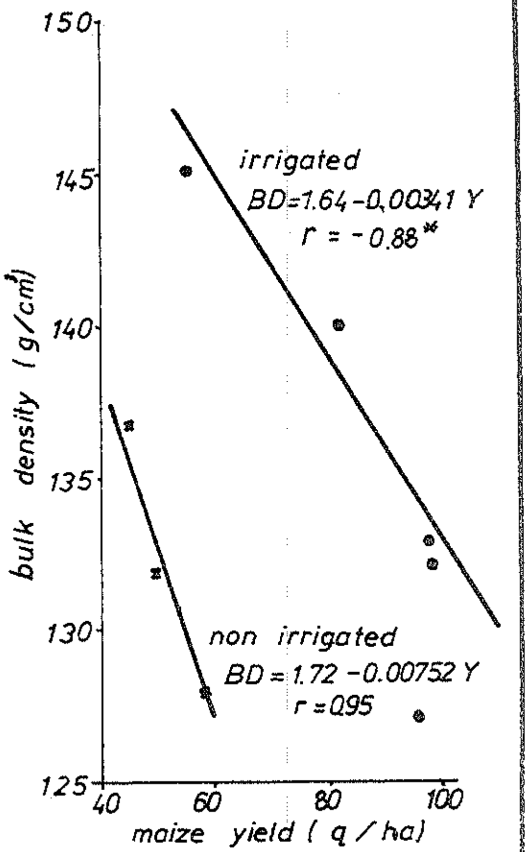

Fig.5 Relationships between yields in differently fertilized treatments and soil compaction (FUNDULEA, 1973-1974)

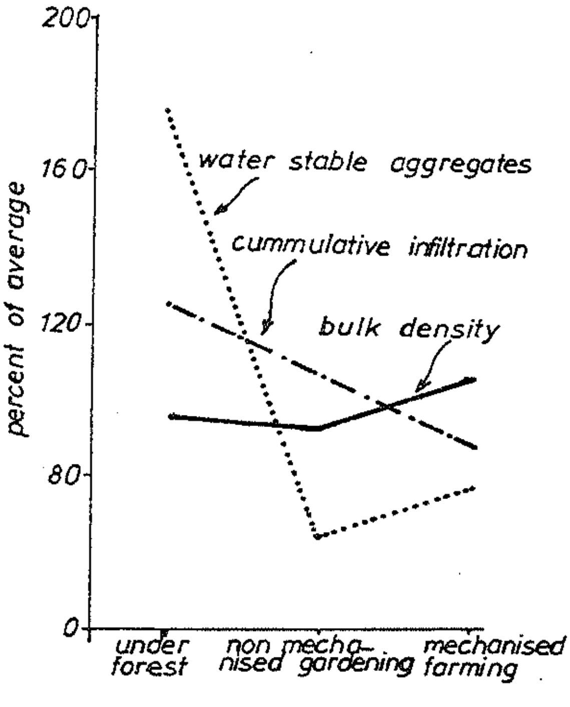

Fig.6 Relative alteration of different soil physical properties due to clearing and cultivation (FUNDULEA - 1973-1974)

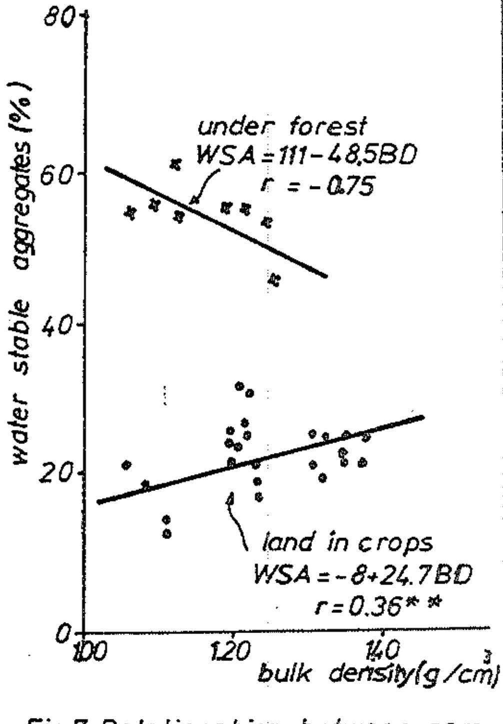

Fig 7 Relationships between compaction and structure (FUNDULEA, 1973-1974)

gates increases with increasing bulk densities. Micromorphological investigations, not reported in this paper, confirm this picture.

Concluding remarks. There is an important deterioration of the physical status of the soil following clearing of forest vegetation. Within cultivated soils most of such deterioration is due to traffic compaction and is only temporary, while differences related to tillage systems are relatively small. A significant improvement of the soil physical status is related to crop rotation, impoving crops, and adequate fertilization.

Literature. Canarache (1978), Stiinţa solului, noutăţi,nol,p.33-44.
Canarache,Dumitriu, a.o.(1977),Publicaţiile SNRSS,vol.16A,p.4o-64
Canarache,Dumitriu,a.o.,(1979,Publicaţiile SNRSS,vol.17(in print).
Canarache,Florescu,a.o.(1978), Analele ICCPT Fundulea,vol.43 p. 265-277.Canarache,Postolache, a.o..(1979),Lucrări ştiinţifice,SCA Mărculeşti (in print).Vasiliu,Canarache,a.o.(1979),Analele ICCPT Fundulea,vol.44 (in print).

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INFLUENCE OF THE TILLAGE SYSTEM ON PHYSICAL PROPERTIES IN SOME SW. SPAIN SOILS.

F. Moreno and J. Martín

Centro de Edafología y Biología Aplicada del Cuarto.
C.S.I.C. Sevilla (Spain).

ABSTRACT

Three different clayey soils -one, salt-affected, virgin; another salt-affected, cultivated (rice); and a third salt-free, cultivated (winter and summer crops)- belonging to a common area, have comparatively been studied.
Physical and physicochemical properties have been analyzed in terms of the effect of salts and cultivation.

The influence of technical management, crop rotations and weather conditions on soil structure status and development has been considered by many authors and need not further comentary.
Amongst the soils which present special interest for improving their physical characteristics those affected by salts have to be mentioned in first place. Reclamation of saline and/or alkali soils deserves particular attention in most countries.
In SW. Spain, there is a vast zone (140.000 ha) at the end of the Guadalquivir river valley, formerly a lake and now a flat, colmatated area affected by salts. Part of this area is under large reclamation projects, another part is cultivated with salt-tolerant crops (rice) and the rest still remains virgin and almost bare.
General information on this area can be found in Grande (3).
The object of this paper is to present and discuss the main differences encountered, as a consequence of salts and cultivation, in physical and physicochemical properties of three soils: two of them belonging to the above mentioned area (one virgin and the other cultivated) and a third situated outside the area but near its boundary, as detailed in next paragraph.

Material and methods

Soils.

Three representative profiles have been chosen, whose data are presented here. The first corresponding to a salt-affected virgin soil (profile 1), the second to a salt-affected cultivated soil (profile 2) and the third to a salt-free cultivated soil (profile 3).

Soil of profile 2 is dedicated to rice crop. It is a typical solontchak-like with salinity much reduced, in surface horizons, due to cultivation practices. This soil is maintained flooded from begining April (sowing) till September (harvesting).

Soil of profile 3 is dedicated to winter (wheat, beetroot) and summer (cotton, sorghum, sunflower) crops, in appropiated rotations, as normally cultivated in the area; sunflower is sometimes used as a second crop. Sprinkling irrigation is operating during late spring and summer. These soils are respectively considered as typic halaquept, halaquept and typic pelloxerert according to the Soil Taxonomy.

Methods.

Physical and physicochemical methods normally employed in this Centre have been used. Mechanical analyses have been obtained by a chain hydrometer. Salts have been determined in 1:5 extract.

Results and discussion

As shown by data in table 1, profiles 1 and 2 correspond to salt-affected soils, while profile 3 is practically salt-free. Comparing profiles 1 and 2, the first (virgin soil) presents higher EC (5.2 vs. 3.5 mmhos/cm, mean values to a depth of 90 cm) and Cl^- and Na^+ contents (21.8 vs. 12.2; 21.2 vs. 16.0 meq/100 g). Ca^{++} and Mg^{++} are still higher (17.8 vs. 7.2; 14.3 vs. 4.9 meq/100 g).

The effect of cultivation in reducing the amount of salts present is clear. This effect is more noticeable in surface horizons, as mentioned later.

Table 1. EC, soluble salts, CEC and exchangeable cations

Profile	Depth cm	CE mmho/cm	CO_3H^-	Cl^-	$SO_4^=$ (meq/100 g)	Na^+	K^+	Ca^{++}	Mg^{++}	CEC	Na^+ (meq/100 g)	K^+	$Ca^{++}+Mg^{++}$
1	0-10	2.2	0.4	9.6	6.8	10.0	0.4	4.0	2.4	19.0	1.5	0.6	16.9
	10-20	2.6	0.9	11.2	7.6	12.6	0.3	3.6	3.2	19.0	3.1	1.0	15.0
	20-30	5.8	0.7	18.7	-	19.2	0.6	28.8	25.2	19.9	4.2	1.3	14.4
	30-50	7.6	0.7	29.5	-	26.0	0.6	30.8	25.2	16.3	4.7	1.4	10.2
	70-90	7.6	0.7	40.0	-	38.2	0.5	21.6	15.4	17.2	5.6	0.7	10.9
2	0-10	2.0	0.8	3.8	9.4	6.8	0.6	5.0	3.3	25.3	3.3	3.1	18.9
	10-20	1.4	0.9	4.2	4.0	7.0	0.5	1.8	1.5	24.4	4.0	3.3	17.1
	20-30	1.5	0.9	6.2	2.7	10.0	0.3	0.6	0.8	26.2	5.0	3.4	17.8
	30-50	4.8	0.6	13.8	24.5	20.0	0.7	12.8	6.9	24.4	6.0	3.0	15.4
	70-90	7.6	0.6	33.0	27.4	36.0	0.8	16.0	12.0	27.1	10.0	2.5	14.6
3	0-10	0.2	-	0.2	-	-	-	-	-	37.1	1.3	2.7	33.1
	10-20	0.3	-	0.2	-	-	-	-	-	48.8	1.2	2.6	45.0
	20-30	0.3	-	0.6	-	-	-	-	-	49.7	1.3	2.4	46.0
	30-50	0.3	-	0.6	-	-	-	-	-	47.9	1.5	1.4	45.0
	70-90	0.2	-	0.6	-	-	-	-	-	46.1	1.9	1.6	42.6

Table 2. General physical properties

Profile	Depth cm	Particle size (mm, %) >.2	.2-.02	.02-.002	<.002	Dp $g.cm^{-3}$	Db $g.cm^{-3}$	K $cm.h^{-1}$	COLE $\times 10^2$
1	0-10	0.5	1.0	27.5	71.0	2.70	1.43	0.5	7.0
	10-20	0.5	1.0	35.0	62.5	2.70	1.44	0.2	7.8
	20-30	0.5	1.5	29.0	69.0	2.73	1.44	0.1	7.1
	30-50	0.5	1.0	25.0	73.5	2.74	1.39	0.1	9.4
	70-90	0.5	2.0	62.5	34.5	2.77	1.45	0.5	7.9
2	0-10	0.5	1.0	27.5	69.5	2.72	0.96	2.5	17.1
	10-20	0.5	1.0	28.0	70.0	2.70	1.01	0.1	18.8
	20-30	0.5	1.5	31.0	67.0	2.75	1.27	0.5	13.0
	30-50	0.5	1.5	27.5	70.5	2.80	1.34	0.1	8.8
	70-90	0.5	1.5	32.0	65.5	2.80	1.18	0.1	14.0
3	0-10	2.0	15.5	23.0	59.0	2.75	1.15	6.5	14.3
	10-20	2.5	15.0	23.0	59.0	2.72	1.33	0.1	12.6
	20-30	2.0	16.0	22.5	59.0	2.74	1.25	0.1	13.0
	30-50	2.0	16.5	22.5	58.5	2.78	1.23	0.1	13.0
	70-90	3.0	16.0	22.0	59.0	2.73	1.30	1.5	12.4

Regarding exchangeable cations, profile 3 shows the highest capacity, but Na^+ and K^+ are much lower than in profiles 1 and 2. Within these, profile 2 shows a higher CEC and Na^+, K^+ and $Ca^{++}+Mg^{++}$ contents.

Differences can also be found, in a given profile, at different depths. Thus, in profile 1, EC, soluble Cl^- and Na^+ and exchangeable Na^+ increase downwards. On the other

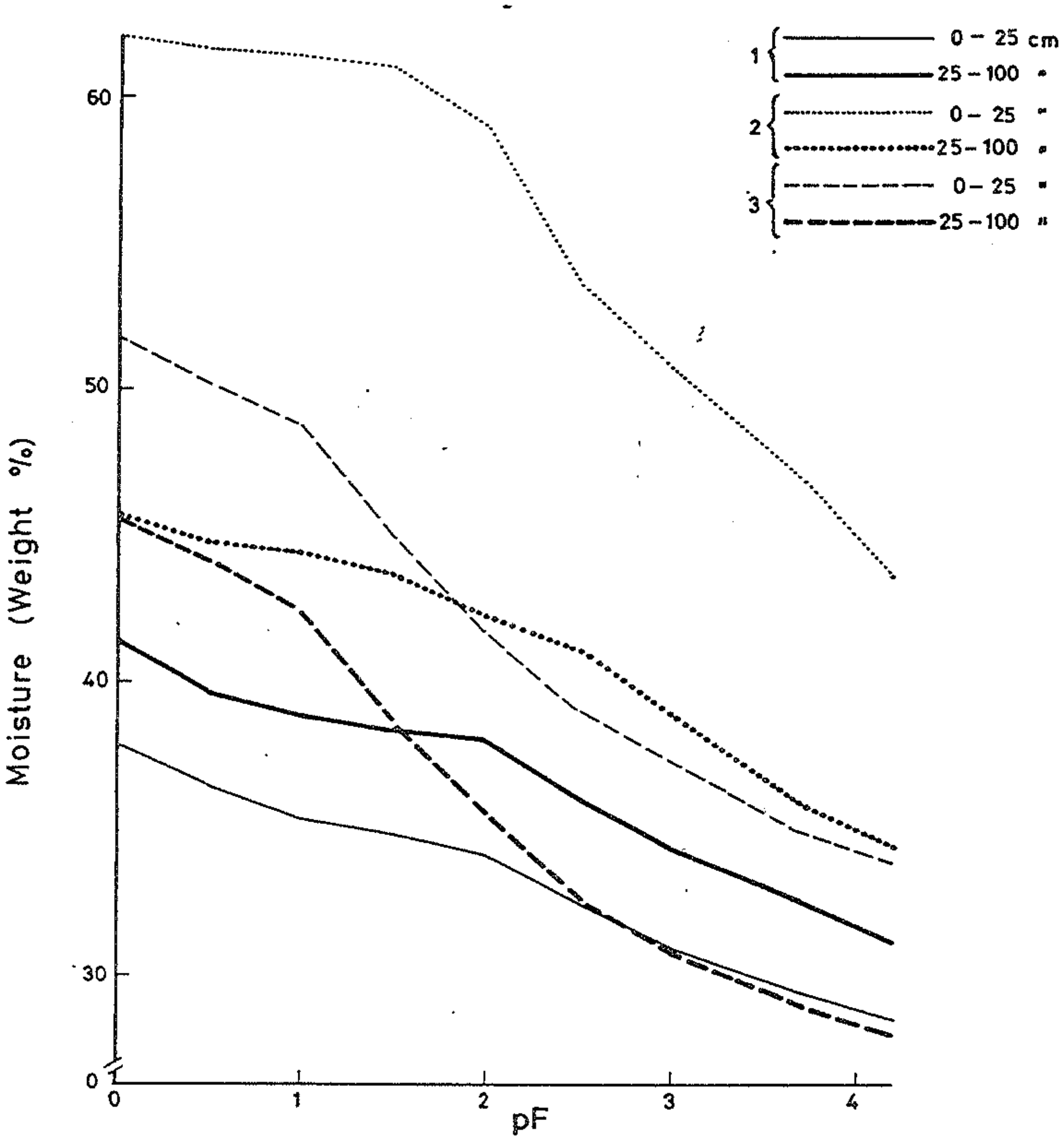

Fig. 1. pF-curves for soil and subsoil

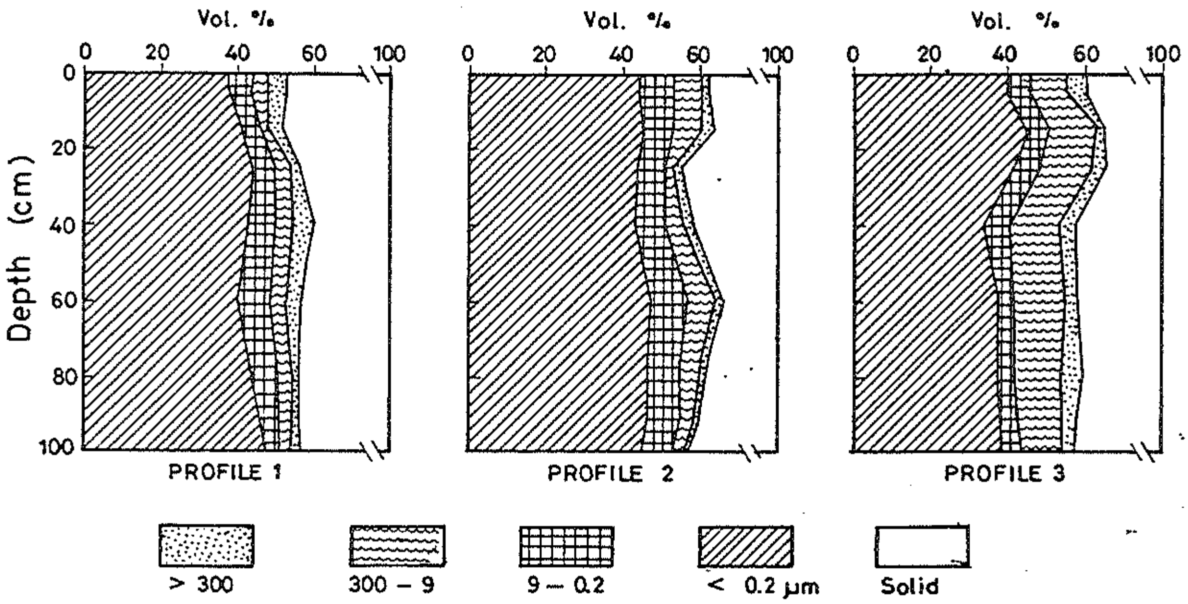

Fig. 2. Differential porosity of soils.

hand, a clear distinction can be made between soil and subsoil with respect to Ca^{++} and Mg^{++} contents. A similar pattern, although with lower values, is observed in profile 2. Exchangeable Na^{+} also increases with depth. Although data for $SO_4^{=}$ in profile 1 are not included in table 1, they are higher (30-40 meq/100 g) at 20 cm depth and downwards than in profile 2, due to gypsum accumulation in these horizons.

General physical properties also differs between profiles and within profiles. As shown in table 2, particle-size distribution is not the same in saline and nonsaline soils; although the three are very heavy soils, the non-saline (profile 3) is less clayey. No difference is found however between virgin and cultivated saline soils (profiles 1 and 2).

Bulk density is higher in the virgin saline soil than in soils under cultivation. This effect is also detected in the hydraulic conductivity of surface horizons. The coefficient of linear extensibility in virgin saline soil is about half that of cultivated soils.

In fig. 1 pF curves for soil and subsoil of the three profiles are presented. A clear difference is found, at low pF values, between virgin and cultivated soils. In the latter, surface horizons show higher values than subsoil horizons, the opposite being the case in the virgin soil. The influence of cultivation in saline soils also is responsible for the much higher pF values of surface layer in profile 2. In all cases, however, pF curve patterns correspond to those of very heavy soils.

Porosity, as shown in fig. 2, also corresponds to this kind of soils. Differences between profiles can easily be observed, particularly at top horizons. Pore-size distribution for ranges >300, 300-9 and 9-0.2 µm are also very distinct for virgin and cultivated saline soils.

Finally, an important fact should be mentioned relative to physicochemical characteristics. Clay fraction in profiles 1 and 2 mainly are of illitic nature while it is montmorillonitic in profile 3. Work done by González et al. (1), González y Pérez (2) and Moreno et al. (4) shows that saline soils in the area studied are predominantly illitic.

Therefore, their high COLE values, mentioned in table 2, are due to salts which hold water and increase the colume around the mineral lattice rather than to an expanding montmorillonite-like lattice as in profile 3.

Acknowledgement.

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REFERENCES

1. González, F.; González, S. and Chaves, M. 1956. The alkali soils of the lower valley of the Guadalquivir: Physicochemical properties & nature of their clay fraction. Rapports. VI Congrès de la Science du Sol. Paris 1956. I-26.

2. González, F. y Pérez, J.L. 1971. Constitución y propiedades físicoquímicas de las arcillas de suelos del valle del Guadalquivir. An. Edafol. Agrobiol. 30, 57-74.

3. Grande, R. 1971. Salt-affected soils in the Guadalquivir river delta (Seville, Spain). European Solonetz Soils and their reclamation, Akadémiai Kiadó, Budapest.

4. Moreno, F.; Arrúe, J.L.; Murillo, J.M.; Pérez, J.L. and Martín, J. 1979. Mineralogical composition of clay fraction in marsh soils of SW. Spain. Submitted to Polish Journal of Soil Science.

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+Pore size distribution of soils

Gary J. Osborne, Don Payne, *Dennis J. Greenland and Trevor Moseley.
Department of Soil Science, University of Reading, Berks, United Kingdom.

*Assistant Director, International Rice Research Institute, Manila, Philippines.

ABSTRACT

Methods currently being used at the University of Reading to measure soil porosity on tillage experiments include: relief metering, moisture desorption, mercury injection, and optical measurements after polyethylene glycol impregnation. These procedures are discussed with reference to direct drilled and ploughed treatments on a tillage experiment on a clay soil.

INTRODUCTION

Soil structure may be defined either in terms of the shape, size and spatial arrangement of individual soil particles and clusters of particles (aggregates) or in terms of porosity and pore size distribution. The importance of soil structure lies in the nature and stability of the pore system between and within the structural units. A continuous stable system is essential to fertility and the avoidance of physical stresses associated with inadequate water or air, resistance to root penetration and unfavourable temperature.

In this paper we aim to present detail of procedures in use to describe the coarse and fine pore systems of agricultural soils, emphasising the results obtained with data from tillage experiments.

MATERIALS AND METHODS

A major problem with a study of this kind relates to soil variability. A number of soils have been studied but the soil reported on here is the Denchworth series developed on Gault clay.

Pore size distribution of soils has usually been obtained from the relationship between moisture content and suction. However, in the case of clay soils which shrink on drying, the moisture content-suction desorption isotherm does not reflect the true pore size distribution of the original saturated sample. Water release

+ We acknowledge the assistance and financial support of the Agricultural Research Council, and the staff of Letcombe Laboratory.

being due to pore collapse rather than pore emptying. Swelling data used in this paper were obtained on natural aggregates at suctions of, pF 1, 2, 3, 4, 4.2, 4.7, 5.2 and 7 using the saran resin method. Field moisture contents were found by neutron moisture meter.

The use of broad and simple classifications of soil pore sizes in terms of suction is difficult. In this paper, pores down to 10 µm are called coarse pores (transmission) and those below this fine pores (storage).

Coarse Pores:-

The soil pores created or modified by cultivation are the corase pores and changes in these have been followed by relief metering on direct drilled and ploughed treatments. Pore size distributions down to 10 µm have been obtained from water content suction curves, in a range of suction where shrinkage is negligible.

An optical procedure based on the sectioning and photographing of soil cores impregnated wet, with polyethylene glycol 6000 (P.E.G) has been developed. Some details of this procedure are given below.

Soil samples previously brought to equilibrium on a sand table (50-100cm) suction, are placed in solutions of increasing P.E.G. concentrations. The solutions contain a fluorescent dye (Pyranine). In our studies, 4 hours in 10 and 25 percent solutions, followed by 12 hours in a 50 percent solution (at a temperature of 65°C) and 24-36 hours in pure wax at 70°C gives a satisfactory impregnation. A light vacuum can assist. The "thick" sections obtained after surface grinding of the cores are photographed for 3 minutes under ultra-voilet light (254 nm) on black and white film rated at 125ASA. A Wratten 15 filter minimizes the effect of stray light. The porosity is then assessed using an image analyser (Quantimet). Thin sections can also be made.

Fine Pores:-

The volume of fine pores can be determined by subtracting the air filled porosity obtained at a suction of 100cm (pF2), from the total porosity. It is possible to allow for the effect of shrinkage by assuming isotropic normal shrinkage.

The fine pores can also be sized using desorption or injection of non-polar liquids such as mercury, in which case it is necessary to dry the sample (usually an aggregate), without disturbing the pore size distribution. Critical point drying seems satisfactory. After drying, however, in the soils examined only limited volumes of pores in the "available water" range have been measured by porosimetry. In the present paper comparisons between results obtained using the different procedures are made.

RESULTS AND DISCUSSION

Coarse Pores:-

Relief Metering:- Graphs were drawn (Figures 1a and 1b) for changes in thickness of soil layers (0.3 - 1.5m), on both ploughed and direct drilled treatments, for the two years 1976-1977. Superimposed on these graphs are the calculated changes due to

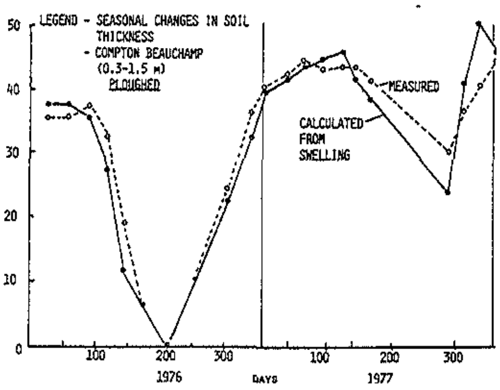

Figure 1a

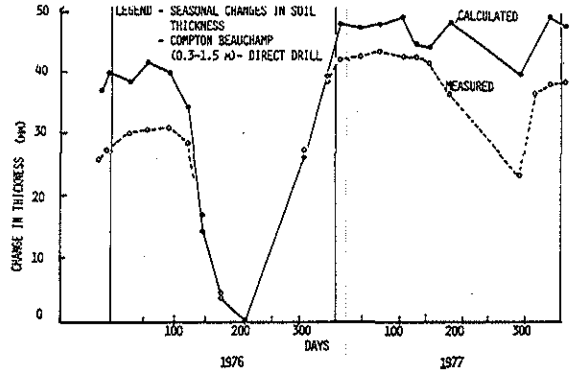

Figure 1b

swelling. The lowest level of the soil surface, coincided in time with the lowest moisture content, and these points were made to coincide on the graphs to facilitate comparisons. The agreement between calculated and measured movement is excellent for the subsoil; the calculated maximum change in thickness of 50mm agreed with the relief meter measurement. The results for the subsoil of the direct drill plots (Fig 1b) show a poorer fit. There is evidence for 1976 (Fig 2a) of the existence of more coarse pores in the direct drilled subsoil which could be water filled, contributing nothing to swelling yet giving higher readings on the neutron moisture meter. It is interesting to note the wide divergence in the neutron moisture meter readings in the dry season 1975/76 (Fig 2a) and the coarse pores (>50 μm) on the ploughed treatment. This result would indicate the more rapid drying of the ploughed soil to plough depth (20-25cm).

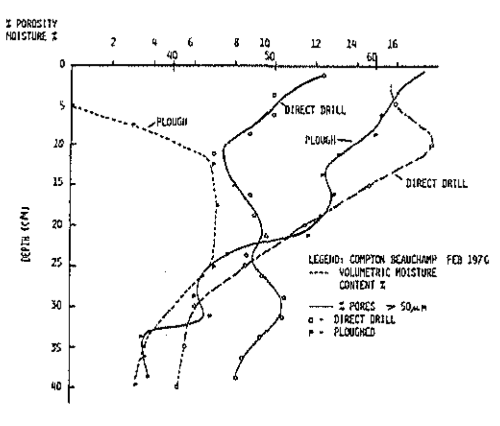

Figure 2a

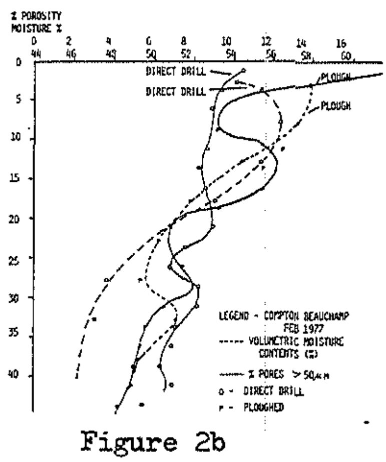

Figure 2b

In 1977 (Fig 2b), while there is evidence for larger coarse porosity on the direct drilled plot, below 30cm, moisture levels as determined by the neutron moisture meter are lower, and the difference between the measured and calculated swelling differ markedly.

The residual soil movement (after adjustment for changes in moisture content, 3:1) of the surface soil (0-30cm) and subsoil (30-150cm) of both direct drilled and ploughed are plotted in Figure 3. The surface soil shows large expansion during the winter, not directly related to water content; it coincided with frost. In the winter of 1976 frost penetrated about 5cm, as shown

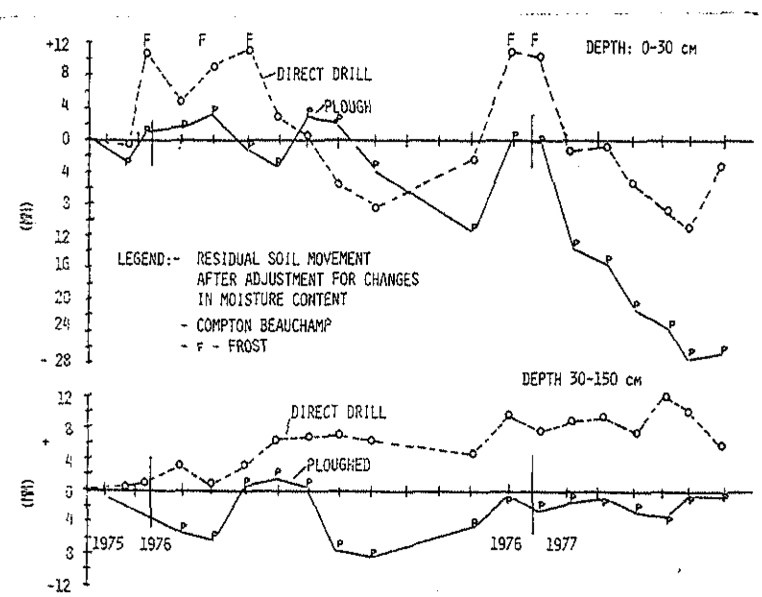

Figure 3

by thermistor records on these plots. With a water content of 50mm in the surface 0-100mm soil layer, this could give an expansion of 2.5mm overall, perhaps entirely upwards. The measured expansion not due to water was 18mm, indicating considerable migration of water into the surface soil. The collapse of the soil to its original state after "frost heave" took several months.

From February to June in 1977, the direct drilled soil (0-30cm) effectively changed in bulk density from 1.05 to 1.06 g/cc, with total porosity changing from 58.8 to 58.4%. The bulk density of the ploughed soil changed from 1.02 to 1.06 g/cc and total porosities from 60.0 to 58.4% over the same period.

Optical Studies:- Date from this aspect of the study will be presented at the Conference.

Fine Pores:-

In Figure 4 results obtained from soil cores and for individual soil aggregates for bulk density, percentage of pore volume less than 10 µm (fine pores), and for total porosity are presented. The results for the soil cores were obtained using moisture desorption procedures and for the soil aggregates using mercury porosimetry on critical point dried samples (pF4.2) and on oven dried samples (pF7.0).

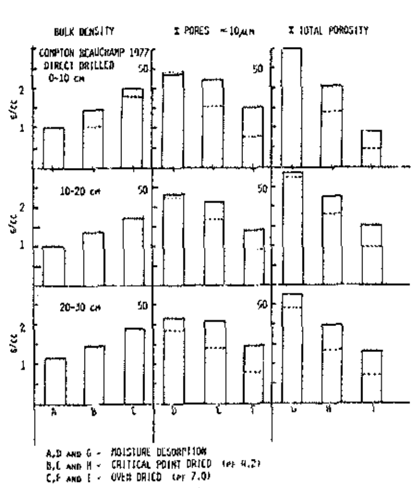

Figure 4

The data is presented to emphasise the care needed in interpreting soil porosity and pore size distribution data. Other studies on this soil have indicated that soil aggregates (0-10cm) have 5% of their volume occupied by coarse pores which are lost on critical point drying, we also know that soil cores have around 13% of their volume as coarse pores. Thus if we add these figures to the total porosities shown for the 0-10cm results, for aggregates critical point dried to pF4.2, we increase the porosity figure from 41 to 59%, which is close to that obtained using moisture desorption (60%).

We have already seen in Figure 2b, that when we have an increase in coarse pores the swelling/shrinkage data does not relate well to the changes in the moisture content in the field. How can this information be extrapolated to individual soil aggregates?

While it is not easy to measure the fine pores in a clay soil, some estimate must be obtained for each soil in each tillage experiment. Our studies have indicated difficulties in the interpretation of data for the fine pores and coarse pores and when this is placed in the context of soil variability some rationalising needs to be done. The question we pose is: What is the minimum soil porosity information needed to characterise our arable soils?

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EFFECT OF TILLAGE ON AGGREGATION AND STRENGTH IN ONTARIO SOILS

J.W. Ketcheson, T.J. Vyn, and T.B. Daynard

Ontario Agricultural College, University of Guelph, Guelph, Ontario Canada, N1G 2W1

ABSTRACT
Aggregation measured by size distribution and water stability, and strength measured by penetrometer were studied under different tillage and cropping systems. Soil aggregates less than 5 mm in size favoured growth of corn (Zea mays L.) on a well-drained silt loam soil in Ontario, Canada. Fall moldboard plowing plus 4 spring secondary tillage operations gave higher corn yields than either fall chisel plow or no-tillage. Resistance to penetration was lowest on moldboard plowing, intermediate on chisel plowing, and highest on no-tillage. A survey of aggregate size fraction and stability on farmers' fields showed less variability when forages were included in rotations with row crops than when row crops were grown continuously but no consistent effect of amount of secondary tillage on aggregate size or stability was found.

Tillage is an important component of soil management for crop production in Ontario agriculture. With a trend toward monoculture and continuous row cropping in rotations which do not include forage crops, farmers are showing greater concern for tillage methods. This concern ranges from a tendency toward more intense and more sophisticated tillage on the one hand to the elimination of tillage on the other hand. We have experimented with no-tillage which is an advantage in erosion control, but is a practice which results in inferior crop yields particularly on finer-textured soils (Ketcheson 1977). The purpose of this paper is to review some effects of tillage on aggregate size distribution and soil strength as an indicator of crop performance in Ontario soils.

Soil strength for the purpose of this paper is taken as the resistance of the soil to penetration. Corn root elongation in an Ontario soil was shown to be markedly reduced as soil strength was increased by increasing bulk density or moisture tension (Mirreh & Ketcheson 1973). Strength in field soil appears to be reduced by primary tillage such as moldboard plowing (Ketcheson 1976).

Good aggregation in a soil favours germination and growth of plants by maintaining proper contact between soil and seed while controlling air and moisture in a favourable range. It may also reduce soil strength and promote unimpeded root development. The size-distribution of aggregates constituting the most favourable tilth is not well documented however. Taylor (1974) suggested a major portion of the aggregates should be in the neighborhood of 2 mm diameter for an East African Vertisol. Generally the size is given as less than 5 mm diameter. Cornforth (1968) found greater root density in a soil with the smaller-sized aggregates. Aggregates less than 0.5 mm on the other hand, may not give adequate-sized pores for proper drainage and root development (Eavis 1972). Barley and Greacean (1967) state there is no simple relationship between density and strength.

There has been little work in establishing recommendations for aggregate size, density or strength parameters for Ontario soils. This paper considers some measurements made on these soils.

MATERIALS AND METHODS

Soils: The soils of Ontario are in the St. Lawrence Lowland group of Canadian Soils and consist of Luvisols, Brunisols, Podzols, Gleysols and Organic soils (Laverdiere and Martel, 1978). They have developed on glacial till, fluvioglacial and glaciomarine deposits. Textures range from clay to sand. In general, drainage and tilth can be a problem with the finer-textured materials, erosion on the more rolling medium-textured soils, and moisture and fertility deficiencies affect the coarser-textured soils. Our tillage studies are carried out mainly on representatives of the medium to fine-textured group which have monoculture or continuous row cropping practices (Vyn et al. 1979).

Size distribution of aggregates: Soil samples (approximately 1 kilogram per sample) were air-dried at 35^{o} C and separated with gentle agitation into aggregate size fractions on a nest of sieves with 25, 8, 5, 2, 1 and 0.3 mm openings. Results are expressed as the percentage each fraction bears to the total sample.

Wet aggregate stability: Samples of the 1-2 mm fraction were agitated at 40 cycles per minute for 10 minutes on a nest of 0.25 and 1 mm sieves in a water bath at room temperature. The aggregates remaining on the two sieves were combined for drying and weighing followed by dispersing to determine any primary particles > 0.25 mm for subtraction. The weight of aggregated material remaining water-stable after the wet sieving is expressed as a percentage of the original 1-2 mm fraction.

Strength: Resistance to penetration was determined in situ with a Soil Test model CN974 Penetrometer (30^{o} cone point; 3.14 cm^2 cross-sectional area) pressed slowly into soil to a depth of 5 cm. Resistance to penetration is expressed as bars. A Soil Test Model NIC-5-TDM surface gauge was used with factory calibration for in situ density and moisture determinations.

EXPERIMENTAL RESULTS

Tillage treatments for corn planter performance study (Vyn 1978).

Secondary tillage for seed bed preparation did not significantly influence uniformity of emergence of corn, spacing or plant population, although it did alter the proportion of aggregates < 5 mm and soil relief (Table 1). While it was expected that some effect might result, it appears the range of aggregate fineness and surface relief resulting from these tillage treatments was within the optimum range for corn germination and emergence on this soil.

Table 1. Effect of secondary tillage treatment on the aggregate size distribution and relief of a silt loam soil.

Tillage Treatment	Proportion of aggregates < 5 mm (%)	Soil relief SD++ (cm)
1. Cultivator (1 pass)	44.1 c+	10.6 a
2. No. 1 & cultivator and spike-toothed harrow	53.9 b	6.8 b
3. No. 2 & PZ crumbler	65.6 a	3.2 c
4. No. 2 & Amazone reciprocating harrow	66.7 a	4.2 c

+ Values not followed by the same letter are significantly different at P = 0.05 by Duncan's Multiple Range Test.
++ Standard deviation of soil height measurements.

Plant height 40 days after planting was influenced by tillage and the resulting aggregation in the soil (Fig. 1). Height was directly proportionate to the amount of aggregates < 5 mm. The lower limit of aggregate size was not determined in this experiment, but it apparently was not small enough to constitute a serious detrimental condition for either germination or subsequent growth. The study continued to determine parameters such as leaf number and yield both of which were positively correlated with the percentage of aggregates < 5 mm.

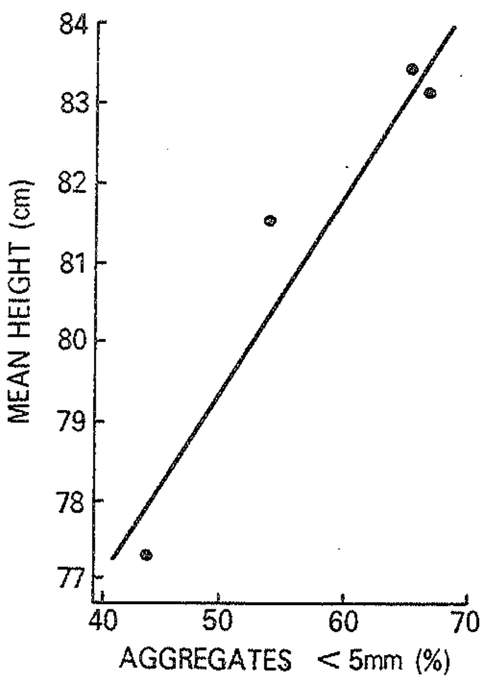

Figure 1. Regression of plant height on the proportion of soil aggregates (by weight), < 5 mm in diameter, for corn grown in four seedbeds (r = 0.96, significant at P = 0.01). (Elora Research Station, 1976 - Vyn, 1978).

A second experiment considered a wider range of primary and secondary tillage implements. Fall chisel plowing without secondary tillage gave the lowest percentage aggregates < 5 mm (Table 2) suggesting that this implement may create larger aggregates than other methods which in turn depend more on subsequent tillage to reduce their size. Bulk densities do not correspond to aggregate size as shown in this same Table, although there is a tendency for finer aggregates to give a lower bulk density. In this experiment finer aggregates reduced the time to emergence by about one day but did not affect uniformity of emergence. Plant height, number of leaves and grain yield were favoured by secondary tillage treatments which produced greater percentages of aggregates < 5 mm (Fig. 2).

Table 2. Effect of tillage treatment on the proportion of fine aggregates and on bulk density of soil.

Tillage Treatment	Proportion of aggregates < 5 mm (%)	Bulk Density (g/cm^3)
Zero tillage	21.0 bc+	1.32 a+
Spring moldboard plow	29.9 abc	1.12 c
Spring moldboard plow, disc, harrow	37.3 a	1.14 c
Fall moldboard plow	29.9 abc	1.30 ab
Fall moldboard plow, disc, harrow	39.9 a	1.17 bc
Offset disc (spring)	39.3 a	1.13 c
Fall chisel plow (sweeps)	17.6 c	1.28 ab
Fall chisel plow (sweeps), disc, harrow	30.5 abc	1.14 c
Fall chisel plow (shovels), disc, harrow	33.0 ab	1.14 c

\+ Values followed by the same letter are not significantly different at the 0.05 level by Duncan's Multiple Range Test.
Variation among treatments significant at P = 0.05 in first column
Variation among treatments significant at P = 0.01 in second column

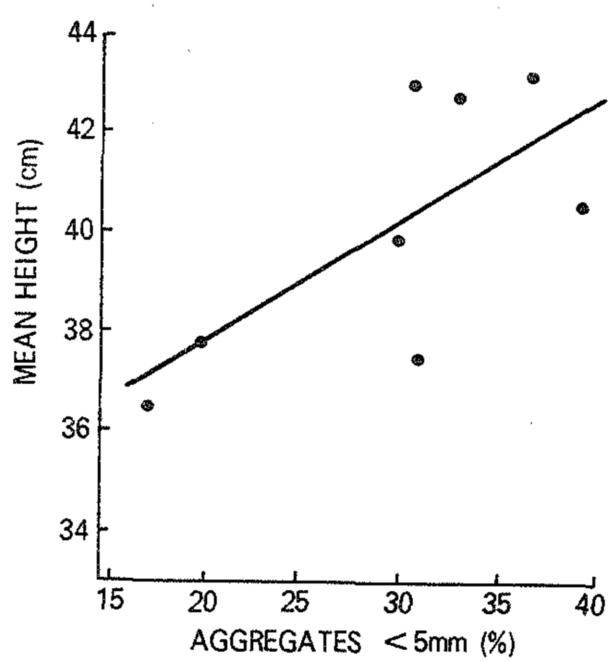

Figure 2. Regression of mean plant height at day 35 on the proportion of soil aggregates (by weight), < 5 mm in diameter, for corn grown with nine tillage treatments (r = 0.51, significant at P = 0.01). (Elora Research Station, 1976 - Vyn, 1978).

Effects of tillage on soil bulk density and resistance to penetration-Elora Research Station.

Table 3 illustrates how strength in a silt loam soil can vary independant of density. While soil moisture reduction can increase strength at a given bulk density (Mirreh and Ketcheson 1973), moisture was not considered to vary sufficiently in this study to account for the variation found in soil strength. Moldboard plowing initially produced a lower bulk density than other primary tillage treatments. Resistance to penetration varied relatively more than density, with higher values in May than in June or July. An exception to this trend occurred with no-tillage where the highest density and resistance was found in June. When soils were divided into tilled and non-tilled, there appeared to be a positive linear relation between bulk density and resistance to penetration as indicated by the regression equations.

Table 3. Relationship of soil bulk density and resistance to penetration with yield of grain corn under different tillage treatments. Elora Research Station 1977.

Tillage Treatment		Bulk	Resistance to		
Primary	Secondary	Density[1]	Penetration[1]	Moisture	Yield
		g/cc	bar	g/cc	t/ha
Fall mold-board plow	2 passes	1.06	1.61	0.22	5.8
	4 passes	1.04	1.29	0.22	6.1
Fall chisel plow	2 passes	1.03	1.85	0.24	5.3
	4 passes	1.05	1.59	0.25	5.6
none	none	1.08	3.38	0.25	5.3
	2 passes	1.02	1.74	0.25	5.6
	Measurement date				
Tilled	May	1.06	2.00	0.23	
	June	1.04	1.44	0.21	
	July	1.00	1.41	0.26	
Y(Resistance to penetration) = 8.5X(Bulk density) - 7.2					
Non-tilled	May	1.07	2.93	0.24	
	June	1.13	4.47	0.22	
	July	1.05	2.73	0.28	
Y = 22.6X - 21.2					

[1] Tillage treatment and date interactions statistically significant at P = 0.01.

Survey of tillage practices on farm fields, 1978.

Of some 32 individual farm fields surveyed for tillage practices, farmers used two to six secondary tillage operations following primary tillage to prepare seed beds (Table 4). Except for a possible decline in water-stable aggregates for soils without forages, there was little apparent effect on these fine-textured soils of the number of secondary tillage operations on the proportion of certain sizes of aggregates or aggregate stability. There was greater variability among soils without forage, as shown by the standard deviations. Thus it was difficult to identify a parameter in this survey which reflected current tillage practice. We plan to study these and other parameters in more detail in an effort to identify tillage needs more precisely.

Table 4. Range in aggregate size distribution and stability for different amounts of spring secondary tillage following fall plowing for corn grown on fine-textured soil with or without forages in rotation.

	Number of Secondary Tillage Operations	Aggregate Size Fraction <50 µm	50-300 µm	1-2 mm	Water-Stable Aggregates >0.2 mm
		-------percent-all fractions--------			percent
Without forages	2	5.6 (7.5)[1]	14.2 (22.8)	15.7 (12.1)	52.6 (19.6)
	3	1.9 (1.4)	1.5 (1.6)	25.1 (4.0)	49.7 (11.3)
	4	7.6	4.3	10.3	32.9
With forages	2	2.2 (1.0)	1.2 (0.5)	20.2 (0.5)	45.0 (10.2)
	3	4.6 (2.7)	2.1 (1.7)	17.0 (4.7)	44.7 (7.4)
	4	2.9 (2.0)	2.1 (0.9)	19.6 (6.3)	49.2 (9.9)
	5	3.5 (0.0)	2.4 (0.7)	23.3 (2.8)	52.0 (4.0)
	6	2.2	5.5	3.3	45.0

[1] Numbers in brackets are Standard Deviations based on two or more farms in each category. Where no S.D. is given, there was only one farm represented.

References

Barley, K.P., and E.L. Greacen. 1967. Mechanical resistance as a factor influencing the growth of roots and underground shoots. Adv. Agron. 19:1-43.

Cornforth, I.S. 1968. Effect of size of soil aggregates on nutrient supply. J. Agric. Sci. 70:83-85.

Eavis, B.W. 1972. Soil physical conditions affecting seedling root growth. I Mechanical impedance, aeration and moisture availability as influenced by bulk density and moisture levels in a sandy loam soil. *Plant Soil* 36:613-622.

Ketcheson, J.W. 1976. in Progress Report, 1975. L.R. Webber ed Department of Land Resource Science, University of Guelph, Guelph.

Ketcheson, John. 1977. Conservation tillage in Eastern Canada. J. Soil Water Conserv. 32:57-60.

Laverdiere, M., and Y. Martel. 1978. The soils of the St. Lawrence Lowlands. in Annual Report, 1977, Canadian Geoscience Council, GK Rutherford, et al, ed. Energy Mines and Resources Canada, Ottawa, Canada.

Mirreh, H.F., and J. W. Ketcheson. 1973. Influence of soil water matric potential and resistance to penetration on corn root elongation. Can. J. Soil Sci. 53:383-388.

Taylor, M.S. 1974. The effect of aggregate size on seedling emergence and early growth. E. Afric. Agric. Forest. J. 40:204-213.

Vyn, Tony J. 1978. Plant to plant variability in corn - agronomic considerations. M.Sc. Thesis. University of Guelph, Guelph, Canada

Vyn, T.J., T.B. Daynard, and J.W. Ketcheson. 1979. Tillage practices for field crops in Ontario. Ontario Agricultural College, University of Guelph, Guelph, Ontario Ministry of Agriculture and Food, and Ontario Ministry of Energy, Toronto. 49 pp.

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The effect of strain rate on soil mechanical properties pertinent to tillage implement performance

J.V. Stafford
National Institute of Agricultural Engineering,
Wrest Park, Silsoe, Bedfordshire, U.K.

Abstract

Tillage implement performance may be predicted under quasi-static conditions with reasonable accuracy. This paper considers the possibility of predicting the effect of speed on performance by considering the effect of strain rate on relevant soil properties. Prediction of the forces on an implement is shown to be achievable.

Introduction

Timeliness of cultivation operations has been given more and more emphasis over recent years. This has meant that the gradual increase in cultivation speed that has been evident for many years has continued and, indeed, accelerated. Increased cultivation speeds result in a change in the quality of work as well as a change in power requirement. Knowledge of the effect of speed is required so that the quality of work can be controlled and so that the specific power requirement can be kept within the capability of available machinery.

There have been very few investigations on the effect of speed on implement performance, although work was carried out by Soehne and Moller (1) on the design of mould-boards for high speed operation. They concentrated on the kinematics of soil movement over the mouldboard and did not consider the effect of speed on cutting forces. Several workers have demonstrated that draught force invariably increases with speed but there appears to be a lack of agreement between the various results. With mouldboard ploughs, the relationship between draught force and speed is generally of square-law form (1) but for tines the relationship varies between square-law and the inverse (2). Recently, Stafford (3) has shown that the type of relationship depends on the soil moisture content and has been able to reconcile apparent contradictions in some of the previous work.

Even less work has been reported on the effect of speed on soil failure patterns caused by tined implements. There are two phenomena to be considered; the effect of speed on the nature of failure pattern formed and on the degree of pulverisation. Wilton (4) examined the effect of tine speed on the shattering of unsupported clods and found that the arithmetic mean size of fragments decreased with speed. Olson and Weber (5) observed, in soil tank experiments, that the zone of failure increased as speed was increased from 0.2-1.1 m/s and that soil shatter also increased. Similar observations were made by Stafford (3) in both sandy clay loam and clay soils. At higher speeds (5 m/s), clearly defined failure zones were not formed but there was a high degree of pulverisation of soil in front of the tine.

In considering the performance of implements with respect to speed, the ideal to aim for is a predictive model which can be used to aid implement design and indicate the range of performance to be expected under given soil conditions. This paper briefly reports some measurements of tine performance both in a soil tank and in the field and then considers the role of some soil properties on tine performance and the possibility of establishing a predictive model.

Tine Performance

Measurements of the draught force due to a rigid tine of 40 mm width working at 150 mm depth were made in sandy clay loam and clay soils in a soil tank (6) up to a speed of 5 m/s and at several soil moisture contents. The variation of draught with speed at several moisture contents is shown in Fig. 1 for a 90° rake angle tine. The draught/speed curve was one of two types, dependent on whether moisture content was high so that soil failure was by plastic deformation or low so that it was of a brittle nature. For both soils, the transition between the two types occurred near to the drop-cone plastic limit (7) of the soil. The intercept of the fitted curve on the force axis ('draught force at zero speed') could be predicted with reasonable accuracy, particularly at low moisture contents, by the predictive model for soil cutting forces proposed by Hettiaratchi et al (8). The calculated forces are indicated by arrows on the axes on Fig. 1.

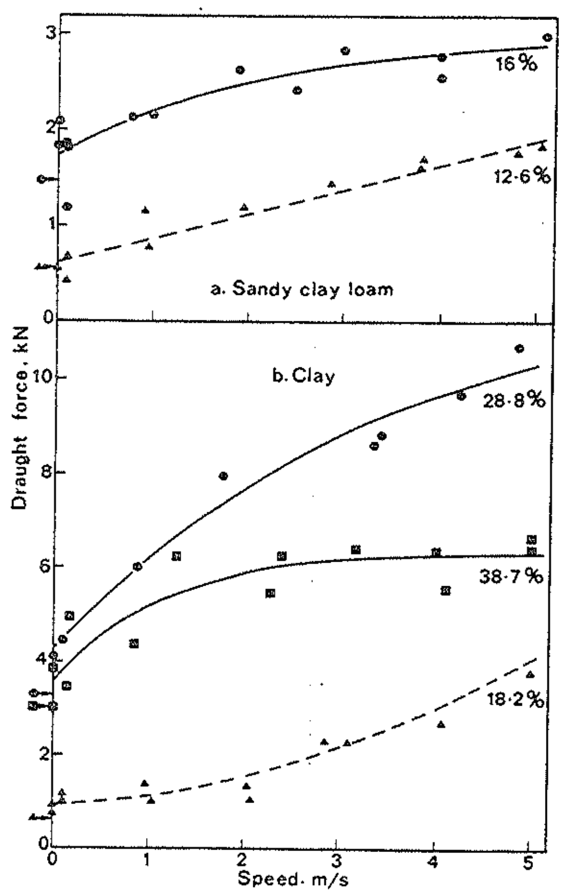

Fig.1. Draught/speed characteristics in soil tank

The performance of the same tines as used in the soil tank experiments was assessed in the field in terms of draught force and soil disturbance in a wide range of soil types and conditions. Representative examples of the draught force/speed relationships are shown in Fig. 2. Scatter in the experimental points restricted the choice of curve fit to linear regression except in a few cases (such as Fig. 2a, 45° tine). Without exception, draught increased with speed, the rate varying from 0.15 to 0.8 kN per m/s. In most cases, the increase in draught was shown to be accompanied by an increase in cross-sectional area of the furrows formed by the tines so that specific draught was almost constant with speed. Scatter in the results precluded a detailed comparison with the soil tank results but, under similar conditions, draught levels were similar.

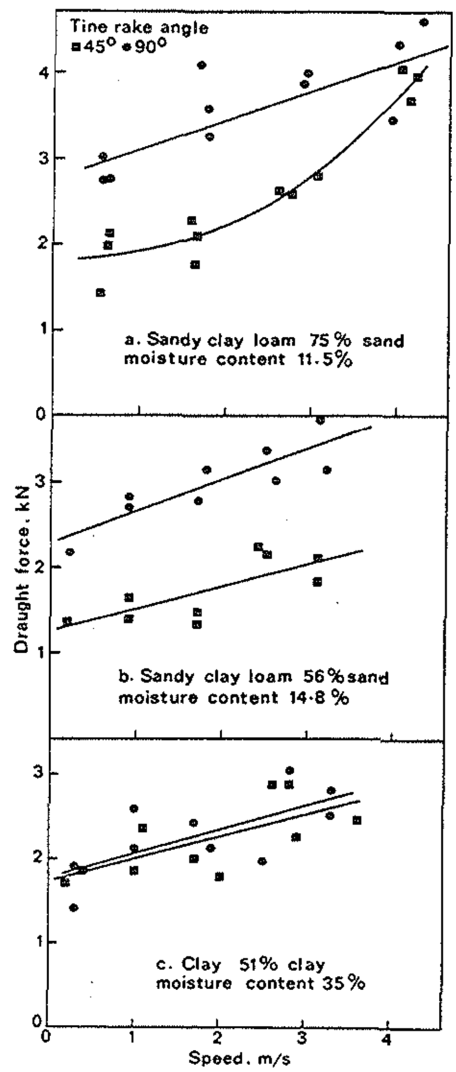

Fig.2. Draught / speed characteristics in field

The effect of strain rate on pertinent soil properties.

Observations of the effect of speed on soil rupture have shown that a very different tilth will be obtained at low speed that at high and that the increase in force with speed varies with moisture content. Until recently, it has been assumed that soil inertia accounts for the increase of draught with speed, particularly for mouldboard ploughs, although Rowe and Barnes (9) indicated that the increase in shear strength with strain rate was a major cause. It has, however, been shown (10) that inertia forces with tined implements are negligible.

Soil behaviour in front of a tine moving so slowly that strain rate effects are negligible, can be explained in terms of the soil cutting model of Hettiaratchi et al (8). An analysis of the model as applied to the results in the previous section showed that the shear strength term was the dominant component, accounting for 90% or more of the draught force. The predictive equation for draught force (F) can therefore be reduced to a form:

$$F = a \; c \; \exp(b \tan \varphi) \; \sin(\alpha + \delta)$$

where a, b and α are constants for a given tine, c and φ are shear strength parameters and δ is the soil-implement friction angle. From this equation, it may be deduced that the effect of speed on draught must be due to c, φ and δ being strain-rate dependant. From the literature, it is known that c and δ do vary with strain rate and some of the available data has been surveyed (3). A clear picture of the effect of strain rate does not, however, emerge and so an investigation is being undertaken using a miniature torsional shear annulus mounted on a high speed drive.

An example of the effect of strain rate on cohesion and soil/metal friction is shown in Fig. 3a and b. The clay (at 38% moisture content) is the same as that used in the tine experiments. Cohesion increased significantly with strain rate. The angle of internal friction was almost constant at 15°. As the clay was in a 'non-scouring' condition at 38% moisture content, the 'adhesion' measured was, in fact, the residual cohesion of the soil. However, at speeds below 0.1 m/s, soil did not stick to the annulus and so the true adhesion was measured. The values of peak shear strength and soil-metal friction/'residual' shear strength so measured have been used in the predictive equation for tine draught force and the result is plotted on Fig. 3c together with the relevant experimental data from Fig. 1. The curves are of similar shape but the increase in calculated draught is greater than the measured increase.

The example given illustrates that the effect of speed on draught force of a tine can probably be explained by the change in shear strength and soil-metal friction due to strain rate. This hypothesis can be confirmed when the effect of strain rate over a range of soil types and moisture content has been elucidated.

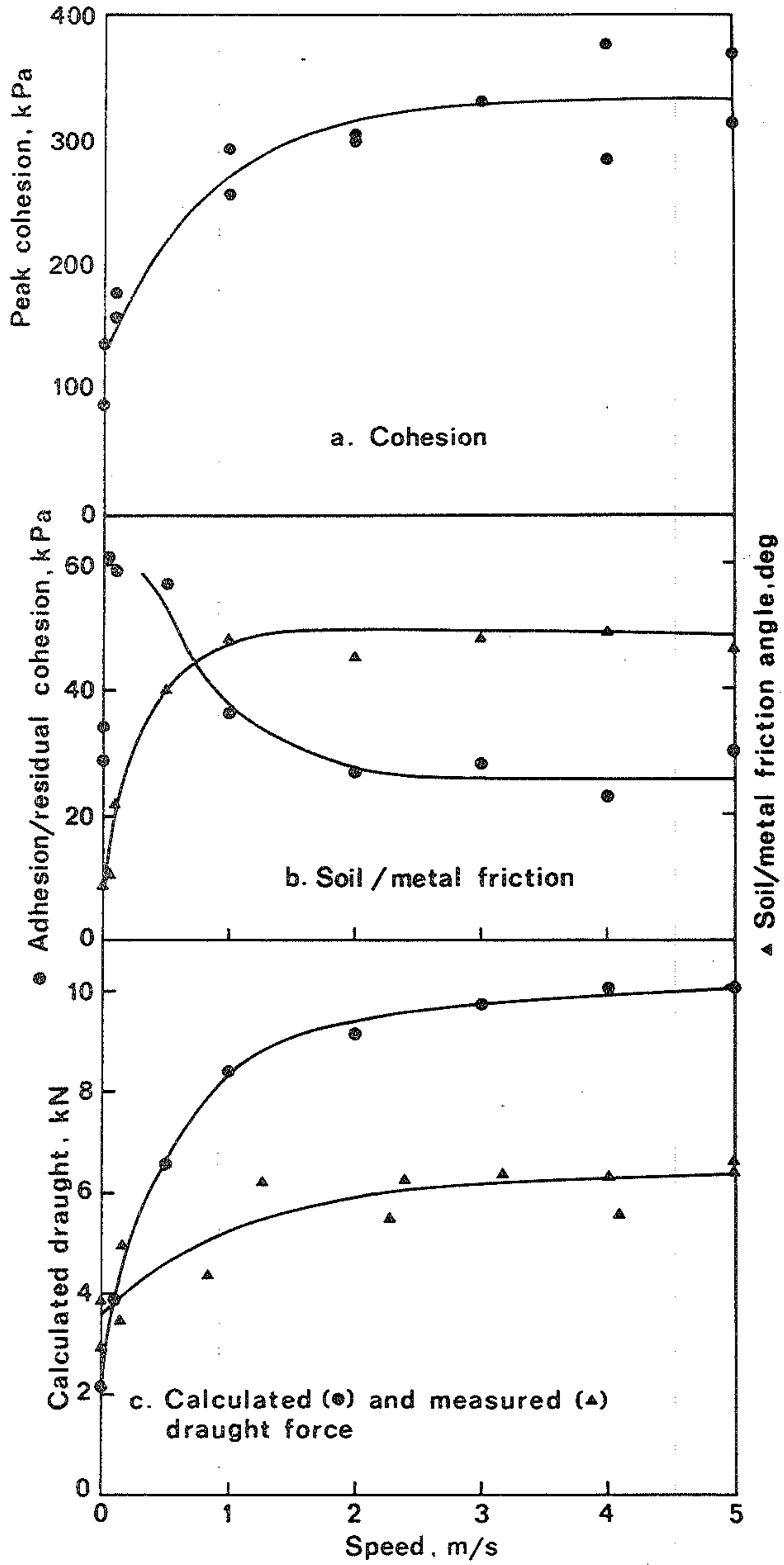

Fig.3. Strain rate effects in clay at 38% moisture content

Conclusion

A mathematical model to predict the performance of draught implements in terms of forces and soil disturbance would be of considerable value as a design aid. The possibility of developing a comprehensive model is doubtful but simplified models to predict forces and soil failure volume for quasi-static conditions exist. Prediction of the effect of speed on implement forces has been shown to be feasible taking the strain rate dependency of soil properties into account. Prediction of soil pulverisation by an implement, however, has not been achieved even for the quasi-static condition and is the most complex aspect of the modelling problem.

References

1. Soehne, W. and Moller, R. The design of mouldboards with particular reference to high-speed ploughing. Grundl. der Landtechnik 15 1962, p. 15

2. Wismer, R.D. and Luth, H.J. Rate effects in soil cutting. J. Terramech. 8 1972 p.11

3. Stafford, J.V. The performance of a rigid tine in relation to soil properties and speed. J. agric. Engng Res. 24 1979 p.41.

4. Wilton, B. The use of high-velocity tines in breaking clods. J. agric. Engng Res. 8 (2) 1963 p.107

5. Olson, D.J. and Weber, J.A. Effect of speed on soil failure patterns in front of model tillage tools. S.A.E. Paper No. 65-691. 1965

6. Stafford J.V. A versatile, high speed soil tank for studying soil and implement interaction. J. agric. Engng Res. 24 1979 p.57

7. Campbell, D.J. Plastic limit determination using a drop cone penetrometer. J. Soil Sci. 27 1976 p. 295

8. Hettiaratchi, D.R.P., Witney, B.D. and Reece, A.R. The calculation of passive pressure in two-dimensional soil failure. J. agric. Engng Res. 11 (2) 1966 p. 89

9. Rowe, R.J. and Barnes, K.K. Influence of speed on elements of draft of a tillage tool. Trans. A.S.A.E. 4 1961 p. 55

10. Stafford, J.V. and Tanner, D.W. An investigation into the effect of speed on the draught requirements of a chisel tine. 7th Conf. I.S.T.R.O., Sweden, 1976.

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EFFECT OF PERMANENT CORN PRODUCTION IN MONOCULTURE ON YIELD OF CORN AND PHYSICAL, CHEMICAL, AND MICROBIOLOGICAL PROPERTIES OF CHERNOZEM SOIL UNDER DIFFERENT SYSTEMS OF FERTILIZATION

Prof.Dr. Živojin Marković, Prof.Dr. Petar Drezgić,
Prof.Dr. Bogosav Živković, Prof.Dr. Zora Sarić,
Faculty of Agriculture Novi Sad
Institute of Field and Vegetable Crops
Novi Sad, Yugoslavia

ABSTRACT

Effects of permanent corn production in monoculture have been studied for 17 years. This report covers a three-year period (1975 - - 1977). Physical, chemical, and microbiological properties of soil did not suffer considerable changes as the result of different fertilization systems; it was observed that the shortage of manure may successfully be compensated by harvest residues. It may be concluded on the basis of the obtained yields that it is possible to grow corn in permanent monoculture, even for several consecutive years, providing that other agrotechnical conditions had been met, primarily deep and quality tillage which should be performed as early as possible in combination with an intensive mineral and organic fertilization.

INTRODUCTION

In Yugoslavia, particularly in the province of Vojvodina, a considerable change in the structure of field crop production has taken place in recent years. It conditioned an increased production of corn in monoculture, even for several consecutive years.

Recent studies and results of contemporary corn production correct to a certain measure the role of organic matter, attributing to it more and more the role of an activator of microbiological processes and factors of physical properties of soil, while mineral fertilizers become the basic source of plant nutrients. Obviously, it is necessary to keep applying organic matter; however, a reduction in cattle production, resulting in a decreased production of manure, imposes the problem of provision of sufficient quantities of organic matter. That is why attempts have been made to replace manure by harvest residues left over in plots after corn harvest.

This problem started to be studied in 1961/62 at the Institute of Field and Vegetable Crops of the Faculty of Agriculture Novi Sad. The work was established on permanent basis.

METHOD AND PERFORMANCE OF EXPERIMENT

The experiment is conducted at the experimental field of the Institute, at Rimski Šančevi, after the method of "standard" in four replications. The area of basic plot is 296.4 m^2. The type of soil is chernozem, of favorable physical properties, slightly alkaline, with medium humic content, moderate quantity of lime, medium provision by total nitrogen and readily available phosphorus, rich with readily available potassium.

The experiment includes the following variants:

1. Plowing under of corn harvest residues applying regular quantities of mineral fertilizers (243 kg/ha of pure NPK nutrients in the ratio 117:63:63).

2. Plowing under of 25 t/ha of manure in alternate years applying 243 kg/ha of NPK each year.

3. Application of mineral fertilizers alone (243kg/ha of NPK).

4. Non-fertilized.

(The corn is grown in monoculture in the above variants.)

5. Corn growing in two-crop system applying manure and mineral fertilizers as in variant 2.

6. Corn growing in two-crop system applying only manure as in variants 2 and 5.

In order to follow the effects of the applied measures on the changes in some important soil properties, morphological analyses of soil were performed per individual variants after corn harvest; soil samples were taken at the same time to analyse chemical, water-physical, and microbiological properties of soil.

RESULTS AND DISCUSSION

Results of the experiment conducted from 1962 to 1974 were reported in June 1975 at the Symposium on Intensification of Agricultural Production and Optimal Utilization of Ecosystem in Semicontinental Climate, held in Keszthely, Hungary. This report covers the period from 1975 to 1977, when we introduced into the experiment the mid-early hybrid NSSC-555, developed at Novi Sad.

As related with the initial years of the experiment, certain changes were observed in recent years in the morphological properties of plowing layer in different variants. The soil structure in the variants in which harvest residues or manure were plowed under (var. 1 and 2) is fine and medium crumby; in variant 1, in which corn harvest residues are plowed under, the remains of cellulose fibers may be seen, while in variant 2, in which manure is plowed under, the remains cannot be seen. In variant 3, in which only mineral fertilizers are applied, the plowing layer is somewhat more compacted, with an increased number of large crumbs which still crumble easily. In variant 4, non-fertilized one, clods up to 12 cm may be found in the plowing layer, between which there is ample space. In general, the plowing layer in this variant is non-homogeneous, with increased compaction in the layer 0 - 10 cm. The plowing pan is identical with all variants, having fine granular and fine crumby structure and uniform moisture.

Table 1 shows the basic agrochemical properties of soil per test variants. It may be seen that there were no significant differences in reaction (pH). Regarding the other properties, it may be seen that the non-fertilized variant (4) had lower values of contents of humus, total nitrogen, available P_2O_5 and K_2O in respect to the other variants. It may also be noticed that the variants fertilized with organic fertilizers (1, 2, 5, and 6) had a somewhat higher humic content in respect to variant 3, fertilized with mineral fertilizers only, and variant 4, non-fertilized. Significantly higher contents of phosphorus and potassium were found in variants with manuring (2,5,6).

Tab. 1 - Chemical properties of soil

Var.	pH		%			gr. per 100 gr of soil	
	in KCl	in H_2O	$CaCO_3$	Humus	N	P_2O_5	K_2O
1	6.53	7.50	0.33	3.11	0.172	12.8	25.5
2	6.47	7.39	0.41	3.18	0.170	21.6	32.0
3	7.07	7.98	0.38	3.02	0.184	12.0	20.5
4	6.33	7.41	0.52	2.85	0.149	3.9	10.3
5	7.02	7.90	2.00	3.20	0.189	25.1	32.2
6	6.95	7.83	1.57	3.08	0.164	20.9	32.9

The values of water-physical properties of the plowing layer (0-30 cm) are shown in Tab. 2. These values were rather uniform both per test variants and per soil layers within the variants, which is probably the result of favorable natural properties of chernozem soil. Still, a certain increase in volumic weight and a decrease in air capacity were observed in variant 4, which was non-fertilized. In general, the volumic and specific weight showed highest values in deeper soil layers in the majority of the variants. Conversely, the air capacity decreased with depth which may be attributed to the effect of tillage.

Tab. 2 - Water-physical properties of soil

Var.	Depth cm.	Volumic weight	Specific weight	Wilting point Vol. %	Total available water Vol. %	Air capacity Vol. %
1	to 15	1.41	2.59	16.45	15.92	13.18
	15-30	1.43	2.61	17.24	15.71	12.32
2	to 15	1.36	2.59	16.90	15.72	13.53
	15-30	1.38	2.58	16.60	15.45	14.87
3	to 15	1.36	2.61	16.49	15.28	15.46
	15-30	1.39	2.60	16.44	15.92	14.38
4	to 15	1.43	2.59	16.75	17.96	12.05
	15-30	1.48	2.61	17.89	17.85	11.59
5	to 15	1.38	2.59	17.01	14.69	14.42
	15-30	1.38	2.58	16.80	15.63	13.40
6	to 15	1.30	2.59	14.60	15.80	18.74
	15-30	1.35	2.60	15.40	16.70	17.79

Long-term microbilogical studies performed after harvest showed certain differences in the concentration of microorganisms in different variants. Largest changes were found in the total number of microorganisms which was higher in two-crop system than in monoculture. The plowing under of corn harvest residues and mineral fertilizers increased the total number of microorganisms in two-crop system as well as in monoculture. The results of our microbiological analyses indicate that the application of organic and mineral fertilizers causes changes in the biogenic properties of chernozem soil, which is manifested as an increase in the total number of microorganisms, especially of nitrogen-fixing bacteria. When these results were compared with the obtained yields of corn, a correlation was found between the biogenic properties of the plowing layer and the yields.

Tab. 3 shows three-year corn yields obtained in 14th, 15th, and 16th year of the experiment. The following may be concluded on the basis of these results:

In contrast with the results from the previous 13 years, when practically there were no differences between variants 1 and 2 (Marković, Drezgić, 1975), the observed three experimental years favored the application of manure over the application of harvest residues. The differences, however, were non-significant compared either per year or on the average, for 5% or 1%. Similar results were obtained by Mihalić (1967, 1971, 1973) who maintains that high and profitable yields may be obtained in monoculture by plowing under harvest residues at 30 cm and applying mineral fertilizers in the ratio 2:1:1; Škorić and Rac (1969) found that in conditions of intensive cultural practices and supplementary irrigation the largest part of plowed under corn harvest residues (93%) is decomposed in the first year, releasing by the same token 40 kg/ha of N, 12 kg/ha of P_2O_5, and 49 kg/ha of K_2O. Jovanović et al. (1972) concluded that the plowing under of corn harvest residues affects positively the soil structure and corn yield; Amberger and Aigner (1969) emphasized that the plowing under of corn harvest residues in combination with nitrogen fertilization increases the yields of subsequently grown crops.

Tab. 3 - Yields of dry grain at 14% moisture

Var.	Yield of dry grain (mtc/ha)			
	1975	1976	1977	Average
1	107.2	102.9	106.4	105.5
2	110.3	105.0	110.1	108.5
3	87.9	98.1	93.4	93.1
4	31.3	45.9	29.4	35.5
5	107.0	106.9	112.6	108.8
6	96.0	106.0	99.0	100.3

LSD 5% = 4.68
1% = 6.26

The application of mineral fertilizers alone (var. 3) significantly lowered the yields in relation to variants 1 and 2 in all three years. On the three-year average, this difference is 15.4 mtc/ha which is considerably higher than the differences found in the previous 13-year period.

Although the experimental years had favorable climatic conditions for corn growing, very low yields were obtained in the variant which had not been fertilized for an extended period (var. 4). On the three-year average, the yields were lower by 70 - 74% as compared with the first three variants, which approximates the results from the previous experimental period.

In two-crop system, the fertilization with manure and mineral fertilizers (var. 5) brought significant yield increases in relation to manuring alone (var. 6); on the three-year average, the difference was 8.5 mtc/ha in favor of variant 5, which is significant for both 5% and 1%.

The highest average yield (108.8 mtc/ha) was obtained in two--crop system, variant 5; however, this increase is non-significant (only 0.3 mtc/ha) in relation to the yield of variant 5 in monoculture. On the other hand, the plowing under of corn harvest residues and mineral fertilizers in monoculture (var. 1) brought 5.2 mtc/ha higher yield than the manuring alone (var. 6) in two-crop system.

According to the results of Stojanović et al. (1970, 1971, and

1972), it is possible to obtain high yields of corn on smonitza soils of eastern Serbia providing that intensive cultural practices are applied; Bulgarian authors Stoimenov (1971) and Calov (1972) also maintain that high and profitable yields may be obtained in monoculture, especially if irrigation, intensive fertilization, deep tillage, and weed control are applied.

LITERATURE

1. Amberger, A., Aigner, H.: Ergebnisse eines acht jährigen Feldversuches mit Strohdüngung, Zeitschrift für Acken und Pflanzenbau, Hamburg - Berlin, Band 130, Heft 4, 1969.
2. Calov, J.: Minimalni obrabotki na počvata pri otgleždanie na carevicata kato monokultura, Rastenievodni nauki, no. 10/1972, Sofija, 1972.
3. Jovanović, R. et al.: Uticaj zaoravanja kukuruzovine na neke osobine zemljišta i prinos kukuruza u uslovima sa i bez navodnjavanja, Arhiv za poljoprivredne nauke, sv. 89, Beograd, 1972.
4. Marković, Ž.: Osnovni elementi proizvodnog procesa za kukuruz, izdanje Saveza inžinjera i tehničara Jugoslavije, Beograd, 1973.
5. Marković, Ž., Drezgić, P.: The results of the investigation on permanent monoculture of maize (thirteen years) with plowing in of harvest remains and fertilization with manure and mineral fertilizers in comparison with two-crop rotation of maize and wheat, Keszthely, Hungaria, 1975.
6. Mihalić, V.: Kukuruz u sistemima biljne proizvodnje (Gotlin, J. et al., Suvremena proizvodnja kukuruza, str. 229), Zagreb, 1967.
7. Mihalić, V. et al.: Istraživanja sa zaoravanjem kukuruzovine uzgojem kukuruza u monokulturi, Savremena poljoprivreda, no. 1-2, Novi Sad, 1971.
8. Mihalić, V. et al.: Zaoravanje kukuruzovine u monokulturi kukuruza na aluvijalnom tlu, Agronomski glasnik, no. 1-2, Zagreb, 1973.
9. Stojanović, M.: Rezultati ispitivanja gajenja ozime pšenice i kukuruza u monokulturi u agroekološkim uslovima istočne Srbije, Zbornik radova Poljoprivrednog fakulteta, sv. 503, Beograd, 1970.
10. Stojanović, M., Žikić, M.: Ispitivanje uticaja monokulture i plodoreda na prinos pšenice i kukuruza, Arhiv za poljoprivredne nauke, sv. 85, Beograd, 1971.
11. Stojanović, M. et al.: Uticaj sistema gajenja kukuruza i đubrenja na visinu biljaka i prinos na smonici u Zaječaru, Agrohemija, no. 9 - 12, Beograd, 1972.
12. Stoimenov, I.: Torene na carevica monokultura pri napojavane, Počvoznanie i agrohemija, no. 5, Sofija, 1971.
13. Škorić, A., Rac, Z.: Neki pokazatelji razgradnje i uticaja organske tvari tla u ponovljenom uzgoju (monokulturi) kukuruza, Zemljište i biljka, vol. 18, no. 1-3, Beograd, 1969.

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THE NOTION OF "NORMAL BULK DENSITY" IN ARABLE SOILS

Reijo Heinonen

Department of Soil Sciences
Swedish University of Agricultural Sciences
S-750 07 UPPSALA, Sweden

ABSTRACT

Soil compaction may or may not be harmful, and packed soils may or may not improve spontaneously. Different field observations may be easier to understand if a predictable "normal" bulk density (NBD) of the soil can be used as a reference value. By sampling a suitable range of soils, which have reached an equilibrium bulk density after a period of arable farming, it is possible to derive regression equations giving the NBD as a function of soil composition. The notion of NBD seems to be useful in many soils, but there are cases where it is obsolete or irrelevant.

Introduction

The bulk density (BD) of arable soils is regularly subjected to large changes caused by mechanical loosening and compaction treatments. Between the treatments, however, there are long periods of rest, when various natural processes may modify the structure of the soil, and adjust the BD towards a state where loosening and compacting processes eventually balance each other. The hypothesized equilibrium value, which can be called "normal bulk density" (NBD) of a given soil layer, is a function of the composition of the soil (especially texture and organic content), the depth, and the environment.

Voorhees et al. (11) reviewed a number of American studies showing spontaneous loosening of packed <u>topsoils</u> under the influence of annual moisture variations and freezing-thawing, and Vetter & Lichtenstein (10) observed a similar case in Germany. In <u>subsoils</u> the loosening process seems to be slower, and sometimes negligible (1, 2, 3, 8, 11). The aim of this paper is to indicate possibilities to assess the NBD of different soils and to use it as a reference value in soil structure studies.

The bulk density of topsoil

The notion of NBD is relevant only under conditions where a regular system of arable farming has continued long enough to remove the specific features of soil strucutre which may have developed during the previous history of the soil. Besides, the cyclic variations of soil structure, taking place under moisture variations and the cropping cycle, should be smoothed over.

A useful way to assess the NBD is to sample fields under 2 to 3 year old rotation grasslands (fields under plowless farming would probably do as well). If the sampling is done under uniform moisture conditions (field capacity), and covers a suitable range of textures and organic matter contents, it is possible to derive regression equations giving the BD as a function of soil composition. Such a study, made before the introduction of heavy machinery, and covering 111 fields in Finland (5), resulted in the following equation, where the BD of layer 5-15 cm is given as a function of the percentages of organic carbon (X_1), clay under 2 µm (X_2), and sand 0.06-2 mm (X_3):

$$BD = 1.40 - 0.072\,X_1 - 0.0013\,X_2 + 0.0014\,X_3 \qquad (1)$$
$$R = 0.84^{***}$$

Sandy soils with a narrow range of grain sizes are not suitable for this type of regression analysis; the direct correlation between bulk density and sand percentage seems to cease above the sand content of 50%. Theoretically, there should be a curvelinear relationship with maximum values between 50 and 85% (see papers reviewed by Larson and Allmaras, 7). In very humuous soils with BD below 1 g/cm^3, soil composition also failed to explain satisfactorily the observed variations in bulk density.

Experimental data obtained at our department show that the NBD of topsoil, predicted by equation (1), lies in the optimum BD-range for cereal crops. It should be stressed, however, that most of the experiments with soil compaction were carried out under conditions of rather low rainfall. Under rainy conditions the optimum BD would be lower.

The bulk density of subsoils

The problems of natural and artificially induced variations in soil BD are more complicated in the subsoil than in the plow layer, because the changes are usually small and slow. It may be difficult to distinguish the effects of heavy traffic from "compaction" caused by shrinking, slaking and filling of the cracks. The loosening processes by swelling and freezing may be ineffective or exceedingly slow. Under certain conditions the bulk density is merely a result of specific soil forming processes. At least 3 cases where the notion of NBD as an equilibrium value is rather irrelevant, can be pointed out:

1. Sandy soils where clay and silt content is too low to facilitate effective loosening through irregular swelling and shrinking by varying moisture content, and through lense formation by freezing. A compact structure, whether natural or artificial, is therefore very persistent (4, 8).

2. Loamy soils under conditions of intense downward migration of caolinitic clay (lessivage). This is an oneway process which can lead to extremely high bulk densities in the absence of freezing, notably in certain old tropical soils (there is very little swelling and shrinking in caolinitic clays).

3. Heavy montmorillonitic clays with a notable amount of exchangeable sodium (especially tropical vertisols). Cracking and swell-

ing processes are so powerful, that the structure of the soil profile is effectively "zeroed" after every major rain period (personal communication with Prof. Ahmad, Trinidad). The notion of NBD is therefore obsolete.

On the other hand, the notion of NBD seems to be useful in clay soils in less extreme climates. In a group of Finnish subsoils (glacial sediments low in sand and very low in organic matter), the texture explained the BD-variation about as well as texture and organic matter together in topsoils (5). The BD of layer 30-50 cm could be given as a function of the soil's clay (X_1) and silt 2-20 µm (X_2) percentages as follows:

$$BD = 1.42 - 0.0016\ X_1 + 0.0021\ X_2 \qquad R = 0.79^{***} \qquad (2)$$

The natural BD of these soil layers obviously reflects an equilibrium state after many cycles of wetting-drying and freezing-thawing. Plant root activity and other biological structure-forming agents are rather weak, or too recent, to have any pronounced effect on soil structure.

In undisturbed soils where biological agents have had a strong influence on soil structure formation, as in deep black soils, the root zone BD is much lower than indicated by equation (2). Continuous cultivation will then gradually break down the natural porous structure of the soil, whereby its BD increases (1, 9) and may ultimately approach the NBD as defined in this paper. If the structure is disturbed artifically by puddling and compaction, it is probable that moisture variations and freezing-thawing will loosen the soil only as far as the compaction has gone beyond the NBD (6). It is also obvious that a certain hysteresis gap remains between the equilibrium BD-values approached from different initial states.

The persistence of subsoil compaction has become an important issue in the restoration of construction sites, and in the estimation of damage of agricultural lands caused by military manouvres or other extraordinarily heavy traffic. It would, therefore, be highly desirable to obtain more experimental data on the rate of spontaneous loosening processes under different conditions. We know that in most cases our crop yields return to normal level during the second season after extraordinary compaction, but there are indications that the restoration of subsoil porosity and permeability may sometimes take much longer (2, 11). Hedberg (4) studied the loosening effect of artificial freezing-thawing cycles in a group of about 50 Swedish soils, ranging from loam to sand, and found that most soils needed 5 to 10 cycles to reach an equilibrium BD. The effext of the first cycle was, naturally, always largest and in some cases it produced almost all of the loosening effect attainable by the freezing-thawing processes.

References

1. Blake, G.R., Nelson, W.W. & Allmaras, R.R. 1976. Persistence of subsoil compaction in a mollisol. Soil Sci. Soc. Am. J. 40, 943-948.

2. Danfors, B. 1974. Packning i alven. Jordbrukstekn. Inst. Specialmedd. 24.

3. Dickerson, B.P. 1976. Soil compaction after tree-length skidding in Northern Mississippi. Soil Sci. Soc. Am. J. 40, 965-966.

4. Hedberg, 4. 1976. Volymförändringar hos jordarter efter upprepad frysning och tining. Ph.D. Thesis, Univ. of Stockholm.

5. Heinonen, R. 1960. Das Vólumgewicht als Kennzeichen der "normalen" Bodenstruktur. J. Sci. Agric. Soc. Finland 32, 81-87.

6. Heinonen, R. 1977. Towards "normal" soil bulk density. Soil Sci. Soc. Am. J. 41, 1214-1215.

7. Larson, W.E. & Allmaras, R.R. 1971. Management factors and natural forces as related to compaction. ASAE Monogr. Compaction of agricultural soils, p. 367-427.

8. Ouwerkerk, C. van 1968. Two model experiments on the durability of subsoil compaction. Neth. J. Agric. Sci. 16, 204-210.

9. Page, J.B. & Willard, C.J. 1946. Cropping systems and soil properties. Soil Sci. Soc. Am. Proc. 11, 81-88.

10. Vetter, H. & Lichtenstein, H. 1968. Die biologische Auflösung von Unterbodenverdichtungen. Landw. Forsch. Sonderheft 22, 85-88.

11. Voorhees, W.B. Senst, C.G. & Nelson, W.W. 1978. Compaction and soil structure modification by wheel traffic in the Northern Corn Belt. Soil Scil Soc. Am. J. 42, 344-349.

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Mechanics of subsoiled structure

K.H. Hartge

Institut für Bodenkunde, Universität Hannover
Fed. Rep. Germany

ABSTRACT
The effect of subsoiling and deep ploughing is only temporary in very many cases. To keep a subsoiled area from recollapsing usually soil conditioners are necessary. At two examples it is shown, how the stress-situation in a soil is changed by subsoiling or deep ploughing. From the relation of main-stresses it can be seen, that cultivated soils usually are overconsolidated in equilibrium with heaviest routine traffic. This state can only be changed by avoiding heavy machinery, increasing soil strength or partly by changing geometric patterns of loosening.

There has been some emphasis on experiments to meliorate soils by deep ploughing down to 100 cm depth or even more, or by subsoiling with different kinds of chisels or similar tools down to about the same depths.

Most of these experiments were started about the end of the sixties and quite obviously the response was not so good, as to encourage introduction of these techniques into practical agriculture to any larger extent.

At the institute of soil science in Hannover two experiments were started in 1967 and 1968 respectively. The results have been presented at ISSS-Meeting, 1971 Stuttgart, Excoursion C, 1971 and at XI. Int. Congr. Soil Sci. Edmonton 1978 respectively. The first experiment was conducted in the experimental orchard of the horticultural faculty at Hannover. This proved not to be a success, as the desired effect was only partly achieved and did not last for more than half a year on one part and just one year on another part of the plot. The other experiment was run in the greenhouses of a commercial horticulturist. Subsoiling was accompanied here by severe liming (7 g/l = 70 t/ha for 1 m depth). This proved to be successful for 10 years whereas in some greenhouses where the subsoiling had been done in the first years without lime the structure collapsed within the first 4 years (Hartge, 1978).

Both these soils were formed on glacial loess deposits of ~1,5 m thickness. They were Parabraunerde according to German systematik and Udalf according to 7th approximation.

Now the question is why do these soils collapse again and what is the reason for different stabilities of these soils.

To investigate this, the approach of general soil mechanics was adapted. First the compression curves of the soils were drawn, plotting void ratio against vertical stresses on the abscissa. The results which have been published elsewhere in detail (Hartge u. Sommer, 1978) are schematically shown in fig. 1. From this can be seen, that void ratios do not fit in with a log-normal stright lime in a soil used in normal agriculture (a). Only at stresses $\gtrsim$100 cN cm^{-2} an approximation to a stright line was visible. When this soil was deep-ploughed, then the part of the regression fitting the stright line was extended to minor stresses so much longer, so more successful the loosing action was. This is represented for the melioration in the successful case, -that is relatively stable structure-in the orchard by (b). But even this was changed back to (a) within the relatively short time of one year. Still better fit was obtained in the greenhouse, where no heavy traffic occurred on the soil (c) but even this did not last suffiently, so subsoiling had to be repeated to keep this standard. By adding lime (CaO) the stability of the soil had been increased severely which gave a specially long fit to the stright line. At the same time this line moved towards higher stresses for a given void ratio (d).

These results show a situation but do not give any information on the mechanisms involved. Therefore again an approach from general soil mechanics is adapted. This is shown in fig. 2 for the greenhouse soil. The orchard soil showed a similar result. The deviation from the linear regression however on the left hand side of the drawing (σ_x values) goes down to greater depths after melioration than in the greenhouse soil.

Both cases show at their right hand side the increase of vertical stress σ_z plotted against depth below soil surface. The stresses are calculated by summing up the weights of the soil above a given point. In the shown examples these relations seem to be approximately linear. The line corresponding to the state of highest loosing effect is seen to the left of the original curve, thus showing the decrease of vertical stress in a loosened soil if equal depths, measured from soil surface downward, are compared. On the left hand side the horizontal stresses (σ_x) have been plotted against depth of soil. The values from σ_x were obtained by using the wellknown equation (Kezdi, 1969):

$$\sigma_3 = \sigma_1 \left(\frac{1 - \sin\varphi}{1 + \sin\varphi}\right)$$

In this equation σ_3 represents the active earth pressure. Values for angle of internal friction (φ) and cohesion (c) were arbitrarily taken to be 30° and 0 respectively. This last condition was introduced for simplicity of calculation. For $c > 0$ the value of σ_3 will decrease. The lower value (σ_{3c}) can be calculated from the Mohr-circle starting with the relation

$$\frac{\sigma_3}{\sigma_1} = \frac{c \cdot \mathrm{ctg}\,\varphi + \sigma_{3c}}{c \cdot \mathrm{ctg}\,\varphi + \sigma_1}$$

to be

$$\sigma_{3c} = \frac{\sigma_3 \, (c \cdot ctg \, \varphi + \sigma_1)}{\sigma_1} - c \, ctg \, \varphi$$

Values for σ_x calculated as explained would result in a stright line as shown on the left hand side of fig. 2.

There is however another possibility to calculate horizontal stresses. To this end from the void ratios at subsequent depths in the soil the corresponding maximal vertical stresses are taken from the primary branch - that is right hand end - of the compression curve (vis. fig. 1). According to the general principle horizontal stresses do not relax when the vertical load is removed. So they can be calculated using the same formula as before. The results given in fig. 2 (left) show, that actually both soils investigated here are precompacted i.e. their horizontal stress is much in excess to what is brought about by the weight of the soil itself.

This compaction is strongest near the soil surface and decreases toward deeper layers. Furthermore it is much more pronounced in the orchard soil than in the greenhouse soil. This is easily understandable since the surloads applied in the orchard are much greater than those usually occurring in greenhouses.

Apart from this, these results give an indication that the collapse of the structure is not invoced by the weight of the soil itself but by temporary greater loads. Therefore loosening actions are only successful for a longer time if one of the following conditions is met:

1) Avoiding or diminishing temporary loads.
This is difficult to achieve in general agriculture because it means decrease of machinery weight and this is contrary to current technical trends. It should be thought over however whether it is possible to arrange that only parts of the cultivated area are met by traffic i.e. riding all machinery on special wheel paths. This would come to be same thing that is done

in intensive horticultural cropping, when all traffic is kept strictly to walking or riding paths.

2) Increasing intrinsic stability of the soil.
This could be achieved by keeping the soil drier as before but this is not desirable for the crop. So the only remedy is using soil conditioners. An example for this is the greenhouse soil shown in fig. 2. This had been stabilized thoroughly, not because of the weight of expected machinery, but because of the expected low stability at the high water contents at which horticultural crops are grown.

3) Theoretically there is still a third possible approach.
This consists of increasing the heterogenity of packing of the soil by partial loosing. The effect of such an action can be further increased, when the geometric shape of the newly created voids is favourable to withstand compression in vertical direction. This means that holes pressed into the soil axial to the expected maximal stress will not as easily collaps as randomly formed voids or planar cracks in directions rectangular to the maximal stress.

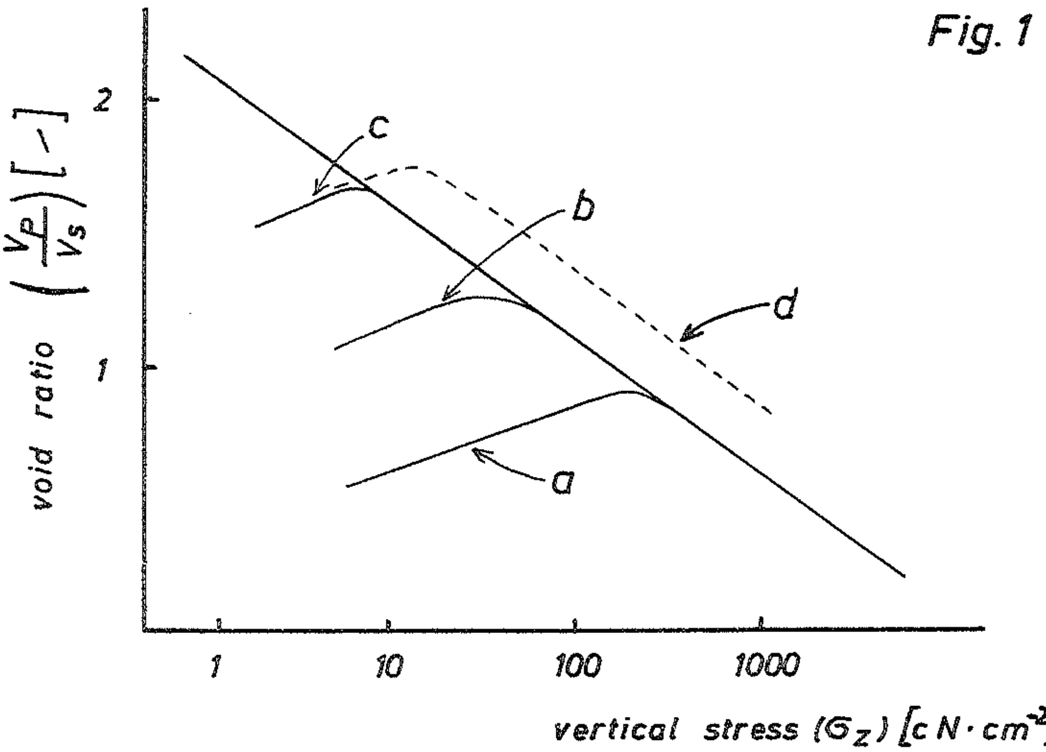
Literature

Hartge, K.H. (1971) Mitt. Dtsch. Bodenkundl. Ges. 13, 245-262

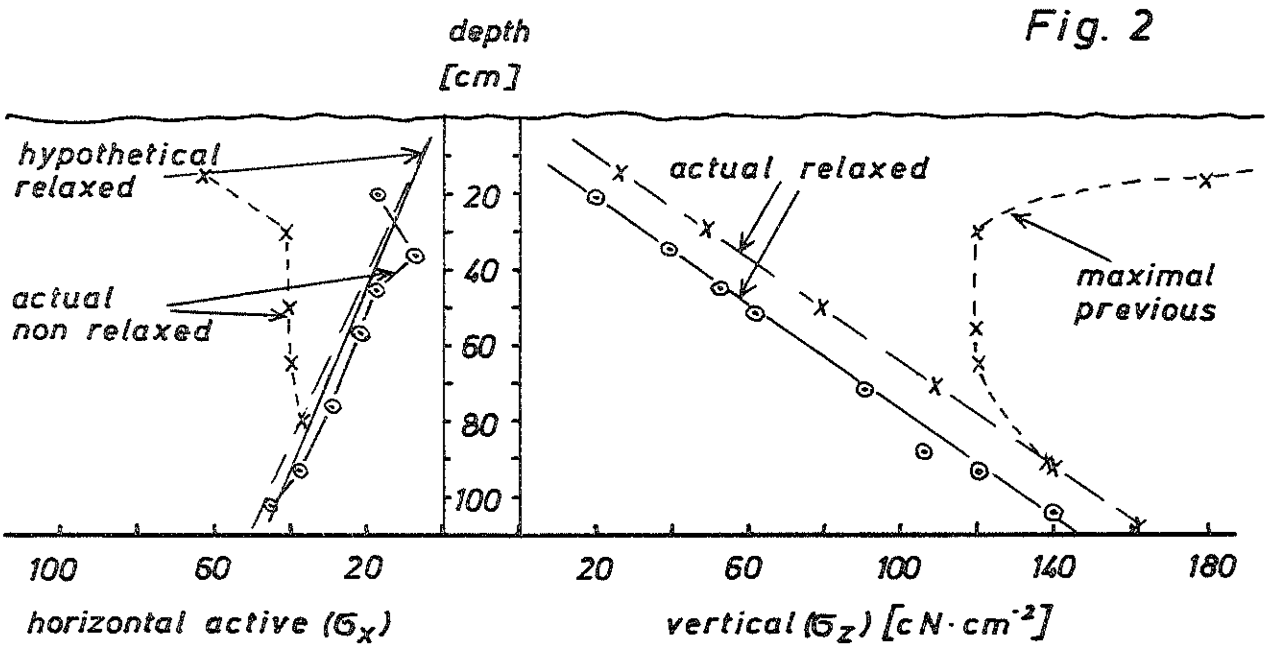
Hartge, K.H. (1978) Trans. XI, Congr. Int. Soc. Soil Sci. Edmonton I, 291-292 (File Nr.335)

Hartge, K.H. u. Sommer, C.(1978) Z. Kulturtechn. u. Flurber. (im Druck)

Kézdi, A. (1969) Handbuch der Bodenmechanik I. Bodenphysik VEB-Verlag Bauwesen, Berlin



Void ratio versus vertical stress calculated from weight of overlying soil: routine agriculture (a), deep ploughing 6 months ahead of sampling (b), subsoiling in greenhouse 1 year ahead of sampling (c), subsoiling and liming in greenhouse 2 years ahead of sampling (d)



Principal stresses in the greenhouse soil, calculated from weight of soil (stright lines) before (stroked) and after subsoiling (fulldrawn) and assuming maximal vertical load from void ratio using fig. 1 (curved lines)

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PENETRATION RESISTANCE OF PELOSOL SAMPLES AS AFFECTED BY THEIR MOISTURE STATUS

H.H.Becher

Lehrstuhl für Bodenkunde, Technische Universität München,
D-8050 Freising-Weihenstephan

ABSTRACT

Penetration resistance to a 1.5 mm probe at 5 different soil moisture tensions was measured on soil core samples from a Pelosol profile. Penetration resistance was significantly correlated with the moisture tension and water content of the sample. Penetration resistance at about 450 cm moisture tension is large enough to strongly impede plant root growth. Under field conditions, this soil type can only be ameliorated by decreasing the bulk density by subsoiling and manuring.

Introduction

Clayey soils are noted for the problems they present to tillage practices because there is only a relative short time in which soil moisture conditions are optimum for tillage. Clayey soils also cause problems for plants, particularly the less adapted agronomic plants, because these soils offer a high resistance to penetration by plant roots. To obtain an idea of the forces which plant roots must overcome, penetration resistance of soil core samples from a Pelosol was measured at different moisture tensions.

Methods

Three soil core samples (~370 cm³) were taken from each of 4 horizons of a Pelosol profile which contained 55% clay in the A horizon and 60-64% clay in the typical Pelosol horizons (Tab.1). Each core was equilibrated to the required moisture tension and the penetration resistance measured by means of a recording penetrometer (Becher,1978a) using a 1.5 mm probe, the shaft of which was reduced behind the 30° probe tip. The measurements were replicated 3 times per core for each moisture tension. The cores were equilibrated to tensions of 200, 300, 400, 50 and 100 cm of water in that order. The probe shaft was not reduced along its entire length, therefore only the force-to-depth relationship for the range in which the shaft was reduced was used in subsequent calculations. Using this graphically recorded force-to-depth relationship (an example for each tension is given in Fig.1), the resistance to penetration /kp/cm²/ at 3 cm penetration depth was calculated by linear regression. The averages of these values for each tension and horizon were correlated with moisture status and other soil properties.

Results

The avergae penetration resistance at 3 cm depth (Tab.2) is slightly larger for 50 and 100 cm water tension than for higher tensions. This is due to equilibrating the samples at 50 and 100 cm of water after having measured at 400 cm of water as already mentioned. Nevertheless, the resistance to penetration increased for each horizon with increasing soil moisture tension(Tab.2). This is more pronounced when one considers the 50-100 cm and 200-400 cm ranges separately. In 4 of these 8 cases the dependance of penetration resistance on moisture tension was significant at the 0.1% level while the others were significant between the 1% and 5% levels.

Penetration resistance increases with soil depth (Tab.2) as does bulk density and clay content (Tab.1), resulting in high correlation with soil properties. Considering the whole profile, the relationship between moisture tension and penetration resistance is very bad (r=0.023) which is due to the order in which the samples were equilibrated. However, the reletionship with water content is highly significant (r=0.784). Bulk density, clay content and organic matter content significantly influenced penetration resistance (r=0.775, 0.716, 0.755 resp.) with bulk density having the greatest influence because the coefficient of multiple regression for these three properties was R=0.776. Including water tension and water content results in R=0.793, the best correlation coefficient obtained.

Discussion

Friction between soil and metal was not taken into account in this study. Plant roots, which unlike metal probes excrete musilages, can hardly penetrate soil when the penetration resistance is 25 /kp/cm²/

(Taylor et al. 1966, Cockroft et al. 1969). This means that in the Pelosol studied, root growth will be strongly impeded if soil moisture tension exceeds 400-500 cm of water in the A_p horizon. Root growth will be impededat even lower tensions in underlying horizons. Measurements made on aggregates of this Pelosol (Becher, 1978b) confirm this.

Impeded root growth, and therefore poor growing conditions, beginning at such low soil moisture tensions is the reason for the relatively low and very uncertain crop yields observed for this soil type. It should be kept in mind that rewetting the soil after a long dry period does not necessarily decrease penetration resistance drastically (Tab.2) even though the equilibration time at 50 cm of water (from 400 cm of water) was at least 6 weeks.

For ameliorating such a Pelosol, it is recommended that the bulk density of the soil be decreased by subsoiling in several stages and/or manuring. It should be kept in mind that the better aeration status of the soil after subsoiling will lead to faster decomposition of the organic matter which would cause some increase in penetration resistance. However, very high rates of manuring will result not in a decrease in penetration resistance according to results obtained from aggregate samples (Becher,1978b).

In conclusion, penetration resistance in Pelosols, such as in the soil studied, is high enough to impede root growth at soil moisture tensions of 450 cm of water. This penetration resistance can only be reduced by decreasing the bulk density of the soil.

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References

Becher,H.H.(1978a): Ein verbessertes Verfahren zur Messung des Eindringwiderstandes. Zeitschr. f. Kulturtechnik u. Flurber. 19, 138-146

Becher,H.H.(1978b): Wasserspannungsabhängiger Eindringwiderstand eines Pelosols. Geoderma 21,105-118

Cockroft,B.,Barley,K.P.,and Greacen,E.L.(1969): The penetration of clays by fine probes and root tips. Austral.J.Soil Res. 7,333-348

Taylor,H.M.,Roberson,G.M.,and Parker,J.J.(1966): Soil strength-root penetration relations for medium-to-coarse textured soil material. Soil Sci. 102,18-22

Table 1: Some properties of the Pelosol profile.

horizon	pH	Carb. [%]	o.m. [%]	texture [%] clay	silt	sand	b.d. [g/cm³]
A_p	7.2	8.7	4.1	55	31	14	1.23
A_hP	7.2	7.5	1.7	61	30	9	1.50
P_1	7.3	17.8	1.6	60	33	7	1.62
P_2	7.4	25.3	1.3	64	34	2	1.67

b.d. = bulk density

Table 2: Mean penetration resistance [kp/cm²] at 3 cm penetration depth for different soil moisture tensions.

horizon	depth [cm]	tension [cmWC] 50	100	200	300	400
A_p	0-20	13.1	16.2	10.6	14.3	18.1
A_hP	20-28	19.3	27.1	19.5	21.7	27.1
P_1	28-50	21.7	38.5	20.5	25.4	24.8
P_2	50-75	25.1	33.1	25.4	26.7	27.6

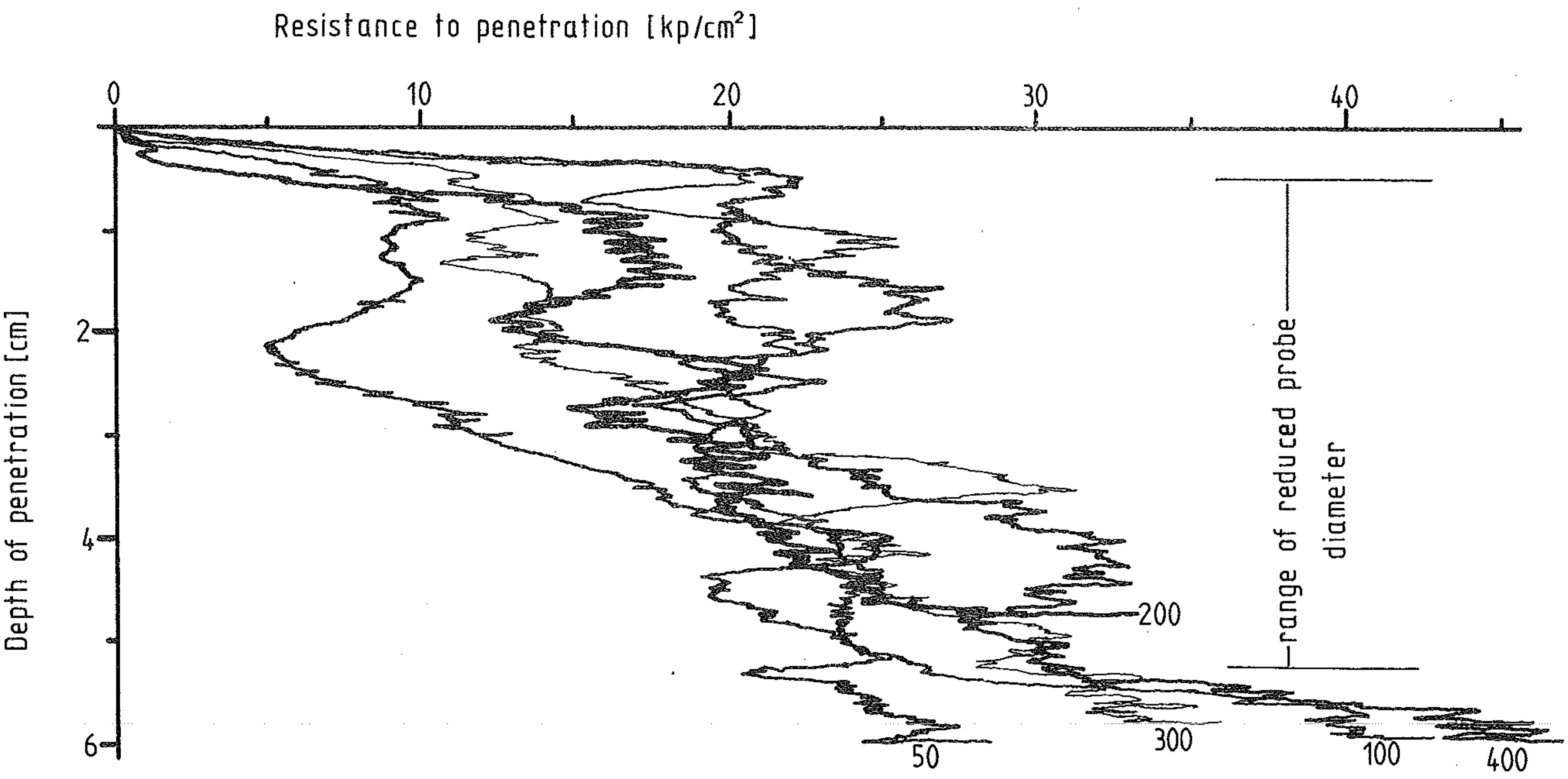

Fig. 1: Depth-penetration resistance for the same core of the A_hP of the Pelosol as affected by watertension [cmWC]

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TILLAGE WITH TILE DRAINAGE IN RESTORED SOIL[1/]

Stanley J. Henning, Don Kirkham, and Stephen B. Affleck[2/]

ABSTRACT

Maize physiological maturity and grain yield have been influenced by deep tillage of compacted soil at a reclaimed surface mine. Farming operations have been delayed at this site by waterlogged soils. These observations and other calculations have indicated that both tile drainage and deep tillage may be necessary in replaced soils where compacted horizons hinder root growth and water movement.

Background

Iowa is a state with a history of coal mining. Coal was discovered here over 100 years ago, and at the turn of the century a flourishing mining industry existed. After World War II, coal as a source of energy was displaced by petroleum and natural gas. During the past few years, decreasing supplies and increasing costs of petroleum and natural gas have forced Iowans to turn to coal once again as a dependable source of energy.

As the coal mining industry in Iowa declined after World War II, the technology of coal mining and processing did not keep pace with developments elsewhere in the United States and the world. To update the technology of mining and processing coal, the Iowa General Assembly in 1975 funded a three-year research project at Iowa State University. This research effort became known as the Iowa Coal Project. One of the major accomplishments of the project was to operate successfully its own coal surface mine in southeastern Iowa. That mine operated from July 1975 to November 1977. During this period, approximately 100,000 metric tons of coal were extracted from a 16.2-ha tract, and the land was reclaimed for farming. This report is intended to provide background information on the progress made toward producing an agricultural crop and on the problems encountered since the site was reclaimed, in particular the problems of tillage and drainage.

The Iowa Coal Project Demonstration Mine is located in Mahaska County, Iowa (legal description: SW 1/4, NW 1/4 of section 11, Tier 74 N, Range 17 W, 5th P.M.). The topography of the site before mining was a hillside with slopes up to 15% and a south-southeast aspect. Soils consisted of Boone fine sandy loam (mesic, uncoated, typic quartzipsamment), Clinton silt loam (fine, montmorillonitic, mesic, typic hapludalf), and Colo silty clay loam (fine-silty, mixed, mesic, cumulic haplaquaoll) soil series (Soil Conservation Service, 1977). The Clinton soil had developed from loess and dominated the

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1. Journal Paper No. J-9518 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa 50011. Projects No. 2166 and 2324.

2. Assistant Professor and Distinguished Professor Emeritus of Agronomy, Iowa State University, Ames, Iowa 50011, and Assistant Professor of Civil Engineering, Utah State University, Salt Lake City, Utah 84121.

site. The subsoil of this soil had a finer texture (silty clay loam) than the surface soil.

Surface soil (0-0.5 m), subsoil, and consolidated overburden were removed separately during mining, stockpiled as was necessary, and replaced sequentially into a benched terrace configuration instead of the original contour. Rubber-tired, twin engine scrapers of 14 and 18 cubic yard capacity were the primary earth-moving equipment. Agricultural research was initiated on restored soil in 1976. The entire 16.2-ha tract became available for agricultural studies in 1978.

Agricultural Cropping Studies

Compaction of soil and overburden resulted when these materials were replaced with the rubber-tired scrapers. The density of replaced surface and subsurface soil materials was approximately 1.6 gm/cm^3. Trials to determine the response to deep tillage of the compacted soil were initiated in 1976 on a 1-ha portion of the site that was restored in April of that year. *Zea mays*, hereafter referred to as maize, was the crop. Comparisons of maize yields were made for plots that received no deep tillage, plots tilled with a "V" agricultural subsoiler, and plots ripped with a construction ripper attached to a bulldozer. Tillage was 0.5 m deep with a 0.6-m spacing between subsoiler or ripper shanks. The shanks of the agricultural subsoiler were 2.54 cm wide and were one-fifth as wide as a ripper shank.

Larger clods resulted from tillage with the construction ripper than resulted from the agricultural subsoiler. These larger clods later interfered with seedbed preparation.

Maize yield results from 1976 are given in Table 1. Although the grain yields are one-third to one-half the yields normally achieved in Iowa, they show that maize responded markedly to different tillage treatments, and that tillage can have a significant role in restoring mined land productivity. The greater plant density in the plots tilled with the agricultural subsoiler indicated that the best seedbed resulted from this treatment.

Table 1. Maize plant density and grain yield data from tillage trials at the Iowa Coal Project Demonstration Mine, 1976.

Tillage implement	Plant density	Grain moisture content	Grain yield+
	Plants/ha	Percent by weight	Quintals/ha‡
Check, no deep tillage	26,050	37	17.5
Agricultural Subsoiler	33,950	22	37.0
Construction ripper	27,050	25	25.5

+Average of eight samples.

‡Adjusted to 15% moisture content.

In 1977 another trial was conducted to again measure the response of maize to different tillage treatments. But plant stress due to drought and high temperature occurred in late June and early July and caused a total loss of maize grown on plots receiving the various deep tillage treatments. The stress of drought and high temperature coincided with pollination, and that can significantly reduce, or cause a total loss of, maize grain yield (Shaw and Laing, 1966). The check plot, however, yielded approximately 16 q/ha, almost the same as in 1976. This check plot yield was achieved because pollination did not occur until one week later than in the maize grown on the deep-tilled plots, and the later pollination coincided with a period of cooler weather with some precipitation.

The delayed pollination in maize grown on check plots in 1977 and a greater moisture content of grain harvested from check plots in 1976 (Table 1) indicated that maize plants grown without deep tillage of the compacted soil were delayed in reaching physiological maturity. That is, moisture and oxygen were early and simultaneously made available to maize roots by the deep tillage and that enhanced rapid and early growth of maize. Rapid and early growth of maize is normally desired in Iowa (Benson and Thompson, 1974).

After the early summer drought of 1977 had destroyed most of the corn crop, an extremely wet period began in August. Water-table levels were measured at or slightly below the ground surface in deep-tilled plots, and this condition persisted throughout the fall. These high water tables prevented timely tillage and other farming operations. To correct this problem, installation of a subsurface tile drainage system was investigated.

Tile Drainage

Figure 1 shows a cross-section drawing of a portion of the reclaimed demonstration mine. Hydraulic conductivity values were estimated with an _in situ_ double ring infiltometer apparatus. The ranges of hydraulic conductivities for replaced surface soil, subsoil, and compacted consolidated overburden were 60-90, 1-10 and 0.1-1 cm/day, respectively. It is clear from these data that the movement of groundwater resulting from infiltrated rainfall will be confined to the upper two layers because of the extremely low hydraulic conductivity of the compacted consolidated overburden.

Calculations

Calculations were undertaken to determine if groundwater under normal conditions of flow through the replaced soil materials would cause waterlogging problems on the terraces or the slopes portions connecting the terraces, which might cause instability and slides. It was assumed that 25 cm of the 84 cm of annual rainfall at the mine site would reach the groundwater and that a rate of recharge to be expected in the spring would be 1.4 times the annual rate. The calculations showed that accumulated water would break out of the sloped portion connecting the terraces after moving 370 horizontal feet across the site. This was good evidence to show that a tile drainage system was needed.

Equations based on Dupuit-Forchheimer theory were developed to find the expected water table for the hydrologic conditions previously estimated. In a first analysis, a tile line was "located" at the toe of the slope connecting the terraces and 8 feet below the ground surface, as shown in Figure 2. The 1% slope of the terrace was neglected in the analysis. The points along the theoretical water table, shown as the dotted line, were determined by solving the two simultaneous equations:

<u>For Region A</u> (Horizontal Region)

$$\left(\frac{y^2 - d^2}{2}\right) + \frac{R}{K}\left(\frac{x^2 - S^2}{2}\right) + c(S - x) = 0$$

<u>For Region B</u> (Sloped Region)

$$\ln(x - cK/R) - \frac{a}{2g} \ln \left(\frac{2u - a - g}{2u - a + g}\right) + \frac{1}{2} \ln(u^2 - au + R/K) + f(c) = 0$$

where $u = \frac{y - acK/R}{x - cK/R}$, $g = (a^2 - 4R/K)^{1/2}$, and f(c) was determined from boundary conditions. In these equations (p is the center of the coordinate system)

x = horizontal distance
y = vertical distance
a = slope
R = recharge rate
K = hydraulic conductivity
c = a constant.

More recently, Prunty and Kirkham (1979) provided an additional analysis of the problem of placing a tile drain in an optimum location on each benched terrace. Their study determined the maximum water table height for six combinations of R/K and depth of tile. They determined that the optimum position of the drain in general was beneath the terrace bench and relatively near the toe of the slope connecting terraces.

In the spring of 1978, plots were established to compare the effects of tile-drained plots with undrained plots. Deep-tillage treatments were also placed on these plots. A wet spring prevented timely installation of tile and farming operations. Although yields ranged from 0-78 q/ha, no definitive responses could be measured in this first year of the experiment. This study will be continued.

<u>Summary</u>

Maize physiological maturity and grain yield have been shown to be influenced by deep tillage of compacted soil at a reclaimed surface mine. Farming operations, however, have been delayed at this site by water-logged soils. These observations and other calculations have indicated that both tile drainage and deep tillage may be necessary in replaced soils where compacted horizons hinder root growth and water movement.

Continuing studies at the Iowa Coal Project Demonstration Mine will study the effect of various combinations of deep tillage and tile drainage on restoring a compacted soil and its productive capacity. Deep tillage can affect immediate changes in soil properties, but the degree of success may be dependent on water content at the time of tillage and thereafter. Changes in soil properties from tile drainage, other than lowering the water table, are much slower to demonstrate.

For example, Hundal, Schwab, and Taylor (1976) reported improvements in several soil properties but only 16 years after installation of the tile drainage system. It is hoped that combinations of deep tillage and tile drainage can affect desirable changes in soil properties in a much shorter time at this reclaimed mine site.

Literature Cited

Benson, G. O. and H. E. Thompson. 1974. Corn planting dates. Cooperative Extension Service, Iowa State University, Ames, Iowa. Pm-595.

Hundal, S. S., G. O. Schwab, and G. S. Taylor. 1976. Drainage system effects on physical properties of a lakebed clay soil. Soil Science Society of America Journal 40:300-305.

Prunty, Lyle, and Don Kirkham, 1979. A drainage model for a reclaimed surface mine. Soil Science Society of America Journal 43:28-34.

Shaw, R. H. and D. R. Laing. 1966. Moisture stress and plant response. In W. H. Pierre, Don Kirkham, John Pesek, and Robert Shaw (eds.) Plant environment and efficient water use. American Society of Agronomy and Soil Science Society of America, Madison, WI.

Soil Conservation Service. 1977. Soil survey of Mahaska County, Iowa. U.S. Department of Agriculture.

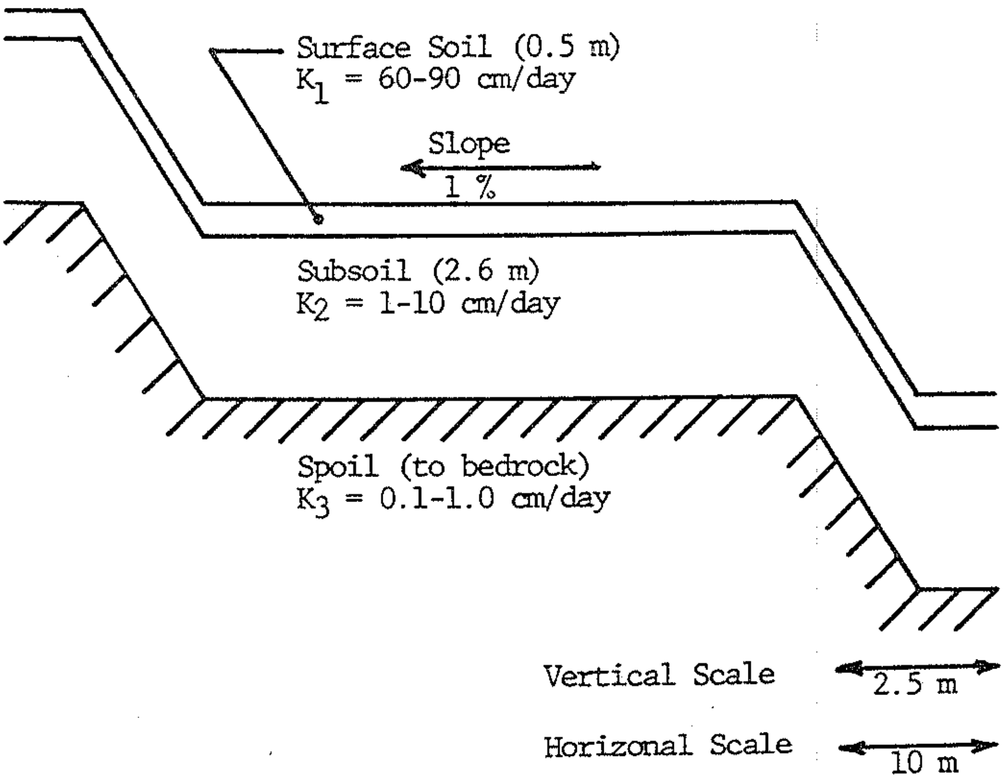

Figure 1. Cross section of terrace profile at the Iowa Coal Project Demonstration Mine.

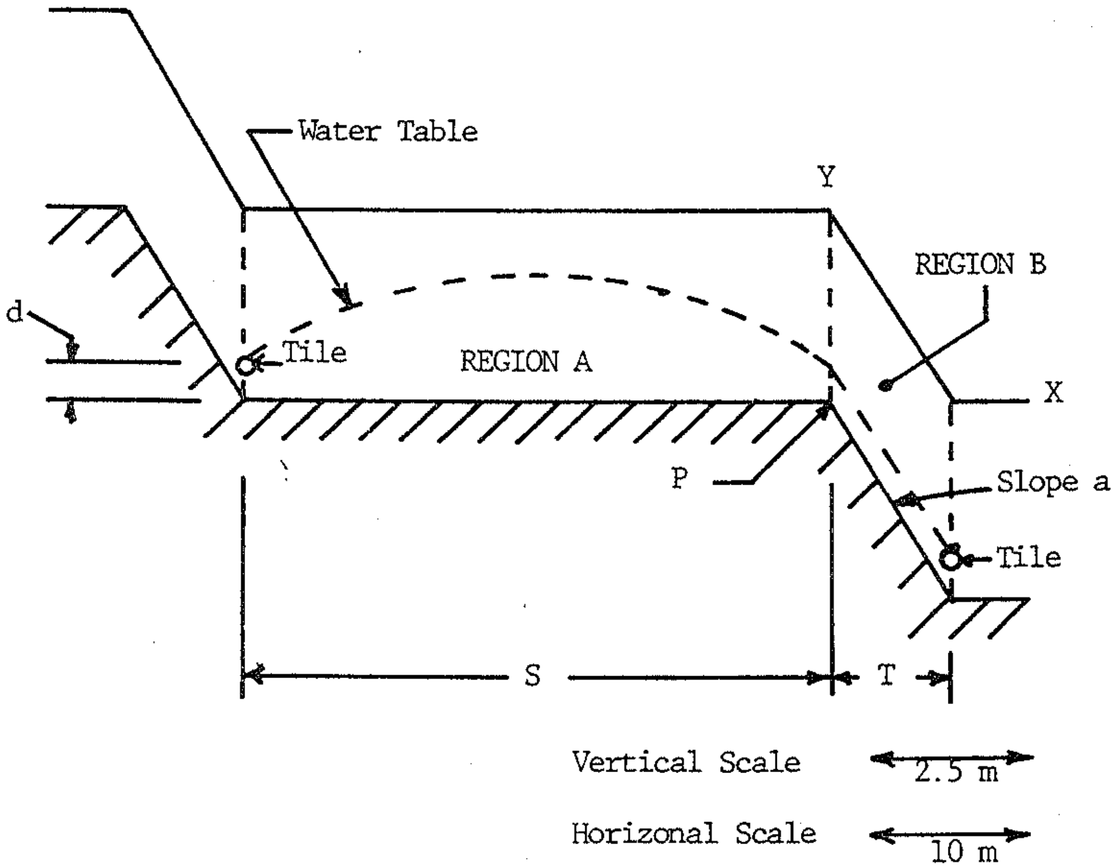

Figure 2. Example of calculated water table shown with tile "located" 0.6m above spoil barrier and at the toe of the slopes.

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Pot experiments on the influence of soil porosity and soil-water-potential on the development, yield and water consumption of sugar beets.

C. Sommer
Institute of Crop Science and Seed Research, Federal Research Center of Agriculture Braunschweig-Völkenrode (FAL), Bundesrepublik Deutschland

Abstract
By means of greenhouse experiments the influence of a differentiated water supply and different soil porosities on the development and production of sugar beets has been investigated. Three different but constant levels of soil-water-potential have been maintained over the whole vegetation period of twelve weeks. Results of those investigations might be important for soil tillage and irrigation schedules.

1. Introduction

Pot experiments have special advantages in investigating the requirements of sugar beets for physical contents of soils and for water supply:

- controlled and natural environments can be included (2);
- pot experiments allow the reduction of the numerous soil parameters on the most important ones (3); soil density and soil heterogenity can be offered to the plant without any difficulties;
- a new developed method for maintaining the soil-water-potential in greenhouse pots can be used for a good water distribution in the pot even at times with high plant growth (5);
- the water consumption in relation to the plant growth can be investigated either under constant

or not-constant soil-water-potentials.

2. Materials and methods

Big pots (D = 39 cm, H = 44 cm) were filled with a loamy soil (water content = 22 % by weight) at different soil porosities by means of an hydraulic jack and were placed in greenhouses (4), (7), fig. 1

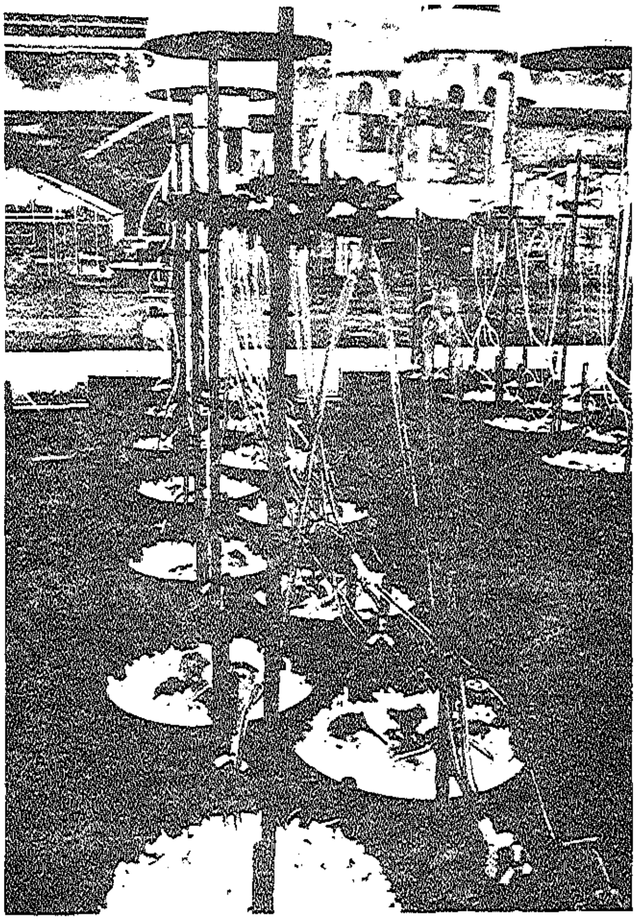
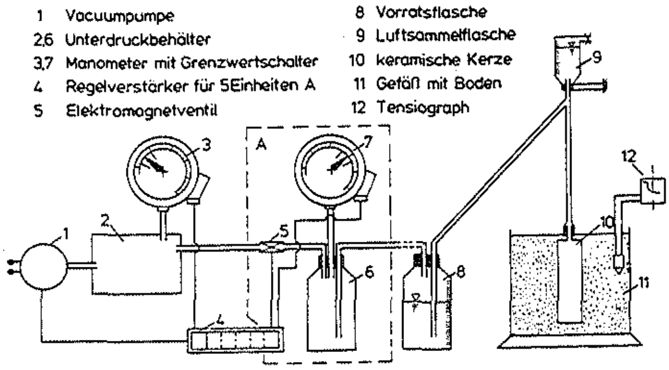


Fig. 1: Some of the used pots placed in a greenhouse; styropor material reduces evaporation

A special system of ceramic candles allowed to investigate the quantitative water consumption of single beet plants (species: Gemo). This system consists of vertical ceramic candles, which are installed in the soil, storage water bottles 8, switching manometer 7, an electronical equipment 4 and a vacuum pump 1, fig. 2. For the control of the soil-water-potential (Ψ_1 = - 0.05 bar, Ψ_2= - 0.20 bar,Ψ_3 = - 0.60 bar) tensiometers were installed in some of the greenhouse pots.

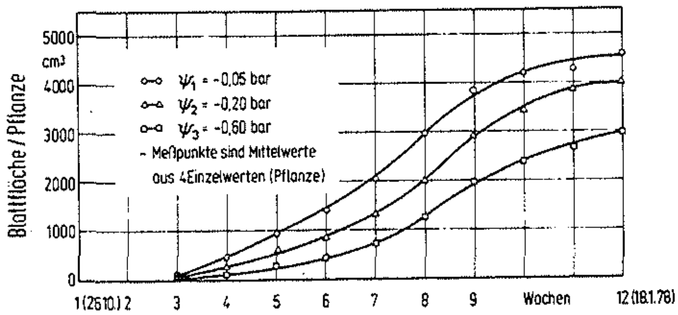


<u>Fig. 2:</u> A system for supplying greenhouse pots with water according to the soil-water-potential

<u>3. Results</u>

3.1 Development of the leaf area during 12 weeks

As drawn in <u>fig. 3</u> the measurements of leaf areas shows obvious differences related to water supply.



<u>Fig. 3:</u> The leaf area - time-relationship of sugar beets at three different constant soil-water-potentials Ψ (bar); average values of 4 single plants.

Data suggest that the highest soil-water-potential (Ψ_1) produced maximum leaf area which was 4.500 cm^2 at yield time. Only 3.000 cm^2 leaf area were reached when soil-water-potential was Ψ_3 = - 0.60 bar.

3.2 Dry matter yield of beets

The yields of sugar beets in relation to three different soil-water-potentials and two different soil porosities are given in table 1. The higher soil porosity increased beet root yields if potential values are not too high.

	Pore volume (Vol %)	
	40	47.5
Ψ_1 = - 0.05 bar	70.4 g	89.1 g
Ψ_2 = - 0.20 bar	101.5 g	116.2 g
Ψ_3 = - 0.60 bar	84.6 g	84.7 g

Table 1: Dry matter beet yields related to different soil porosities and soil-water-potentials; average values of 3 single plants.

3.3 Water consumption

Accumulated water consumption and the leaf area development of fig. 3 are shown in fig. 4.

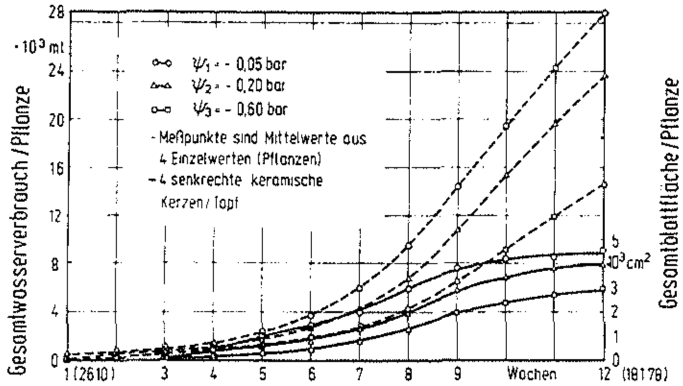


Fig. 4: Accumulated water consumption - time-relationship (dotted curves) at three different constant soil-water-potentials (bar); not dotted curves are the same as in fig. 3.

Decreasing the soil-water-potential to - 0.05, -0.20 and - 0.60 bar water consumption after 12 weeks decreased by 28, 24 and 14 l, respectively. The weekly consumption of all the single plants was nearly linearly related to leaf area per plant, with a slope of 1.1 and a correlation coefficient of 0.97, fig. 5, indicating that the slope is not correlated to soil-moisture tension.

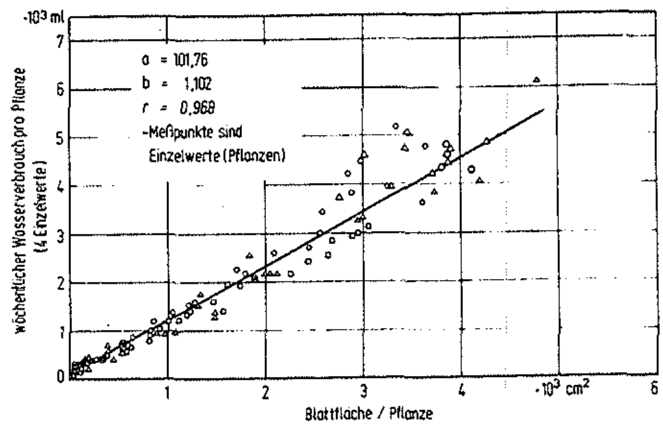


Fig. 5: The effect of leaf area on the weekly water consumption of single sugar beet plants

4. Conclusions

Using the described method for maintaining the soil-water-potential in greenhouse pots the influence of soil porosity and soil-water-potential on the development, yield and consumptive use of water can be investigated for sugar beets. Especially those data are available which describe the relationship between water consumption and available water-holding capacity of soils due to single sugar beet plants. In the future not-constant Ψ-levels will bring results showing water requirements for sugar beets.
In combination with evaporimeters the leaf area might be a first parameter available to irrigation schedules (6). It is necessary to check this thesis by new pot experiments in greenhouses and outside in the field. Including artificial leaf area reduction the question is to be answered which amounts of water might be saved in irrigated fields. Positive results will be an impulse for the plant breeders to

select smaller leaf apparatus for sugar beets (1).

5. References

1) Bramm, A.; Sommer, C.: Gedanken zur Optimierung der Wasserversorgung von Zuckerrüben. - Ztschr. Die Zuckerrübe Nr. 4 (1978); S. 17-19

2) Dambroth, M.; Sommer, C.: Das Phytotechnikum des Instituts für Pflanzenbau und Saatgutforschg. - Landbauforsch. Völkenrode (1977), Heft 3, S. 141-148

3) Sommer, C.: Über die Verdichtungsempfindlichkeit von Ackerböden. - Grundl. Landtechnik Bd. 26 (1976), Nr. 1, S. 14-23

4) Sommer, C; Ziemer, K.: Zur meßtechnischen Erfassung des Eindringwiderstandes von Böden. - Meßtechnische Briefe (1978), Heft 4.

5) Sommer, C.: Eine Methode zur kontinuierlichen Wasserversorgung von Vegetationsgefäßen nach dem Bodenwasserpotential. - Landbauf. Völkenrode (1978), Heft 1, S. 17-20.

6) Sommer, C.: Beziehungen zwischen dem Verdunstungswert einer keramischen Scheibe und dem Wasserverbrauch von Zuckerrüben. - Landbauf. Völkenrode (1978), Heft 2, S. 103-104.

7) Sommer, C.; Bramm, A.: Wasserverbrauch und Pflanzenwachstum bei Zuckerrüben in Abhängigkeit von der Wasserversorgung. - Landbauf. Völkenrode 28 (1978), Heft 3, S. 151-158.

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EFFECTS ON SEEDLING EMERGENCE OF SOIL SLAKING AND CRUSTING

Inge Håkansson & József von Polgár

Dept. of Soil Sciences, Swedish University of Agricultural Sciences, S- 750 07 Uppsala, Sweden.

ABSTRACT

The objectives of the seedbed preparation were studied in model experiments. Seedbeds of defined characters were built up in shallow plastic boxes, and the crop emergence was studied. One group of experiments concerned problems connected with surface slaking and crusting. It was concluded that - in the field - oxygen deficiency hampering the crop emergence is rare, but can occur if the biological activity in the soil is high. Normally no problems arise until a dry surface crust forms. To decrease the risk of poor emergence by crusting, the sowing should be shallow - as shallow as possible with regard to the risk of drought. Coarse structure in the surface layer increases the risk rather than decreases it.

INTRODUCTION

In Swedish agriculture the seedbed preparation and sowing often cause problems. The main crops are spring sown small grain cereals, normally sown in fields ploughed in the autumn with a mouldboard plough. In most cases the soil is wet at the end of the winter, but it drains rapidly as soon as the frost leaves the soil. Tile drainage is usual. In the spring the weather is normally dry and the uppermost few centimeters dry out by evaporation. At sowing time the moisture gradient in the seedbed is usually sharp. Clay soils are widespread and in them the moisture content of the surface layer is often far below the wilting percentage (Kritz 1976 b). Concequently, and because dry weather frequently occurs after sowing, a suitable sowing depth and a good protective effect against evaporation are essential. Occasionally rainfall may cause surface crusting.

Sowing should be done as early as possible in order to maximally utilize the vegetation period and to get germination before the surface layer dries out. High machinery capacity that enables sowing to be finished within a few days is important.

At the Division of Soil Management, Swedish University of Agricultural Sciences, one of the experimental programs concerns seedbed preparation and sowing. At this conference some results from three closely connected projects are presented: The conditions at spring sowing (Kritz), the objectives of the operations (this paper), and the means and implements available (Henriksson).

MODEL EXPERIMENTS INTO THE FUNCTION OF THE SEEDBED

Since 1968 the objectives of the seedbed preparation have been studied in about fifty model experiments with the function of the seedbed. Some results have been reported earlier (Håkansson & von Polgár 1976, 1977). Most of the experiments have been carried out as pot experiments in shallow plastic boxes. In most cases small grain cereals were sown, in others, oilseed rape, sugarbeet, clover or timothy. The most important crop emergence problems in Swedish agriculture were studied, especially the following:

1. How should the seedbed be formed to give good emergence when dry weather follows the seeding? (Previously reported).
2. In which way is the emergence hampered by surface slaking and crusting? What can be done to improve the emergence?(Summarized in the present paper).
3. What is the effect on the emergence of a packing of the seedbed by rolling after sowing?
4. How does the quality of the seed influence the demands on the seedbed, and what are the demands from crops with small seeds?

The following factors are regarded as decisive for crop emergence under Swedish conditions and most of them were used as variables in the experiments.

1. Factors characterizing the seedbed at sowing time (the initial state): Soil type, depth of the seedbed and depth variations, aggregate size distribution of the seedbed, structure of the layer below, moisture conditions of the seedbed and of the layer below, seed depth distribution, state of looseness or compactness of the seedbed (possibly rolling immediately after sowing).

2. Factors determining or modifying the conditions in the seedbed during the germination and emergence period: Temperature, precipitation (time, amount, intensity), potential evaporation, tillage operations.
3. Factors characterizing the seed: Crop (species, variety), seed quality.

In the first of the previous reports the techniques used were presented. Most of the experiments comprised a large number of treatments in a polyfactorial design (for instance, 3 x 3 x 2 x 2 = 36 treatments in duplicate, in all 72 boxes). Seedbeds of well-defined characters were built up in plastic boxes with an area of 0.2 m^2 and a depth of 11.5 or 22.5 cm. Many different soils were used. The soil was dried or moistened to desired moisture content. Often it was sieved into different aggregate fractions. A prescribed number of seeds were sown at a pre-determined depth.

After sowing, the boxes were placed in the field, directly on the soil surface. They were protected from rainfall by a plastic roof. Watering, if done, was normally done by hand. Sometimes "rolling" or crust breaking was carried out. From the first day of emergence, daily counts of the emerged plants were made for two or three weeks. After that the experiments were finished.

THE SEEDBED AS A PROTECTIVE LAYER AGAINST DROUGHT

Although it goes outside the theme of this paper, a short summary is given here of the previously reported experiments (Håkansson & von Polgár 1976, 1977) into problem 1, mentioned above. The first report dealt with seven experiments with the question: How deep and how fine must the seedbed be to provide an effective protective layer against evaporation? The seed was placed directly onto a moist bottom and covered by a nearly air-dry surface layer. No watering was made. The soils had a clay content between 33 and 57 per cent. On such soils poor emergence through drought often occurs in Sweden.

From the results the following practical conclusions were drawn. For small grains a seedbed at least 4 cm thick and dominated by aggregates finer than 4 mm gives sufficient protection. This applies if seed of good quality - including rapid germination - can be placed directly onto the bottom of the seedbed and there is at least 5 per cent plant-available water in the bottom layer. At spring sowing in Sweden a poorer moisture situation than that is very seldom found (Kritz 1976 a). If the requirements mentioned can be fulfilled, then good emergence can nearly always be expected, even when no rain falls and the potential evaporation is high. Thus, improved seedbed preparation and sowing could nearly completely remove the risk of poor emergence through drought.

The second report dealt with four experiments with the question: If the seedbed contains coarse as well as fine aggregates, which treatment gives the best emergence result, a mixing of the aggregates or a sorting with the coarse aggregates at the surface? The boxes were not watered. The soils had clay contents ranging between 28 and 52 per cent.

The results showed that when the coarse and the fine aggregates had the same moisture content, then it made little difference whether they were mixed or stratified. If the coarse aggregates were driest, then they should be placed at the surface, and if they were wettest, then they should be placed as deep as possible. Thus, when harrowing in conditions with a sharp moisture gradient, the dry surface material should be retained near the surface and the moist bottom material near the bottom, irrespective of aggregate size. Under dry weather conditions there is no reason for sorting the coarse aggregates to the surface. The ideal implement has both a low mixing effect and a low sorting effect.

EXPERIMENTS WITH OGYGEN DEFICIENCY IN THE SEEDBED

Two new reports are now under preparation concerning experiments with problem 2, mentioned above (slaking and crusting problems). The first of these covers three experiments in which the aim was to elucidate the extent to which slaking and high moisture saturation could cause oxygen deficiency hampering the emergence.

These experiments were carried out in 22.5 cm deep boxes with a soil depth of 20 cm. After sowing, the boxes were watered until free water formed in the bottom. The level was controlled by small holes bored through the walls near the bottom. The experiments were carried out at a time of the year when the potential evaporation was very low (mean value less than 0.4 mm/day for all the experiments). Therefore it was possible by repeated, small waterings throughout the experimental period to compensate for the evaporation and keep the soil continuously wet, without adding large amounts of water with dissolved ogygen. Each watering was normally 2 mm.

The first experiment (M7/69) was performed outdoors with two soils of rather low organic content, a clay soil and a silt loam soil. Three aggregate fractions in the surface layer were used (<4, 4-8 and 8-16 mm), 3 sowing depths (2, 4.5 and 7 cm) and two watering treatments (repeated watering and no repeated watering). Both the large watering immediately after sowing and the repeated waterings were done gently, so that there was a minimum of surface slaking. In the clay the slaking was very shallow, but in the silt loam it was deeper. The crop was barley.

At no repeated watering the final emergence (Table 1) on average reached the high level of 91 per cent for both soils.This shows that the conditions were very good. No hardening of the surface layer ocurred. At repeated watering the emergence was still better in the clay, proving that there was no oxygen deficiency. In the silt loam a slight decrease of the emergence ocurred, especially at the finest aggregates. There was probably a slight oxygen deficiency. The experiment shows that under Swedish conditions an oxygen deficiency hampering the crop emergence must be uncommon. (The situation when the ground water rises to the seed level for more than a short period is disregarded).

To test a still more severe situation two new experiments (M6/74 and M7/74) were carried out. They were arranged similarly to the previous one, but the initial watering was done at high intensity, providing a deeper slaking. The soil (a fine sandy loam) slaked easily. The organic content was 4.5 per cent and the soil had a small content of undecomposed grass sod. Three crops were sown (oilseed turnip rape, wheat and peas) at two sowing depths (3 and 6 cm). To produce a high oxygen consumption, easily decomposable organic matter was added to the soil. The layer covering the seed was homogeneously mixed with barley meal in amounts 0, 0.25 and 2 per cent. In most boxes repeated waterings were carried out as previously described, but in addition there were some boxes, sown with wheat, whith no repeated waterings. The two experiments were carried out in a greenhouse, and were identical apart from the temperature (constant temperatures of +17^{0}C and +7^{0}C).

Table 2 shows the final emergence. It was quite clear that a severe oxygen deficiency ocurred. In the boxes with barley meal there was an intensive microbial activity and striking signs of anaerabic conditions (odour, change in colour). Even in the boxes without barley meal there were some signs of oxygen deficiency. The deeper slaking and the small amount of grass sod made the oxygen supply poorer than in the earlier experiment. Small variations in treatments between the replicates caused drastic differences in emergence, showing that the oxygen supply was just at the critical level. The differences between the crops are not statistically significant.

TABLE 1. Experiment M7/69. Per cent emergence at the final plant counting.

	Clay	Silt loam
No repeated watering	92	91
Repeated watering	95	88

TABLE 2. Experiments M6/74 and M7/74. Per cent emergence at the final plant counting.

Barley meal, %	Sowing depth, cm	M6/74, + 17^{0}C				M7/74, + 7^{0}C			
		Rape	Wheat	Peas	Wheat, no watering	Rape	Wheat	Peas	Wheat, no watering
0	3	6	37	13		56	49	21	64
	6	0	32	8	84	11	21	23	58
0.25	3	0	2	1		0	1	0	2
	6	0	0	0	73	0	0	0	2
2.0	3	0	0	0		1	0	0	3
	6	0	0	0	64	0	0	0	3

The boxes with no repeated waterings show results which might appear unexpected. However, both the germination and the oxygen shortage developed more slowly at the lower temperature than at the higher, and apparently the emergence was less delayed than the development of oxygen deficiency.

On the whole, the three experiments show that under normal field conditions, oxygen deficiency hampering the crop emergence can occur if heavy rain causes deep slaking and continuously moist weather follows at the same time as the ground water level is high, and there is a high biological activity in the soil. This situation, however, must be regarded as rare, even on fine sandy and silty soils with a weak structure. Thus, from a practical point of view, on most localities the slaking can be regarded as no problem until a crust forms that is too dry and hard for the seedlings to penetrate.

EXPERIMENTS WITH SURFACE CRUSTING

The second of the reports under preparation covers a group of ten experiments, in which the problems with impedance from a surface crust were studied. The soils used had clay contents between 20 and 48 per cent. In many cases they were rich in fine sand and silt, and were chosen because they show crusting problems in practical farming. The initial moisture content was always so high that there was water enough for the germination. In eight experiments the crop was barley, in two oilseed rape. The crust was produced by irrigating the boxes and then leaving them for drying.

It is normally considered that a coarse structure in the surface layer reduces the crusting problems. Consequently the aggregate size of the surface layer was used as a variable in all the experiments. In most cases the sowing depth was also varied, and in addition one or more of the factors time, amount, intensity and drop size of the irrigation. In two experiments crust-breaking treatments were introduced.

The crust formed earlier or later depending upon the moisture content of the soil and the evaporation rate. The effect on the emergence varied depending upon the hardness, thickness and cracking of the crust and upon the time of hardening. The time of irrigation was important. Early irrigation caused early hardening, before the plants emerged. After a small amount of water the crust was relatively thin and weak, but it formed early and the emergence effect therefore sometimes was worse than after a large amount.

The sowing depth appeared to be a very important factor (Fig 1). At shallow sowing a larger number of plants emerged before the crust began to harden than at deep sowing.

The aggregate size did not have the expected effect (Fig 2). The effect varied slightly between the experiments depending upon the initial conditions, the irrigation and the weather, but in most cases the effect was small. On the whole, on average, there was a decrease in emergence with increasing aggregate size rather than an increase. In addition, in the practical situation when the risk of dry weather after sowing must also be regarded, shallow sowing is possible only if the structure is fine. Thus, the practical conclusion is that shallow sowing should be used, and this necessitates a fine structure.

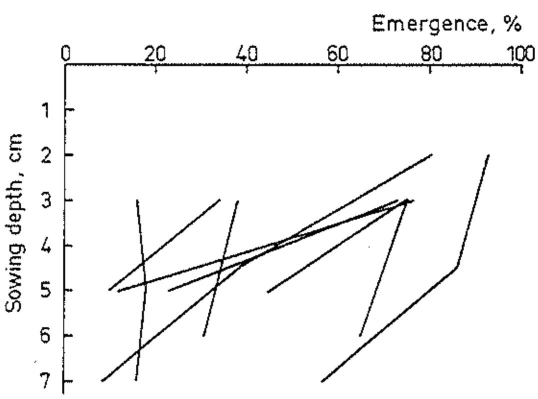

FIG 1. Crop emergence as a function of the sowing depth in the different experiments with surface crusting.

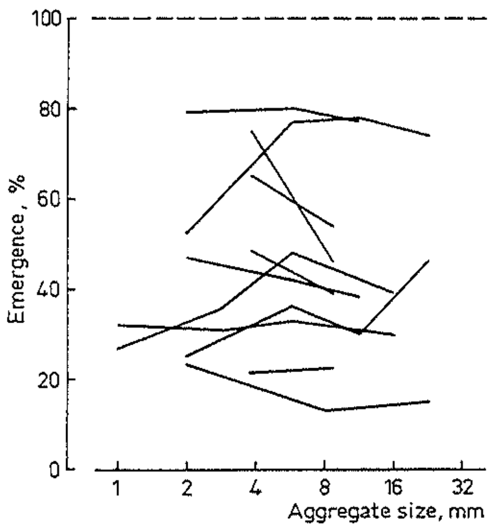

FIG 2. Crop emergence as a function of the aggregate size in the surface layer in the different experiments with surface crusting.

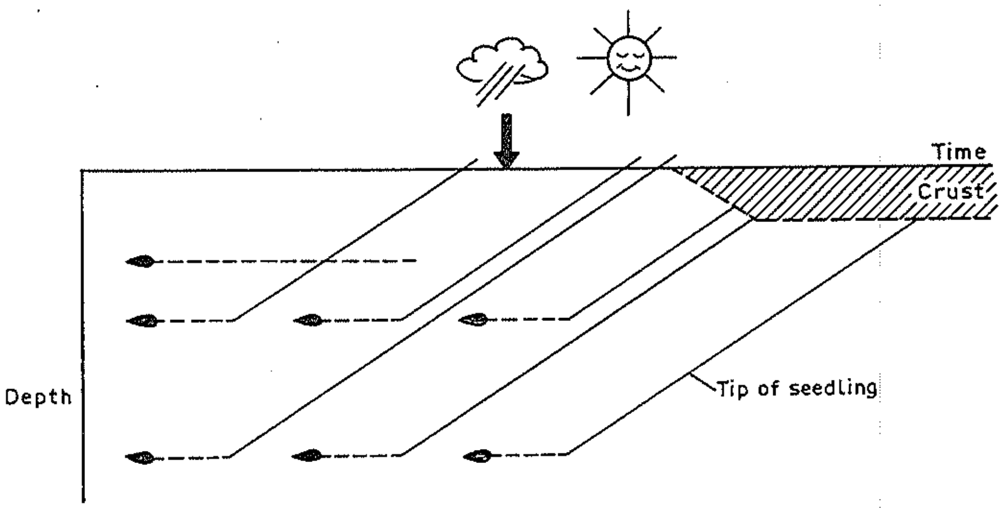

FIG 3. Time-depth diagram illustrating the importance of the sowing depth and of the time of sowing in relation to the time when a slaked surface layer begins to harden. Shallow sowing decreases the risk of poor emergence by surface crusting. However, at too shallow sowing there is not - in dry weather - sufficient moisture for germination. Coarse structure increases the depth of the moisture deficiency layer.

The importance of the sowing depth and of the time of sowing in relation to the time when a slaked surface begins to harden is illustrated in Fig 3. This figure also indirectly shows the desirability of having a seed with rapid germination and seedling growth.

A limitation for the experiments described is that they only cover the germination and emergence phase of the crop. Field experiments giving the effects on crop yield are necessary before recommendations for practical farming can be made. Another limitation is that all the experiments described were carried out with a flat soil surface (the roughness caused by the aggregate size being disregarded). Field observations have shown, however, that the microtopography can influence the orientation of the cracks through the crust, and thereby also the emergence. Therefore in 1979 new experiments were started to study this influence.

In the new series of experiments a microrelief is formed with small ridges and furrows, and the crop rows are sown in different positions relative to them. Sometimes the cracks have shown a tendency to form along the tops of the ridges, sometimes in the bottom of the furrows, most often, however, at the foots of the ridges. If the rows are sown where the cracks will form, the emergence can be substantially facilitated. Different strenghts of the crust and times of hardening on the ridges and in the furrows are also of importance.

The orientation of the cracks seems to depend upon type of soil, aggregate size, amount and intensity of irrigation and probably other factors. No simple rules have yet been found. However, even in these experiments coarse aggregates have not been better than fine. These experiments are being continued.

FIELD EXPERIMENTS

A field experiment activity has recently been started in order to obtain a basis for practical recommendations concerning the seedbed preparation on soils where crust formation is a severe problem. The first step was a series of 24 field trials carried out in 1975-1978. The soils were rich in fine sand or silt and had a clay content between 8 and 36 per cent. The crop were barley and oats.

The trials comprised four treatments in a 2 x 2 split-plot design:

Shallow and deep harrowing and sowing.

Coarse and fine structure in the seedbed.

In the shallow harrowing treatment the mean harrowing depth in the whole series of trials was 3.7 cm and the sowing depth 2.7 cm, in the deep harrowing treatment the depths were 6.3 and 4.2 cm respectively. In the coarse structure treatment the amount of aggregates coarser than 5 mm in the seedbed was 45 per cent, in the fine structure treatment it was 36 per cent. However, there were large differences among the trials concerning both the depths and the aggregate sizes of the seedbed.

There was no pronounced crusting situation in any of the 24 trials. In nearly all the individual trials the fine structure gave a higher crop yield than the coarse structure. On average, the advantage was 5 per cent. Depending upon the harrowing depths obtained in the individual trials sometimes the shallow and sometimes the deep seedbed gave the highest yield. The optimum seemed to be a harrowing depth between 4 and 4.5 cm and a sowing depth in the close proximity.

Thus, when no crusting occurs, a fine structure is preferable. Because a crusting situation arises at the most one year in four, a fine seedbed suitable for a dry situation should be used even on soils where the crusting can be severe, unless such a seedbed gives very big yield decreases in the crusting years. The model experiments indicate that a fine structure is acceptable or possibly preferable even those years.

Because of the consistent results in all the trials carried out, this series will not be continued. Instead, we are planning new experiments, in which irrigation after sowing will be used to induce crusting. In these experiments many factors will be varied, such as aggregate size, harrowing and sowing depth, time of sowing, microrelief of the soil surface and time and amount of irrigation. The microrelief seems to be important, and we hope to find a relief that on one hand favours crop emergence in both dry and crusting situations, and on the other hand facilitates the breaking up of the crust.

LITTERATURE

Håkansson, I. & von Polgár, J., Model experiments into the function of the seedbed. I. The seedbed as a protective layer against drought. AGRICULTURAL COLLEGE OF SWEDEN, UPPSALA. REPORTS FROM THE DIVISION OF SOIL MANAGEMENT. Nr 46, 1976.

Håkansson, I. & von Polgár, J., Model experiments into the function of the seedbed. II. Experiments with stratified and unstratified seedbeds. SWEDISH UNIV. OF AGRICULTURAL SCIENCES, UPPSALA. REPORTS FROM THE DIVISION OF SOIL MANAGEMENT. Nr 53, 1977.

Kritz, G., Seed bed preparation and properties of the seed bed in spring sown fields in Sweden. III. Sampling investigation 1969--72. Primary results from 300 investigated places. AGRICULTURAL COLLEGE OF SWEDEN, UPPSALA. REPORTS FROM THE DIVISION OF SOIL MANAGEMENT. Nr 44, 1976 (a).

Kritz, G., Seed bed preparation and properties of the seed bed in spring sown fields in Sweden IV. Sampling investigation 1969--72. A general survey of some important factors. AGRICULTURAL COLLEGE OF SWEDEN, UPPSALA. REPORTS FROM THE DIVISION OF SOIL MANAGEMENT. Nr 49, 1976 (b).

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AGGREGATE SIZE DISTRIBUTION IN THE SEED BED: EFFECTS ON SOIL TEMPERATURE, MATRIC SUCTION, AND EMERGENCE OF BARLEY (HORDEUM VULGARE L.) - A REVIEW OF SOME RESEARCH ON CLAYEY SOILS IN SOUTH EASTERN NORWAY

By

ARNOR NJØS

Department of Soil Fertility and Management, Agricultural University of Norway, N-1432 Ås-NLH, Norway.

ABSTRACT

The report presents results of some measurements of soil physical parameters and rate of emergence of barley in seed beds of variable aggregate size distributions. The soils used in the experiments were loams and clay loams with organic matter content in the range from 4 to 7 percent.

The total porosity was high and only slightly influenced by the size of aggregates for sieved fractions. Mixing of fractions resulted in a marked decrease of porosity. The air porosity at pF 1.3 decreased with decreasing aggregate size, and was strongly reduced by mixing of sieved aggregate fractions. The rate of emergence of barley was most rapid in the 6-2 mm and 2-0.6 mm aggregate fractions, and was delayed for coarser and finer fractions. It was also delayed for the most intensive mixing (lowest total porosity).

The soil temperature at 5 cm and 10 cm depth under a 3 cm thick layer of different aggregate fractions attained the highest maxima for the 2-0.6 mm and 6-0.6 mm fractions. The matric suction was lower under a 3 cm thick layer of 6-0.6 mm aggregates than under larger and smaller aggregates. The annual variation of the aggregate size distribution due to climatic influences may exceed the variation caused by soil treatments.

INTRODUCTION

Research concerning the effects of aggregate size distribution on other soil physical parameters and yield has been conducted in pot, frame, and field experiments throughout the last 15 years at the Department of soil fertility and management, Agricultural University of Norway. A review of some of the research findings is given in this report. YODER (1937) found the most rapid emergence of cotton plants in seed beds containing about half the aggregates in the range of 1/8 to 1/4 inch diameter and the other half finer.

MATERIALS AND METHODS

Dry sieving

The soils used for the experiments were air dried and sieved with an electric sieving machine. The sieves were made from wire and had 20 mm, 6 mm, 2 mm, 0.6 mm square openings. The movement of the sieve set was along one axis in the horizontal plane. The frequency was 240 per minute, the amplitude 12 mm, and the sieving time 3 minutes. See NJØS (1965).

Soil physical measurements

The cumulative pore size distribution (pF curve) was determined by pressure extraction. For the low pressure range, viz. 0.02 - 0.1 - 1.0 bars, the soil samples had a volume of 100 cm^3 with a height of 4 cm. For the high pressure extraction, 15 bars, the volume of each soil sample was approximately 4 cm^3, with a height of 0.5 cm. The grain size distribution was determined according to the method of GANDAHL (1954). In the frame experiments matric suction was measured with mercury manometre tensiometres. The soil temperature was measured with ordinary copper-constantan thermocouples, recorded and logged for computor processing.

Experimental techniques

In the pot experiments containers with 20 cm diameter and 20 cm height were filled with 5 kg dry soil. The containers were watered through rubber tubes, perforated near the bottom of the container. 20 seeds of barley were placed approximately 2 cm below the surface. The watering regime was controlled by weight according to pre-determined filling-up and drying-out limits. The nutrients were mixed with soil in the dry condition. In one experiment N-fertilizer was either mixed or placed in a band. In the frame experiments the soil was prepared by ordinary tillage followed by application of a 3 cm layer of the actual aggregated soil on one square metre plots. Tensiometres and thermocouples were then placed at pre-determined depths.

Experiment I - Pot experiment in growth house. In experiment I the soil was a clay loam (33% clay - 38% silt - 29% sand) with 6-7 percent humus. The treatments are given in table 1.

Table 1. Treatments in experiment I Aggregate fractions

Treatment	>20mm	20-6mm	Percent of fraction 6-2mm	2-0.6mm	<0.6mm
A0	50	50			
A1	25	25	16.7	16.7	16.7
A2			33.3	33.3	33.3
B0	100				
B1		100			
B2			100		
B3				100	
B4					100

V0 Watered to pF 1.3 after drying out to pF 3
V1 " " " " " " " pF 4.2

N0 6 g N as $Ca(NO_3)_2 \cdot 4$ aq per m^2
N1 24 " N " " " "

Experiment II - Pot experiment in growth house. In experiment II the soil was a clay loam (appr. 30% clay - 40% silt - 30% sand) with 4-5 percent humus. The treatments are given in table 2.

Table 2. Treatments in experiment II

Aggregate size	N as $Ca(NO_3)_2 \cdot 4aq$	Application method for N
A0 6-0.6 mm	B0 8g per m^2	C0 Mixed in upper 5 cm
A1 < 0.6 mm	B1 16g " "	C1 Band at 5 cm depth
	B2 32g " "	

Experiment III - Frame experiment in the field. In this experiment the soil was a loam (24% clay - 35% silt - 41% sand) with 4-5 percent humus. The treatments are given in table 3

Table 3. Treatments in experiment III

Treatment	3 cm top layer of	
B0	aggregates	>20 mm
B1	"	20-6 "
B2	"	6-2 "
B3	"	2-0.6 mm
B4	"	<0.6 "
B5	"	6-0.6 "

RESULTS AND DISCUSSION

Experiment I

The soil physical parametres measured in the different aggregate treatments are given in table 4.

Table 4. Volume of pores, water, and air for the aggregate fractions of experiment I

		Volume percent			
		Water at			Air at
Treatment	Pores	pF 1.3	pF 3.0 (VO)	pF 4.2 (VI)	pF 1.3
A0	60	40	25	13	20
A1	52	45	32	15	7
A2	57	47	33	15	10
B0 - >20 mm	71	38	21	11	33
B1 - 20-6 "	70	39	21	12	31
B2 - 6-2 "	70	42	21	12	28
B3 - 2-0.6 mm	70	49	23	12	21
B4 - <0.6 mm	69	53	34	13	16

It is interesting to note that in the sieved fractions (B0-B4) the total porosity was very high and nearly independent on size, while the air porosity at pF 1.3 decreased steadily with decreasing aggregate size. In the mixtures, (A0 - A2) the porosity was much smaller and at a minimum in treatment A1, the mixture of all aggregate fractions. The air porosity at pF 1.3 was very low in treatment A1, only 7 percent, without any forced compaction.

The relative dates of emergence (45 percent of planted grains having emerged) and heading of barley (Hordeum vulgare L.), var. Varde are given in table 5.

Table 5. Relative dates of emergence and heading for barley in experiment I. + = delay

	Relative dates	
Treatment	emergence	heading
A0	0	+2
A1	+7	+3
A2	+2	0
B0	+4	+11
B1	+1	+6
B2	0	0
B3	0	+1
B4	+9	+19

These dates are given for the combination of low N application with drying out to pF 4.2 before watering. The average date of heading was delayed by frequent watering, and it was speeded up by higher N application.

It is seen from table 5 that the fastest development for the single aggregate fractions occurred in the range 6 mm to 0.6 mm, while the slowest development took place in the finest fraction. A yellowing of the plants during a rather long period after emergence was observed for the treatment B4. This may indicate lack of aeration due to blocked pores (See BLAKE and PAGE 1948), even though the air porosity of the fraction was quite high. For the mixed aggregate distribution the slowest development took place in the treatment A1 - the densest treatment. A very clear delay in date of heading occurred for this treatment when combined with frequent watering and low N. The interaction Nitrogen x Water has been thoroughly discussed by FRIIS NIELSEN (1963).

The yield results will not be discussed here, but may be found in NJØS (1967). It should be mentioned, however, that the consumptive use of water was influenced by the interaction Nitrogen x Watering as shown below (numbers indicate kg water per kg dry matter).

	6g N per m^2	24g N per m^2
Watering after drying to pF 3	690	280
" " " " " 4.2	570	350

The numbers indicate the tremendous water saving effect by nitrogen fertilizers.

Experiment II

In table 6 the length of plants 9 days after planting of barley, var. Herta is given.

Table 6. Length of barley plants, cm, 9 days after planting

Aggregate size	N g per m^2	Fertilizer application Mixing	Band(Ring)
6 - 0.6 mm	8	7.0	7.0
	16	6.0	7.0
	32	5.0	5.5
< 0.6 "	8	6.5	7.5
	16	6.5	7.5
	32	5.0	6.5

The influence of band placement was pronounced for both aggregate treatments at the two higher N levels. The salt concentration at the higher N levels increased the electric conductivity, and the osmotic potential became more negative, reducing the growth. The number of emerged plants was affected in a similar way as the length. After 12 days the effect of band placement was noticeable only in the finest fraction. Further information may be found in NJØS (1972a).

Experiment III

In experiment III the effect of a 3 cm top layer on temperature and moisture of a field soil was investigated (NJØS 1972b). The soil temperatures for a period with clear days are given in table 7.

Table 7. Soil maximum temperatures, °C, at 5 cm and 10 cm depth in a loam soil under a 3 cm top layer of different aggregate fractions. Period June 11 - 16, 1968 (clear days). No plant cover.

Aggregate fraction	Temperature, °C, at 5 cm	10 cm
>20 mm	27.9	24.2
20 - 6 "	28.3	25.0
6 - 2 "	29.6	26.3
2 - 0.6 mm	31.6	26.7
<0.6	30.0	26.3
6 - 0.6 "	30.8	26.3
Air temperature, 2.0 m height	30.4	
Air " 0.2 " "	38.8	

The highest maximum soil temperatures during the daily cycle have been recorded for the 2 - 0.6 mm fraction, followed by the combined 6-0.6 mm fraction.

During a later period the mean, maximum and minimum soil temperatures together with the time of occurrence were calculated from the automatically recorded data. The results are given in Table 8.

Table 8. Soil temperatures, °C, and time occurrence for maximum and minimum, at 5 cm and 10 cm depth, in a loam soil, under a 3 cm layer of three aggregate fractions. Period June 28 - July 3, 1968 (clear days). No plant cover.

Aggregate fraction	Depth	Soil temperature, °C Mean	Max.	Min.	Time reading Max.	Min.
20 - 6 mm	5 cm	19.9	25.8	14.9	1450	0520
6 - 0.6 "	"	20.9	27.3	15.5	1450	0500
<0.6 "	"	19.6	25.6	14.6	1500	0450
20 - 6 "	10 cm	19.1	22.3	16.1	1720	0640
6 - 0.6 "	"	19.6	22.7	16.7	1750	0640
<0.6 "	"	18.9	21.9	15.9	1740	0620

While the depth differences were significant for all 5 parametres, the aggregate size differences were significant only for the soil temperatures. It is seen that the time readings of maximum at 5 cm and 10 cm depth were approximately 1500 hours and 1740 hours, respectively. The corresponding time readings for minimum were 0500 hours and 0630 hours. The daily amplitude at 5 cm depth was 11°C to 12°C, and at 10 cm depth roughly 6°C. In a cloudy period the amplitudes were 5°C and 3°C and 3°C for the 5 cm and 10 cm depths. In the period referred to in table 8 the soil surface temperature during one day varied between 50°C and 11°C. The time of maximum for the surface temperature was approximately 1200 hours.

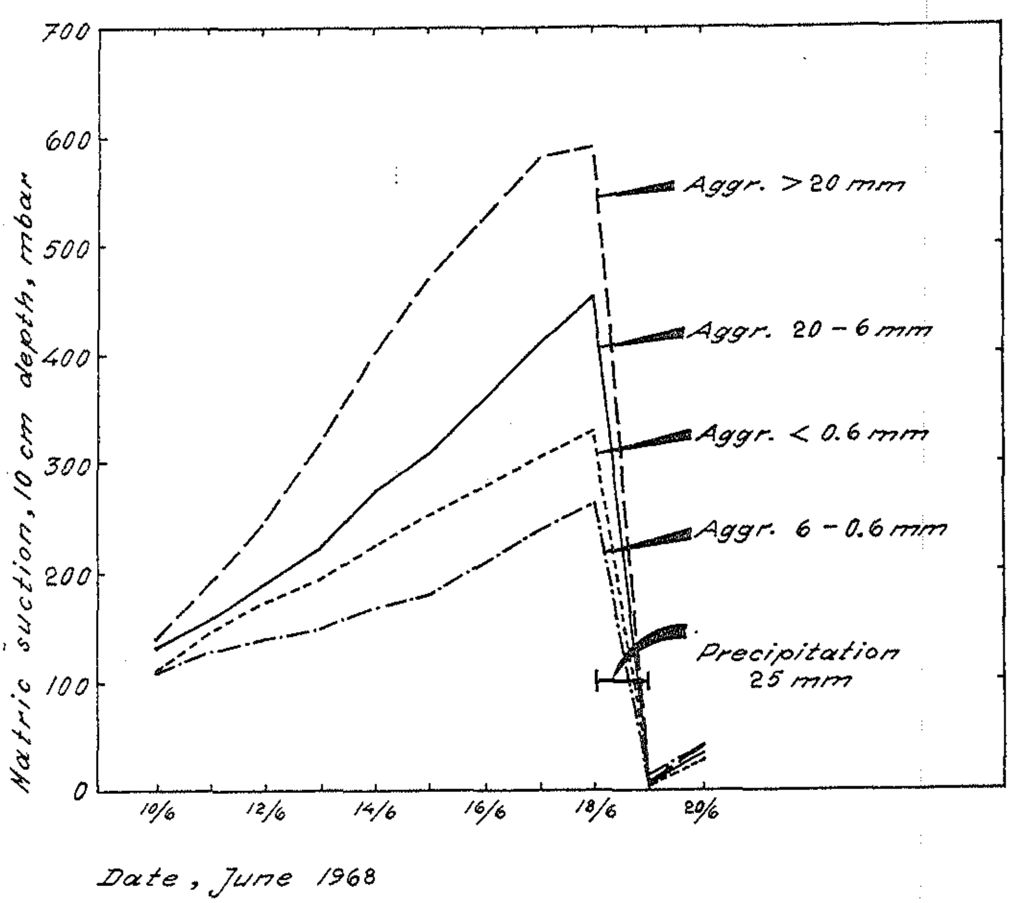

FIG. 1 DRYING SEQUENCE OF A CLAY LOAM, COVERED BY AN AGGREGATE LAYER, 3 CM IN THICKNESS. JUNE 1968.

In experiment III the soil matric suction was recorded by means of tensiometers. The results for one period are given in fig.1. It is seen that the lowest matric suctions are recorded for the 6-0.6 mm fraction, followed by the fraction smaller than 0.6 mm, the fraction 20-6 mm, and the coarsest fraction in direction of increasing suction values. This soil was kept free of plant growth. During a later period, in August, the differences were smaller, but the fraction 6-0.6 mm still showed the lowest suction values.

The duration of a given aggregate size distribution

In experiment III the coarser aggregates became smaller, while the smaller aggregates clustered together - after periods of rain and drought. A similar levelling effect was observed in experiment I after two growth seasons (and one winter in between). The results are shown in table 9.

Table 9. Aggregates larger than 20 mm at start and end of experiment I

	Aggregates >20 mm, percent		
Treatment	Start	End (VO)	End (VI)
A0	50	38	40
A1	25	37	27
A2	0	37	20

As will be recalled VO indicates watering after drying out to pF 3, while VI indicates watering after drying to pF 4.2. For the wettest treatment there were no differences in the amount of coarse aggregates after two growth seasons. In the dryest treatment the original size distribution was better preserved.

Field experience

HEINONEN (1963) found considerable differences in aggregate size distributions according to soil cultivation treatments. In Norway large effects of soil moisture variations at the time of cultivation on the coarseness of aggregation have been observed (NJØS 1976), mainly in direction of a coarser aggregation after cultivating the soil in a wet condition. However, the effects of annual variations may outrange these effects as shown in table 10.

Table 10. Aggregates larger than 6 mm in a soil compaction experiment on a loam soil at Ås, Norway

Treatment	Years	Aggregates > 6 mm Percent
Wet compaction	1962-74 (13 years)	60
Moist "	" "	35
Average of treatments	1962	72
" " "	1974	22

The percentage of aggregates larger than 6 mm was 25 units higher after wet soil compaction as compared to a moist compaction (normal soil moisture condition during spring cultivation). However, the average of the two years 1962 (late, wet spring) and 1974 (dry early spring) differed by as much as 50 units. A wet soil condition corresponded to a matric suction in the surface layer of less than 50 mbar.

REFERENCES

BLAKE, G.R. and J.B PAGE. 1948. Direct measurement of gaseous diffusion in soils. Soil Sci. Soc. Amer. Proc., 13: 37-42.

FRIIS NIELSEN, R. 1963. Plant production, transpiration ratio and nutrient ratios as influenced by interactions between water and nitrogen. Diss. Kgl. Veterinær og Landbohøjsk.København 1-162

GANDAHL, R. 1954. Hydrometermetoden. Geol. Fören. Förhandlingar. Bd. 74, H.4: 497.

HEINONEN, R. 1963. Markens vattenhushållning och jordbearbetningen. Aktuellt från Lantbrukshögskolan 69: 1-40.

NJØS, A. 1965. Dry sieving. West European methods for soil structure determinations. The West European Working Group on Soil Structure of The International Soil Science Society, Gent, Belgium, Ed. M. de Boodt: V, 43.

NJØS, A. 1967. Aggregatstørrelsesfordeling i såbedet i forhold til jordarbeiding og plantevekst. Foredrag NJF-kongress i København 1967. Fortrykk Seksjon VIII: 9-18.

NJØS, A. 1972 a. Spiringsforsøk med N-mengder og spredningsmåter i bygg og raigras. NJF-seminar Helsinki juni 1972. Stencil, 7p.

NJØS, A. 1972 b. Fysiske forhold i såbed til korn. Temperatur og fuktighet under ulike aggregatstørrelser. NJF-seminar Helsinki juni 1972. Stencil, 10 p.

NJØS, A. 1976. Long term effects of tractor traffic in two field experiments in Norway. Proc. The 7th Conf. of the International Soil Tillage Research Organization, ISTRO, Uppsala, Sweden 27: 1-7.

YODER, R.E. 1937. The significance of soil structure in relation to the tilth problem. Soil Sci. Soc. Amer. Proc., 2:21-33.

The 8th Conference of the International Soil Tillage Research Organization, ISTRO, Bundesrepublik Deutschland, 1979.

PHYSICAL CONDITIONS IN THE SEEDBED. A SAMPLING INVESTIGATION ON SPRING-SOWN FIELDS IN SWEDEN.

Göran Kritz
Department of Soil Sciences, Swedish University of Agricultural Sciences, S-750 07 UPPSALA, Sweden.

ABSTRACT

In 1969-72 a sampling investigation was carried out on Swedish spring-sown cereals fields in order to get basic data on the properties in the seedbeds. 300 sites were investigated. On each site parameters such as depth of the seedbed, aggregate size distribution, number of seeds, moisture content, etc., were determined. Parameter values for each site were visualized in seedbed profile diagrammes and average values for different factors were studied as functions on clay content.

INTRODUCTION

For generations farmers in Sweden, as elsewhere, have strived to attain such properties in seedbeds that would minimise poor emergence. Common reasons for poor emergence are drought, soil crusts and extreme sowing depth. Research work into these problems started in the thirties, mostly with field trials. The complexity of the subject, however, made it difficult to analyse and evaluate the trial results also with the help of international literature. Therefore it was clear by the late sixties that also other types of investigations must be applied. One of these was the sampling investigation (Kritz, 1976 a, b) summarized below.

SAMPLING METHODS

The task is to determine on a sample of farms the properties in the seedbeds just at the time of sowing. One method to get a strict random sample could have been to sample a number of farm addresses from a farm register. Contact could then made with each farmer. There would undoubtedly be a large drop-out from the sample, but the greatest problem with this method is, however, the high risk of "manipulation", i.e., that seedbed preparation and sowing may well be done better at the sampling sites than is normally the case. Another approach could be to ask someone in the district to report when sowing starts on the selected farms. This would also preclude all risk of "manipulation" and presumably fewer farmers would refuse cooperation when the investigator arrived at site without any previous contacts being made. This approach might perhaps prove feasible for small districts.

In the actual sampling investigation the approach we chose was to drive into a region where sowing was in progress, stop at fields with drills and ask permission to interview the farmer or operator and to make some measurements. Here there was no risk of "manipulation" and we experienced few refusals. During the four years 1969-72, 300 sites were taken out proportionally to the spring-sown area in different regions. At 289 sites the crops were cereals. At that time in Sweden there were 150.000 farms with 1.4 million hectares of spring sown crops, i.e., we got 1 site per 500 farms or per 4.700 hectares, with only 1% refusals.

Since Sweden is a long country and the 7 per cent area of arable land is widely spread, the investigation became more difficult than if the arable area had been more concentrated. Since this sampling investigation was not based on a strict random sampling, it was necessary to check whether the sample was representative. Three known population statistics, namely, area of spring-sown cereals, farm size and registered makes of tractor, were compared with the sample statistics. The results gave relatively good concordance between sample and population, which indicated acceptable representativity.

MEASURING METHODS

On entering the field, we interviewed the man who was doing the sowing about tillage operations, type of implements used etc. He was asked to estimate the depth of the seedbed and the sowing depth. He was also given an answer card to post about three weeks later with notes about the emergence of the crop. Determinations in the seedbed were carried out with a method developed for this investigation, here called method 1 and discussed below. Another method, here called method 2, was developed for small special investigations and is also presented below.

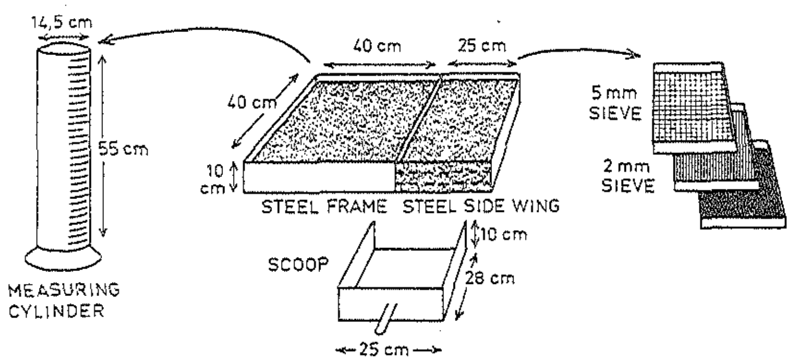

Fig. 1. Method for conducting seedbed investigations, here called method 1.

Method 1, see Fig. 1. A steel frame measuring 40 x 40 cm and a height of 10 cm is pressed into the seedbed. A steel side wing, 25 x 40 cm, is then fitted in to the frame. By determining the highest and lowest point within the frame a measure of the topography is obtained. The loose soil within the frame is then removed and transferred to a measuring cylinder graded directly in cm depth of the seedbed. Within the side wing, area 0.1 m^2 the seedbed is separated in three sublayers by a 25 cm wide scoop. Material from each sublayer is sieved in three aggregate size fractions, the ones chosen in the present context being <2, 2-5 and >5 mm. The number of seeds found in each sublayer are counted. Samples for determination of moisture content are taken from each sublayer. A simple topography determination is also carried out in the bottom of the seedbed. At each site we normally take three replicates spaced at 3 m intervals. In this investigation soil samples were taken at each site for particle size analyses and determination of water content at the matric tensions 1, 10 and 150 m water column. The results from each site are given in diagrammatic form as a seedbed profile, see Fig. 3.

Method 2, see Fig. 2, was developed for more detailed determinations in special situations, for instance more exact determinations in field trials. The method of slicing certain defined sublayers is used in different countries (inter alia, Breitfuss, 1954). We use a steel frame measuring 90 x 25 cm, which is placed in the seedbed. Loose soil at one end of the frame is taken away to make room for the scoop to be put inside it. An area of 0.1 m^2 (25 x 40 cm) will be undisturbed, in which the determinations will be made. With a frame of 24 measuring rods the average surface height is determined. A 25 cm wide height-adjustable scoop is put in at the height of the average soil surface. Material from this first slicing will form sublayer 1. In each sublayer, normally 1 cm thick, the same determinations will be made as in method 1. With the 24 measuring rods the average bottom height is measured as was done with the surface height, and from these two determinations the depth of the seedbed is obtained. With this equipment it has also been possible to make determinations in 5 cm broad zones with the rows in the middle and in the 7.5 cm broad intermediate zones. In an area of 0.125 m^2 (25 x 50 cm) in the frame, perpendicular to the drilling direction, determinations were made in and between four rows.

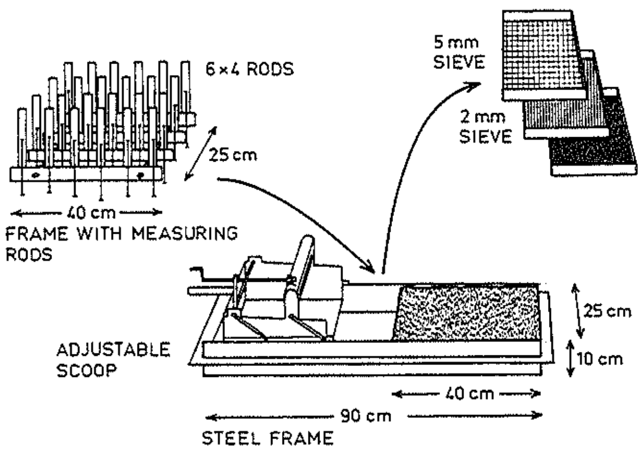

Fig. 2. Method for conducting more detailed seedbed investigations, here called method 2.

Comparisions of the methods shows that the depth of the seedbed is determined quite accurately with both methods, but method 2 takes longer. The thickness of the sublayers is determined in method 1 rather inexactly, particularly on aggregated soils. Control measurements have namely showed that the soil from the surface sublayer will be more packed in the measuring cylinder than in the seedbed, and thus there will be an underestimation of this sublayer. In contrast, the material from the bottom sublayer will be more loose in the measuring cylinder, resulting in overestimation. In method 2 it may be difficult to determine the thickness of the surface and the bottom sublayers, but the thickness of the sublayers in between will be very exactly determined. For aggregate size distribution, moisture content and seed distribution, method 2 gives more exact results than method 1. Tests have shown that method 1 seems to be the best for sampling investigation of the present kind. It is also easy to measure the bulk density by determining the weight of the soil in the cylinder. A more accurate determination of the depth of the seeds, perhaps in a special frame, would also be useful.

RESULTS FROM INDIVIDUAL SEEDBEDS

The results fromeach site are shown in the form of seedbed profiles, see Fig. 3, each consisting of three diagrammes, where aggregate size distribution, seed distribution and moisture content of each sublayer are given. Moisture contents at three matric tensions are also given. These profiles give us good information about the seedbed situation which can be used in making predictions and diagnoses for emergence.

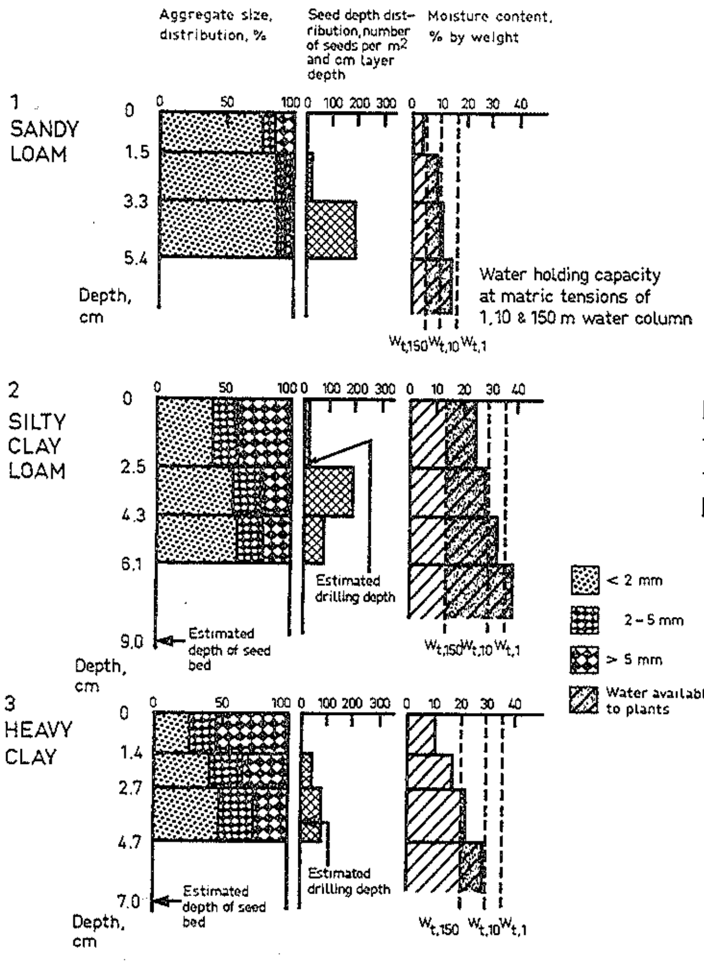

Fig. 3. The seedbed on three type soils presented in the form of seedbed profiles.

Soils 1, 2 and 3 in Fig. 3 represent three type soils which also show three possible reasons for poor emergence. These diagrammes give good examples of the conditions in Sweden. Soil 1 is a sandy loam with about 2.5 mm plant available water in the seedbed. Here the good protection against evaporation ensures that emergence will not be poor in cases of drought, and as the seeding depth is suitable the emergence will not be poor because of that. Soil 2 is a silty clay loam with about 7.5 mm plant available water in the seedbed. Moisture is not limiting here. Soil crust however may be formed, and here it is positive that the seeds are not placed too deep. Soil 3 is a heavy clay with no plant available water in the seedbed. Structure here gives good protection against evaporation, but there will be poor emergence if no rain falls, since a relatively high percentage of the seeds are in sublayer 2, which has no contact with the wet bottom layer.

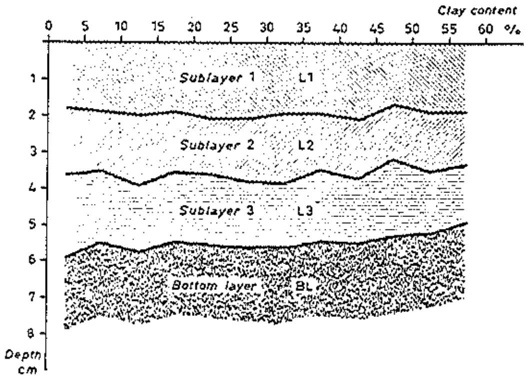

Fig. 4. The median depths of the sublayer boundaries as functions of the clay content.

RESULTS SHOWING THE NORMAL MOISTURE CONDITIONS

Results showing the normal situations are given in Fig. 5 as median values for each 5 per cent clay content class. The moisture conditions in different sublayers are given. The determinations were made in the four sublayers whose thicknesses are shown in Fig. 4. Four unbroken curves show in Fig. 5 the actual moisture content in the sublayers ($w_{a,L1}$, $w_{a,L2}$, $w_{a,L3}$ and $w_{a,BL}$) as functions of the clay content. The three broken curves show the moisture content at matric tensions of 1, 10 and 150 m water column ($w_{t,1}$, $w_{t,10}$ resp. $w_{t,150}$) as functions of the clay content. The shaded part shows approximately the water that is unavailable to plants. The w_a-values are only

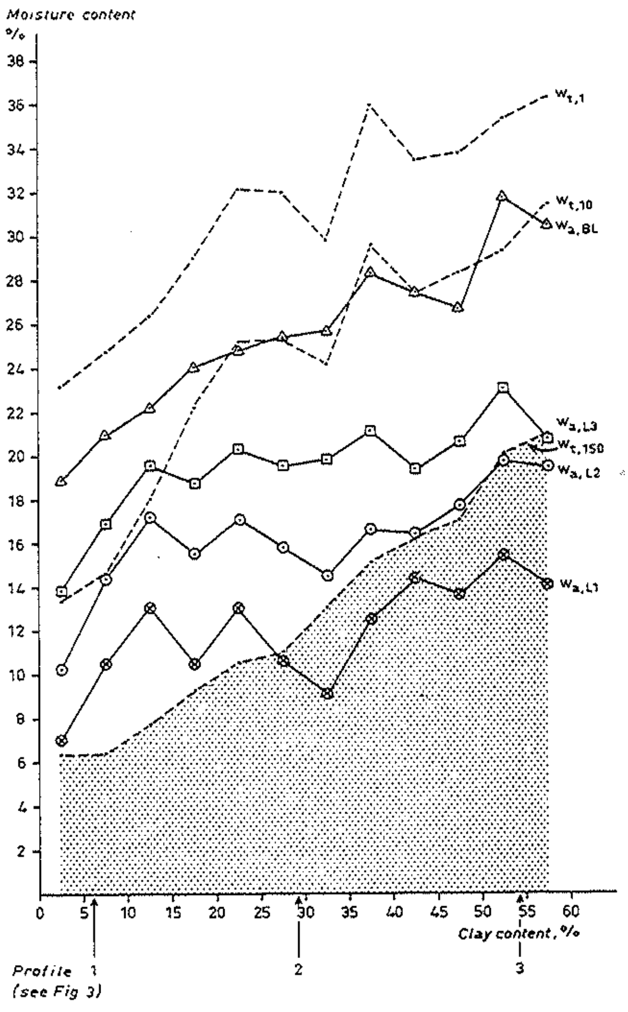

Fig. 5. The moisture conditions in the sublayers of the seedbed as functions of the clay content. $w_{a,L1}$, $w_{a,L2}$, $w_{a,L3}$ and $w_{a,BL}$ stand for the actual moisture content in sublayers 1, 2, 3 and the bottom layer (see Fig. 4). $w_{t,1}$, $w_{t,10}$ and $w_{t,150}$ stand for the moisture content at matric tensions of 1, 10 and 150 m water column. (Median values per cent by weight.)

weakly dependent on the clay content, whereas the w_t-values are strongly dependent on it. In sublayer 1 there is plant available water up to 25 per cent clay content and at higher clay contents there is a deficit. Sublayers 2 and 3 also have a deficit at high clay contents. To make it possible to compare the moisture conditions in the three type soils - shown in Fig. 3 by seedbed profiles - with the normal situations, the clay content for each type soil has been marked.

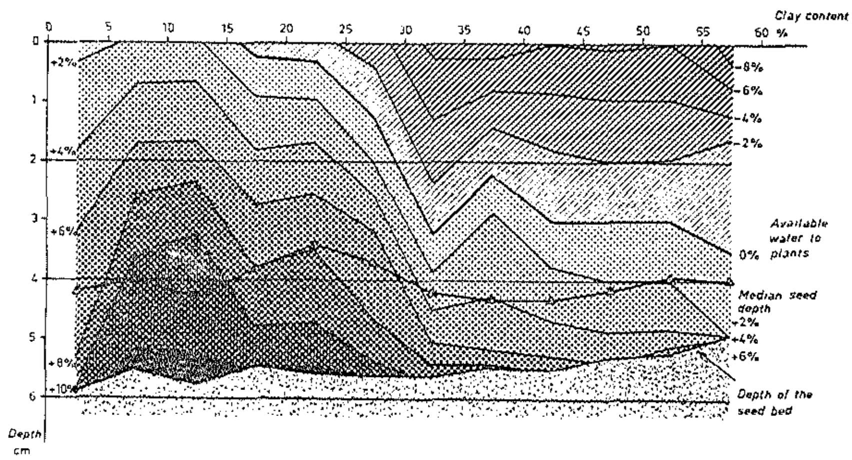

Fig. 6. The moisture condition in the seedbed as a function of the clay content. The curves in the diagramme connect points with the same amount of plant available water. The dotted part of the figure stands for a surplus of plant available water and the lined part for a deficit. (Median values, per cent by weight.)

Fig. 6 shows a clay content/depth diagramme. The coordination curves with intervals of 2 per cent connect points with the same amount of plant available water. The part of the diagramme corresponding to a surplus of plant available water is dotted, while the part corresponding to deficit is lined. The median seed depth is also given, but for high clay content it is probably inexact in the determinations. In the group of soils with 5-14 per cent clay content the plant available water reaches a maximum, whereas the content decreases little in the group < 5 per cent. In soil with clay content of ≥ 15 per cent the moisture content decreases with increasing clay content. The situation is especially critical in the upp 3 cm.

REFERENCES

Breitfuss, J. Untersuchungen über die gleichmässige Tiefenlage der Saat von Rübensägeräten. Landtechnische Forschung, München, 1954.

Kritz, G. Seedbed preparation and properties of the seedbed in spring-sown fields in Sweden III. Sampling investigation 1969--72. Primary results from 300 investigated places. Reports from the Division of Soil Management, Swedish University of Agricultural Sciences, S-750 07 UPPSALA , Sweden, No. 44, 1976 a.

Kritz, G. Seedbed preparation and propertes of the seedbed in spring-sown fields in Sweden IV. Sampling investigation 1969--72. A general survey of some important factors. Reports from the Division of Soil Management, Swedish University of Agricultural Sciences, S-750 07 UPPSALA, Sweden, No. 49, 1976 b.

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IMPLEMENTS FOR SEEDBED PREPARATION. AN APPROACH IN PERFORMANCE STUDIES.

by Lennart Henriksson

Dept. of Soil Sciences, Swedish University of Agricultural Sciences, S- 750 07 Uppsala, Sweden.

ABSTRACT

An approach to the study of tillage implements, especially their work in the soil, is described, and examples of results obtained are given.

INTRODUCTION

As a part of the work on problems of seedbed preparation in Sweden we have started field studies of the effects in the soil of different kinds of tools, positions of tools and of different makes of implement. The aim is to better understand the possibilities of preparing a seedbed suitable for the requirements of different crops. By comparing different implements we hope to be able to advise farmers and give manufacturers and dealers suggestions for the development of new implements.

The tests reveal the general characteristics of different harrows, but the main efforts are laid on the measurements of the properties of the harrowed layer. The result of these measurements can be compared with requirements obtained in modal experiments and field trials and with investigations of what is achieved in practice (Håkansson & von Polgår, 1976; Henriksson, 1974; Kritz, 1976). Relative comparison between different implements are also made.

Ordinary harrows commonly used in Sweden have been tested and in addition we have also made a flexible s-tine harrow to be able to study different factors one at a time, such as number, position and kind of tines. Some of these tests are carried out as ordinary field trials to get estimations of the crop yield effects. The tests are made under normal field conditions, often on fields belonging to private farmers, which means that all the heterogeneity of the soil surface layer is encountered. Thus, there is difficulty in getting significant differences between treatments in measurements of variables, which in fact require very homogeneous original soil conditions. The very accurate measurements made in a soil bin are impossible here. In our studies we try to fill a gap between the more fundamental work done in soil mechanics, agricultural engineering and on crop establishment. We try to work very close to the situation in practical farming.

METHODS TO STUDY EFFECTS IN SOIL

Basically we deal with the amount of soil that is loosened and worked by the implement taking samples of suitable size for further analyses. The size of the individual samples is chosen according to the heterogeneity of the soil that can be expected. When studying the seedbed after spring tillage on an autumn-ploughed field, we work with samples sized 0.25 m^2. With a greater heterogeneity, e.g. in seedbeds for winterwheat, we use larger samples, 0.5 m^2. Steel frames are used to delimit the samples, and the loose soil within the frame is weighed and measured for volume in a bucket. Normally there are no problems in finding the border between the tilled and untilled soil, if the soil has settled after the previous tillage, and if the sample is taken soon after the latest treatment. The border is felt as a firm bottom often of rather irregular depth. A mean working depth can be calculated from the volume of the soil if the bulk density is considered to be approximately the same as in the tilled layer. Alternatively, the seedbed can be divided into different layers, the thicknesses of which can be determined by a height measuring apparatus constructed by I. Håkansson (unpublished).

Before the soil is removed the roughness of the soil surface and afterwards that of the bottom surface, can be measured by a reliefmeter. Subsamples of the soil are taken for determination of the water content. Other samples are dry sieved to get the aggregate size distribution.

For a general description of the test site we determine the water content at tensions of 0.1, 1 and 15 bar, the strength of soil by a vane shear test, and the roughness of the soil surface before tillage.

PROPERTIES OF THE SEEDBED

Dry weather often prevails during the spring and the early summer in Sweden and there are many clay soils where the capillary transport of water from below to the seed is very limited. Thus we attempt to place the seed on a moist bottom surface and to cover it with a layer of soil deep and fine enough to serve as an evaporation barrier during the germination.

As the coulters are usually adjusted to follow the bottom surface of the tillage layer the depth of harrowing largely determines the depth of sowing. Accurate control of the depth of harrowing is thus very important. The mean depth must be adapted to the crop grown and the prevailing soil conditions. The variation of the depth must also be considered and kept as small as possible in order to obtain an even emergence of the crop.

The roughness of different surfaces influences the placing of the seeds and the depth of the seedbed. A rough ploughing makes it difficult for the tines in a harrow to operate satisfactorily and during the first run most of the work is done by the levelling bar. One object of the harrowing is to prepare an even surface at a proper depth in the soil (the bottom surface of tillage) that the coulters can follow and where they can place the seed. This bottom surface of tillage is often so hard that the coulters do not penetrate it. Consequently, if the bottom is uneven the coulter will jump up when it hits an obstacle and the seed will be placed shallower in the seedbed. An uneven upper soil surface may also contribute to the varying depth of the covering soil.

A fine tilth provides effective protection against evaporation in deeper layers of the seedbed, and is a good help for suitable placement of seed. Big clods can also interfere with the work of the coulters. The ability of the harrows to crush clods must be evaluated by determination of the aggregate size distribution.

Lack of water is the most common reason for unsatisfactory emergence and the water content in the seedbed is a factor that must be determined if the possibilities for germination are to be estimated. Our interest in depth, roughness and clod size is due to the fact that these qualities influence the water situation around the seed. An uneven drying due to the microrelief is common, higher parts of the original plough furrow dry faster than lower parts. The variation of the water content is thus an important property.

In the seedbed there is often a strong gradient with depth both with regard to water content and aggregate size distribution. Therefore it is very important to take samples from the same depths when different implements are compared. Thus, it is difficult to study sorting and mixing effects in the field when the seedbed has to be divided in a number of layers. As yet only some preliminary studies have been made.

ECONOMIC ASPECTS

Complete evaluation of a tillage implement includes comparison of the amount of soil handled and the structural changes received with the amount of energy and time required. Until now we have concentrated on the soil measurements and have not made any determinations of draught.

EXAMPLES OF RESULTS
WORKING DEPTH

The mean depth is controlled by adjustment of the implement. Once we have made the draught measurements now planned, it will be interesting to compare different implements with regard to the amount of soil tilled and the power needed.

A current problem is to produce a seedbed with as few variations of depth as possible. Table 1 shows examples of mean depths and corresponding mean standard deviations obtained in trials on level sites smaller than 1 ha and with homogeneous soils.

In the field trials the measurements have shown that the range of variations of depth for a single harrow may frequently be 3 - 4 cm, and in fields of normal size where greater differences in soil texture and structure occur, even larger ranges can be expected. There are no clear differences in the mean standard deviation of depth after seedbed preparation with types of harrows normally used. The depths vary from spot to spot, and differences in height between lower and higher parts of the initial plough furrow and in the structure of the soil surface seem to be the most common reasons for these variations.

Harrows with narrow sections and with depth wheels instead of runners have been considered to give a more even seedbed. We have not been able to confirm this. The yields after harrows with runners are slightly higher, but the differences are small.

Table 1 also shows measurements of the water content in the tilled soil. The standard deviation is considerable, and as the mean water content may be near the permanent wilting percentage, this may explain spots with poor germination.

TABLE 1. Depths and water contents of the harrowed layer and grain yields in trials tilled with different implements for seedbed preparation to spring sown cereals. Four soil samples of 0.25 m² are taken from each plot normally with four replicates in each trial.

Comparisons	No of trials	Depth cm		Water content %		Grain Yield kg/ha
		Mean	Mean Standard deviation	Mean	Mean Standard deviation	
Harrows equipped with						
runners	14	5.8	0.68	14.3	1.64	4 620
depth wheels		4.8	0.63	14.2	1.64	4 480
Different makes of harrows						
Harrow A	4	4.8	0.70	11.5	1.56	3 560
Harrow B		5.7	0.55	13.1	1.31	3 590
Harrow C	1	4.8	0.66	17.0	2.16	6 590
Harrow D		3.9	0.57	14.6	1.75	6 580
Harrow E	2	5.7	0.60	10.1	0.92	4 770
Harrow F		2.7	0.51	7.6	1.20	4 700

TABLE 2. Roughness of the tillage bottom and percentage of soil aggregates<4 mm after tillage with a flexible s-tine harrow. (Olsson, 1978).

	No of trials	Roughness[a)] cm	Percentage of aggregate < 4 mm
No of harrowings			
2	5	0.77	52
3		0.69	55
Tine spacing cm			
10	3	0.83	56
6.7		0.69	55
5		0.72	57
Approach angle of the tines			
Figure 1 a	5	0.73	52
Figure 1 b		0.74	54

a) The roughness is calculated as the mean standard deviation of 162 height measurements on a surface of 0.25 m².

ROUGHNESS OF THE TILLAGE BOTTOM

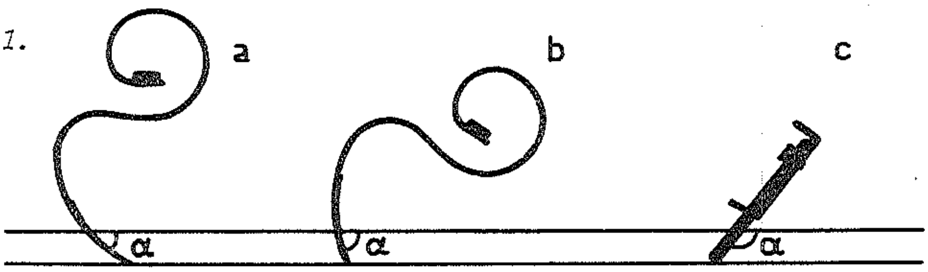
The depth of the coulters and consequently the placing of the seeds is often determined by this surface. Among the narrow tines, s-tines are mostly used and will be discussed here. With these tines the tillage bottom is always more or less rough. One way of making the tillage bottom more even (table 2), is to increase the number of harrowings. Another way is to put more tines on the implement, but a narrower spacing than about 7 cm does not seem to be useful.

Variation in soil resistance causes a spring movement of the tines which influences their working depth and the roughness of the tillage bottom. In theory an approach angle α, like figure 1 a, should give the smallest variation in depth, but in reality changes of the approach angle have had little effect. On harrows used in Sweden the depth adjustment is commonly done by turning the tine axes.

THE AGGREGATE SIZE DISTRIBUTION

The approach angle of the tines seems to have an effect on the aggregate size distribution received during the soil loosening process.

FIGURE 1.



With an angle like figure 1 a the soil is lifted and there is no counter pressure as in 1 b, where the tine works against the untilled soil and crushes clods more effectively. Heavy clodcrushers with rigid tines working with an approach angle greater than 90° (figure 1 c) are very effective in crumbling a surface crust. Hard loose-lying clods in clayey soils are especially difficult to break as the tines only push them aside. Most Swedish harrows are furnished with levelling bars, and if of a suitable construction they can be very effective in crumbling the soil. Some manufacturers now pay special attention to this part of the implement. The tractor wheels also do a lot of crushing especially broad twin mounted wheels. On lighter soils trailer harrows of roller type can be very effective.

CONCLUSIONS

According to our experience the collection of large soil samples makes it possible to evaluate the work of the tools in the soil. Until now we have only measured some of the parameters. Other effects, e.g. mixing, sorting and water losses during tillage remain to be measured.

The soil sampling is fairly laborious and the number of treatments or types of analyses must be restricted if the work is to be done during the time when appropriate soil conditions for tillage are prevailing.

We have planned a continuous programme for these investigations in order to collect further experience and to follow the development of new tools. Development of the theory of soil mechanics with special emphasis on the soil surface conditions would be of great value in explaining the empirically found results.

REFERENCES

Henriksson, L., Studier av några jordbearbetningsredskaps arbetssätt och arbetsresultat. Rapporter från jordbearbetningsavdelningen nr 38. Uppsala. 1974.

Håkansson, I. & von Polgár, J., Modellförsök med såbäddens funktion. I. Såbädden som skydd mot avdunstning. Rapporter från jordbearbetningsavdelningen nr 46. Uppsala . 1976.

Kritz, G., Såbäddens utformning på vårsådda fält. IV. Stickprovsundersökningar 1969 - 1972. En översiktlig studier av några viktiga faktorer. Rapporter från jordbearbetningsavdelningen nr 49. Uppsala 1976.

Olsson, U., Harvens konstruktion och harvningens utförande - inverkan på bearbetningsresultatet. Rapporter från jordbearbetningsavdelningen nr 54. Uppsala 1978.

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Seedbed Preparation for Arid and Semi-Arid Conditions- Problems and Solutions.

by

D. Wolf[1], A. Stibbe[2] and A. Hadas[2]

Introduction

Under arid and semi-arid climatic conditions, dry-land agricultural practices are directed toward improving the water balance for the crops through top soil layer-physical properties modification by tillage operations. This is true for irrigated agriculture and more so for rainfed agriculture under adverse climatic conditions.

Tillage operations affect crops development and yields by:

a. Improving water storage of winter precipitation by increasing soil infiltrability, weeds eradiction and decreasing evaporative losses.

b. Producing a "proper"- seed bed for crop establishement while modifying the soil physical conditions to help root development and proliferation.

Unfortunately these operations involve a heavy toll to be paid in labour, machinery and energy inputs. This comes as a consequence to the fact that most tillage activities are carried out on a dry soil aiming at minimize soil compaction- a very severe problem in the soils of the dry regions which are devoid of organic material.

In order to study this complex problem the scope of this preseutation is too small, however, we shall point out some problems and solutions.

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[1]Senior Lecturer- Agricultural Engineering Department, Technion- Israel Institute of Technology, Haifa, ISRAEL.

[2]Soil Scientists- Institute of Soil and Water, Agricultural Research Organization, Bet-Dagan, ISRAEL.

Water Conservation and Weed Control

Rainwater conservation in the soil is of utmost importance in arid and semi-arid zones. In table 1 annual rainfalls and amounts of water stored in deep soil profiles are given.

Table 1

Amounts of rainfall stored in a clay soil profile (150cm) (After Hadas 1977)

	Amounts of water stored during the winter (mm)			
Rainfall (mm)	Plowing 40 cm	Plowing 25cm	Chisling 40cm	No Tillage
110	67	69	74	73
247	210	201	208	203
450	426	403	375	365
608	523	504	485	470

The data show that for annual rainfalls exceeding 200-300mm, up to 10-15% more water are conserved under plowed plots as compared to non-tilled plots. This appreciable amount of potentially available water for plant growth can be used by various crops either during the winter rainy season (wheat, barley, vetch, sunflower) or summer's- dry season crops (cotton, millet, sorghum, corn), provided the soil is impregnates with roots.

Not always are tillage operations effective in increasing soil water storage. Under winter rain conditions loessial or silty soils tend to form crusts and according to data presented by Hadas and Stibbe, 1977, and more recent unpublished measurements, the crust is formed during and immediately after the first rain storm and hardly changes its properties afterwords. It was found on a lossial soil having a slope of 2% that on a coarsely plowed plot, 3-7% of the seasonal rainfall is lost due to runoff as compared to 20-35% on ridges, or diskes or plowed and disked plots. These data suggest that plowing alone is an effective water conserving measure aggregated and non-aggregated soils and as compared to other tillage operations, but one disking operation will help produce a crust which may not inhibit seedlings emergence (Hadas and Stibbe, 1977) but will drastically diminish infiltration and enhence runoff and erosion.

It was found (Hadas, 1977) that on plowed plots only 66 to 70 weed seedlings were as on nontilled disked or chisled plots 227 to 241 seedlings per m^2 were counted. Thus plowing acts as an effective weed eradicting measure on one hand helping to diminish transpirative loss of water stored in the soil profile by weeds, and reducing runoff losses on the other hand.

Seed Bed Preparations

In arid and semi-arid regions rainfed dryland farming practices strive to help the sown seeds complete on the measer supply of soil water which diminishes during their germination and emergence due to direct evaporative losses from the soil. The importance of the knowledge of the proper seed-bed physical properties by which evaporative loss will be retarded (Hadas, 1968) and water supply to seeds will be maintained by good seed-soil contact was heavily stressed by Hadas and Stibbe (1977), Hadas (1974), and Hadas and Russo (1974a). Hadas and Russo (1974b) have also recommended that in order to ensure a good seed-soil contact with in the soil matric potential range of -300 to -1000 mbrs, the soil aggregates seed bed layer should be made of crumbs one fifth to one tenth of the seeds size. Their laboratory based recommendation was in support to field experiments concerning small like sorghum seeds (Dasberg, et. al., 1966) but was not significantly so when fairly larger seeds were used such as cotton seeds (Hadas, et. al., 1978) even though lower stands were counted wherever coarser tilth was involved (e.g.- deep plowing). This trend was predicted by Hadas and Russo (1974b), however the cost-energy and Labour wise- on one hand and the runoff, erosion hazards involved in finer tilth on the others, is tremendous according to Hadas, et. al., 1978. This state of affair imposes a grim dilema: how to till the soil properly?

The current Israeli trend is to reduce tillage operations and plant in coarser tilth whenever crust may be formed on the soil, thus placing water and soil conservation as the most important goals, while taking some risks as total yields may be lower. Yet, such an approach adoptes in an intensive, highly mechanized and efficiently manages farming system can not be directly and literaly adopted by extensive, non mechanized systems without carrying experiments and tests before a decision is taken.

Literature Cited:

1. Dasberg, S., Hillel, D., and Arnon, I. 1966. Response of grain sorghum to seed bed compaction. Agr. J. 58: 199-201.

2. Hadas, A. 1968. Evaporation and drying processes in layered soils. Ph.D. dissertation, 106pp with English summary. Rehovot.

3. Hadas, A. 1974. Water transfer to germinating seeds as affected by soil hydraulic properties and seed-soil water contact impedance. pp. 501-512 In "Heat and Mass transfer in Biosphere 1-Transfer process in plant environment. Halstead Press, N. Y.

4. Hadas, A. 1978. Tillage soil physical conditions and crops response. pp. 441-459. In Proc. of Int. Symp. on Rainfed Agriculture in Semi-Arid Regions, Riverside, California.

5. Hadas, A. and Russo,D. 1974a. Water uptake by seeds as affected by water stress, capillary conductivity, and seed-soil water contact. I Experimental study. Agr. J. 65:643-647.

6. Hadas, A. and Russo, D. 1974b. Water uptake by seeds as affected by water stress, capillary conductivity and seed-soil water contact. II Analysis of experimental Data. Agr. J. 65:647-652.

7. Hadas, A. and Stibbe, E. 1977. Soil crusting and emergence of wheat seedlings. Agr. J. 69:547-550.

8. Hadas, A., Wolf, D. and Meirson, I. 1978. Tillage implements- Soil structure relationships and their effects on crop stands. Soil Sci. Soc. Amer. J. 42:632-637.

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Nonerodible Soil Aggregates in Surface Soil as Related to Tillage Practice 1/

D. E. Smika, Soil Scientist, USDA
Central Great Plains Research Station
Akron, Colorado 80720, U.S.A.

ABSTRACT

Percentages of nonerodible soil aggregates on the soil surface were determined after seeding of winter wheat in conventional stubble mulch, minimum and no-tillage fallow systems. The total percent of nonerodible aggregates was 64.2, 68.1, and 69.4% for conventional stubble mulch, minimum, and no-tillage systems, respectively. The increased aggregation is attributed to the larger amounts of straw mulch on the soil surface left as a result of fewer mechanical tillage operations during fallow. Residue increases were nearly twice as effective as the nonerodible aggregate increases in decreasing the wind erosion hazard.

Soil erosion by wind is active on most cultivated soils in the Central Great Plains of the United States today. Wind erosion is a potential threat in most years--it may occur whenever soil, vegetative, and climatic conditions are conducive. Conditions that promote wind erosion are (i) loose, dry, and finely divided soil, (ii) a smooth soil surface where vegetative cover is sparse or absent, (iii) a large enough field, and (iv) wind strong enough to initiate soil movement (5). Wind erosion is most serious in the Central Great Plains late in winter and early in spring (February through April) when atmospheric conditions are the least stable and create periods of high wind velocities. The period is one during which vegetative growth is dormant, and follows a period of weathering degradation of both vegetative materials and soil aggregates.

Soil erosion can be controlled by creating a soil surface that is resistant to erosion, decreasing windspeed (through shelterbelts or barriers), protecting the erodible-sized soil particles from the wind, or a combination of these practices. Increasing the surface roughness of the soil increases the resistance of a soil to erosion. Surface roughness can be increased by increasing the proportion of soil aggregates that are resistant to erosion on the surface. When about 67% of the aggregates on the soil surface are greater than 0.84 mm in diameter, the smaller, erodible-sized particles are protected and less likely to be picked up by the wind (6). Ridging the soil surface, or vegetative residue also protect the soil surface.

1/ Contribution from Soil, Water, and Air Sciences, USDA-Agricultural Research.

Minimum and no-tillage fallow practices for winter wheat production have recently been introduced into the Central Great Plains (4). These practices have increased the quantity of residue that is maintained on the soil surface, which, in itself, helps to protect the soil from wind erosion. However, the formation and stability of nonerodible-sized soil aggregates is highly related to the quantity of wheat straw residue on the soil surface (3). Therefore, minimum or no-tillage fallow practices should increase the nonerodible soil aggregate fraction of the surface soil. This study was conducted to determine whether minimum tillage and no-tillage practices were influencing the percentage of nonerodible aggregates in the surface soil as compared with conventional stubble mulch tillage.

METHODS AND MATERIALS

Soil aggregate size distribution was determined on research plots that had been under conventional stubble mulch tillage, reduced tillage, or no-tillage fallow practices since 1973. Conventional stubble mulch tillage consisted of an average of six tillage operations during fallow. Common implements used were a series of 1.8 m wide blades or a rodweeder with semichisels used in various operational sequences. In all sequences, the first operation was a blade operation and the last was a rodweeder operation. Total width for each implements was about 4 m. Reduced tillage fallow consisted of weed control for the first 12 months with herbicides plus two tillage operations just before seeding for weed control with either the blades or the rodweeder. Under no-tillage, weeds were controlled with herbicides during the entire 14-month fallow period. The plots were on Weld silt loam (fine, montmorillonitic, mesic Aridic Paleustolls). They were 11 m by 30 m, and treatments were replicated 3 times. The plots were sampled for aggregate analysis after seeding of wheat in September 1975, 1976, 1977, and 1978. Six samples, each 15 by 25 by 5 cm, were randomly collected within each plot of each replication. Aggregate sizes of less than 0.84, 0.85 to 6.4, 6.5 to 12.6, 12.7 to 38, and more than 38 mm in diameter were determined on oven dry samples using dry rotary sieving procedures (1).

The amount of residue on the soil surface was determined from 3 sites within each plot using standarized procedures (5). Residue in the surface 7.6 cm of soil was determined using techniques described by Greb et al. (2).

RESULTS AND DISCUSSION

The amount of wheat straw residue left on the soil surface at seeding time was significantly increased by minimum and no-tillage practices as compared with conventional stubble mulch tillage (Table 1). The quantity of residue destroyed was directly related to the number of tillage operations. Each tillage operation destroyed about 200 kg of straw/ha from the soil surface.

The quantity of nondecomposed wheat straw found in the upper 7.6 cm of soil was also influenced by fallow tillage practice (Table 1). The least amount of residue was present in the plots under conventional stubble mulch tillage, and the most was in the plots under the no-tillage practice. The tillage treatments had been used for one wheat-fallow cycle before sampling was initiated, which had permitted incorporation of residue into the soil by two drilling operations. Also, the experimental area had been stubble mulch farmed for several years before the minimum and no-tillage practices were initiated, and, therefore, some straw had accumulated from this practice and was probably at about the level found in the conventional stubble mulch tillage plots during this study. The number of tillage operations did not affect residue in the soil as directly as it did residue on the soil surface. The residue in the soil ranged from an average of a 160 kg/ha decrease per operation for conventional as compared with minimum tillage to a 385 kg/ha decrease per operation for minimum as compared with no-tillage.

The total percent of nonerodible aggregates was significantly higher for both the minimum and no-tillage systems as compared with conventional stubble mulch tillage (Fig. 1). This trend was consistent each year of the study and the percent nonerodible aggregates for no-tillage ranged from a high of 75% to a low of 66%. There was no significant difference in total percent nonerodible aggregates between the minimum and no-tillage systems.

The total percent nonerodible aggregates was favorable on all treatments, but the minimum and no-tillage systems provided greater protection to the soil from wind erosion than did the conventional stubble mulch treatment. With conventional stubble mulch tillage, the total percent nonerodible aggregates could be inadequate for protecting the soil.

In the 0.85- to 6.4-mm nonerodible aggregate size, the percent of aggregates was highest with conventional stubble mulch tillage, but the difference was not statistically significant. I think that the higher percentage of aggregates in this size classification is important, however, because when these aggregates break down into the next smaller size, either naturally or by tillage, they will form a larger percentage of erodible sized aggregates than would be formed under minimum or no-tillage.

In the 12.7 to 38 and >38 mm aggregate size classes, the percent of nonerodible aggregates was largest with the minimum and no-tillage systems as compared with conventional stubble mulch tillage. The high percentage of these large aggregates is important, because the larger aggregates require more breakdown to reach the erodible size.

The total percent of nonerodible soil aggregates was highly related to the quantity of wheat residue on the soil surface ($r^2 = 0.990^{**}$). The correlation between nonerodible soil aggregates and residue in the surface 7.6 cm of soil was high ($r^2 = 0.891^{*}$), but not as good as the correlation with residue on the surface. This lower correlation with residue in the soil is not surprizing, because this residue probably lost the original bonding agents, so that its presence was not so influential in aggregate formation as residue on the soil surface.

The relative effectiveness of nonerodible aggregates or residue on the soil surface for wind erosion protection was determined with the use of the wind erosion equation (7). The increases in the soil aggregate and crop residue factors obtained with minimum and no-tillage over those obtained with the conventional stubble mulch tillage were used in the comparison, keeping all other terms in the equation constant. Increasing the nonerodible aggregate percentage by 3.9% with minimum tillage decreased potential erosion by 22.2% as compared with conventional stubble mulch tillage. With no-tillage, the additional 1.3% nonerodible aggregates decreased erosion potential an additional 5.6%. The 880 kg/ha increase in residue with minimum tillage decreased the erosion potential 36% as compared with conventional stubble mulch tillage. The 1050 kg/ha increase in residue with no-tillage decreased erosion potential by 45.6% as compared with conventional tillage. The residue increases were about twice as effective as the increases in nonerodible aggregates in decreasing the wind erosion hazard.

SUMMARY AND CONCLUSIONS

The minimum and no-tillage systems of fallow for winter wheat production in the Central Great Plains are superior to the conventional stubble mulch tillage system for developing nonerodible soil aggregates. The presence of greater quantities of wheat residue on the soil surface as a result of fewer mechanical tillage operations is probably the major factor responsible for the increased aggregation. The residue increases were nearly twice as effective as the nonerodible aggregate increases in decreasing the wind erosion hazard.

Literature Cited

1. Chepil, W. S. 1962. A compact rotary sieve and the importance of dry sieving in physical soil analysis. Soil Sci. Soc. Am. Proc. 26:4-6.

2. Greb, B. W., A. L. Black, and D. E. Smika. 1974. Straw buildup in soil with stubble mulch fallow in the semiarid Great Plains. Soil Sci. Soc. Am. Proc. 38:135-136.

3. Smika, D. E., and B. W. Greb. 1975. Nonerodible aggregates and concentration of fats, waxes, and oils in soils as related to wheat straw mulch. Soil Sci. Soc. Am. Proc. 39:104-107.

4. Smika, D. E., and G. A. Wicks. 1968. Soil water storage during fallow in the Central Great Plains as influenced by tillage and herbicide treatments. Soil Sci. Soc. Am. Proc. 32:591-595.

5. U. S. Department of Agriculture, Committee Report. 1962. A standardized procedure for residue sampling. U. S. Dept. of Agr., Agr. Res. Serv. Ser. 41, No. 68, 9 p.

6. Woodruff, N. P., Leon Lyles, F. H. Siddoway, and D. M. Fryrear. 1972. How to control wind erosion. USDA Agr. Info. Bull. 354, 22 p.

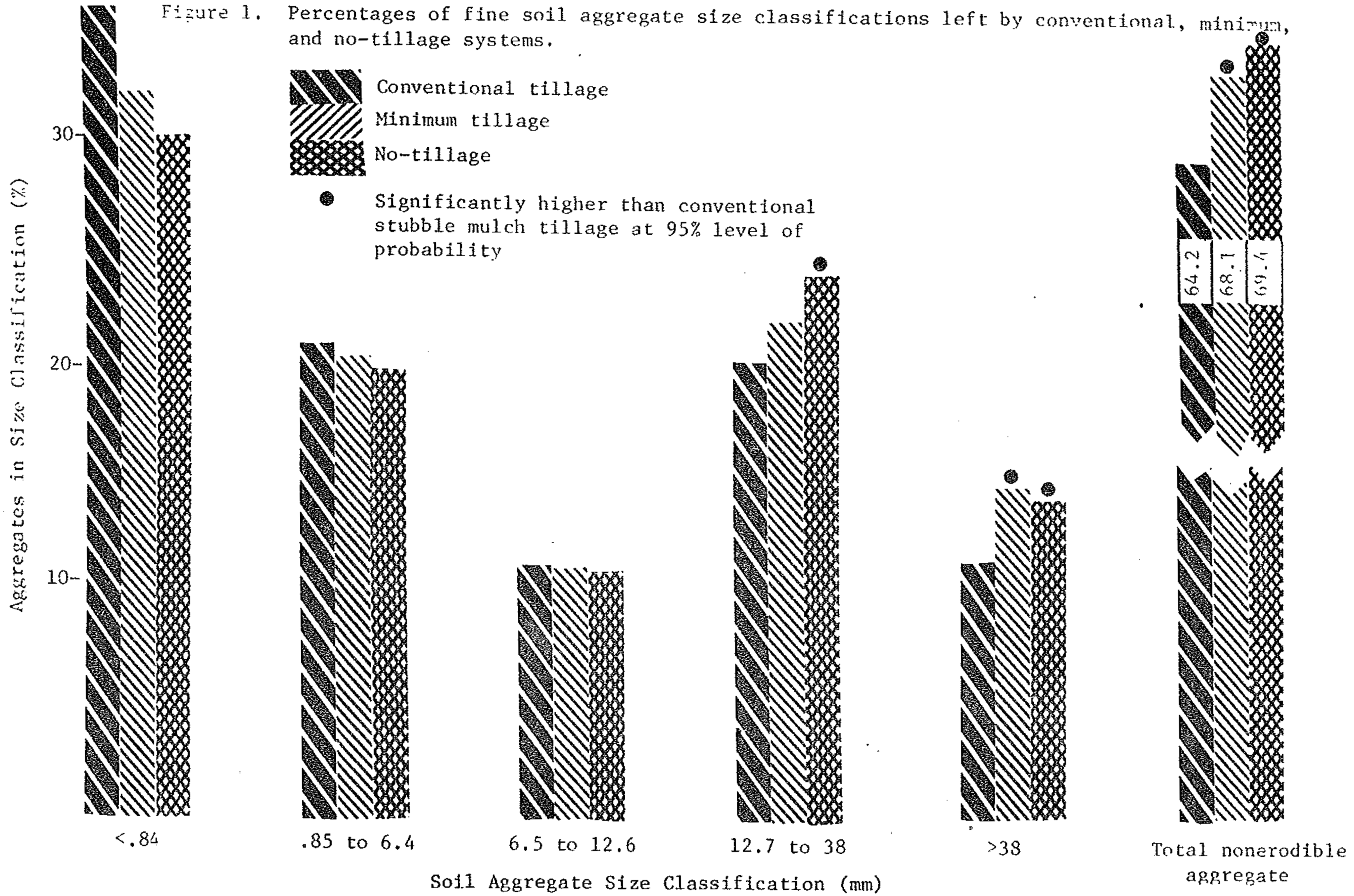
7. Woodruff, N. P., and F. H. Siddoway. 1965. A wind erosion equation. Soil Sci. Soc. Am. Proc. 29:602-608.

Table 1. Wheat straw residue as related to fallow tillage practice.

Treatment	Residue Amount		
	Left on soil surface	Left in upper 7.5 cm of soil	Total
	kg/ha		
Conventional tillage	1000 a*	3160 a	4160
Minimum tillage	1800 b	3800 b	5680
No-tillage	2050 b	4570 c	6620

* Column values followed by the same letter are not significantly different at the 5% level.

Figure 1. Percentages of fine soil aggregate size classifications left by conventional, minimum, and no-tillage systems.



The 8th Conference of the International Soil Tillage Research Organization, ISTRO, Bundesrepublik Deutschland, 1979.

The Effectiveness of Erosion Control in No-Till Corn Production.

A.R. Pesant, Soil Physicist,
Agriculture Canada, Lennoxville, Quebec, JIM 1Z3, Canada.

ABSTRACT

During 4 sequent growing seasons (May through September) rainfall, runoff, soil and nutrients losses (NO_3-N, P K) were measured from $45m^2$ erosion plots with 9% slope for no-till and conventional corn systems. The no-till system controled 63% of the rainfall loss as runoff and 94% of the soil losses when compared with conventional system. The 4 year total soil losses amounted to 0.19 mm for no-till corn and 3.45 mm for conventional corn. Aside from reduced runoff and soil erosion, no-till benefits included a striking reduction in NO_3-N, P, K losses, respectively amounting to 27%, 92%, and 72% of the applied fertilizer.

INTRODUCTION

Soil erosion has been described as a serious source of agricultural pollution. The increase in acreages of corn silage in mountai - nous regions have resulted in a dramatic reduction of the soil productivity.

The practice of planting corn in grass sod or established cover crop treated with herbicide has gained favor on sloping land by reducing the amount of runoff and soil erosion (1, 4, 5, 6, 7, 8). Little is known, however, about the relative conservation of soil and runoff nutrients from the no-till system for corn production (2, 3, 9).

The purpose of this study was to evaluate, the effectiveness of soil and nutrient erosion control for the no-till corn production system as compare to the conventional corn system.

EXPERIMENTAL PROCEDURE

Field studies were conducted in the heart of rolling hill Apalachian region, at the Lennoxville Research Station, Quebec, Canada. Six runoff plots were constructed for no-till corn and conventional corn systems on tile drained Coaticook clay loam soil, one of the benchmark soils of the area. The study was a completely randomized design with three replicates. The plots were 15 m long up and down a 9% slope and 3 m wide. The runoff was collected in a downslope through, and a pipe carried the runoff to silt boxes and side tanks. A multislot diviser was installed between the silt boxes and the side tanks to collect the soil suspension overflow. The amount of runoff collected was measured and corrected for rainfall. The contents of the tanks were thoroughly mixed and sampled. The sample of the suspension taken was then filtrated and the proportion of sediment to water was determined to calculate the percentage of the runoff occurring during any given storm.

A few days prior to planting the residual sod was killed with 4.5

kg/ha of Atrazine for no-till corn system. Conventional tillage method of turn plowing and disking was practiced prior to seeding. Atrazine, at the rate of 2.5 kg active ingredient/ha, was sprayed on the conventional seed bed plots to control weeds in lieu of cultivation.

The corn was hand planted on all plots in each of the 4 years to minimize stand variability. The corn was planted in rows 75 cm apart on a 20 cm spacing, which provided a 4 year average population density of 59,703 plants/ha. Fertilizer was surface broadcast on all plots at the average annual rate of 71, 53, and 143 kg/ha of N, P and K respectively. Corn yields were recorded at harvest in kg/ha of dry matter. The amount of NO_3-N, P, K nutrients dissolved in runoff water and available NO_3-N, P and exchangeable K in eroded soil were determined.

RESULTS AND DISCUSSION

Monthly precipitation averaged 128 mm for the 4 growing seasons having the lowest rainfall in June and the highest in July. The year 1975 was the dryest and 1976 the wettest. The average rainfall intensity was 7 mm/hr ; the year 1974 was the highest with 10.33 mm/hr.

Runoff and soil losses.

No-till corn system reduced runoff and soil erosion to appreciable amounts. Mean annual surface runoff amounted to about 14 and 38 mm or 4.5 and 12% of the growing season precipitation on no-till and conventional corn, respectively. (Table 1).

Table 1 - Annual runoff and soil losses from no-till and conventional corn systems, 1973-76.

YEAR	No-Till Corn			Conventional Corn		
	Runoff (mm)	Soil losses kg/ha	mm	Runoff (mm)	Soil losses kg/ha	mm
1973*	2.89	99	0.007	4.83	159	0.01
1974	25.33	907	0.060	72.43	17245	1.17
1975	4.05	454	0.030	26.14	17420	1.18
1976	23.40	1317	0.090	47.45	15976	1.08
Total	55.67	2777	0.190	150.85	50800	3.44
Annual Average	13.91	694	0.047	37.71	12700	0.860

* First collection was taken 50 days after seeding.

The dead sod mulch provide by the no-till procedure was highly effective in reducing runoff volumes. We estimated that the average annual soil water storage capacity has been increased by 37% from the no-till system. Differences in soil losses in runoff waters were striking. The effectiveness of the no-till system in controling soil losses was similar to that for controling runoff. The annual soil loss savings averaged 12,0006 kg/ha in favor of the no-till system. The 4 year total soil losses amounted to 0.19 mm for no-till corn and 3.45 mm for conventional corn. Thus, residual sod effectively reduced soil particle erosion by 94%.

Nutrient losses

Generally, growing season NO_3-N losses in measured runoff ranked second to K during the course of this study. (Table 2).

Table 2 - Annual runoff and sediment nutrient losses (NO_3-N, P, K) from no-till corn and conventional corn erosion plots, 1973-76.

	No-Till Corn			Conventional Corn		
Year	NO_3-N	P	K	NO_3-N	P	K
	Runoff nutrient losses (kg/ha)					
1973*	0.769	0.019	-----	0.194	0.007	-----
1974	0.618	0.095	3.956	0.918	0.114	6.418
1975	-----	0.004	0.593	-----	0.021	5.809
1976	0.362	0.028	1.705	1.040	0.066	5.159
Mean	0.583	0.037	2.085	0.717	0.052	5.795
	Sediment nutrient losses (kg/ha)					
1973*	0.0009	0.0017	0.0086	0.0021	0.0109	0.0139
1974	0.0099	0.1350	0.1244	0.0594	2.0155	1.8760
1975	0.0020	0.0440	0.0624	0.1708	2.3616	2.7570
1976	0.0023	0.2790	0.4337	0.0210	3.6818	3.0718
Mean	0.0038	0.1149	0.1573	0.0633	2.0175	1.9296

* First collection was taken 50 days after seeding

---- Missing data

The average annual K loss from both systems exceeded the NO_3-N loss by a proportion of 6:1. Under these field conditions, phosphorus was the least mobile of the plant nutrient with 0.037 kg/ha from no-till corn and 0.052 kg/ha from conventional corn. Runoff nutrient best saving from no-till corn was potassium by controling 64% of the losses. The no-till corn P and NO_3-N reductions were 32 and 19% respectively.

The 4 year average of NO_3-N soil nutrient losses were negligeable while P and K losses amounted to more significant values. These losses were approximately 93% higher from conventional corn system and directly related to the amount of soil loss. As a rough approximation, total NO_3-N, P and K losses (runoff + soil losses) amounted to about 0.62%, 0.28% and 1.2% of that applied as fertilizer on no-till corn. The percent losses in the washoff for the conventional corn were 1.4, 13 and 3.6 times greater, respectively.

Corn yield values evaluating the no-till method of corn production with conventional tillage, are summarized in table 3. Average

Table 3 - Effect of tillage treatments on yield of corn (kg/ha of dry matter), 1973-76.

Year	No-Till Corn	Conventional Corn	Mean
1973	12,381 a*	9,717 b	11,049 a
1974	3,560 c	9,166 b	6,363 b
1975	12,531 a	12,255 a	12,393 a
1976	11,927 a	11,863 a	11,895 a
Mean	10,099 a	10,750 a	

* Means followed by the same letter do not differ significantly at 5% level by Duncan's multiple range test.

yield for the 4 growing season (kg/ha of dry matter) was not significantly different between the two systems.

CONCLUSION

Based on our research, there is a tremendous potential for no-till corn production in sloping areas and expanded corn acreage is safely possible on many sites previously used only for perennial crop.

LITERATURE CITED

1. Benatti, R., Bertoni, J. and Moreira, C.A. 1977. Erosion losses in corn crop with no-tillage and conventional management methods in two Sao Paulo soils. R. Bras. Ci. Solo 1: 121-123.

2. Free, G.R. 1970. Minimum tillage for corn production. Cornell. Agric. Exp. Stn. Bull. 1030: 1-12.

3. Harding, G.B. 1978. Conserving nitrogen for corn. Agric. Res. 27 (2): 6-7.

4. Harrold, L.L., Triplett, G.B., and Youker, R.E. 1967. Less soil and water loss from no-tillage corn. Ohio Report 52 (2): 22-23.

5. Harrold, L.L., Triplett, G.B. and Edwards, M.W. 1970. No-tillage corn. Characteristics of the system. Agr. Eng. 51 (3): 128-131.

6. Harrold, L.L. and Edwards, W.M. 1972. A severe rainstorm test of no-till corn. J. Soil Water Conservation 27 (1): 30.

7. Harrold, L.L. and Edwards, W.M. 1974. No-Tillage System reduces erosion from continuous corn watershed. Am. Soc. Agric. Eng. 17 (3): 414-416.

8. Heinemann, H.G. 1975. No-till systems prove ideal on clay pan soils. Agric. Red. 24 (1): 14.

9. Triplett, G.B. and Van Doren, D.M. 1969. Nutrient utilization of no-tillage corn. Ohio Rep. Res. Develop. Agr. 54 (4): 59-60.

EROSION STUDIES FOR DIFFERENT TILLAGE AND CROP SYSTEMS IN THE STATE OF PARANÁ, BRAZIL

MONDARDO, A.;* VIEIRA, M.J.;* BISCAIA, R.M.;* CASTRO FILHO, C.DE.;* RUFINO, R.L.*

ABSTRACT

The present paper shows the preliminary results of soil erosion control research in the State of Paraná, Brazil. Using simulated rainfall and natural rainfall, soil erosion paramaters were provisionally determined in relation to soil type, cropping system, soil tillage practices, and in the case of the coffee crop, the management system adopted.

In the summer months soil losses are more than in winter due to the higher rainfall intensity at this time of year. Soils left uncovered during cropping intervals are subject to heavier losses than soils planted with a growing crop. Soils planted with cotton have *shown to be more subject to erosion than* soils planted with other annual crops which provide a better leaf canopy as the crop develops. No tillage, because of the fact that farmer crop residues remain on the surface of the soil, has proved to be a very effective means of erosion control.

In coffee, which is a perennial crop, the planting system, density, and weed control methods can influence to a great degree erosion in the crop.

Results obtained up to now, although preliminary, are being used as a basis for recommended soil conservation techniques in the state of *Paraná.*

INTRODUCTION

Highly produtive land in the State of Paraná has been exposed to erosion since it was cleared initially for coffee plantations and latterly for annual crops. In the last ten years soil losses due to erosion became worse due to a more intensive mechanized agriculture.

The increase in area of soybean and wheat without proper erosion control methods has resulted in rapid soil degradation.

A research Program on Soil Management and Conservation covering the *whole of the State, was started* by IAPAR *in 1974 in order* establish erosion control methods.

This program has, a s a general objective, the development and adaptation of soil conservation technology for the climatic and soil conditions of Paraná. This includes the following aspects:

a) to quantify, in a short and medium term, parameters of soil erosion losses;
b) to evaluate and define economical and technical alternatives for erosion control, and
c) to establish soil conservation systems, at farm or watershed level, *in order to preserve and/or improve* soil productivity.

METHODOLOGY

Short term erosion parameters were obtained by using rotating boom rainfall simulators, measuring soil losses in 11,0 x 3,5 m plots under different crops, soil tillage and crop management. Mesurements were also undertaken under natural rainfall conditions in similar plots.

Collection and measurement of runnof was made with HS-FLUME type collectors, equipped with a water level recorder in the case of rain-

* Soil Scientists, Soil *and* Water Conservation *Program. Fundação Instituto* Agronômico do Paraná - IAPAR. Caixa Postal 1331, CEP 86.100 Londrina, *Paraná*, Brazil.

fall simulators. Under natural rainfall conditions, collecting tanks were used with GEIB divisions.

The evaluation of erosion using rainfall simulators was based on the following rain pattern:

1st rain - 65 mm/h during 60'; 2nd rain - 65 mm/h during 30';18-24 hours after the first; 3rd rain - 130 mm/h during 18'; 15-30 minutes after the second.

The treatments under simulated rainfall were: a) bare soil of different types; b) 4 different growth periods of the following crops: wheat, soybean, corn cotton, coffee and forage; c) different soil tillage systems.

The treatments under natural rainfall conditions were: a) bare soil of two slope lengths; b) wheat and soybean crops in conventional tillage and no-tillage; c) coffee crop; d) forage.Except for treatment c) (which was conducted in a cattle region), all were conducted in different soil types.

These soils include: Distrophic Red Latosol,clay-LRd (Hophortox); Distrophic Red Latosol, clay-LVEd (Haplohumox); Distrophic Dark Red Latosol, sandy loam-LEd (Haplortox); Red Yellow Podzol, sandy loam -PVA (Apludult).

RESULTS AND DISCUSSION

Rainfall erosivity

Preliminary data from 1976, indicates annual EI30 values varying from 705 to 1.699 in 4 different locations in the State. Rainfall figures vary from 1.330 to 1.854 mm/year. For these 4 locations, the higher monthly EI30 values are concentrated in October, and account for more than 20% of the annual values. It is necessary to point out that during October, most soil preparation and movement is carried out in preparation for the planting of summer crops such as soybeans,corn, cotton, rice, etc., and the soil isleft unprotected, desagregated and more susceptible to erosion.

Soil erodibility

Table 1 shows erodibility values for different soil types in Paraná, which were obtained with simulated and natural rainfall.

A high degree of similarity can be observed between erodibility values for both methods, showing that the use of rainfall simulators is reliable for such studies.

Comparing the erodibility values obtained on the same soil type, a higher erosion susceptibility can be observed on those that have been cultivated more years with annual crops. This indicates higher physical, chemical and microbiological degradation of soils, when they are intensively cultivated. Among the soil types studied, HAPLORTOX-sandy loam showed less susceptibility to erosion.

Table 1: Preliminary erodibility indexes for some soils of Paraná, determined with natural and simulated rainfall.

Soil type	Natural Rainfall	Simulated Rainfall
Red Latosol - short term use	-	0,149
Red Latosol - long term use	0,373	0,390
Dark Red Latosol, clay	0,074	0,091
Dark Red Latosol, sandy loam	-	0,072

Soil use and Management

Data in Table 2 shows the soil loss relationship between different tillage methods.

Table 2: Soil losses from double cropping (soybean-wheat) under natural rainfall conditions on three soil types in Paraná.

Crop/Soil tillage	Soil Type/Different Local B.V.Paraiso PVA	C.Mourão LRd	P. Grossa LVEd	Total loss	% loss
	----------	kg/ha	----------	----------	
Soybean (summer)					
Bare soil	12.699	2.941	20.746	36.386	100
Conventional Tillage	1.991	720	3.346	6.057	16,6
No-tillage	89	647	240	976	2,7
Wheat (winter)					
Bare soil	1.533	2.003	14.768	18.304	100
Conventional Tillage	385	1.576	998	2.959	16,2
No-tillage	0,0	1.220	380	1.600	8,7
Soybean/Wheat					
Bare soil	14.231	4.944	35.514	54.689	100
Conventional Tillage	2.376	2.296	4.344	9.016	16,5
No-tillage	89	1.867	620	2.576	4,7

Heavy losses occur under bare soil conditions. Under conventional tillage soil losses decreased to 16,5%, and to less than 5% under the no-tillage system.

Under bare soil, greater losses occur in summer than in winter. This is associated with the highen rainfall during the summer months.

Table 3 shows that soil losses increase according to the amount of soil tillage whilst with no-tillage losses substantially reduced.

Table 3: Percentage of soil and water losses in two soils of Paraná, subjected to different soil tillage systems, using rainfall simulators.

Soil tillage system (performed up and down slope)	Dark Latosol, Red clay		Red Latosol, clay	
	Soil	Water	Soil	Water
1. One ploughing + 4 light disc harrowings	100	100	-	-
2. One heavy disc harrowing + 2 light ploughing disc harrowings	75	162	100	100
3. One chisel ploughing + 2 light disc harrowings	52	143	-	-
4. 4 light disc harrowings	37	48	-	-
5. 2 light harrow disc harrowings	27	57	-	-
6. One ploughing + 2 light disc harrowings (conventional)	23	90	26	30
7. One ploughing	13	38	-	-
8. No-tillage*	5	95	1	98

* crop residues left the surface; for all the other treatments the crop residues were removed.

Table 4 shows soil losses for different annual crops at four growth stages.

Higher total losses occur in cotton, followed by soybean and then wheat. In the cotton crop which does not completely close and so protect the soil, losses continued to occur during the latter growth stages. In the case of soybeans most losses occured during the first growth stage and decreased in the stages, due to its protective leaf cannopy whilst wheat continues to have significant losses in the second growth stage.

Corn provided the best soil protection of all.

Table 4: Percentage of soil losses from different annual crops at four growth stages, in Red Latosol with a 8% slope, using the rainfall simulator..

Crop*	Crop Growth Stages				Total
	I	II	III	IV	
1. Bare soil	100	100	100	100	100
2. Cotton	36,7	5,2	7,6	1,4	12,6
3. Soybean	26,7	0,2	0,0	2,5	7,2
4. Wheat	8,8	7,0	0,0	2,7	4,5
5. Corn	3,9	3,0	0,1	0,0	1,7

I - sowing to 30 days; II - 30 to 60 days; III - 60 to 90 days; IV - after harvest.

* Conventional tillage up and down the slope.

Table 5 shows soil losses in coffee under different management systems. Up to the 3rd year, losses in a crop planted up and down the slope were 39% less than on bare soil. In coffee planted on the contour, losses were 63% less. In both these cases inter-row cultivations were carried out with disc harrows. On the other hand, where living plant cover was left between the rows or, through the use of contact herbicides a dead mulch, losses were most effectivety controlled.

It is also obvious that spacing influence the susceptibility of a crop to erosion. Where the crop was planted at 4x1 m spacing these was significantly less erosion than in a crop planted at 4x2 m.

Table 5: Percentage of soil losses, from coffee plantations under different management system, in Red Latosol with a 6% slope, using the rainfall simulator.

Cultivate Systems	Crop Age Month					Total of period
	4	14	24	34*	34**	
1. Bare soil	100	100	100	100	100	100
2. Coffee up and down slope 4x2m	38	94	29	47	67	61
3. Coffee on contour disk cultivations 4x2m	52	80	21	17	34	37
4. Coffee on contourdisk cultivations 4x1 m	35	64	18	5	36	27
5. Coffee on contour Herbicides use 4x2 m	16	2	1	0,4	19	6
6. Coffee on contour rotary mower 4x2 m	-	-	1	-	-	-

* Vegetable residues heaped up for the coffee harvest

** Vegetable residues spread after harvest

Table 6 shows total soil and water losses in a 3 year old coffee plantation on bare soil for two different slope lengths: 11 and 22 meters. Coffee planted up and down the slope when compared to bare soil, showed a reduction in losses of 23,5%. Comparing both slope lengths on bare soil, there was a soil loss ratio of 1:1,41. The avarage annual loss of Red Latosol on a 6% slope of 11 and 22 m length was 110 and 155 t/ha respectively.

Under these same conditions but with a slope length of 44 m, annual soil losses can reach 657 t/ha.

Table 6: Soil losses in 3 year old coffee, on a Red Latosol of 6% slope, under natural rainfall conditions.

Treatment	Year 1976	1977	1978	Total of 3 years	%
	----------	t/ha	--------		
1. Bare soil (plot size 22x3,5m)	162,6	153,0	150,6	466,2	141,3
2. Bare soil (plot size 11x3,5m)	105,5	115,0	109,3	329,8	100
3. Coffee up and down slope 4x2m spacing (plot size 11x3,5m)	83,0	93,3	76,0	252,3	76,5

GENERAL CONCLUSIONS

The results here discussed refer to a relatively short period of research, of no more than three years. For this reason, information obtained cannot be regarded as conclusive . However, it does give us a clear indication of the effects of erosion under present conditions in Paraná and leads us to the following conclusions:

1. Soil erosion in the State of Paraná is reaching critical levels on cultivated land where inadequate tillage and management practices are employed.
2. Losses caused by erosion, are directly related to the amount of soil movement and cover.
3. Soils under annual crops are most susceptible to erosion in the first stages of development and this coincides with the period when rainfall is at its higher erosivity potential;
4. Erosion in annual crops is greaty influenced by the vegetative characteristics of the crop and by cultural practices,
5. Soil erodibility varies according to soil type and previous land use and management,
6. The use of rainfall simulators has shown to be of great value in providing in a relatively short period of time, comparative data relating to erosion on soils, crops and tillage practices.
7. Research results shown in this paper, although preliminary, have been used as a basis for recommending methods of erosion control and soil conservation, and to call the attention of the public to the necessity for soil conservation in order to maintain the productivity of agricultural land.
8. Experience in obtaining the present results, shows a need to study erosion on larger experimental units, (macro plots or micro watersheds), using different cropping and management systems.

STUDIES ON THE SUSCEPTIBILITY OF SOILS TO EROSION AND ON SOIL PROTECTION METHODS IN PARANÁ/BRAZIL.

by B.KEMPER and R.DERPSCH

SUMMARY

On Latosols (LR) and Alfisols (Terra Roxa TR) in the north of Paraná, unlike podsolic soils of the same region, soil compaction has been found in the lower part of Ap-horizon due to the fact that tillage practices have destroyed the high natural porosity of these soils. This compaction impedes water infiltration, in these otherwise very permeable soils and, although it can be removed for a short period through new tillage operations, it will eventually appear again after soil has settled down sufficiently.

In order to achieve efficient erosion control on these soil types, it is necessary to increase permeability and water infiltration rates. Infiltration studies made under different cover crops, showed increases of up to 416% on LR and of up to 629% on TR, when compared to those under a wheat crop. The cover crops resulted in a much more friable soil because of the biological loosening effect created by the root system.

Another possibility for efficient erosion control has shown to be the use of the no-tillage technique. Average wheat yields taken from two locations were 37% higher than in conventional tillage. The higher moisture content, lower soil temperature, especially at planting time, and higher biological activity of the soil under no-tillage are felt to be the most important factors affecting wheat yields. Soybean yields on LR were consistently higher in no-tillage than in conventional tillage due to the better moisture retention under mulch covered plots at planting time. On TR soybean yields were slightly higher under no-tillage compared to conventional tillage but both systems produced more than 3000 kg/ha.

These are the preliminary results from research work started in 1977.

INTRODUCTION

While virgin forest devastation in the last decades has reduced the tree cover of the state of Paraná from originally 84% to less than 9%, mechanised large scale farming of wheat has increased from 97.000 ha in 1968 to 1,3 million ha in 1978, and of soybeans from 214.000 ha in 1969 to 2,5 million ha in 1979. More than 6 million ha are now planted with annual crops each year.

High rainfall intensity of as much as 80 mm in 30 minutes, together with excessive soil tillage in a double cropping system, have led to serious erosion all over the state.

Erosion studies and extrapolations at IAPAR based on a 6% slope have shown that when tillage is performed up and down the slope, erosion losses can be as high as 700 t/ha/year. When tillage operations are performed on the countour, losses can be up to 400 t/ha/year, whilst, where the combination of terraces (countour dikes)and good tillage practices are used, erosion losses can be reduced to 97 t/ha/year. (1, 8). This shows a relative efficiency of terraces in reducing soil erosion, but soil losses are still too high to maintain soil fertili-

*Dr. B.KEMPER, Federal Institute for Geosciences and Natural Resources, Hannover, Germany and R. DERPSCH, German Agency for Tecnical Cooperation, Ltda (GTZ), Eschborn, Germany, working at Programa Manejo e Conservação de Solos, Fundação Instituto Agronômico do Paraná - IAPAR - Londrina, Brazil.

ty and make permanent land use possible.
For these reasons a project was initiated in 1977 between IAPAR and GTZ, the main objetives of which were to study and develop seeding and tillage practices which reduce raindrop impact on the soil surface, increase water infiltration, decrease runoff velocity and soil detachability, in order to achieve effective erosion control. (11,12).

Project activities are concentrated mainly in the northwestern and greater part of state, were 2/3 of the soils are derived from basalt developing into red latosols (LR) and the famous "terra roxa estruturada" (TR). Since these soils are very deep, have very good physical properties and were formerly used mainly with permanent crops such as coffee, it took many years until damage due to sheet erosion reflected on yields, despite higher fertilizer inputs.

With the introduction of double cropping wheat and soybeans, when the soil is prepared twice a year, erosion was drastically accelerated. Adopted soil tillage systems, using disced implements which do not leave crop residues on the surface, and the wide use of pre-emergence herbicides that require incorporation in a very finely granulated soil during periods of heavy rainfalls, are the main factores affecting soil erosion on farm land in Paraná.

MATERIALS AND METHODS

Experiments were started at the end of 1977 and the preliminary results are shown in this presentation. Work was directed mainly towards the following fields:

1. Selection and evaluation of different plant species to protect the soil (cover crops).
2. Evaluation of the best of these cover crops in the no-tillage system.
3. Development of soybean-wheat rotations including cover crops, in conventional, minimum and no-tillage.

Up to the present time, three experiments, one initiated in 1977 and two in 1978, have been laid down to evaluate more than 50 plant species including also some tropical and European varieties of these same species. The following selection criteria was used:climatic adaptation, time from planting to 80% soil cover, height, weed supression, resistance to diseases and pests, time from planting to flowering, as well as production of green and dry matter per unit area. From this trial 8 cover crops were selected and planted in winter after soybeans, and in spring after wheat, on plots of 320 to 400 m^2 in the two main soil types. These were Lupinus luteus, Vicia villosa,Phacelia tanacetifolia,Sinapis alba,Brassica campestris/chinensis,Brassica napus L. (for fodder) and Brassica napus L. (oilseed rape). Later results showed that Raphanus sativus and Brassica juncea adapted very well to local conditions and these will be used on bigger plots next season.Contrary to expectations, all of the selected crops are to our knowledge unknown in Paraná and are in fact traditional cover crops used in Europe. None of the tropical species tested developed well in the colder season of the year, some of them being destroyed by frost. In the third experiment four rotations with soybeans were compared in three different tillage systems:conventional tillage (disc plow and two diskings), minimum tillage (chisel plow with packing rings and cage roller) and no-tillage using a rotary hoe drill, which cuts slots in the ground, 1 to 2 inches wide.
In order to determine relevant erosion parameters in local soils, it was necessary to install laboratory facilities for soil physical analises and to introduce apropriate equipment for field measurements. Main emphasis was given to the following soil characteristics: Infiltration rate (Haise), moisture content (neutron moisture probe), pore distribution,water retention curves (Richards), bulk density, and per-

meability of undisturbed samples (Hartke). The measurements were used: a) to obtain data on the effects of tillage treatments, rotational systems and cover crops on soil physical parameters, and b) for erosion hazard classification as a basis for erosion susceptibility maps relating to the important soils of Paraná.

TRIAL SITE CHARACTERISTICS

Both sites have the same history which is typical of northern Paraná. They were cleared from virgin forest some 40 years ago, then planted with coffee and only changed into double cropping in the last 2 years (TR) and 4 years (LR). TR and LR are due to their topographic position in the landscape the only soil types developed from basaltic parent material which are suitable for annual crops. (5,6).Both soils are very deep and originally did not impede root growth. LR is found on plateaus and is older than TR which is found on slopes. LR does not contain weatherable minerals and is very low in exchanegable cations. The clay activity is extremely low, which leads to a missing structure although the soil is very porous (coffee powder). TR on the other hand, has a higher base saturation and clay activity and a strong blocky structure.This is obviously the reason for its higher permeability and infiltration rates. Both soils have about the same high clay content, but they do not present the tillage problems that soils from northern latitudes with such clay contents would. Very few hours of sunshine after a heavy rain are sufficient to allow tillage without damaging the soil. The clay does not disperse in water, but because of its high content of amorphous iron stays stable in water in the form of little soft iron concretions.

TABLE 1 - TRIAL SITE CHARACTERISTICS

ROLÂNDIA
Soil typ: Terra Roxa Estrutu rada (TR)
Rhodic Paleudalf
Parent material: basalt
slope: 8%
mean anual rainfall: 1608- mm

Horizon	Depth cm	pH H_2O	C E C me /100g soil	C E C me /100g clay	Base-saturation %	C %	Clay %	Silt %	bulk-density	Soil moisture Vol % field capacity	Soil moisture Vol % Available	Permeability cm/dia	Infiltration rate mm/dia
Ap_1	0-8	6,1	18,9	15	72	1,9	69	17	0,93	33	11,3	6271	256
Ap_2	-20	5,9	17,0	16	75	1,2	71	15	1,19	41	10,3	162	
B_1	-60	5,3	11,9	12	65	0,6	77	12	1,01	40,5	11,2	642	
B_2	-120	5,4	11,4	13	71	0,3	80	10	1,01	41,5	11,9	-	

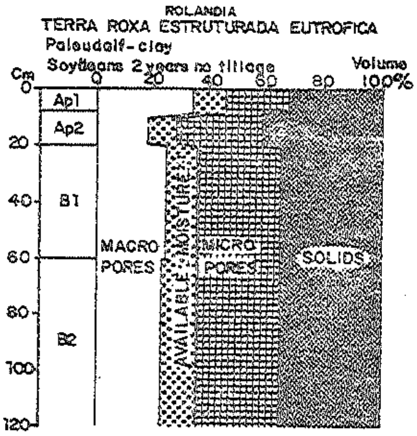
LONDRINA
LATOSOL ROXO DISTRÓFICO (LR) basalt 6% 1508 mm
Typic Haplorthox

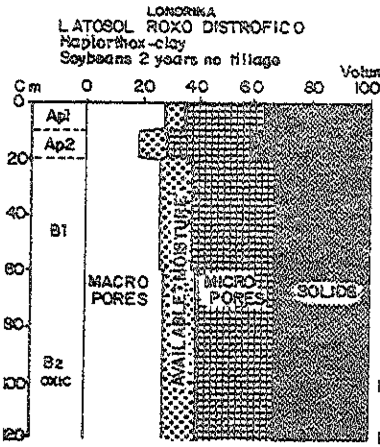
Horizon	Depth cm	pH H_2O	C E C me /100g soil	C E C me /100g clay	Base-saturation %	C %	Clay %	Silt %	bulk-density	Soil moisture Vol % field capacity	Soil moisture Vol % Available	Permeability cm/dia	Infiltration rate mm/dia
Ap_1	0-8	5,9	14,2	9	67	1,6	76	13	0,96	33,5	10,6	4102	70
Ap_2	-20	5,1	11,7	6	49	1,6	79	13	1,16	43	9,2	75	
B_1	-45	4,7	8,1	9	39	0,2	82	10	1,02	40,5	11,9	276	
B_2	-120	4,6	7,3	6	23	0,5	81	11	1,05	37	7,4	231	

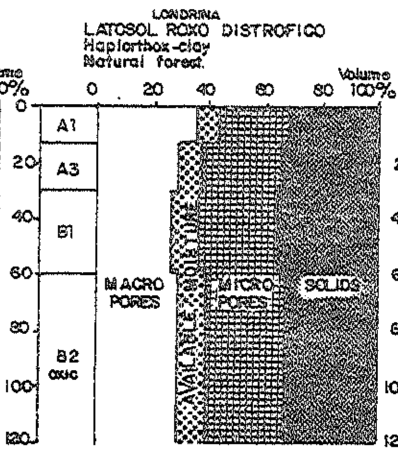
SOIL COMPACTION

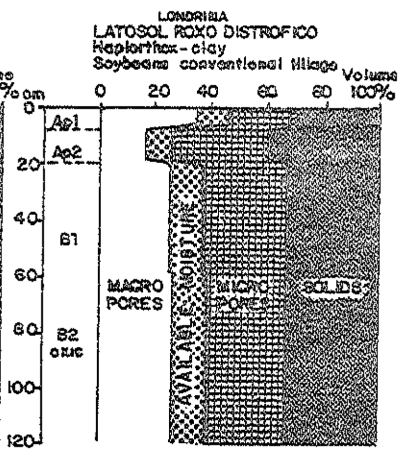
In order to achieve efficient erosion control on the studies soils, it is necessary to increase permeability and infiltration rates. Measurements have shown that there is a strong relationship between permeability and bulk density, or permeability and macropores. The figure below shows the pore distribution of representative soils in the northwest of Paraná. The soils of Rolândia and Londrina are derived from basalt, whilst the soils of Paranavaí originated from eolien deposits. It is noticiable that all latosols have a naturally very high percentage of macropores (20 to 30%) and also have a very homogeneous structure throughout the profile which is correlated to their high natural draining capacity. When soils are tilled however, natural porosity is destroyed and soon compaction will develop in the lower Ap horizon. This process is accelerated by a reduction in organic matter and by high rainfall. Compaction can be eliminated for a short period by new tillage operations, but it will always appear again after soil has settled down sufficiently. This compaction impedes water infiltration in these otherwise very permeable soils, and can lead to a complete loss of Ap_1 horizon during one vegetative period of annual crops.

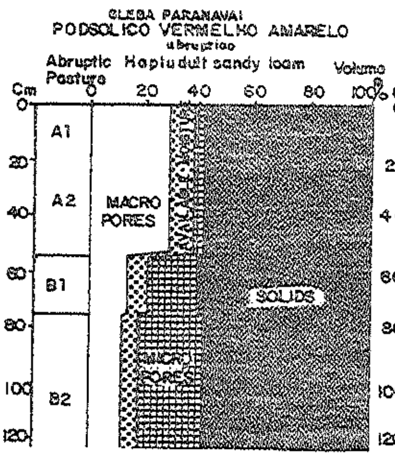
soil pores distribution and available moisture content

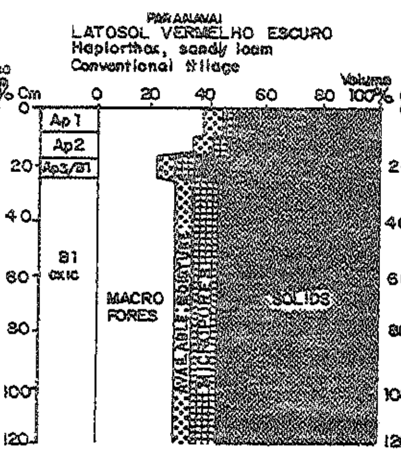


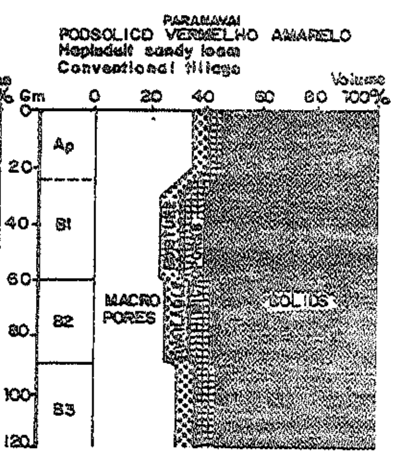












A different situation occurs on the podsolic soils of Paranavaí. Here, natural soil forming processes (illuviation) have led to a clearly differentiated porosity throughout the soil profile. The percentage of macropores decreases in the B horizon causing an impediment to drainage mainly at the abrupt transition from the A to B horizon and hence heavy erosion, especially on soils with a thin A horizon. Compaction due to tillage, as described for clay soils, could not be found on podsols with a sandy top soil.

ELIMINATION OF TILLAGE CAUSED SOIL COMPACTION

Infiltration rates under different cover crops was studied at the two experimental sites. Wheat and cover crops were direct drilled at the same time and measurements were made just after harvest.

	Average of 6 measurements (mm/h)						
	Wheat	Sinapis alba	Brassica napus	Vicia villosa	Brass. c/ch.	Lupinus luteus	Phacelia tanacet.
Latosol LR	44	76	79	87	103	125	183
Terra Roxa TR	64	-	303	402	-	-	-

The measurements show a consistent increase in infiltration rates when cover crops were used. Compared to the infiltration rates in wheat, the increase was up to 416% on Latosol and up to 628% on Terra Roxa. All cover crops produced a noticiably higher root mass than wheat. Cruciferous plants and soybeans showed typical root windings and can be considered to some extent sensitive to compaction present in the soil. Leguminous cover crops on the other hand seemed to have no difficulty in penetrating compacted layers of soil.

In the no-tillage plots, because of previous tillage, compaction was also present. According to Phillips (10), soils will revert to their natural condition only after aproximately 10 to 12 years of continious no-tillage. The loosening effect of cover crops on described soil compaction can be clearly seen in the photograph shown below.

On both experimental sites, the plowing of conventional plots showed the positive effect of cover crops on soil consistance as compared to that of plots planted with wheat. Cover crops left a much more friable soil because biological loosening (3) had taken place.

Observations so far lead us to assume that soil compactions in the Ap_2 horizon, caused by tillage, will not disappear by altering the depth of tillage, nor by changing the tillage implement, but by enhancing the biological activity in the soil.

BIOLOGICAL ACTIVITY, SOIL TEMPERATURE AND SOIL MOISTURE

The first step in measuring biological activity was made by counting earthworm populations per square meter up to a depth of 10 cm. Data collected at Rolândia (TR Febr.1979), showed an increase from 6 earthworms/m^2 under conventional tillage to an average of 13 earthworms/m^2 under no-tillage. This was recorded only one and a half years after the experiment was initiated. Counts at Londrina (LR) revealed very low earthworm populations but showed similar tendencies.

Biological activity in the soil is very much related to soil temperature and soil moisture. Soil temperature is particularly important in the tropics. Recordings at IAPAR on January 24.1979 taken at a depth of 2 cm show a temperature of 50,8°C on bare soil and of 25,8°C on the adjacent mulch covered plot. Similar data has been collected by Medcalf (7) in coffee plantations in the state of São Paulo.

The importance of mulch tillage for tropical agriculture has been demonstrated recently also at the IITA, Nigéria(4,9) and is related to a great extent to a better enviroment for seeds and plant roots, mainly because of higher moisture contents in the soil and cooler soil temperatures. Moisture readings have been made at IAPAR up to a depth of 1,5 m. Measurements under wheat in Rolândia (TR) show a higher moisture content in no-tilled soils as compared to those conventionally tilled during the whole vegetative period. The conservation of soil moisture was found to be higher under the mulch cover of no-tillage, than under bare soil, and confirms data obtained by many researchers throughout the world. At the end of a drought period of almost 2 months, which started soon after planting, no-tilled soils had stored at a depth of 30 to 80 cm, 12mm more water than conventionally tilled soils and, after a second drought period of one month, they had stored at the same depth, 10 mm more water. In Londrina, where wheat yields did not show such big differences, the moisture content under the two tillage systems was more alike.

Moisture readings in plots under cover crops showed that these plants took much more moisture out of the soil than wheat. At 20 to 100 cm the water content was 17 mm lower under Brassica napus than under wheat in the no-tillage plot, and 13 mm lower in the conventional plot. The differences were not so great in Londrina, where water content under Brassica napus was only 8 mm lower in the conventional plot.These moisture differences virtually disappeared after the next heavy rain when the cover crops had been cut or sprayed off with herbicides.

YIELDS OF WHEAT, SOYBEANS AND COVER CROPS UNDER DIFFERENT TILLAGE SYSTEMS

In Londrina and Rolândia wheat yields from no-tillage plots were significantly higher than those from conventional tillage treatments. The higher moisture content, lower soil temperature and higher biological activity in the soil are felt to be the most important reasons for these increased yields.

Wheat yields kg/ha 14% moisture 1978.

	No-tillage		Minimum tillage		Conventional tillage	
	kg/ha	%	kg/ha	%	kg/ha	%
Londrina (IAC-5)	1713	123	1404	101	1387	100
Rolândia (Tanori)	1319	161	981	120	818	100

Preliminary results show an average soybean yield in Rolândia of over 3000 kg/ha, yields being slightly higher in no-tillage than in conventional tillage. Average yields in Londrina were much lower than in Rolândia. Conventionally tilled soybeans yielded less than 1500kg/ha as compared to 2000 kg/ha in no-tillage. The experiment was planted after a 15 mm rain in November 1978 and, whilst moisture was sufficient for the seeds in the no-tillage plots to germinate and thrive, the soil dried out quickly under conventional and minimum tillage resulting in poor germination. Germination was in fact so low in these plots that is was necessary to replant 10 days later. This is the main reason for the lower soybean yields in conventional tillage.

Contrary to expectations, soybeans planted after *Brassica napus* L. yielded about 10% less in Rolândia and about 20% less in Londrina compared to soybeans after wheat. Nitrogen fixation by the cover crop is believed to be the main reason for this decrease in yield. As other trials in Paraná have shown (2) corn planted after leguminous cover crops showed increases of more than 2000 kg/ha (i.e. 4540 kg/ha compared to 2130 kg/ha), the effect of the cover crop being almost equivalent to a nitrogen aplication of 80 kg/ha.

Average yields of cover crops direct drilled into soybean stubble after a 5 month vegetative period, expressed in kg of dry matter per ha, were as follows: Lupinus luteus 6725; Vicia villosa 6400; Vicia sativa 5375; *Phacelia tanacetifolia* 4025; Sinapis alba 5550; Brassica campestris/chinensis 5035; Brassica napus L. Var. Akela 4600; Brassica napus L. Diamant 3300.

REFERENCES

1 BERTONI, J., LOMBARDI NETO, F.; BENATI, R. Equação de perdas de solo. *Secretaria da Agricultura do Estado de São Paulo*, Instituto Agronômico, Campinas, S.P. (Boletim Técnico nº 21), 1975.

2 IAPAR, Manual Agropecuário do Paraná Londrina, 1976, 1978.

3 KAHNT, G., Ackerbau ohne Pflug, Eugen Ulmer, 1976.

4 LAL, R., Role of Mulching Techniques in Tropical Soil and Water Management, IITA Technical Bulletin nº 1, 1975.

5 LARACH, J.O.L. et al., Levantamento de reconhecimento dos Solos do Noroeste do Estado do Paraná, (Boletim técnico nº 14), 1970.

6 ________, Levantamento de reconhecimento dos Solos do Nordeste do *Estado do Paraná*, (*Boletim técnico* nº 16), 1971.
Curitiba, Dep. Nac. de Pesquisa Agropec. Div. de Pesquisa Pedológica.

7 MEDCALF F.C., Estudos preliminares sobre aplicação de cobertura morta em cafeeiros novos do Brasil, IBEC Research Institute, nº 12, 1956.

8 MONDARDO, A., IAPAR, Unpublished data, 1978.

9 OKIGBO, B.N. and LAL, R., Role of Cover Crops in Soil and Water Conservation, IITA, Nigéria, 1978.

10 PHILLIPS, S., No-tillage Crop Production, Presentation at IAPAR, March 6. 1979, Unpublished.

11 PROBST, M., Erosionsbekaempfung in Paraná, research report, GTZ-Eschborn, 1977.

12 WISHMEYER, W.H., Conservation Tillage to Control Water Erosion, Proceedings, Conservation Tillage Conference, Des Moines, Iowa, 1973.

The 8th Conference of the International Soil Tillage Research Organisation, ISTRO, Bundesrepublik Deutschland, 1979.

Factors related to the suitability of soils for reduced tillage.

Gary.J.Osborne [†], Don Payne and Dennis J.Greenland [††]

Department of Soil Science,University of Reading,Berkshire,U.K.
† Presently located at Imperial Chemical Industried Limited Jealotts Hill Research Station, Bracknell, Berkshire, U.K.
†† *Deputy Director General of the International Rice Research Institute, Manila, Phillipines.*

ABSTRACT

The suitability of soils for reduced tillage has been related to soil drainage, aeration and ability to resist compaction. The primary effect of compaction on the soil is to decrease pore volume, particularly the coarse pores (transmission pores). This paper outlines procedures being used to examine a range of soils from the United Kingdom in regard to compaction. The effects of compaction on soil respiration are also considered.

INTRODUCTION

All agricultural soils must be well drained and have a good and stable porosity. Increase in intensification of arable cropping and declining organic matter levels, has meant that the introduction of new tillage systems demands very high skills of management for successful crop production. This has meant that research workers and farmers alike have had to look closely at the physical management of their soils. A major problem with reduced tillage systems,such as direct drilling,has been soil compaction,evidenced by surface ponding of water, and the instability of some surface soils (particularly silts),which tend to slake,crust and smear,reducing seedling establishment and subsequent yield.

Cannell et al (1978), have published a guide for selecting soils in Britain suited to direct drilling, based on the local soil classification system of soil series,with emphasis given to drainage and compaction. Larson et al (1978), examined a range of soils from various countries and presented a model for predicting the compaction of agricultural soils. They related compression curves to the type and amount of clay, and concluded that these curves, obtained on beds of sieved aggregates, reflect the behaviour of agricultural surface soils in the field.

The biological effects of soils on plant nutrition are related to the cycling of nitrogen,phosphorus and sulphur; in particular the nitrogen nutrition of all soil grown crops is associated with microbiological activity. A decline in microbiological activity as evidenced by changes in carbon dioxide evolution, may reveal the effects of compaction on air porosity. The measurement of carbon dioxide evolution on intact soil cores from direct drilled and ploughed treatments may indicate changes in the behaviour of soil biomass in these different tillage systems. Jenkinson and Powlson (1976) and Anderson and Domsch (1978) have proposed methods for estimating soil biomass (the total amount of biologically active material). These authors used sieved aggregates of soil in their studies. There is evidence (Osborne et al (1979) that soil porosity varies under direct drilled and ploughed treatments. Changes in the distribution of organic matter and porosity in the direct drilled soil profile may improve the stability of unstable surface soils and affect the distribution of biomass in the soil profile. The use of compacted and uncompacted "minimally disturbed" soil cores may be a more instructive method of assessing the significance of changes in biomass in tillage experiments. Lynch (1978) found estimates of biomass in a clay soil to be 65 and 48 mg carbon per 100g soil for direct drilled and ploughed soil respectively,using soil cores. The respective results for sieved soil were 82 and 57.

In this paper details are given of procedures in use at the University of Reading and in the laboratories of Imperial Chemical Industries, Jealotts Hill, to assess the susceptibility of soils to compaction, and the efforts being made to measure the effects of compaction on oxygen permeability and soil porosity. In an attempt to relate these changes to soil biology, carbon dioxide production from soil cores is being examined.

MATERIALS AND METHODS.

The principal soil used in this study was a silt loam (Hamble series). The site is a tillage experiment run by † Letcombe Laboratory, chosen because it was considered to be unsuitable for direct drilling,because of its surface instability.

Soil variability in a study of this type is a significant problem and a preliminary assessment of this was made. The grass reference area was used for this aspect of the study and the results are shown in Table.1.

These results indicate that in excess of 25 cores are required to obtain valid statistical results at the 90% confidence level.

Table 1. Variability of bulk density and porosity on uncompacted and compacted soil cores.

Measurement	Depth cm	Soil uncompacted	Soil compacted	No. of samples
Bulk Density	0-5	1.33 g/cc	1.52 g/cc	> 25
Air filled porosity %				
10 cm suction	0-5	10.6(5.1) *	6.7 (3.5) *	> 25
20 cm	"	2.4(1.8)	1.8 (1.8)	>> 25
50 cm	"	2.3(2.0)	2.0 (2.0)	>> 25
100 cm	"	2.1	-	>> 25

* Results in brackets were obtained when the techniques were modified to remove errors associated with water trapped between the samples and plastic liner.

SOIL SAMPLING METHOD

Soil cores (75mm diameter) were taken to a depth of 50cm using a hand held jack-hammer,steel sampling tube and removable plastic liner. The cores were cut into 50mm lengths, using a piano wire and coated on the outer surface with a silicone rubber solution. This coating effectively sealed the edges of the core, so that it could be handled without damage. The seal also ensured that there was no "edge effect" (movement of gas down the side of the sample) when oxygen permeability and carbon dioxide evolution was measured. The seal also removed the need to have a liner around the sample during moisture desorption, removing the possibility of water being trapped between the liner and

† We gratefully acknowledge the assistance and co-operation of the staff, Agricultural Research Council, Letcombe Laboratory.

core, which could contribute to large errors in air porosity results (Table 1).

The cores were saturated at zero water suction, weighed and placed on sand tables at 10cm suction. After equilibration the samples were weighed and the same procedure followed for 20,50 and 100cm suction. Samples were placed in a gas flow cell to measure permeability to oxygen at suctions of 10 and 100cm suction. Rates of carbon dioxide evolution (biomass estimates), were also measured at these two suctions. Brief details of these procedures are given below.

The soil cores coated with rubber were placed inside a plastic tube which was lined with a rubber sheath (similar to that used in triaxial compression cells). The sheath was inflated within the plastic liner; the air was withdrawn by sucking on a small hole on the outside of the liner, and the sheath then lay flat within the liner. The rubber coated soil core,greased with vacuum grease was inserted into the liner and the air was allowed to enter the rubber sheath. The sheath now closed firmly around the edge of the soil core preventing any air movement down the edge of the core. For the measurement of permeability the core and liner was placed in a special brass cell, across which a manometer measured the differential pressure and a flow meter measured the rate of flow of oxygen through the sample. If carbon dioxide evolution was to be measured, the plastic liner was sealed at both ends and carbon dioxide free air was drawn through the soil core (usually 0.51/hr). An infra-red gas analyser recorded the concentration of carbon dioxide in the air which was passed through the soil. This was converted to the amount of carbon respired by the soil organisms per gram of soil per day.

In one aspect of this study the field compacted areas (tramline areas) were compared with uncompacted areas. In another aspect the samples were compacted in a consolidation apparatus (oedometer). The results in Table 1 were obtained with a uniaxial stress of 200 kPa on samples which had been equilibrated at 100cm suction.

Results obtained using the oedometer to compact beds of aggregates are currently being compared with the results obtained by Dr.W.E. Larson (USDA, University of Minnesota).

RESULTS AND DISCUSSION

The data plotted in Figure.1, were obtained from Larson et al (1978), and are presented on the basis that compression curves reflect the behaviour of agricultural surface soils in the field. Dr. Larson and his co-workers consider that their results indicate four groups of soils, represented by curves 1,2,3 and 4 in Figure 1. The Andepts represent the soils derived from volcanic ash with allophane as the dominant clay mineral. They have relatively low bulk densities even under stress. The second group are the medium textured highly weathered soils with iron oxide dominating the clay fraction, the Typic Haplustox is an example. These soils have moderate bulk densities at low stress, and moderately high bulk densities at high stress. A third group contain medium textured soils with expanding clay types. These are exemplified by the Aquic Hapludolls and respond to stress rather like the second group. The fourth group are the coarse textured soils with a wide range in the particle size. Particle size distribution dominates their behaviour, rather than type of clay. Usually these soils have high bulk densities at all stresses. Data for 3 English soils, plotted in Figure.1, indicate that these soils may fit into the 3rd and 4th classes of Larson et al. That is the silty clay loam into class 3 and the silt loam and the silt into class 4.

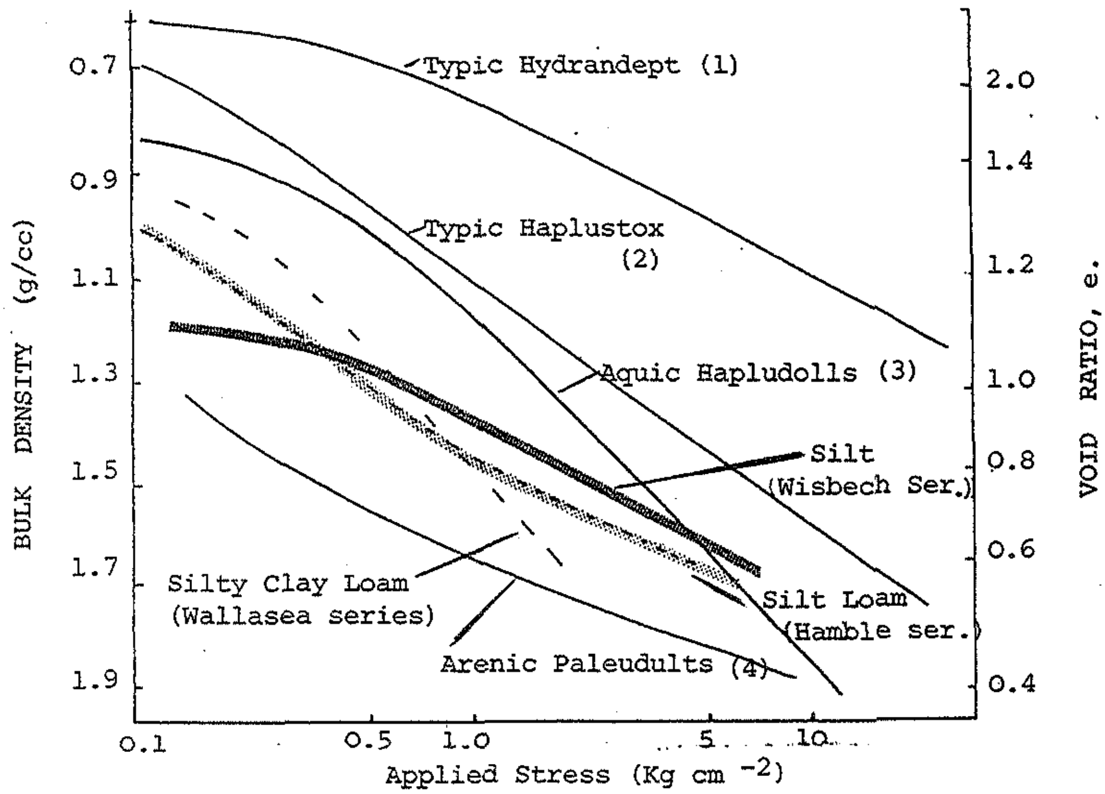


FIGURE 1.

The silty clay loam has a similar compression curve to the Aquic Hapludoll of Dr Larson.

Upon examination of these three soils (0-10 cm), for bulk density and air filled porosity, using large clods of soil (Wallasea series, silty clay loam and the Wisbech series silt), and soil cores for the Hamble series silt loam, we find the following (Table 2).

Table.2

Measurement	Soil			
	Silty clay loam	Silt loam DD	Silt loam Ploughed	Silt
Bulk density (g/cc)	1.54	1.29 + (1.43)	1.19 (1.49)	1.34
Air filled porosity % 10 cm suction	3.65	1.02 (0.93)	1.84 (0.83)	0.70
20 cm suction	1.50	1.03 (0.68)	1.10 (0.53)	0.70
50 cm suction	2.30	1.48 (1.26)	1.32 (0.95)	1.80

+ Compacted in the field, ie, Tramlines.

Field experience has shown that these three soils are difficult to direct drill because of their liability to compact and in the case of the two silts this compaction is often associated with surface crusting. It is important to note, however, that with the possible exception of the Wisbech series soil, successful continuous direct drilling has been carried out. The problems associated with compaction on these soils is suggested by the data in Figure 1. Improved management and possible changes in levels and distribution of organic matter may be the key to successful drilling on these soils. Hamblin and Davies (1977) emphasised the important effects of organic matter on the physical properties of silt soils. Higher organic matter levels result in higher water holding capacities,porosities and reduced compaction. There is evidence to suggest that organic matter levels increase in the surface of soils when direct drilling or reduced tillage is practised, and this could have a marked effect on the potential of these soils for reduced tillage systems.

Results of a more detailed study of some of the soil physical characteristics of the silt loam soil (Hamble series.), are presented in Table 3a and 3b.

The data in Table 3a is for the compacted (0-3 cm) samples from both tillage treatments. It was not possible to obtain intact cores from this depth on the non-tramlined areas.

Table 3a

Measurement	Treatment		SE	Sig
	Direct Drill	Plough		
Bulk density (g/cc)	1.29	1.45	0.13	*
Total porosity (%)	51.4	45.1	4.8	*
Permeability ($10^{-10}cm^2$)	56.0	10.6	51.7	ns
Air filled porosity(%)				
- 10cm suction	2.24	1.96	0.86	ns
- 20cm suction	1.54	0.85	0.46	*
- 50cm suction	1.67	1.67	0.42	ns
-100cm suction	1.50	0.89	0.68	ns
Carbon dioxide evolution (µg C/g soil/day)				
- 5-10 hours	21.9	19.0	6.6	ns
-10-15 hours	22.9	18.1	6.3	ns

Bulk densities were higher on the ploughed plots, and the total porosities consequently lower. There were only small and generally non-significant differences in air pososities (coarse pores). The slightly higher non-significant differences in carbon dioxide evolution from the direct drilled treatments may reflect a higher organic matter content.

In Figure 3b data for the 3-8cm sampling is presented, and shows lower bulk densities for the ploughed treatment, higher permeabilities to oxygen, and a tendency to have higher air porosities at the low suctions (10cm), this trend tends to be reversed at the higher suctions (100cm).

It must be remembered that these soils were sampled at the end of the fourth year of the experiment, prior to cultivation for the 5th crop; thus we are looking at more than the short-term effects of treatments.

The results for the 3-8cm depth reflect more closely field experience with this soil. It has been shown (Cannell and Ellis,1977) that in wet seasons direct drilling seeding equipment may produce a drill slit with smeared walls, which restricts water movement and impedes the extension of the seedling roots. The potential for this to occur is reflected in the data for this soil plotted in Figure 1. It is also reflected in the lower oxygen permeability and air porosity figures for the direct drilled soil in Table 3b. In the last two seasons on this soil the yields of winter oats and winter wheat have been as good as those on the ploughed treatment. The use of another reduced tillage system (shallow tine cultivation), has given greater yields than either the direct drilled or ploughed treatments on this soil (Ellis et al) 1978).

The use of a compaction model as proposed by Larson et al 1977), which relates compression index (slope of the compression curve) to soil texture, should provide a useful guide to the liability of soils to compact. It has been found, however, that as management skills improve along with organic matter levels in these highly compactable silty soils, they may be included in a continuous reduced tillage programme.

Table 3b

Measurement	Treatment				SE	Sig
	Direct drilled		Ploughed			
	† 1	2	1	2		
Bulk density (g/cc)	1.29	1.43	1.19	1.49	0.05	**
Total porosity (%)	51.5	46.2	55.1	43.7	1.89	**
Permeability (10^{-10} cm^2	530	20	14877	256	8160	**
Air filled porosities (%) -10 cm suction	1.02	0.93	1.84	0.83	0.46	**
-20 cm suction	1.03	0.68	1.10	0.53	0.25	**
-50 cm suction	1.48	1.26	1.32	0.95	0.27	**
-100cm suction	1.74	1.09	1.29	0.89	0.44	**
Fine pores	46.2	42.3	49.7	40.5	1.9	**
Carbon dioxide evolution (µg C/g soil/day) 5-10 hours	14.6	10.9	15.8	11.9	4.3	**
10-15 hours	14.8	11.1	14.8	12.0	3.6	**

† The numbers 1 and 2 indicate the uncompacted and compacted samples respectively.
** Significant at the 1% level

REFERENCES:

Anderson.J.P.E. & Domsch,K.H. (1975) Can.J.Micorbiol. 21. 314-322

Cannell,R.Q., Davies,D.B. Mackney,D. & Pidgeon J.D.(1978) Outlook on Agriculture. 9. 306-316

Cannell, R.Q. & Ellis, F.B. (1977)Agricultural Research Council Letcombe Laboratory Annual Report 1976, 25, 1977

Ellis,F.B., Christian,D.G. Graham,J.P. Jackson,R. & Torfrida Wakley (1978) Agricultural Research Council Letcombe Laboratory Annual Report 1977, 32, 1978

Hamblin,A.P. & Davies, D.B. (1977) J. of Soil Sci. 28. 11-22

Jenkinson,D.S. & Powlson,D.S.(1976) Soil Biol. and Biochem.8.209-213

Lynch,J.M. (1978) Agricultural Research Council Letcombe Laboratory Annual Report 1977, 52, 1978

Larson,W.E., Gupta,S.C. & Useche,R.A.(1977) Abstracts 11th Int. Congress of Soil Science. Volume 1. p44.

Osborne,G.J., Payne,D.,Greenland,D.J. & Moseley,T. (1979) Proceedings of the 8th Conference of the International Soil Tillage Research Organisation, ISTRO, in Stuttgart-Hohenheim.

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PRELIMINARY EXPERIMENTS WITH ALTERNATIVE ZERO TILLAGE SYSTEMS FOR CEREALS

J.D. Pidgeon*

Scottish Institute of Agricultural Engineering, Bush Estate, Penicuik, Midlothian, EH26 0PH, Scotland.

ABSTRACT: A field experiment has been initiated to study soil and crop responses to two 'alternative' zero tillage systems in comparison with conventional direct drilling, reduced cultivation and ploughing systems. The two 'alternative' systems of scratch drilling and zero tillage/broadcasting offer scope for avoiding the use of heavy machinery and hence reducing compaction problems. Results from the first two years of the experiment showed no significant differences in yield between treatments on this sandy loam soil, classified as suitable for conventional direct drilling. Wheel tracking and poor surface tilth did cause some reduction in plant emergence for the conventional direct drilling and scratch drilling treatments. The alternative zero tillage systems may offer a promising approach to improved management for more difficult soils and in wetter seasons.

THE NEED FOR ALTERNATIVE ZERO TILLAGE SYSTEMS

A recent review of soil suitability for long term direct drilling of cereals in the U.K. (Cannell et al., 1978) suggested that perhaps 70% of the cereal growing area had soils suitable for direct drilling of winter cereals. However, for spring cereals the estimated area considered suitable fell to 30% in England and Wales. The most common soil problems giving rise to yield reductions under direct drilling were compaction, waterlogging and lack of surface tilth. Direct drilling was considered to be favoured by relatively dry soil and climatic conditions. It was noted that at present all experimental and commercial direct drilling of cereals is carried out with heavy drills and at least 60 kW tractors, and that this must affect the success of the technique and the suitability of soils. Pidgeon and Ragg (1979) point out that a rather different approach to management is required for successful drilling in wetter areas, particularly for soils with very limited ability to recover from structural damage, where the avoidance of compaction may largely determine the scope for direct drilling. Heavy machinery may be necessary, or at least acceptable,for dry autumn conditions but not for wet autumn or for spring conditions. Some flexibility in the choice of systems for establishing cereals without tillage is thus desirable to cope with the range of different seasons. The present preliminary experiment is designed to examine a necessarily very limited range of alternative zero tillage systems in comparison with conventional drilling, reduced cultivation and ploughing systems.

CHOICE OF ALTERNATIVE ZERO TILLAGE SYSTEMS

The two alternative zero tillage systems chosen for investigation were 'scratch drilling' and broadcasting with no prior tillage but with harrowing to seeding depth immediately afterwards.

* Present address: Seale-Hayne College, Newton Abbot, Devon TQ12 6NQ England.

In the former system the soil is cultivated to the depth of seeding only, prior to drilling. Potential advantages of this system are that sufficient 'tilth' is formed that the need for heavy specialist direct drills is avoided, and for some soil types this surface cultivation is known to be necessary (Cannell et al., 1978). This is an intermediate system in the continuum between reduced cultivation and direct drilling.

The zero tillage/broadcasting system offers further simplification of machinery, and a considerable potential for reduction of compaction from implements and vehicles, together with a corresponding increase in the number of available work days and of work rate. Many of the factors that led originally to the abandonment of broadcasting of cereals such as weed control problems, irregularity of seed spacing and sowing depth, and poor germination may no longer occur in moist conditions with certain modern cultivation or zero tillage systems. Indeed, amongst the limited recent studies of broadcasting, that of Heege (1969) is noteworthy in showing that in some circumstances yield increases of about 10% may be obtained due to more uniform seed distribution than can be obtained by drilling.

EXPERIMENTAL DETAILS

The experiment is sited on a moderately well drained sandy loam soil of Macmerry series classified as a stagnogleyic brown earth (Avery, 1973) or aquic eutrochrept (Soil Survey Staff, 1975). The site is about 10km east of Edinburgh and has a mean annual rainfall of 650mm with an average date of return to field capacity in early November. The experiment has a randomised complete block design with 4 replicates and 8 main treatments covering a range of reduced cultivation and zero tillage systems for spring barley. In the present short paper not all the reduced cultivation treatments will be considered and the 5 main treatments reported here are:-

1. Conventional mouldboard ploughing (20cm) - control treatment
2. Shallow mouldboard ploughing (10cm)
5. Conventional direct drilling, 60 kW tractor with triple disc drill
7. Scratch drilling; very shallow spring-tine cultivation (5cm) before drilling
8. Broadcasting seed followed by very shallow spring-tine cultivation (4cm).

The entire site was ploughed uniformly to a depth of 20cm in spring 1976. It was then managed uniformly to produce a spring barley crop in 1976, after which straw was baled and the remaining stubble burnt. The experimental treatments were first applied in autumn 1976, with treatments 5, 7 and 8 being sprayed with paraquat at 6.3 l/ha. In the spring a dressing of 375kg/ha of 23:10:10 fertilizer was applied uniformly over the site and treatments 1 and 2 cultivated with a spring-tine harrow. Apart from treatment 8, all treatments and discard areas were drilled with a triple disc drill with spring barley (variety Midas) as a seed rate of 188kg/ha and subsequently harrowed. For treatment 8, seed was broadcast by hand at 220kg/ha, the plots being subdivided into 20m^2 sub-plots each receiving an individually weighed aliquot of seed to ensure reasonable uniformity of seed distribution. During May the crop was top dressed uniformly with 40kg N/ha and sprayed appropriately for broadleaved weed control. At harvest 25m X 2m areas were sampled from each plot using a plot combine harvester. Each plot had dimensions of 29m x 18m and had separate areas for yield, soil and crop studies, the entire site covering about 4ha.

Soil bulk density was measured at 3cm intervals down to a depth of 39cm at 4 positions per plot by a gamma-ray transmission method (Soane, Campbell and Herkes, 1971). A source/detector separation of 22cm and a source of 5mCo ^{137}Cs were used. Soil moisture content was determined at 6cm depth intervals by over drying at 105^{o}C. The depth of seeding was determined by measuring the length of the chlorotic part of the coleoptile for 28 randomly selected seedlings per plot. Plant population at full emergence was determined by counting the number of plants within 10 quadrats of 0.25m^{2} each per plot. Shear strength of the 0-3cm horizon was measured with a 'Pilcon' hand shear vane in 100 locations in and out of wheeltracks.

RESULTS AND DISCUSSION

Crop yield results for 1977 and 1978 (Table 1) show no significant differences between treatments. This result for conventional direct drilling is consistent with other experiments on this soil type (Holmes, 1976) which led to this soil being classified as suitable for direct drilling (Cannell et al., 1978). The results for scratch drilling and zero tillage/broadcasting are particularly interesting as they were obtained even though it was not possible in this experiment to exploit fully the potential advantages of these systems, particularly in reducing soil compaction because lightweight vehicles were not available to us. These preliminary results suggest that development of these systems may offer a useful complementary approach to the current development work on direct drills.

The small yield reductions for the conventional direct drilled treatment in 1978, and the scratch drill treatment in both years, though not statistically significant ($P < 0.05$) may, however, be real effects. Poor seedling emergence was observed in wheeltracks on several treatments but particularly the scratch drill treatment. Detailed investigations showed that seeds were present and had germinated but had failed to emerge due to mechanical impedance of the shoots. Measurements of soil shear strength at 0-3cm showed a significantly higher value in wheeltracks than in adjacent untracked areas and in addition the mean depth of seeding in wheeltracks was greater, presumably due to the action of the final harrow in 'filling up' wheeltracks. A solution to this problem would be to ensure that harrowing, drilling and any final harrowing is a one pass operation. The small yield reduction in 1978 for the conventional direct drilled treatment may be associated with the poor surface tilth in that year, when again detailed investigation revealed restrictions to plant emergence (see Table 1) due to mechanical impedance. By contrast, there was a good surface tilth in 1977.

Table 1 shows that the percentage germination and emergence for the zero tillage/broadcasting treatment was significantly greater than for any other treatment in 1977. This was perhaps due to the shallow mean depth of seeding combined with moist conditions after sowing on March 9th. The rainfall for the remainder of the month was 38.2mm, very evenly distributed with only 4 dry days, although April was drier with 24.2mm rainfall and 11 dry days during the whole month. These two months were rather wetter in 1978 but only similar plant populations were achieved for the zero tillage/broad cast treatment compared to other treatments, despite the 17%

Table 1. Crop yield, emergence and depth of seeding data, 1977 and 1978

Year	Crop Parameter	Tillage and Crop Establishment Treatment					L S D P 0.05 (sig. F)
		Conv. plough	Shallow plough	Direct drill	Scratch drill	Broadcast	
1977	Yield t/ha at 85% D.M.	7.8	7.7	7.7	7.1	7.5	0.8 (ns)
	Plants emerged 10^6/ha, mean+	2.4	2.0	2.1	2.4	3.6	0.5 (***)
	Plants emerged CV	34%	31%	32%	32%	33%	
	Seeding depth mm, mean	46	45	43	44	14	10 (***)
	Seeding depth CV	33%	29%	26%	34%	77%	
1978	Yield t/ha at 85% D.M.	6.2	5.7	5.2	5.3	5.7	0.9 (ns)
	Plants emerged 10^6/ha, mean+	3.3	3.4	2.9	3.2	3.1	0.3 (**)
	Plants emerged CV	22%	18%	24%	17%	20%	
	Seeding depth mm, mean	44		27	38	28	16 (ns)
	Seeding depth CV	5%		46%	48%	53%	

+ seed rate treatments 1-7; 188 kg/ha: treatment 8; 220 kg/ha.

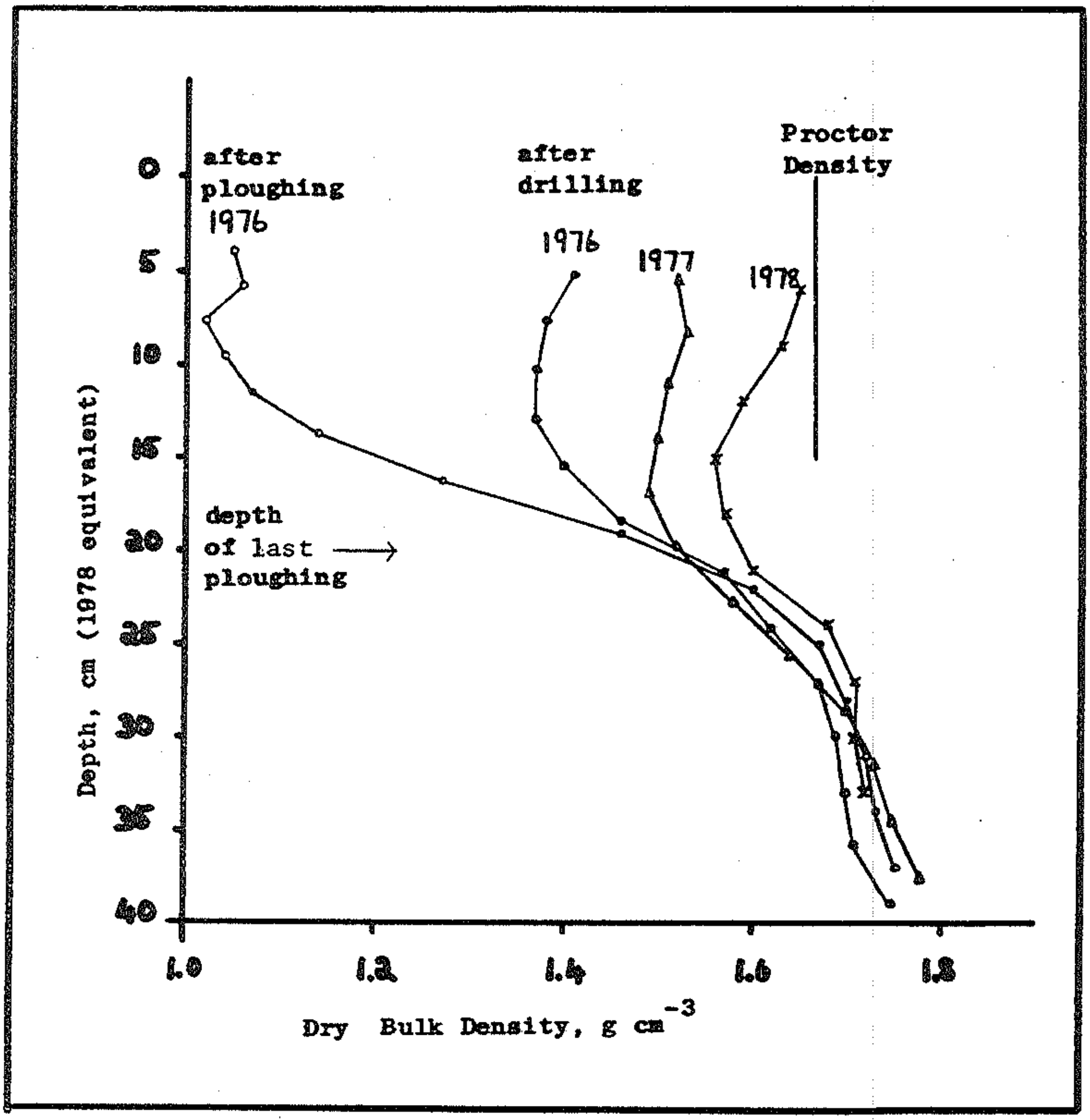


Figure 1. Increase of dry bulk density over time on a sandy loam soil under conventional direct drilling.

higher seed rate (Table 1). Thus although more detailed studies are needed there is no evidence in these two years that zero tillage/broadcasting in moist conditions gives worse results than use of a direct drill. The same conclusion is reached from examination of the standard deviations of the depths of drilling for each treatment, although of course the very shallow depth of seeding on the broadcast treatment in 1977 gave rise to a high coefficient of variation.

No significant differences between treatments were found for dry bulk density measured during the growing season in 1977. However, by mid season 1978 the conventional direct drill and scratch drill treatments had significantly higher dry bulk density at 6cm depth than the two ploughed and the zero tillage/ broadcast treatments. There were no significant differences at other depths. Figure 1 shows dry bulk density for the conventional direct drill treatment, plotted on the basis of corrected depths to compare equivalent horizons (Pidgeon and Soane, 1977). Although statistically valid comparisons between occasions cannot be made, the good agreement of results from below the depth of ploughing for the different occasions of measurement suggests such comparisons are meaningful. The data suggests that the difference in density between treatments noted in 1978 but not before is due to increasing compaction on the conventional direct drill and scratch drill treatments. This increase may at least temporarily have been reduced on the zero tillage/broadcast treatment with its lesser number of passes over the seedbed.

In conclusion, it would seem from this preliminary investigation that alternative systems of crop establishment to the use of heavy direct drills and tractors in cereal production without tillage may hold promise, particularly for the solution or avoidance of problems on difficult soils and/or in wet seasons.

REFERNCES

Avery, B.W. (1973). Soil classification in the Soil Survey of England and Wales. Journal of Soil Science 24, 324-338.

Cannell, R.Q., Davies, D.B., Mackney, D., and Pidgeon, J.D. (1978). The suitability of soils for sequential direct drilling of combine-harvested crops in Britain: a provisional classification. Outlook on Agriculture 9, 306-316.

Heege, H.J. (1969). Drilling versus broadcasting of grain. ASAE Paper 69-165. St. Joseph, Michigan.

Holmes, J.C. (1976). Effects of tillage, direct drilling and nitrogen in a long term barley mono-culture system. Compterendue des seances, semaine d'etude cerealiculture. Univ. Gembloux, Belgium, 177-190.

Pidgeon, J.D. and Ragg, J.M. (1979). Soil, climatic and management options for direct drilling cereals in Scotland. Outlook on Agriculture 10, 49-55.

Pidgeon, J.D. and Soane, B.D. (1977). Effects of tillage and direct drilling on soil properties during the growing season in a long-term barley mono-culture system. Journal of Agricultural Science 88, 431-442.

Soane, B.D., Campbell, D.J. and Herkes, S.M. (1971). Hand-held gamma-ray transmission equipment for the measurement of bulk density of field soils. Journal of Agricultural Engineering Research 16, 145-156.

Soil Survey Staff. (1975). Soil taxonomy, a basic system of soil classification for making and interpreting soil surveys. Agric. Handb. U.S. Dept. Agric. No. 436. Washington, U.S.A.

The 8th Conference of the International Soil Tillage Research Organization, ISTRO, Bundesrepublik Deutschland, 1979

THE SUITABILITY OF CLAY SOILS IN ENGLAND FOR GROWING WINTER CEREALS AFTER DIRECT DRILLING OR SHALLOW CULTIVATION

R.Q. Cannell, M.J. Goss and F.B. Ellis
Agricultural Research Council Letcombe Laboratory, Wantage, England

ABSTRACT

Clay soils occupy a large proportion of the cereal growing area of England. These soils have been provisionally classified as suitable for direct drilling of autumn sown crops provided that drainage is good. Recent results from experiments on two clay soils are considered in relation to this classification. In a dry season yields of winter wheat were higher after direct drilling and shallow cultivation than ploughing; in a wet year yields of 10 t/ha of wheat were achieved after all methods of cultivation except on the heavier of the two soils where direct drilling gave 9.4 t. In the dry year there was deeper root growth and greater uptake of water from the lower horizons on the direct-drilled areas, whereas in the wet season lower oxygen concentrations and restricted root growth after direct drilling were associated with the depressed yield on the heavier soil. These results emphasise the need to continue cultivation experiments for sufficient time to enable the effects of contrasting weather patterns and changes in soil conditions to be observed.

Introduction

More than 40 per cent of the cereal growing area in the United Kingdom is on soils with more than about 35 per cent clay in the topsoil (Table 1). These soils are suited to autumn sown crops, and when adequately drained have the potential to produce high yields. In wet conditions problems can often arise in establishing cereals after time-consuming methods of cultivation, involving ploughing and secondary cultivation. This limits the total area of winter cereals sown each year, and the proportion established within the optimum period. Early sowing of spring crops on these heavy soils is often difficult and yields may be depressed. Interest therefore arises in the possibility of growing winter cereals after more rapid techniques of simplified cultivation or zero tillage (direct drilling) when weeds are controlled by herbicides.

Soil suitability for simplified cultivation

Many experiments have been carried out in Britain during the past ten years to compare the more rapid cultivation methods with mouldboard ploughing. Based on the results for 1969-77 a provisional classification on the suitability of soils for sequential direct drilling of cereal crops has been proposed (Cannell et al, 1978). In summary there are three categories.

Category 1: soils with favourable properties, and yields similar to those from well managed conventional cultivations can be expected from both autumn and spring sown crops; the group includes chalk and limestone soils and well drained loams.

Category 2: soils where, with good management the yield of winter cereals is likely to be similar after direct drilling and conventional cultivation, but where the yield of spring crops is likely to be appreciably reduced (Table 1); it includes the calcareous clays and other clay soils that have been improved by installation of artificial drainage.

Category 3: soils where there is a substantial risk of loss of yield after direct drilling, especially of spring sown crops; this Category contains coarse sands, silts, wet alluvial and undrained clay soils.

TABLE 1. The percentage of the cereal growing area of England occupied by clay soils, and cereal yields on clay soils grown after ploughing or direct drilling, 1969-77.

Soil group (U.K., U.S.D.A., F.A.O.)	% of cereal area	Direct-drilled yield, % of ploughing		Number of experiment years	
		Winter wheat	Spring barley	winter wheat	Spring barley
Calcareous pelosol Aeric haplaquept Calcaric gleysol	8.0	100	93	29	12
Stagnogley Typic haplaquept Eutric gleysol	36.5	101	91	44	22

(from Cannell et al, 1978)

This classification is considered provisional, since it is not possible to carry out experiments on all soil types, few experiments have lasted long enough to experience the effects of variation in weather patterns between years, and the reasons for yield differences are not always evident.

Experimental

In the remainder of this paper recent results from long-term experiments at Letcombe Laboratory on two clay soils, classified as being in Category 2, are considered in relation to the classification. These experiments commenced in 1974. Both soils had been artificially drained with pipes and mole drains. Some properties of the soils are summarized in Table 2. The aim is to study the long-term effects of different cultivation methods (ploughing, shallow cultivation and direct drilling) on soil conditions and on the growth of both the roots and the shoots of the crop. To avoid possible confounding effects from soil-borne diseases such as take-all (*Gaeumannomyces graminis*), a rotation of autumn sown crops is being grown, with winter wheat in alternate years. During these experiments the weather has been characterised by contrasts; unusually dry in 1975-76 and wet in winter 1977-78. Winter wheat was grown in both years.

TABLE 2. Summary description of experimental soils

Soils A and B are both Stagnogleys, Verti-eutric gleysols or Typic haplaquepts in the U.K., European and U.S.D.A. classifications, respectively.

	Soil A	Soil B
Particle sizes (%)		
< 2 μm (clay)	35	49
2-63 μm (silt)	34	47
> 63 μm (sand)	31	4
Texture	Clay loam	clay
Organic Matter (%)	5.4	7.4
Previous Cropping	Arable	Permanent grass

Crop yield: In the exceptionally dry conditions of 1975-76 the yields of winter wheat were significantly heavier after direct drilling and shallow cultivation than after ploughing (Table 3). The yields obtained in the wet season of 1977-78 are of particular interest; with adequate nitrogen fertilizer, yields of about 10 tonnes per hectare were achieved whatever the cultivation method. Such favourable conditions for the growth of cereals have not existed previously in the period when direct drilling and ploughing have been compared. This is most important evidence that crops grown with minimum cultivation can yield satisfactorily in high yielding conditions. The contrast in yield between cultivation treatments on these two soils in the wet season is also of interest. On soil A the yields after direct drilling and shallow cultivation were similar to that after ploughing, but on the heavier soil B the yield after direct drilling was less than after ploughing (Table 3).

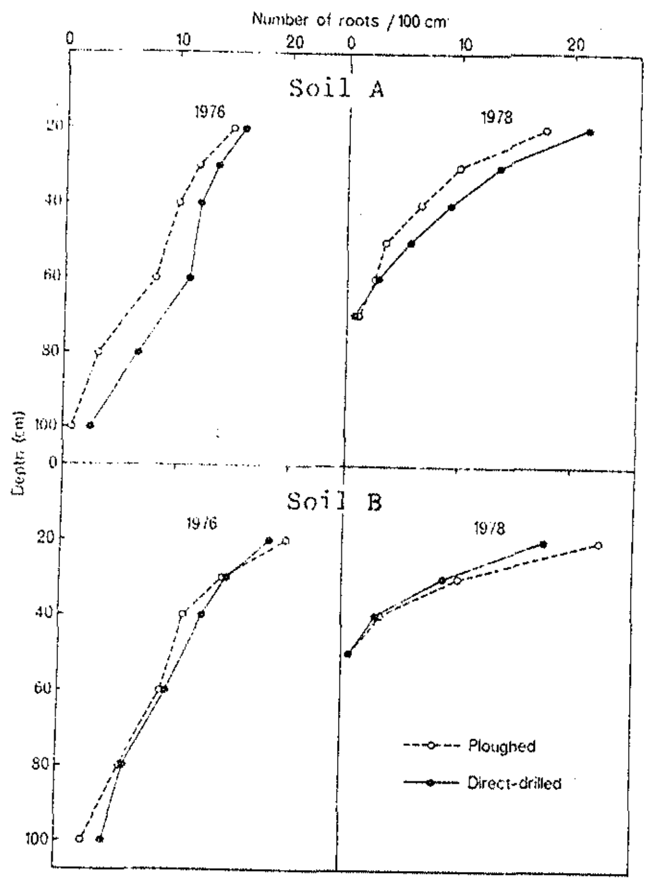
TABLE 3. Effect of method of cultivation on yield (tonnes/ha) of winter wheat on clay soils in two contrasting years, 1976 (dry) and 1978 (wet)

	Soil A			Soil B	
	Direct-drilled	Shallow tined	Ploughed	Direct-drilled	Ploughed
1976	5.5	5.2	4.8	6.4	5.8
1978 Low N	8.6	8.3	9.3	7.5	9.0
High N	10.5	10.2	10.2	9.4	10.0

Soil B was characterised in the wet year by patches where growth was poorer in April with direct drilling. On these patches yield was about 2.5 t ha^{-1} less than on the areas of better growth.

Root growth: There was a large difference between the dry and wet years in the number of roots at different depths at the end of tillering in April. In the dry year (1976) some roots had reached 100 cm by this time, whereas in the wet year the maximum depth of rooting in April was about 70 cm on soil A, but only about 50 cm on the finer textured soil B (Fig 1). There was also a pronounced interaction between the cultivation treatments and the soil moisture content during the seasons. In the dry year on both soils the roots of the wheat were more numerous below about 40 cm after direct drilling. In the wet season, on soil A this pattern of rooting was less evident, but on the heavier soil B, roots were shallower after direct drilling (Fig 1).

FIGURE 1. Root growth of winter wheat in clay soils after direct drilling or ploughing, measured in April at Zadoks growth stage 30



On soil B in the patches of poor growth on the direct-drilled treatment rooting in April was much restricted and not exceeding 40 cm, but on the areas of good growth on the direct-drilled treatment the maximum depth of root growth and the number of roots down the profile were similar to that on the ploughed land.

Soil conditions: In the classification of soil suitability the main soil factors limiting the success of direct drilling were considered to be lack of tilth, topsoil compaction and wetness caused by slow drainage in the subsoil (Cannell et al, 1978). It is thus relevant to consider the extent to which these factors were operative in these two experiments, and how far the observed differences in root growth and yield were associated with these factors.

Topsoil conditions: Both these soils show a tendency to self-mulch in the surface 2-3 cm, and this together with removal of residues of the preceding crop by burning has provided a satisfactory environment for germination after direct drilling. In previous work on a calcareous pelosol (Ellis et al 1979) all forms of cultivation not involving soil inversion increased the stability of surface aggregates to slaking and dispersion. This trend became greater as the experiment continued. However, on soil A, the old arable site, there has been little difference between direct drilling and ploughing but aggregates from the shallow tine treatment are more stable. Initially on soil B, the old grassland site, the stability of aggregates from the direct-drilled plots was greater than those from ploughed land but stability has declined over the last 4 seasons and the mean value for direct-drilled soil is lower than that for ploughed. This is associated with a separation of the silt fraction and a greater tendency for surface ponding of water to occur.

Topsoil compaction: On both soils the total pore space and air-filled pore space in the top 20 cm were less after direct drilling than after ploughing. On soil B in the first year the mean values after direct drilling and ploughing were 65 and 70 per cent respectively. However, these bulk properties of the soil were poor indices of the soil for root growth after a dry season, when cracks and fissures in clay soils which can be deeper and more continuous after direct drilling (Ellis et al, 1979) and the presence of more earthworms (Barnes and Ellis, 1979) have favoured root growth.

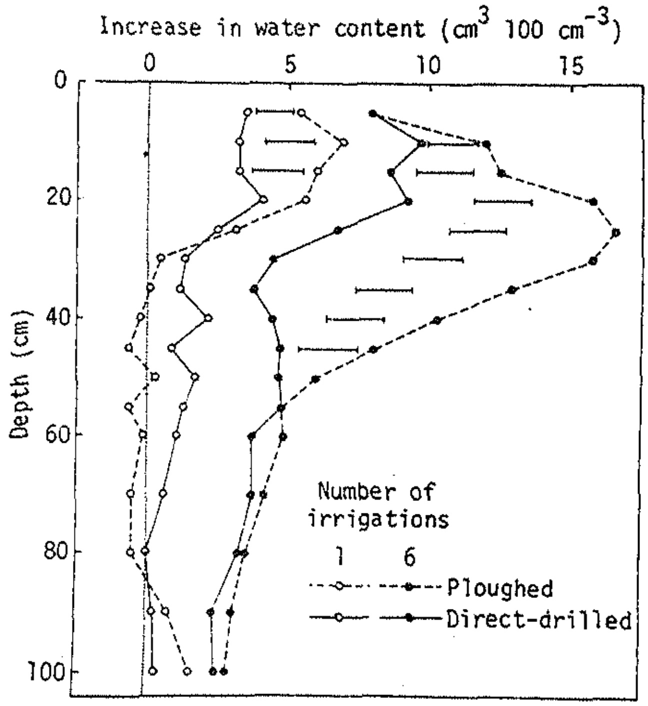
In the wet season the oxygen concentration on soil B was much less after direct drilling than after ploughing (Burford et al, 1979) whereas in the dry season, little difference was observed.

On the areas of bad growth on the direct-drilled plots on soil B, the clay content was greater and the air-filled pore space in the top soil was less than on the areas of good growth.

Drainage in the sub-soil: Evidence was obtained, using the neutron meter, that with ploughing the infiltration of water following rain or irrigation was retarded compared with direct drilling resulting in higher water content especially at the depth of ploughing (c. 25 cm) (Fig 2). Even in wet conditions in spring 1977 there was more rapid movement of water to depth in direct-drilled soil. The importance of differences in the continuity of the macro-pores was further shown by determination of the saturated hydraulic conductivity in soil cores from soil B. At the depth of ploughing hydraulic conductivity was much less in ploughed land, due to the absence of earthworm channels.

In the dry year, the deeper infiltration led to storage of more water in the direct-drilled treatment on both soils (Goss et al, 1978) and contributed to the higher yield. In wetter conditions in soil B the water-table was consistently higher in 1977-78 in the direct-drilled treatment. This raises the question as to whether the lateral component of hydraulic conductivity in the subsoil is less in uncultivated soil. In ploughed clay soils it is known that the lateral movement of water in the topsoil is important for drainage (Trafford and Rycroft, 1973). The greater density of uncultivated topsoil could impede this flow. The need to study the requirements for artificial drainage of clay soils to be shallowly cultivated or direct-drilled is therefore evident.

FIGURE 2. Increase in water content of direct-drilled and ploughed clay soil B after one or six daily irrigations, each of 15 mm; soil water content was measured 30 minutes after irrigation ceased.



REFERENCES

1. Cannell, R.Q., Davies, D.B., Mackney, D. and Pidgeon, J.D. (1978) Outl. Agric. 9, 306-316.

2. Ellis, F.B., Elliott, J.G., Pollard, F., Cannell, R.Q. and Barnes, B.T. (1979) J. agric. Sci. Camb. 93 (in press)

3. Barnes, B.T. and Ellis, F.B. (1979) J. Soil Sci. 30 (in press)

4. Burford, J.R., Dowdell, R.J., Crees, R. and Hall, K.C. (1979) Ann. Rept. Agric. Res. Coun. Letcombe Lab. 1978 (in press).

5. Goss, M.J., Howse, K.R. and Harris, W. (1978) J. Soil Sci. 29, 475-488.

6. Trafford, B.D. and Rycroft, D.W. (1973) J. Soil Sci. 24, 380-391.

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SOIL SUITABILITY FOR SEQUENTIAL ZERO TILLAGE IN THE U.K.

D.B. Davies,[1] R.Q. Cannell[2] and D. Mackney[3]

[1] Soil Science Department, ADAS, Coley Park, Reading, England.
[2] Letcombe Laboratory, Wantage, Oxford.
[3] Soil Survey, Rothamsted, Harpenden, Herts.

ABSTRACT

A classification based largely on experimental results is proposed for the suitability of land in Britain for repeated zero tillage of cereals (Cannell). Chalk and limestone soils and other well-drained loams are classified as equally suitable for zero tillage of spring and winter crops; with good management most clay soils are suited for winter crops and may benefit from timeliness of sowing. But zero tillage on sandy soils and some other weakly structured soils can lead to lower yields than those from conventional cultivations.

The factors predisposing land in Britain to successful zero tillage are inherent resistance to compaction, good drainage, drier climate and level or only moderately sloping land.

INTRODUCTION

The area of cereal crops grown without deep cultivation in Britain is steadily increasing as farmers take advantage of the substantial savings in time, and the opportunities for reducing labour and machinery costs, which are afforded by reduced cultivation and especially by direct drilling. The advantages of timeliness are particularly important for autumn-sown cereals and oilseed rape.

The experimental results used to assess the suitability of zero tillage have been derived from many sources of published information together with more recent unpublished work. The results from experiments carried out from 1969 to 1977 inclusive are summarised in Table 4. Inevitably the classification is tentative. Many experiments are still in progress and some, especially those on heavy soils, have only recently started.

SOIL FACTORS LIMITING ZERO TILLAGE

Lack of tilth: Soils exhibiting a tendency for the surface layers to pack tightly either through slaking or inability of the soil to form a natural surface tilth by weathering are less suitable for zero tillage unless it includes shallow surface cultivation. When crops are drilled into a compacted surface there is likelihood of inadequately covering seeds, of smearing the soil by drill coulters, and of both excessive soil strength and local ponding in the vicinity of seeds.

Topsoil compaction: Timely cultivations provide an opportunity to relieve compaction in the topsoil and to the extent that excessive compaction may occur in zero tilled land, the system is more at risk. Where extensive compaction develops, the risk of surface ponding and water erosion is increased during wet periods and during prolonged dry periods, effects of drought will be accentuated.

Resistance to compaction in soils is usually associated with the following soils and soil properties:

Drainage: Soils which drain rapidly are less at risk from both wheeling and slaking damage than soils that drain slowly.

Texture: Loamy and peaty soils and some calcareous clayey soils are relatively resistant to compaction. Conversely low organic matter sandy soils, non calcareous silty soils and sandy clay loams tend to compact more easily because of weak structure.

Organic matter content: Additional organic matter in soil tends to reduce the effect of compacting forces and to enhance recovery of an open structure in compacted soils.

Surface mulching: Many clayey and loamy soils in England break down to give a fine surface tilth under the influence of weathering cycles. This characteristic of a soil although not essential for zero tillage enhances its success.

SITE FACTORS LIMITING ZERO TILLAGE

Slope: Zero tillage is possible in a wide range of topographical situations but, on sloping land, there is a greater risk of gully erosion after zero tillage on soil in which the infiltration rate is low, for example on weakly structured slaking soils.

Spring lines: Land subject to spring lines, or to reception of much surface water during wet periods, is unsuitable for zero tillage unless the water can be satisfactorily controlled by pipe drains and cut-off ditches.

Field variability: When the classification system, described below, is applied to individual farms and fields, soil and topographical variability are inevitably encountered and need to be identified by field examination.

CLIMATIC FACTORS LIMITING ZERO TILLAGE

Experience has shown that zero tilled crops can be more at risk in wet years, when there is an early return to field capacity and the rainfall is high during the period of seedling establishment. The limitations imposed by wet weather which could affect zero tillage on a farm scale may be much less evident in well-managed experiments. The problems encountered in wetter areas are:

- more structural damage and rutting at harvest and during subsequent field operations,
- later harvest, reducing the opportunity for disposal of crop residues and for weed control,
- more risk of surface ponding and waterlogging on clayey and weakly structured soils,

- less development of surface tilth produced by weathering,
- more risk of grass weed competition and slug damage; certain weeds, particularly creeping bent, rough-stalked meadow grass and black-grass are encouraged in wet soil conditions, and may compete strongly with the crop,
- more delay in drilling of spring crops because of surface wetness.

In an attempt to take account of these factors the mean date of return to field capacity in the autumn has been chosen as an index The area where the mean date of return is later than 31st October includes most of lowland England. In this zone the climate is most favourable for zero tillage.

CLASSIFICATION OF SOIL AND SITE SUITABILITY

Three categories of soil suitability for sequential zero tillage are identified: Category 1, soils with favourable properties, on which yields similar to those from well managed conventionally cultivated crops can be expected for both winter and spring sown cereals; Category 2, soils on which winter cereals would be expected to give similar yields with zero tillage and conventional cultivation, but where there is an appreciable risk of lower yield from zero tillage in spring crops. Category 3, soils where reduction in yield is expected, especially of spring sown crops. Categories 2 and 3 include soil types in which the physical properties appear to restrict the performance of zero tilled crops.

The classification should not be interpreted as excluding the possibility of good results from zero tillage on category 2 and 3 soils, but it highlights the need for careful attention to appropriate management techniques on these soils.

CLASSIFICATION CATEGORIES

The soil, site and climatic characteristics of each of the three categories are listed below, and linked with the current classification of soil groups and series (Avery 1973).
It should be noted that the comparisons of tillage methods are within a soil group, not between groups. In particular, for the clayey soils in Category 2, the calcareous pelosols are generally much more suitable for arable farming than the stagnogleys. Both of these categories, but especially the latter, can present considerable difficulties for conventional cultivation methods, particularly in wet autumns.

Category 1

These are soils with favourable properties on which yields similar to those from well-managed conventional cultivations can be expected, from both autumn and spring-sown crops. The group includes chalk and limestone soils, and well-drained loamy soils, and occupies about 30% of the cereal-growing area of the country.

Soil characteristics

Drainage: Usually well and moderately well-drained soils.

Topsoil: Generally loamy, but including some humose clayey soils. Frequently the soils have appreciable natural lime in both topsoil and subsoil. These soils generally have reasonably high organic matter content (more than about 2% in sandy soils, 3% in loamy and silty soils and 5% in clays). Humose and peaty soils and peat soils are normally in Category 1. Soils which slake easily when wet are excluded.

Site characteristics

Sites not subject to severe spring lines or other influx of water from higher land which cannot be satisfactorily controlled by ditches and drains. Sites should not be subject to frequent surface flooding. Field surfaces generally level or sloping regularly, without depressions into which surface water may drain.

Land consisting predominantly of Category 1 soils with small proportions of Categories 2 and 3.

Climate

For soils in this category, the date of return to field capacity is not likely to be a limiting factor.

The soil groups in Category 1 are given in Table 1.

TABLE 1. Category 1: Soil groups

Rendzinas and brown calcareous earths (chalk and limestone soils)

Loamy brown earths and argillic brown earths (well and moderately well-drained soils)

Humic sandy gley soils (humic sands)
Humic alluvial gley soils (humic loams and clays)
Peat soils (organic soils)
Brown sands, brown clacareous sands and brown podzolic soils (coarse sands) with high organic matter content

Category 2

These are soils where with good management the yield of winter cereals is likely to be similar after zero tillage and conventional cultivation, but where the yield of spring crops is likely to be appreciably reduced. It includes the calcareous clays and clayey or loamy over clayey soils which have been improved by drainage measures; it covers about half of the cereal growing area, but is largely confined to England.

Soil characteristics

Drainage: Mainly imperfectly and moderately well-drained soils in which drainage is impeded by a relatively impermeable sub-surface layer at moderate depths, which can be partially remedied by field drainage.

Topsoil: Clayey or loamy.

Site characteristics

Land with level to moderately sloping topography including areas with local depressions receiving water in wet times. Category 2 land includes fields with a mixture of Categories 1 and 2, and land of Category 2 soils with a small but insignificant proportion of Category 3 soils.

Climate

Excluding areas in which the return to field capacity is before 1 November.

The soil groups in Category 2 are given in Table 2.

TABLE 2. Category 2: Soil groups

Argillic pelosols (non-calcareous clays)
Calcareous pelosols (calcareous clays)
Stagnogley soils* (clayey, loamy and loamy over clayey soils with slow drainage)

Loamy stagnogleyic and gleyic argillic and paleo-argillic brown earths
Stagnogleyic brown sands (with high organic matter content)
Cambic gley soils (loamy soils)

* Stagnogley soils with unstable A horizons may be more appropriately downgraded to Category 3.

Category 3

Soils on which there is a substantial risk of loss of yield after zero tillage, especially of spring-sown crops. This group includes sandy soils with low organic matter content, silty soils, many wet alluvial soils and clayey soils, it accounts for about 20% of the cereal growing area.

Soil and climatic characteristics

i. Clayey and loamy soils: in which the mean date of return to field capacity is before November 1; the soil characteristics are given in Category 2.

ii. Other soils:
Drainage: Excessively well-drained soils and soils affected by fluctuating water and/or flooding.
Topsoil: Mainly sandy and silty soils with low organic matter content and some clayey alluvial soils. Problems with compaction can arise which impede root growth and give rise to waterlogging on the soil surface.

Site characteristics

Land subject to spring lines or other influx of water from higher areas which cannot be satisfactorily controlled; also land subject to flooding or poorly controlled regional water levels. Steeply sloping land with sharp variations in gradient and land with very stony patches. Variable fields in which Category 3 soils are mixed with Category 1 or 2 soils.

The soil groups in Category 3 are given in Table 3.

TABLE 3. <u>Category 3: Soil groups</u>

Brown sands containing less than 2% organic matter, silty argillic and paleo-argillic brown earths, certain brown earths, podzols and gley-podzols (sandy soils with low organic matter content and silty soils)
Silty argillic gley soils
Alluvial gley soils, brown calcareous and brown alluvial soils (silty soils and soils subject to flooding)

Sandy gley soils (sandy soils)
Brown podzolic soils
Gley soils (poorly drained soils)
Stagnogley soils (poorly drained soils) and calcareous pelosols where the return to field is before 1 November

It is not feasible to carry out experiments comparing zero tillage with other methods of cultivation on all soil types. Therefore, further information both from experiments now in progress and from practical experience with zero tillage on other soils will be needed to assess the classification proposed in this paper.

Zero tillage has only been practicable for a few years and as yet is only used for a small proportion of the cereals grown in Britain. However, there is a rapid trend away from the use of the mouldboard plough, and it seems likely that shallow cultivation will become more common for cereals. Many factors, including the availability of suitable drilling machinery, are likely to influence the extent to which zero tillage may be practised. The practice might be expected to increase with greater incentives to save labour and energy.

TABLE 4. Major soil groups in U.K. cereal growing areas and summary of results of experiments comparing zero tillage and ploughing for crops from 1969-1977 inclusive

Dominant soil group	Proportion of cereal growing areas: England & Wales*	Proportion of cereal growing areas: Scotland	Winter crops (a) and Spring crops (b): Zero till. yield % of ploughing (a)	Zero till. yield % of ploughing (b)	No. of sites (a)	No. of sites (b)	No. of experiment years (a)	No. of experiment years (b)	No. of experiments 3 years or more (a)	No. of experiments 3 years or more (b)
Brown alluvial and brown calcareous alluvial soils	1.0	1.0	-		-		-		-	
Alluvial gley soils	5.0	2.0	93		2		5		1	
Humic alluvial gley soils	2.0	2.0	103		2		3		0	
Earthy peat soils	2.0	-	-		-		-		-	
Rendzinas	11.0	-	100	99	8	5	13	14	2	3
Brown sands	4.0	15.0	95	81	1	3	2	6		1
Brown calcareous earths	4.0	-	98		2		8		2	
Brown earths	10.0	22.0	100	98	2	4	7	19	1	3
Argillic brown earths	9.0	-	103	95	3	4	7	11	2	1
Paleoargillic brown earths	4.0	-	97		3		7		2	
Brown podzolic soils	-	22.0	-		-		-		-	
Gley-podzols	1.0	-	-		-		-		-	
Calcareous pelosols	8.0	-	100	93	8	4	29	12	5	3
Sandy gley soils	1.5	2.0	-		-		-		-	
Cambic gley soils	0.5	4.0	-		-		-		-	
Argillic gley soils	0.5	-	-		-		-		-	
Stagnogley soils	36.5	30.0	101	91	17	8	44	22	9	3
TOTAL	100	100	-	-	48	28	125	84	24	14

* Proportionate extent of soil units of the 1:1,000,000 map of E & W within cereal growing areas.

REFERENCES

AVERY, B.W. (1973) J. Soil Sci. 24 324.

CANNELL, R.Q., DAVIES, D.B. et al 1978 Outlook on Agriculture, 9 No. 6 p. 306.

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EFFECTS OF STRAW RESIDUES ON THE ESTABLISHMENT AND YIELD OF DIRECT-DRILLED CROPS

F.B. Ellis and J.M. Lynch
Agricultural Research Council, Letcombe Laboratory, Wantage, England

ABSTRACT

The decomposition of straw residues in close contact to developing seedlings, especially under anaerobic conditions, can result in toxins being produced which are harmful to seedling establishment. Acetic acid has been identified as an important phytotoxin in this decomposition. Possible ways of overcoming the problems which can arise with direct drilling in the presence of straw residues are suggested.

Introduction

In many countries the return of crop residues is an essential feature of agricultural systems. Advantages of stubble mulch farming are that it reduces erosion of the soil, protects the surface soil against structural deterioration from rainfall and increases infiltration and conservation of water. Despite these advantages, McCalla and Army (1961) stated that yields in the United States are often reduced, particularly in more humid areas. More recently evidence (Cochran, Elliott and Papendick, 1977) has been obtained of reduced yields of wheat grown directly in stubble compared with clean cultivation. The magnitude of the decreases correlated with increase in annual precipitation, which in turn correlated with increased amounts of crop residue from previous crops. Because of the variability of the effects within fields, depending upon the quantity of residues present and the appearance of the plants, phytotoxicity was suspected.

On the continent of Europe many of the soils in the main cereal growing areas contain a high silt fraction and a low organic matter content. Return of crop residues is therefore often desirable, and to encourage rapid decomposition the residues are incorporated into the soil as soon as possible after harvest. In Britain, however, more than 40 per cent of the main cereal growing areas are clay soils, with more than 3 per cent organic matter content (Cannell et al, 1978). These soils are most suited to winter cropping and to maximise the area sown, direct drilling has many advantages. Early experience with direct drilling revealed that severe mechanical and pest problems could arise if straw residues were present and it was recommended that they should be burnt. Experiments had shown, on a range of soil types, that the method of straw disposal on land which had been traditionally cultivated did not affect crop yield when adequate allowance was made for the return of nutrients. Returning straw to land over long periods increased the organic carbon by less than 0.2 per cent (Short, 1973). Ploughing of straw into the soil was therefore not so much a method of improving soil fertility, but the most convenient method of disposing of unwanted material. Increases in yield can however be obtained by the annual addition of straw on soils with poor structural qualities and inherently low organic matter content (Johnston, 1979).

In England and Wales more than 40 per cent of the total straw is surplus to farm requirements (Hughes, 1979). A high proportion of this surplus, irrespective of cultivation treatment, has therefore been burnt (Table 1). Besides removing the straw quickly and economically burning can increase the stability of aggregates close to the soil surface (Douglas, 1977) and the moisture content of the surface soil can be lower (Ellis, Douglas & Christian, 1977). These changes can be very important in minimising the possibility of seed being placed by direct drilling machines, particularly those with a triple disc furrow opener, into a smeared slot in close contact with decomposing straw.

TABLE 1. Straw disposal in the field in England and Wales. Mean results for 1976 and 1977 (Data from Hughes, 1979)

Crop	% of total area		
	Baled	Chopped & Spread	Burnt
Wheat	42	6	52
Barley	82	1	17

It is important to note that any long term changes in soil physical conditions resultant from different methods of straw disposal are likely to be comparable to the changes which can occur when land is direct-drilled rather than ploughed or deeply cultivated.

Straw residues and crop establishment and yield

The advantages of burning have been clearly demonstrated by experiments on 5 of the Ministry of Agriculture, Fisheries and Food Experimental Husbandry Farms during the period 1974-77 (Oliphant, 1978). Smaller yields of winter wheat, especially after direct drilling, were obtained when straw was present. The magnitude of the reduction in yield was greatest when the crop was established in wet conditions. At one site with a high clay content, direct drilling and chopping and spreading the straw resulted in reductions of yield of 71, 17 and 39 per cent in 1974, 1975 and 1976 respectively compared with burning. The autumn rainfall during the period August to November in the years when these crops were sown was 124, 60 and 119 per cent of the long term average. Yield reductions were associated with poor and variable plant establishment.

Similar results (Table 2) have been obtained in experiments at Letcombe Laboratory where particular emphasis has been devoted to ascertaining the reasons for the poor establishment and inability of the crops to adequately compensate for the lower plant populations. It is of course in wet autumns, when removal of straw and stubble is most difficult, that the timeliness advantages of simplified methods of cultivation for establishing winter cereals are most valuable. There is moreover only a short period between harvesting one crop and establishing the next. The problem is dramatically different where spring cropping is adopted.

A common characteristic of many studies has been that effects from the presence of the residues are observed very early in the establishment of the crop. Plant number is often decreased either as a consequence of poor germination or, more frequently, death of seedlings shortly after emergence. Many of the symptoms, over-winter stand loss, less tillering, shortened internodes, spindly stems, leaves corkscrewing, leaf yellowing and shrunken grain and small heads (see review by Elliott, McCalla and Waiss, 1978) resemble nitrogen deficiency. They have not been corrected, however, by nitrogen applications (Davidson & Santlemann, 1973; Kimber, 1973). Immobilisation of soil nitrogen, at least for a temporary period, may be expected when straw decomposes because of the very high ratio of carbon to nitrogen (c 80 : 1) in it compared with the decomposing micro-organisms (c 5 : 1). However, lack of nitrogen appears an unlikely explanation for the observed symptoms because of the early stage of plant development when first observed. A much more likely explanation is either toxic compounds leaching from crop residues or microbial production of toxic compounds during residue decomposition. There is extensive literature on this subject but many of the experiments have been carried out under laboratory rather than field conditions (see reviews by Lynch, 1976 and Elliott, McCalla & Waiss, 1978).

TABLE 2. Effect of method of straw disposal on yield of winter wheat. Results obtained in 1978

Straw treatment	Furrow opener	Soil water content at drilling (0-5cm) % v/v	Yield of grain (t/ha-85% dry matter)
Burnt	Triple disc)	33.8	8.5
	Single disc)		8.1
Chopped & spread			
a) left in situ	Triple disc	44.2	3.8
b) disced	Single disc	41.8	5.4
c) rotavated	Single disc	35.2	4.6

[The burnt area was sown two days earlier than where the straw had been chopped and spread. During the interval 0.75 mm of rain fell]

Microbial production of phytotoxins from plant residues

In the wet autumn of 1974 decomposing straw taken from drill slots in the field was macerated in sterile distilled water and the effect of this suspension on the germination of barley seeds was investigated. No discernible differences in the rate of radicle emergence were observed but after 6 days there were marked differences in root and to a lesser extent shoot growth compared with control plants (Table 3).

TABLE 3. Effect of decaying straw on the development of barley seedlings. Mean results for 10 plants (Data from Ellis, Barber and Graham, 1975)

	Control	Straw residue present
Number of seminal roots per plant	5.8	6.0
Total length of seminal roots (mm per plant)	76.9	11.6
Total dry weight, excluding seed coat (g per plant)	0.115	0.062
Ratio: $\frac{\text{root dry weight}}{\text{shoot dry weight}}$	1.16	0.72

Subsequent laboratory work has been carried out to identify the toxins responsible. There is a vast range of products which could arise from the microbial decomposition of plant residues. However, in order for them to be of practical significance, they must be produced and maintained in concentrations which are biologically active under normal field conditions. They must also be active in the form in which they naturally occur and this usually means that they should be water soluble.

In reviewing the extensive literature on phytotoxicity, Lynch (1976) concluded that aliphatic acids which are volatile in steam (acetic, propionic and butyric) appeared to be the most likely substances responsible. Work in both defined microbial culture media (Lynch, 1977) and in soil (Lynch, 1978) supported this. Whereas straw degraded more rapidly in the presence of oxygen there was less accumulation of soluble carbon products. In anaerobic fermentation 69% of the soluble carbon was accounted for as organic acids, the major component of which was acetic acid. The concentration of acetic acid (15 mM) in this experiment reduced the root extension of barley seedlings to 75% of that of untreated plants. This concentration was shown to have inhibiting effects upon root growth of a wide range of species, including clover, wheat and seed rape. The decomposition of different plant residues produced similar concentrations of acetic acid when decomposing under anaerobic conditions.

Lynch (1979) found that the concentration of acetic acid 1.5 cm away from a continuous layer of straw is only about half that immediately adjacent to it. These findings would explain why the effects are greatest when straw and seed are placed in close contact in an anaerobic environment, and that they are observed mainly in the early stages of straw decomposition. With direct drilling this would mean, therefore, that decomposition became active 2-3 weeks after sowing and incorporation of the straw into the soil. This time interval coincides with that at which toxicity symptoms usually become evident. During that period cellulosic components, which are the principal substrates for the formation of aliphatic acids are being decomposed.

In aerobic conditions acetic acid is used in microbial respiration whereas when the oxygen supply is diminished the acid serves as a substrate for the formation of methane. Thus the extent to which it accumulates in the soil is a function of the soil redox potential. The formation of acetic acid is also associated with a lower pH and the solubilization of iron and manganese.

Fungal colonisation

A common characteristic of many observations of poor crop establishment after direct-drilled in the presence of straw was that death of seedlings occurred at about the time they became photosynthetically independant or sometimes earlier. In some instances, however, death of seed before germination was a contributory factor. An explanation of this could be the increased fungal colonization on the seed with the consequent lowering of oxygen availability to the germinating seed (Lynch & Pryn, 1977).

Possible methods of overcoming the harmful effects of straw on direct-drilled crops.

The highly variable effects of straw residues on direct-drilled crops make it most unlikely that any simple method of alleviation will be appropriate, except perhaps the complete removal by burning. Besides being the most economic method of removing the straw and eliminating any mechanical and toxin problems there are other advantages to burning. These include:-

a) Soil structure is not damaged after harvest by machinery which is necessary to collect and remove straw from the field.
b) Volunteer cereal and weed seeds, especially black grass (*Alopecurus myosuroides*) and wild oats (*Avena spp*) may be destroyed or encouraged to germinate.
c) Slugs can be less numerous.
d) The incidence of diseases can be reduced.

Despite these considerable advantages it may not be possible or desirable to burn because of weather conditions or the need to conserve straw. Furthermore, in some areas a low organic matter content of soil may make it undesirable to burn the straw but direct drilling on such soils is less likely to be as satisfactory as more traditional forms of cultivation (Cannell *et al*, 1978). There is, therefore, considerable incentive to investigating possible methods of successfully establishing crops with minimum or no cultivation before drilling either in the presence of the total straw residues from the previous crop, or when the stubble is left after the cut straw has been removed. Possible methods include:-

1) Improvements in drill design which cause greater soil disturbance and which prevent seed and straw being placed in close contact. In this connection it is important to note that when crops were direct-drilled into soil overlain with straw, plant establishment was poorer than when the straw was removed before drilling but replaced immediately afterwards.
2) Chemical methods, such as the dusting or pelleting of seed with lime to increase the pH in the immediate environment of the seed. (Lynch, 1978).
3) Use of chemicals to change the rate of decomposition of straw so that toxins are not produced at the time when seedlings are most vulnerable.
4) Application of fungicides to seed to reduce fungal damage.

A scientific understanding of the causes of the adverse effects is only recently becoming available. Consequently, many of the potential methods of mitigation are the subject of current experiments both in the laboratory and the field. The results of these experiments should enable practical recommendations on methods of overcoming the problem, or at least minimise the risks, to be made in the future.

REFERENCES

Cannell, R.Q., Davies, D.B., Mackney, D. and Pidgeon, J.D., 1978. The suitability of soils for sequential direct drilling of combine-harvested crops in Britain: a provisional classification. *Outlook on Agriculture*, 9, 306-316.

Cochran, V.L., Elliott, L.F. and Papendick, R.I., 1977. The production of phytotoxins from surface crop residues. *Soil Science Society America Journal*, 41, 903-908.

Davidson, J.M. and Santlemann, P.W., 1973. An evaluation of various tillage systems for wheat. *Agricultural Experimental Station Oklahoma State University, Bulletin*, B 711.

Douglas, J.T., 1977. The effect of cultivation on the stability of aggregates from the soil surface. Agricultural Research Council Letcombe Laboratory Annual Report 1976, 46-48.

Elliott, L.F., McCalla, T.M. and Waiss, A., 1978. Phytotoxicity associated with residue management, in Crop Residue Management Systems, American Society Agronomy Special Publ., 31, 131-146.

Ellis, F.B., 1979. Agronomic problems from straw residues with particular reference to reduced cultivation and direct drilling in Britain. In Grossbard, E (ed) 'Straw decay and its effect on utilization and disposal', in press. Wiley, Chichester.

Ellis, F.B., Barber, D.A. and Graham, J.P., 1975. Seedling development in the presence of decaying straw residues; Agricultural Research Council, Letcombe Laboratory Annual Report 1974, 39-40.

Ellis, F.B., Douglas, J.T. and Christian, D.G., 1977. A preliminary study of the effect of straw-burning on soil physical conditions Agricultural Research Council Letcombe Laboratory Annual Report 1976, 49.

Hughes, R.G., 1979. Arable farmer's problems with straw. In Grossbard, E (ed) 'Straw decay and its effect on utilization and disposal', in press. Wiley, Chichester.

Johnston, A.E., 1979. Some beneficial effects on crop yield from incorporating straw into the plough layer. MAFF, Agricultural Development and Advisory Service Report of 4th Straw Utilization Conference, Oxford, in press.

Kimber, R.W.L., 1973 . Phytotoxicity from plant residues. III. The relative effect of toxins and nitrogen immobilization on the germination and growth of wheat. Plant and Soil, 38, 543-555.

Lynch, J.M., 1976. Products of soil micro-organisms in relation to plant growth. C.R.C. Critical Reviews in Microbiology, 5, 67-107.

Lynch, J.M., 1977. Phytotoxicity of acetic acid produced in anaerobic decomposition of wheat straw. Journal of Applied Bacteriology, 42, 81-87.

Lynch, J.M., 1978. Production of acetic acid in anaerobic soils containing plant residues. Soil Biology and Biochemistry, 10, 131-135.

Lynch, J.M., 1979. Some factors which influence the accumulation and action of microbial metabolites around seeds and roots, in The Root-Soil Interface (Eds. Harley and Russell) p 427. Academic Press, London.

Lynch, J.M. and Pryn, I.S.J., 1977. Interaction between a soil fungus and barley seed. Journal of General Microbiology, 103, 193-196.

McCalla, T.M. and Army, T.J., 1961. Stubble Mulch Farming. Advances in Agronomy, 13, 125-196.

Oliphant, J.M., 1978. Straw and stubble - the burning answer. Big Farm Management, 49-54.

Short, J.L., 1973. Straw disposal trials at the Experimental Husbandry Farms. Experimental Husbandry, 25, 103-136.