PROCEEDINGS

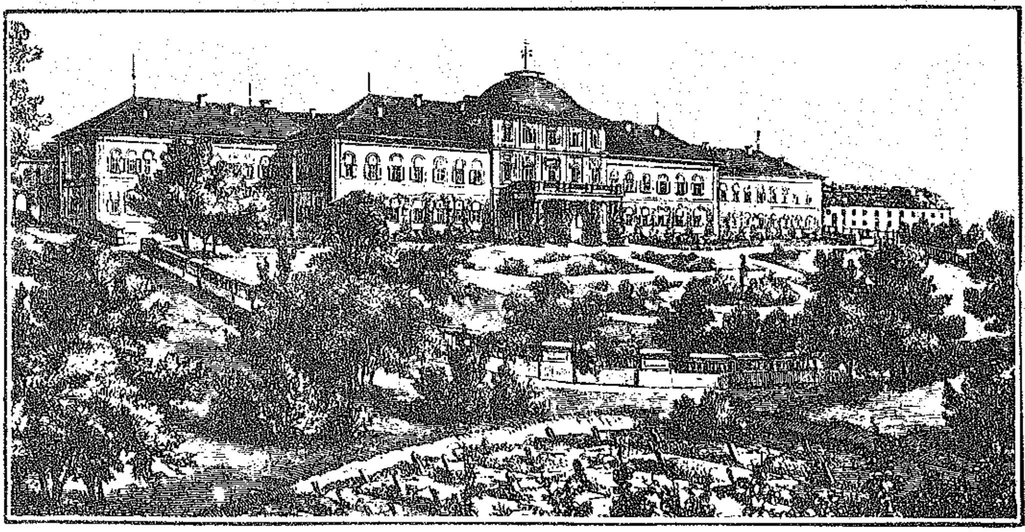
Volume 2

of the International Soil Tillage Research Organization, ISTRO

(8th Conference)

1979

UNIVERSITY OF HOHENHEIM



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CONTENTS

Session 14: Engineering aspects of soil tillage

Addenda:

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

REDUCED CULTIVATION FOR SPRING BARLEY IN DENMARK

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ABSTRACT

Field experiments with spring sown barley have shown that the depth of cultivation can be reduced on most of the Danish soil types. On sandy soils the ploughing to 2o-25 cm depth can be replaced by shallow treatments to 8-12 cm depth. Green manure is usually favourable on sandy soils. On sandy loam ploughing to 2o-25 cm depth gives the highest significance, and rotavating or harrowing to 1o cm depth gives a decrease in yield of 2.1-3.o hkg barley per hectare. On silty loam shallow treatment and green manure usually are favourable. Reduced cultivation and green manure grown as a second crop in the autumn decrease the leaching of nitrogen.

INTRODUCTION

In Denmark spring sown barley was grown on 1.6 mio. hectare in 1978 or 54 per cent of the total farmland. Barley is frequently grown as monoculture. Barley is sown in April and harvested in August. With traditionel cultivation systems stubble treatment and weed control are carried out in the autumn, and in November the soil is ploughed to 2o-25 cm depth. The soil surface is uncroped for 8 months of the year.

Farmers are interested in reduced or ploughless cultivation, though very few farmers practise it. Many field experiments with spring barley are established during the last 4-6 years. Direct drilling for spring barley is of very little interest.

PLOUGHLESS GROWING OF BARLEY

Reduced depth of cultivation is not possible by use of the mouldbord plough. It requires new types of implements and new experiences how to use them. In Danish experiments the rotavator is often used.

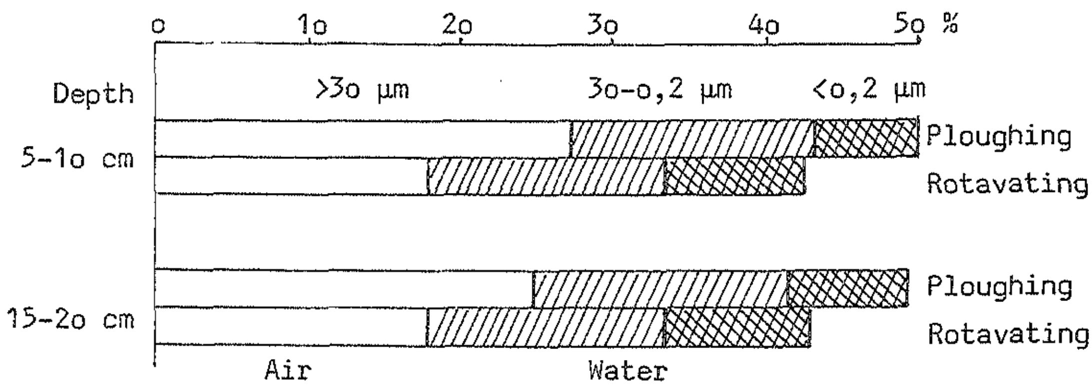
In table 1 the traditionel tillage with ploughing to 2o cm depth is compared with shallow ploughing to 12 cm and rotavating to 6-8 cm. The treatment has been the same during 5 years.

Table 1 — Depth of ploughing and rotavating. Yield of barley in hkg per hectare.

	Sand 1o ex.	Sandy loam 1o ex.	Silty loam 5 ex.	Average 1974-78 25 ex.
Ploughing 2o cm	31.o	42.8	49.8	39.3
Ploughing 12 cm	3o.2	41.6	5o.7	38.8
Rotavating 6-8 cm	3o.3	39.8	5o.6	38.2

Shallow ploughing and rotavating have given a non significant decrease in the yield on sandy soil and an increase on silty loam. Rotavating on sandy loam has given a decrease in yield of 3oo kg barley per hectare. As an average of 5 field trials in 5 years the rotavating to 6-8 cm gives a yield decrease of 11o kg per hectare.

Poredistribution after four years ploughing and rotavating



Rotavating to 6-8 cm depth has reduced the porosity and the air content, but the water content is nearly the same.

In 1968 experiments with reduced cultivation including direct drilling were started on 3 soil types with spring sown barley as monoculture. For direct drilling the right implements were not available. So minimum tillage since 1972 has been one passage with rotavator to max. 5 cm depth just before sowing in spring. Table 2 demonstrates the yield results from the last 6 years.

Table 2 — Different cultivation systems since 1968. Yield in hkg barley 1973-78

	Yield in hkg			Relative		
	sand	sandy loam	silty loam	sand	sandy loam	silty loam
Pl. Ploughing 2o cm	39.5	42.7	44.7	1oo	1oo	1oo
Ha. Harrowing 1o cm	38.8	38.o	43.5	98	89	98
Ro. Rotavating 5 cm	38.1	36.1	43.3	96	85	98

The shallow treatment by harrowing to 1o cm depth and rotavating to 5 cm depth just before sowing gave a yield decrease of 11 and 15 per cent respectively on the sandy loam soil. On silty loam and sandy soil the reduced cultivation gives a non-significant yield decrease of 2-4 per cent.

Table 3 Different cultivation systems since 1968.
Porosity, org. Matter, Potassium Value. Rønhave 1978

	Porosity per cent		Humus per cent		Potassium value mg K/1oo gr. soil	
	o-1o cm	1o-2o cm	o-1o cm	1o-2o cm	o-1o cm	1o-2o cm
Pl. 2o cm	46	4o	2.2o	2.2o	16	17
Ha. 1o cm	45	39	2.36	2.15	21	12
Ro. 5 cm	49	38	2.63	2.24	21	15

Reduced cultivation gives a reduction in the porosity and an increase in organic matter and potassium value.

Root measurement from the same experiments is shown in table 4.

Table 4 Different cultivation systems since 1968.
Root length in barley 1978 cm/cm³

Depth	Sand			Sandy loam			Silty loam		
cm	Pl.	Ha.	Ro.	Pl.	Ha.	Ro.	Pl.	Ha.	Ro.
o- 5	19.8	22.8	21.2	12.7	13.8	22.1	8.8	1o.7	6.6
5-15	12.2	12.7	12.8	5.4	6.7	8.5	6.1	4.9	4.8
15-25	7.6	6.9	7.3	3.6	3.2	3.1	3.9	3.3	3.5
25-35	2.o	4.o	3.5	2.1	2.4	2.o	3.6	2.8	3.3
35-45	o.8	1.1	1.6	1.8	1.8	1.8	3.8	3.4	3.5
45-55	o.4	o.6	1.4	2.o	1.8	1.7	2.5	2.8	4.2
55-65	o.2	o.1	o.4	1.4	1.5	1.6	1.9	1.9	2.7
65-75	o.1	o.1	o.4	1.5	1.4	1.3	o.7	1.1	1.2
75-85		o.1	o.1	1.1	1.3	1.1	o.4	o.5	o.5
85-95				o.9	o.7	o.7	o.2	o.2	o.2

Soil samples for root measurements were taken at the earing in June 1978. Reduced cultivation gives a tendency to more dense and deeper rooting.

STRAW AND GREEN MANURE AS A SECOND CROP

In barley growing the soil is uncropped for 8 months of the year, and in that period the excess of precipitation is 2oo-4oo mm. This gives risk of leaching of plant nutrient and degradation of soil structure. In the experiments we try to protect the soil against degradation by means of straw mulching or by sowing White Mustard as a second crop in combination with reduced cultivation.

The effect of green manuring with White Mustard and cultivation over 5 years are shown in table 5.

Table 5 — Effect of green manuring and cultivation. Yield in hkg barley per hectare 1974-78

	Sand Pl.	Sand Ro.	Sand irr. Pl.	Sand irr. Ro.	Sandy loam Pl.	Sandy loam Ro.	Silty loam Pl.	Silty loam Ro.
Stubble treatment	23.1	23.2	41.4	42.6	48.1	45.3	51.3	51.6
Green manuring (White Mustard)	24.1	24.2	44.2	42.8	47.5	45.4	52.8	53.1
Relative								
Stubble treatment	1oo	1oo	1oo	1o3	1oo	94	1oo	1o1
Green manuring	1o4	1o5	1o7	1o3	99	94	1o3	1o4

On sandy soil and on silty loam soil the White Mustard gives a yield increase, but a decrease on the sandy loam soil. Rotavating to 5 cm depth on sandy loam shows a significant yield decrease. Up to now no difference in soil structure has been demonstrated.

Table 6 shows the results of 4 years experiments with straw mulching and green manure of White Mustard on silty loam soil.

Table 6 — Straw, White Mustard and cultivation depth. Yield in hkg barley per hectare. Højer 1975-78

	Ploughing 2o cm	Shallow treatment 8-1o cm	Relative Ploughing	Relative Shallow treatment
Stubble treatment	49.6	49.o	1oo	99
Straw	48.3	45.7	97	92
Green manure	51.5	45.4	1o4	92
Straw + green manure	48.5	43.8	98	88

Straw mulching on this soil type gives a yield decrease, and the green manure as a second crop gives a yield increase after ploughing, and a yield decrease after shallow treatment.

REDUCED CULTIVATION AND NITROGEN LEACHING

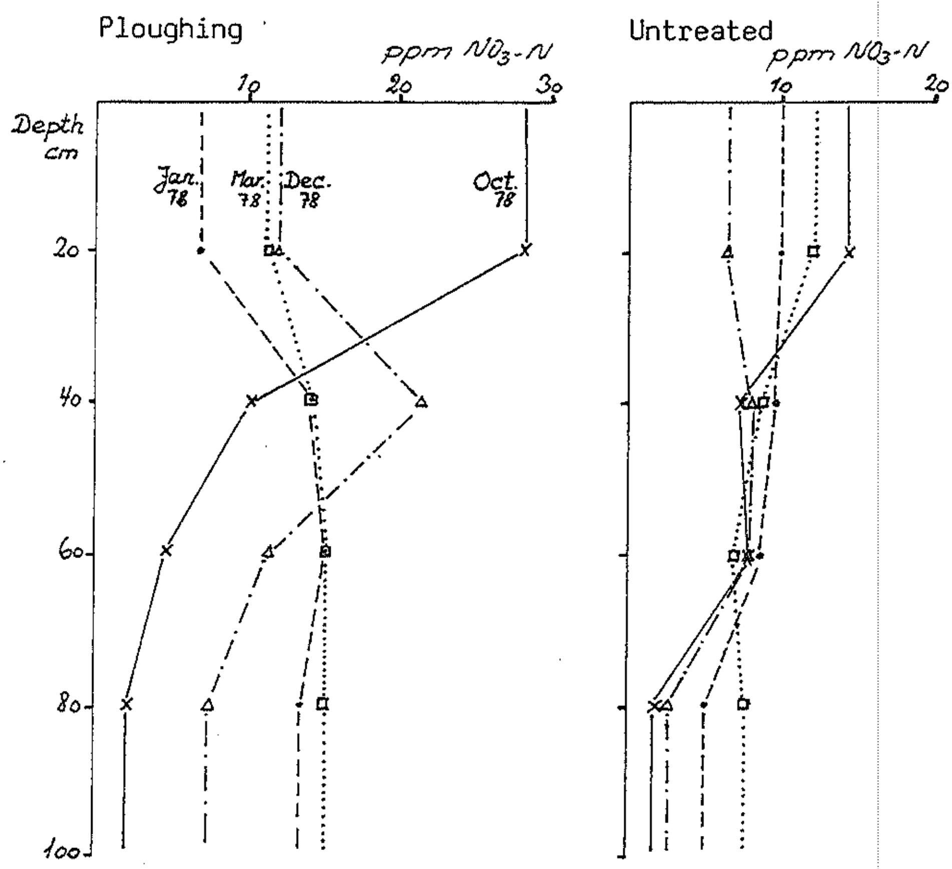
Soil cultivation has great influence on the nitrogen-balance in the soil and the risk of nitrogen leaching below root depth. Leaching of nitrogen is a loss in the farming system and increase the risk of pollution of drainwater and groundwater.

By means of a suction technique soil water is extracted from 2o cm, 4o cm, 6o cm and 8o cm depth. Nitrogen content is measured ones a week in the period October-April. The content of nitrogen in the soil water after different soil treatments is demonstrated in the figures on the following pages.

By estimating the water balance it is possible to calculate the nitrogen content and nitrogen leaching in kg per hectare.

Table 7 shows the leaching of nitrogen below 8o cm depth on silty loam soil for the winterperiods 1977-78 and 1978-79. Discharge the first year was 4oo mm and the second year 2oo mm. By stubble treatment followed by ploughing the loss of nitrogen was 39 kg per hectare and from untreated plots the leaching was 17 kg N per hectare. Strawmulching plus green manure protect nitrogen against leaching, and the loss of nitrogen was only 8 kg and 3 kg respectively the two years.

Content of Nitrogen in Soil Water, Højer 1977-78



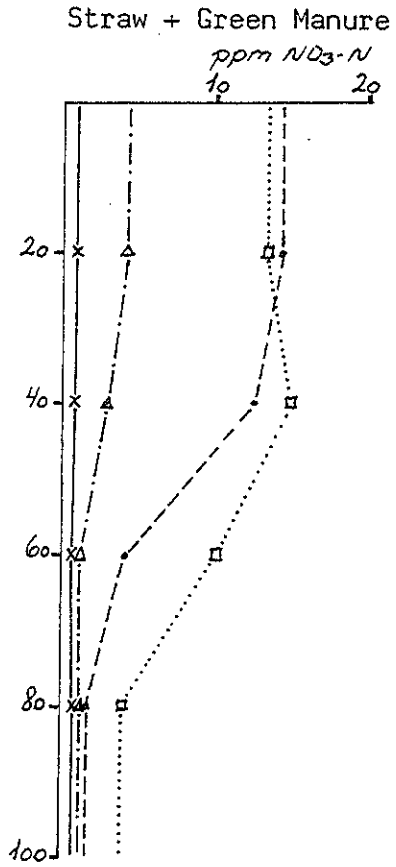
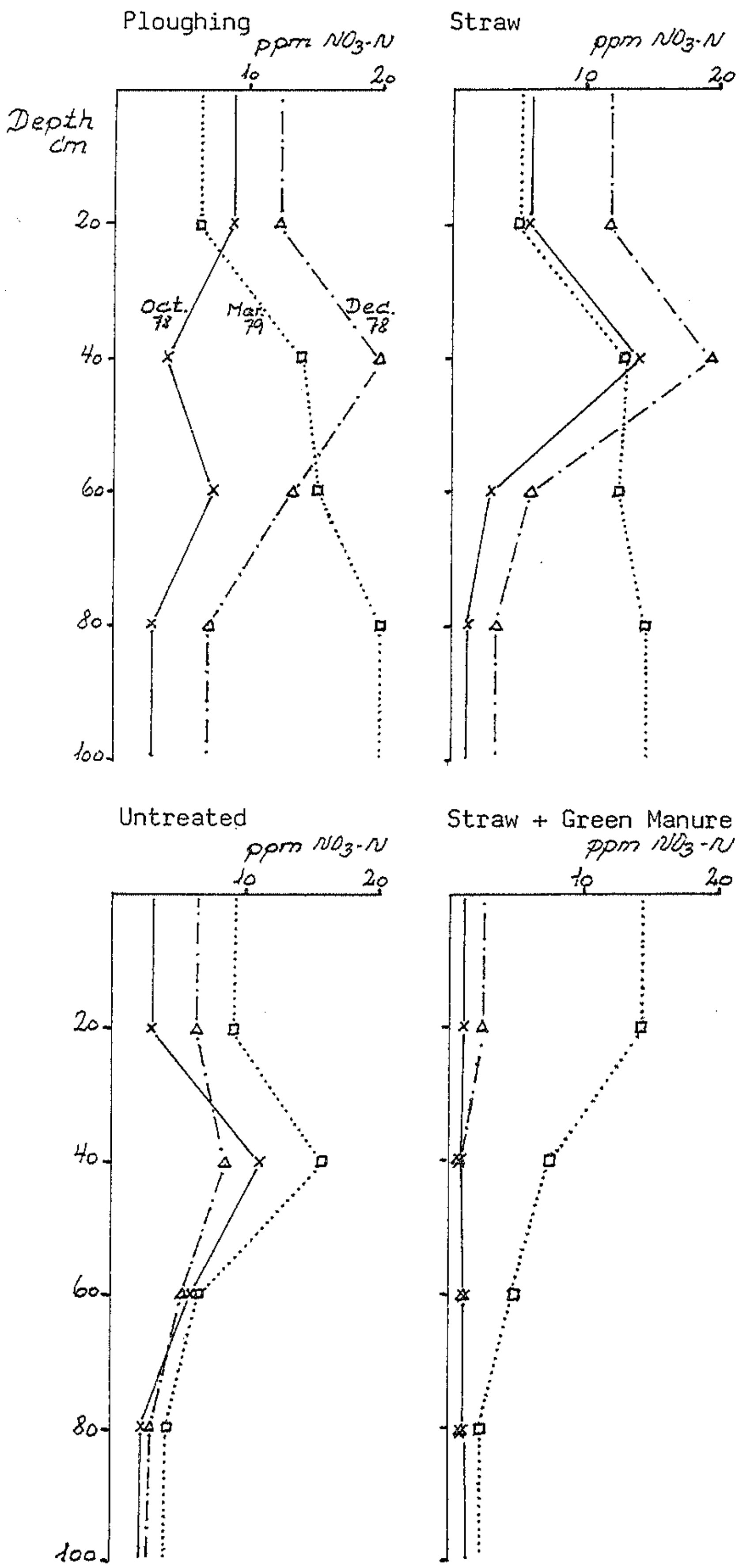


Table 7

Leaching of Nitrogen below 8o cm depth in the period October-April. Kg per ha
Silty soil, Højer

	1977-78	1978-79
Discharge	4oo mm	2oo mm
Ploughing	39	19
Straw	-	11
Untreated	17	6
Straw + Green Manure	8	3

Content of Nitrogen in Soil Water, Højer 1978-79



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

NO TILLAGE SYSTEM IN CROP ROTATION SUGAR BEET - WINTER WHEAT - SPRING BARLEY

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ABSTRACT

Experiments with cultivation of cereals under zero-tillage in the Czechoslovakia proved that the new technology was suitable for winter wheat grown after a good for-crop, on fertile soils of all types except of wet regions. Without undergoing the risk of yield decrease, spring barley may be cultivated under zero-tillage conditions mostly in relatively dry regions of this country on well structured soils, its sufficient yields being compensated by lower yields of the for-crop and higher N-rates. Growing cereals sequentially in zero-tillage system has not provided equivalent results as conventional cultivation did. This has been connected with weed infestation, root and foot rot incidence, structural as well as physical properties of the arable layer etc. Owing to diverse soil climate and weather conditions oft this country fluctuating results are being achieved and yield stability in cereals cannot be ensured.

INTRODUCTION

Intensive technical development and chemization in agriculture produced considerable influence also on methods of soil cultivation. Therefore, in Czechoslovakia a series of field experiments was established for to examine minimum tillage as well as zero-tillage system in various field crops (4,8,14,15). This paper gives information on some results obtained from mentioned experiments.

MATERIAL AND METHODS

Experimental fields were situated on grey brown podzolic soil, the arable layer well supplied by nutrients, humus content 2,3%, pH (KCl) = 6,1. Situation of the locality: latitude 50°04', longitude 14°26', 350m above sea level Long-term average air temperature 7,9 °C, during the vegetation period 14,3 °C. Long-term average of yearly rainfall 517mm, during the vegetation period 348 mm, average duration of sunshine 1750 hrs per year.

Experimental plots were ranged into following crop rotations : sugar beet - winter wheat - spring barley. Soil cultivation in individual crops was as follows: Sugar beet - stubble ploughing, underploughing the manure ($30 t.ha^{-1}$) +PK fertilizers (P 95 kg, K 249 kg per crop rotation), ploughing up to 18 cm. Winter wheat and spring barley were direct-drilled by means of Czechoslovak drilling machine 20-SeXBJ-150. Soil cultivation in this crop rotation is being indicated ZT (zero-tillage).

Experimental variants:

Crop	Cultivar		Fertilizing N (kg.ha^{-1}) F_1	F_2	F_3	F_4
Sugar beet	Dobrovická A	(V_1)	0	100	150	200
	Dobrovická C	(V_2)	0	100	150	200
Winter wheat	Bljičovka	(V_1)	0	40	80	120
	Jubilar	(V_2)	0	40	80	120
Spring barley	Favorit	(V_1)	0	40	80	120
	Rapid	(V_2)	0	40	80	120

In parallel with the described experiment a similar experiment took place with yearly soil cultivation (indicated as ploughing system - PS: stubble ploughing + ploughing for cereals up to 22 cm, for sugar beet up to 28 cm) with following crop rotation: horse bean, winter wheat, sugar beet, spring wheat, spring barley. Experimental variants, inclusive of manure and PK supply as well as cultivation measures, were equal in both experiments. Weather conditions in experimental years within the period April - July were as follows:
Rainfall: 1976 - 154,9 mm; 1977 - 244,5 mm; 1978 - 206,0 mm.
Average air temperature : 1976 - 14,7°C; 1977 - 12,1°C; 1978 - 11,8°C.

RESULTS

Some results of experiments are summarized in Tables 1 - 5. It has to be noted, that results of observations, especially crop yields of 1976 differed considerably from those of other years due to relatively dry weather of 1976, namely in its summer months.

Data on growth and biomass production in winter wheat showed that greater differences in plant height (as much as 20 cm) existed between individual ways of soil cultivation at the beginning of the vegetation period (the second half of May) than prior to the harvest. Before the harvest, the differences were diminished up to 3-5 cm and 10 cm in N non-fertilized and N-fertilized variansts, respectively. In the course of vegetation period also differences in leaf number were stated between variants with conventional cultivation and zero-tillage. Under zero-tillage plants of winter wheat and spring barley produced the maximum leaf number later than plants in convential cultivation. In variants with zero-tillage, however, grain yield of cereals was in no relation to the leaf number per plant.

From data on dry-matter production of overground biomass in winter wheat and spring barley during the vegetation period it may be deduced, that cereals are able to produce equivalent amounts of biomass under conditions of zero-tillage as in conventional cultivation. As compared with conventional method, N-fertilizing in zero-tillage system produced greater effect on biomass production of crops. The cereal stands in zero-tillage variants which produced smaller amounts of overground biomass in spring, were mostly not able to compensate the difference against conventional cultivation in the course of further vegetation.

Analyzing agronomic crop yields in the course of the experimental period demonstrated (Table 1) that, in comparison with ploughing up to 18 cm, deep soil cultivation (up to 28 cm) does not lead to highest root yields in sugar beet. It was proved, however, that timely deep autumn ploughing is able to ensure maximum yields rather in years with extreme weather conditons (1976 and 1977).

Table 3 giving gains in agronomic yields in the experimental period demonstrates that shallow soil cultivation resulted in yield depression of sugar beet by 0-25%. The influence of various N-rates on sugar beet yield was negligible, even in variants with limited ploughing depth.

The effect of soil cultivation on grain yield of winter wheat fluctuated in individual years. In average of two experimental years, however, a slight tendency was observed to higher grain yields under zero-tillage conditions, the difference against the variant with conventional cultivation and N-fertilizing amounting 0,35 $t.ha^{-1}$. As a result of N-fertilizing, grain yields in winter wheat increased by 10-40% and 24% in zero-tillage and conventional variants, respectively. In spring barley, the three years average showed that under zero-tillage grain yields in spring barley decreased by 1,08 $t.ha^{-1}$ and 0,57 $t.ha^{-1}$ in non-fertilized and in the average of N-fertilized variants, respectively. As a result of 120 kg $N.ha^{-1}$ supply under zero-tillage conditions grain yield with spring barley increased by 20-30% while after ploughing the increase due to fertilizing was about 10%.

Considering the effect of the cultivar on crop yields under different soil cultivation systems (Table 4) it was concluded that in sugar beet explicitly higher root yields were produced by Dobrovická A; irrespective of the way of soil cultivation the yields of Dobrovická C were lower by 15%. In winter wheat under zero-tillage, cv. Iljičovka proved slighly more yielding in both experimental years. In conventional cultivation the effect of cultivar on grain yield was fluctuable, though in average of all the experimental period the yield was higher in the cultivar Iljičovka. Under both variants of soil cultivation the spring varley cv. Favorit was in the average more productive than cv. Rapid the difference being more considerable in variants with conventional cultivation.

Analysis of yield structure in winter wheat showed that in 1977 the decrease in grain yield after conventional cultivation was caused mainly by a lower ear number per area unit. Increased grain yields in spring barley under zero-tillage in 1976 were achieved due to higher grain number per ear (the increase amounted 0,6 and 2,0 grains in cultivars V_1 and V_2, respectively). In subsequent experimental years increased grain yields in conventionally cultivated spring barley were caused not only by higher grain number per eat (1977) but also ear number (1978). Thousand kernel weight in cereals was not practically influenced by different soil cultivation (see Table 2).

The proportion of greater seeds (over 2,8 mm) in winter wheat under 120 kg $N.ha^{-1}$ rate droped in the cultivar V_1 and V_2 by 10 % and 5 %, respectively, irrespective of the way of soil cultivation. In spring barley, the 120 kg $N.ha^{-1}$ supply reduced considerably the proportion of seed-size over 2,8 mm, namely by 25 - 27 % and 47 - 53 % in the cultivars V_1 and V_2, respectively; slight tendency to further reduction by conventional cultivation was even observed (according to the cultivar by 2 -6 %).

From data on the harvest index (ratio of total grain to total dry matter at harvest - HI) it is apparent, that its values with sugar beet were not changed neither by different soil cultivation nor by N-fertilizing rates (0 and 200 kg $N.ha^{-1}$). The rate 200 kg $N.ha^{-1}$ having bean applied, a reduction of HI by 5 % was even stated. In winter wheat the highest HI values (0,48) were noted in variants with zero-tillage while in conventional cultivation the harvest index decreased by almost 10 %. The HI values of spring barley fluctuated in individual years.

Calculations concerning the crop rotation productivity based on biomass dry-matter production showed (Table 5) an apparent effect of N-fertilizing in the zero-tillage (ZT) system. In 1977 34,04 t of dry matter were produced by crop rotation under ZT the N-consumption being 440 $kg.ha^{-1}$. In conventional cultivation 37,03 t of dry matter were produced in the crop rotation and the N-consumption was 0 - 180 $kg.ha^{-1}$. In 1978 the biomass production under ZT was 34,11 t and in the ploughing system (PS) 34,18 t, the N-consumption amounting 310 $kg.ha^{-1}$ in both variants. From the calculation also the common effect of N on biomass production has been apparent; this may be illustrated by the yield difference of 6 - 27 % between the non-fertilized and fertilized with 440 kg N variants. In all the crop rotation the effect of soil cultivation shared on crop yield in 10 - 15 %. Experimental results proved the function of N under different soil cultivation and its interaction with the weather and locality conditions.

DISCUSSION

Confrontation of our experimental data concerning winter wheat under zero-tillage with experimental data of other localities (South Moravia, East Slovakia) proved coincidental results (5,6,11). From all observations it follows that winter wheat under zero-tillage system, being grown after suitable forcrop, produces equivalent or even higher grain yields than in conventional cultivation.

Experiments in South Moravia (12,13) documented that in average of 6 years, spring barley after sugar beet produced higher yields in zero-tillage system than in conventional cultivation. Zero-tillage was successful namely in years with unsuffecient rainfall. In spring barley under zero-tillage we have no achieved explicitly good experience. In similar experiments in maizegrowing area (7) the yields with spring barley grown in the second year of the crop rotation were lower under zero-tillage than in conventional cultivation, especially at lower N-rates. However, higher doses of N compensated the differences between directly and traditonally drilled barley.

Comparing the productivity of crop rotations under different soil cultivation system and N-fertilizing rates in our experiments did not lead to ixplicit conculsion. At conditions of sugar beet growing area on eolian soils of South Moravia (10) the crop rotation: sugar beet, spring barley, spring barley, alfalfa, alfalfa, winter wheat, proved practically equivalent productivity in zero-tillage system (except of ploughing up to 24 cm for sugar beet) and in traditional cultivation, when 360 kg $N.ha^{-1}$ per crop rotation were supplied. In the case of our experimental crop rotation we did not get equivalent results in examined ways of soil cultivation not even under increased N-rates.

For a more rational exploiling the land it will be necessary to elaborate a detailed soil classification with regard to possibilities of using zero-tillage system in farming cultivation of cereals (1,9). Extending the zero-tillage practice in the Czechoslovakia needs to elaborate some measures so as in the farming system of soil manging as in cultivation methods with cereals themselves (2,3,4), namely with regard to cultivars, stand density, optimum N-rates etc.

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Table 1 Crop yields ($t.ha^{-1}$)

Year	Cultivar	Zero-tillage F_1	Zero-tillage F_2	Zero-tillage F_3	Zero-tillage F_4	Ploughing F_1	Ploughing F_2	Ploughing F_3	Ploughing F_4
Sugar beet									
1976	V_1	35,52	35,60	36,85	36,00	44,44	44,32	43,90	40,96
	V_2	30,91	30,96	30,63	34,56	40,34	39,69	34,96	36,84
1977	V_1	73,35	72,52	72,15	72,14	81,71	82,25	79,45	82,40
	V_2	62,97	61,52	61,36	62,49	66,61	73,18	67,02	69,20
1978	V_1	61,45	64,44	62,28	63,04	59,57	61,38	61,69	60,89
	V_2	52,51	53,73	55,70	53,63	51,00	52,74	54,99	54,68
Winter wheat									
1977	V_1	4,46	4,83	4,60	4,67	3,57	3,19	3,62	3,32
	V_2	4,75	4,77	4,44	4,05	3,56	3,92	4,13	4,42
1978	V_1	4,39	5,28	5,99	6,18	5,44	6,26	6,57	6,37
	V_2	4,79	5,33	5,67	5,59	5,40	5,34	5,41	5,01
Spring barley									
1976	V_1	3,72	3,38	2,94	2,94	3,56	3,16	3,02	2,87
	V_2	3,42	2,93	2,39	2,41	3,03	2,64	2,25	2,16
1977	V_1	4,06	4,53	4,99	5,22	6,17	6,61	6,38	5,71
	V_2	3,74	4,53	4,91	4,89	6,00	6,70	6,33	6,00
1978	V_1	2,75	3,57	4,31	4,44	4,19	4,98	5,05	4,98
	V_2	3,16	4,07	4,75	4,71	4,38	4,78	4,36	4,34

Table 2 Yield structure in spring barley

Year	Cultivar	Tillage system	Fertile ears per m^2 F_1	F_2	F_3	F_4	Number of grains per ear F_1	F_2	F_3	F_4	1000 kernel weight F_1	F_2	F_3	F_4
1976	V_1	ZT	918	922	860	847	16,0	15,0	14,0	14,3	25,4	24,2	24,4	24,0
		PS	963	989	902	949	15,0	13,6	14,7	13,6	24,6	24,6	22,8	22,3
	V_2	ZT	807	887	807	798	17,3	13,7	12,3	12,7	25,6	24,0	24,2	24,0
		PS	898	907	812	967	14,0	12,3	11,8	9,7	24,1	23,7	23,4	23,1
1977	V_1	ZT	647	688	695	692	15,1	16,1	17,3	15,8	41,5	41,9	41,6	41,4
		PS	607	648	617	643	29,9	25,5	26,4	22,6	40,8	40,0	39,2	39,2
	V_2	ZT	604	681	675	691	13,9	14,8	16,3	16,2	44,6	44,8	44,6	43,8
		PS	532	624	617	590	26,3	25,7	34,6	25,0	42,7	41,8	41,6	40,6
1978	V_1	ZT	610	778	686	702	10,6	11,1	15,5	15,6	42,5	42,2	40,7	40,3
		PS	765	754	812	775	13,1	16,6	16,2	17,3	41,9	39,7	38,3	37,1
	V_2	ZT	614	684	720	684	11,3	13,1	14,8	16,0	45,4	45,6	44,5	43,0
		PS	734	718	768	762	13,4	15,7	14,2	14,6	44,5	42,3	39,9	39,0

Table 3 Yield increase of crops after different soil tillage and nitrogen fertilization

Crop Year	No N-fertilizing V_1	No N-fertilizing V_2	N-fertilizing V_1	N-fertilizing V_2	Zero-tillage V_1	Zero-tillage V_2	Ploughing V_1	Ploughing V_2
Sugar beet								
1976	82,1	76,6	83,9	86,2	100,9	100,2	0	0
1977	89,8	94,5	88,8	88,5	0	0	100,8	109,9
1978	103,1	103,0	103,1	100,4	104,9	106,1	103,6	107,8
Winter wheat								
1977	124,9	133,4	139,0	106,0	108,3	0	101,4	124,1
1978	80,7	88,7	90,9	105,3	140,8	118,4	120,8	0
Spring barley								
1976	104,5	112,9	102,3	109,8	0	0	0	0
1977	65,8	62,3	78,8	75,4	128,6	131,3	107,1	111,7
1978	65,6	72,1	82,2	100,5	161,4	150,3	120,5	109,1

Table 4 The influence ot the cultivar on crop yields after different soil tillage

Crop	Cultivar	Year 1976 ZT	1976 PS	1977 ZT	1977 PS	1978 ZT	1978 PS
Sugar beet	V_1	36,62	43,41	72,54	81,45	62,80	60,88
	V_2	31,77	37,96	62,09	69,01	53,89	53,35
Winter wheat	V_1	-	-	4,63	3,42	5,46	6,16
	V_2	-	-	4,50	4,00	5,35	5,29
Spring barley	V_1	3,25	3,15	4,70	6,22	3,77	4,80
	V_2	2,79	2,52	4,51	6,26	4,17	4,46

Table 5 Dry matter yield (t) in crop rotation after different soil tillage and N - fertilization

Year	Crop	F_1 ZT	F_1 PS	F_2 ZT	F_2 PS	F_3 ZT	F_3 PS	F_4 ZT	F_4 PS
1977	Sugar beet	18,31	20,02	18,19	20,80	18,61	20,42	18,95	20,83
	Winter wheat	8,16	8,86	8,51	7,06	8,24	6,96	7,92	6,74
	Spring barley	5,64	8,24	6,49	9,17	7,08	8,75	7,17	8,19
	Total	32,11	37,12	33,19	37,03	33,93	36,13	34,04	35,76
	%	86,5	100	89,6	100	93,9	100	95,2	100
1978	Sugar beet	13,77	13,22	14,93	14,16	15,47	14,96	15,32	15,09
	Winter wheat	8,14	9,98	9,42	10,92	10,63	11,28	10,75	10,77
	Spring barley	4,85	6,82	6,42	7,60	7,66	7,94	7,84	7,63
	Total	26,76	30,02	30,77	32,68	33,76	34,18	34,11	33,49
	%	89,1	100	94,1	100	98,8	100	101,8	100

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REDUCED TILLAGE IN COMBINATION WITH HERBICIDE TREATMENTS IN CONDITIONS OF APPLICATION OF DIFFERENT IRRIGATION METHODS

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ABSTRACT

It may be concluded on the basis of our three-year results that the tested tillage systems affected neither positively nor negatively the hop quality, yield, and phenophases of development. It should be pointed out that the reduced tillage positively affected the yield because of reduced costs of production. The irrigation brought positive effects. The best results were obtained with the furrow irrigation. The irrigation did not affect the phenophases of hop development. Simazine and atrazine, applied in prescribed dosages, did not bring negative effects in either of the tested methods of irrigation.

INTRODUCTION

Scientific work in the field of hop growing is aimed at the simplification of production technology in order to reduce costs of production and high requirements for human labor. Reduced tillage, according to its basic concepts, implies the omission of certain operation, as the spring throwing-out and the closing of furrows. The most important components in the simplification of hop growing are the surface cutting and the herbicide application to control weeds and defoliate the bottom parts of hop plants.

The introduction of reduced tillage in combination with herbicide treatments into the hop production imposed the problem of finding a suitable irrigation system; the applied herbicides, based on triazine, may affect depressively the irrigated hop, particularly the hop irrigated by furrows, because the hop is not selective, i.e., biologically resistant, towards these herbicides.

Numerous authors worked on the problem of finding the most suitable irrigation schedule for the hop (Middleton, 1963; Nelson et al., 1966; Sachl, 1964; Zattler, 1967; Slanský et al., 1971; Kišgeci, 1974; etc.). However, these papers discussed the factor of irrigation neither as an integral part of contemporary cultural practices nor its relationship with the application of herbicides.

The objective of our work was to determine the most suitable irrigation method for reduced tillage in combination with herbicide treatments which would be harmonious with the contemporary organization of work and would not emphasize the depressive action of herbicides on hop plants.

MATERIAL AND METHOD

The experiment was conducted in a hop garden of the Department of Hop and Broomcorn at Bački Petrovac, on black meadow soil of favorable physical and chemical properties and deep ground water.

The experiment included two factors - the system of tillage and the method of irrigation - in the following variants:

1. Hop growing in the system of deep cutting without herbicide treatments:
   a) non-irrigated
   b) furrow irrigation
   c) sprinkling irrigation
   d) drip irrigation
2. Hop growing in the system of reduced tillage in combination with herbicide application (simazine and atrazine, 0.75 kg/ha each):
   a) non-irrigated
   b) furrow irrigation

c) sprinkling irrigation

d) drip irrigation

During the experiment, the following elements were observed: dynamics of soil moisture, hop yield, quality, and phenophases of development. The hop was also observed for eventual depressive action of herbicides.

RESEARCH RESULTS

Tab. 1 shows the effect of reduced tillage in combination with herbicide treatments on the yield of hop grown in different variants of irrigation.

Tab. 1 - Effect of tillage system and irrigation method on hop yield

Year	Till. system / Irr. method	Deep till.	Reduced till.	Average of irr. variants	Average of irr. factors
1976	Non-irr.	18.00	18.26	18.13	18.13
	Furrow	21.10	20.87	20.98	
	Sprinkling	19.83	19.60	19.71	19.78
	Drip	19.08	18.26	18.67	
	Average	19.50	19.24		
1977	Non-irr.	18.18	17.06	17.62	17.67
	Furrow	22.00	21.50	21.75	
	Sprinkling	20.66	20.43	20.54	20.80
	Drip	20.27	19.74	20.64	
	Average	20.27	19.74		
1978	Non-irr.	17.68	18.10	17.89	17.89
	Furrow	19.75	19.80	19.77	
	Sprinkling	19.06	18.86	18.96	19.24
	Drip	18.98	19.00	18.99	
	Average	18.86	18.94		

	1976		1977		1978	
LSD	5%	1%	5%	1%	5%	1%
Till. system	1.75	2.36	1.14	1.54	1.36	2.42
Irr.	2.53	3.41	1.68	2.26	2.05	3.13
Interaction	4.24	5.69	2.38	3.22	3.82	4.15

It may be concluded on the basis of the above results that in 1976 the applied tillage systems did not affect the yield of hop. The reduced tillage did not affect negatively this important parameter. Only the furrow irrigation positively affected the yield.

In his earlier studies on water requirements of the hop, Kišgeci (1974) found that the hop seldom suffers from water shortage on account of its deep rooting habit which allows the hop plants to take water from deep soil layers. However, it is necessary that the active rhizosphere is provided with easily available water in order to secure the provision of plants by nutrients.

In 1977, the tendency of yield increases in relation to the check persisted with all irrigation variants. The furrow irrigation brought the highest increase. Differences could not be observed between the systems of tillage which is in fact positive because the reduced tillage decreases the production costs.

In 1978, all three irrigation methods affected the yields of hop. There were no significant differences among them; still, the furrow irrigation brought the highest increases. The drip irrigation had a somewhat lower effect, probably because of a strictly limited wetting of the soil around the crown which leaves the zone of the most active part of the root system, 60 - 140 cm from the crown, insufficiently wetted. The sprinkling irrigation was conducted at the stage of cone growth, when the plants were fully developed. As the method of overhead sprinkling was used, the distribution of water was sporadic because the water flowed down the foliage. There were no differences between the deep and reduced tillage which favors the latter one because of its economy.

The irrigation and reduced tillage did not have negative effects on the technological quality of hop.

Different tillage systems and irrigation did not affect the phenophases of development of hop plants. The beginning and duration of all phases were similar in all test variants.

CONCLUSION

It may be concluded on the basis of our three-year results that the tested tillage systems affected neither positively nor negatively the hop quality, yield, and phenophases of development. It should be pointed out that the reduced tillage positively affected the yield because of reduced costs ofproduction. The irrigation brought positive effects. The best results were obtained with the furrow irrigation. The irrigation did not affect the phenophases of hop development. Simazine and atrazine, applied in prescribed dosages, did not bring negative effects in either of the tested methods of irrigation.

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INFLUENCE OF SOIL STRUCTURE AND STRENGTH, FERTILIZATION LEVEL, AND SOIL WATER CONTENT ON THE GROWTH OF ROOTS.

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ABSTRACT

A statistical description of the structure of tilled soil is combined with measurements of root mechanical properties to produce a model for the behaviour of roots in tilled soils of different structure and strength.

The indirect effect of soil structure on soil strength (through its effect on soil water content) is found to have the greatest influence on root behaviour.

Just as the soil structure is found to influence the ability of roots to absorb nutrients, it is also found that the nutrition of the roots influences their behaviour in structured soil.

INTRODUCTION

In many areas, suitable soil structure for plant root growth develops naturally. In the heavy montmorillonitic black earths of Eastern Australia, for example, the "self mulching" behaviour on wetting and drying produces an ideal structure for root growth. In other areas, other processes can produce adequate soil structures. These include the actions of soil fauna (especially earthworms), previous root growth (especially of grasses), and freezing and thawing cycles. In such areas, weed control is probably the only benefit from tillage.

However, tillage will remain a necessary process in many parts of the World both where these natural structure-forming processes are absent or inadequate and where herbicides are not available at low enough cost for weed control.

This paper now considers the behaviour of roots in structured soil and the way in which the behaviour is modified by other soil and environmental factors.

SOIL STRUCTURE MODEL

The structures of tilled soils can be compared by sieving to give the aggregate size distributions. However, this gives no information about inter-aggregate pore sizes or about the relative positions of aggregates and pores.

These deficiencies have been overcome, to some extent, by the method of Dexter (1976). In this, blocks of tilled soil are impregnated and are then sectioned for analysis. Lines, horizontal in the original soil, are drawn on the sections at the required depths. These lines are then analysed at equally-spaced intervals which is usually 1 mm in coarse tilled soil and 0.5 mm in a seed bed. A 1 is written if there is an aggregate at a point and a 0 is written if there is a void. Thus a string of 1's and 0's is written which represents the distribution of aggregates and voids at that depth. Sufficient sections must be measured to give a total effective string length of at least 2000 digits if the results are to be reasonably accurate. The proportion of 0's in the string is called the linear porosity, η_L.

From this raw data, sets of 16 transition probabilities are calculated which give the probabilities of 0's following the previous four digits in the string. From these probabilities, strings of 1's and 0's can be simulated which have the same statistical distribution as the aggregates and voids in the original soil. Alternatively, aggregate and void size distributions can be calculated directly from the probabilities to give data such as the porosity, η_8, in pores larger than 8 mm intercepted length.

Thus the sets of transition probabilities contain information about the structure of the soil. This method has been used to quantify the structures produced at different depths by different implements making different numbers of passes in soil at different water contents (Dexter, 1979).

ROOT GROWTH MODEL

Consider a root growing in a tilled layer of soil. If the aggregates are of zero strength, then a root will not be impeded or deflected by them and it will grow in a straight line. The environment of such a root will be well-described by a distribution of 1's and 0's simulated from the appropriate set of transition probabilities. The proportion, P_p, of the root length in pores will be $P_p = \eta_L$, and the proportion, P_a, in aggregates will be $P_a = (1 - \eta_L)$.

If the aggregates are very strong, penetration never occurs and the roots will then be deflected along the surfaces of the aggregates until they can resume that original, geotropic, direction of growth.

If the aggregates are of intermediate strength, then root penetration of an aggregate may be limited either by the maximum stress, σ_r, which a root can exert, or by the buckling stress, σ_b, whichever is the smaller. It will be assumed here that

$$\sigma_r = 1.5\text{MPa, and} \qquad (1)$$

$$\sigma_b = 1.262E\ d^2/\ell^2, \qquad (2)$$

where E is the Young's modulus of the root, d is the root diameter and ℓ is the length of the pore across which the root has just grown.

For a given type of root, with known values of E and d, it is a simple matter to simulate its passage through a tilled soil whose structure is described by a set of transition probabilities. If a simulated soil structure is, for example,

......1111000011100....

then at every 0-1 transition, the previous void length, ℓ, is known (in this example, it equals 4 digits), and hence σ_b is known. If the root buckles at a stress smaller than that required for penetration of the next aggregate, then it is deflected along the surface of that aggregate.

In this way, the proportions of the length of a root which pass through aggregates, P_a, through pores, P_p, and along surfaces, P_s, can be calculated. This has been done for the roots of a number of different plant species in soils of different strength and structure (Dexter, 1978; Hewitt and Dexter, 1979).

If it is assumed that the roots can absorb nutrients out to some distance from their axes, then it is possible to estimate the effects of soil structure and strength on the relative nutrient availability, N_r, per root axis. For relatively non-mobile nutrients such as P and K, this absorption distance is found to correspond to the radius of extent of the root hairs (Lewis and Quirk, 1967).

For wheat seminal axes growing through beds of sieved soil aggregates of mean diameter, $\bar{D}$, the effects of soil strength on N_r is given approximately by

$$N_r = (1 - \eta_L) \exp\left[-0.025S\right], \qquad (3)$$

where S is the mean stress on a 1.25 mm diameter penetrometer with a 90^{o} enclosed angle. For these beds, $\eta_L = 0.265$. For intermediate aggregate strengths (1 < S < 3MPa), where the differences are greatest, N_r is only about 15% larger for $\bar{D} = 3.7$ mm than for $\bar{D} = 14.7$ mm. Thus, the effect of structure is much smaller than the effect of strength. However, strength and structure are not independent soil properties.

STRUCTURE, WATER CONTENT AND STRENGTH

Tilled soil has a different mean water content, $\bar{w}$, depending on its structure. In particular, $\bar{w}$ is strongly dependent on the porosity, η_8, in pores larger than 8 mm. It is through these larger pores that convective flow of atmosphere air can occur with the consequence of evaporative water loss. In the 1976 growing season (July-Oct.) in South Australia, Ojeniyi (1978) found that

$$\begin{array}{l} \bar{w} = 54.4 + \beta - 1.25\,T_a - 0.10\,u_2 - 0.25h, \%, \\ \quad (\pm 4.1) \qquad (\pm 0.12) \qquad (\pm 0.03) \qquad (\pm 0.04) \end{array} \qquad (4)$$

where the tillage treatment effect, β, took the values -4.01, -3.53, -2.75 and 0 for the disc plough, mouldboard plough, tine cultivator and rotary cultivator, respectively. Under average meteorological conditions (air temperature, $T_a = 12^{o}C$; wind speed, $u_2 = 5$ km hr^{-1}; relative humidity, h = 68%), this becomes

$$\bar{w} = \beta + 22, \%. \qquad (5)$$

The tillage treatment effect, β, is related to η_8 by

$$\beta = 1.7 - 98\,\eta_8. \qquad (6)$$

It has also been found that the soil penetrometer resistance, S, for Urrbrae loam (a hand-setting phase of a red-brown earth, clay content = 17%) varies with water content, w, as follows

$$S = \exp\left[5.60 - 0.29\, w\right], \text{ MPa} \qquad (7)$$

Combination of equations (5) and (7) gives

$$\bar{S} = \exp\left[-0.76 - 0.29\,\beta\right], \text{ MPa} \qquad (8)$$

Of course, the effects of meteorological conditions on S could also be examined with the aid of equation (4).

EFFECT ON NUTRIENT UPTAKE

Combination of equations (3) and (8) gives the overall effect of soil tillage treatment, β, on the relative nutrient uptake per unit length of root:

$$N_r = (1 - \eta_L) \exp\left[-0.25 \exp(-0.76 - 0.29\beta)\right]. \qquad (9)$$

Substitution of β values shows that soil structure, as can be modified by tillage, has a significant effect on N_r. An increase in N_r of 33% through the sequence disc plough-rotary cultivator is obtained which is entirely due to the effect of structure on water content, and hence on strength. Generally, the finer the structure (provided it is not anaerobic), the greater the potential nutrient uptake.

SOIL NUTRIENT STATUS

It is shown above that soil structure affects the ability of roots to absorb nutrients. Conversely, soil nutrient status affects the ability of roots to grow through structured soil. Experiments have been done with roots grown in different concentrations of Hoagland's nutrient solution. It is found that both E and d are modified by nutrient concentration. This modifies the buckling stress, σ_b, of the roots and hence the proportion, P_a, of the root length passing through aggregates. Simulation studies of wheat seminal axes growing in beds of aggregates of 5.1-9.5 mm diameter and of S = 2.5MPa give values of P_a of 0.231, 0.244, 0.278, 0.208, and 0.235 for roots grown in full strength, 1/10, 1/100, 1/1000 and 1/∞ (distilled water) concentration of

Hoagland's solution respectively.

Thus, it appears that soil nutrient status can make up to 30% difference to the proportion of root length passing through aggregates.

This effect may be a consequence of changes in the nitrate or potassium availability to the roots. These nutrients have a large influence on the wall thickness and elongation of cells respectively, and hence can modify root mechanical properties.

CONCLUSIONS

Although soil geometrical structure by itself, and soil nutrient status can modify the behaviour of root axes, the greatest factor affecting root behaviour is soil strength. Soil strength is often strongly dependent on soil water content which is itself influenced by soil structure as can be modified by tillage. Further work is needed to test these predictions in the field, and to investigate quantitatively the effects of soil structure and strength on overall plant development and crop yield.

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SOME RESULTS OF THE BASIC SOIL TILLAGE FOR SUGAR BEET IN SEMI-HUMID CLIMATE

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ABSTRACT

The paper treats the problems of soil tillage for sugar beet, on brown soils on calcareous loess. A comparative study was made of ploughing at various depths and subsoiling. The results showed that the ploughing depth of 3o - 4o cm was satisfactory for sugar beet, but also ploughing at 3o cm with subsoiling to 4o cm was adequate.
The effect of fertilizing was stronger than that of tillage on soils with a more expressed B-horizon.

INTRODUCTION

Sugar beet, the most important industrial plant, is concentrated in the region of semi-humid climate in the continental part of Croatia. It is grown on 14 - 22 % of arable areas in the region, mostly on soils developed on calcareous loess substrata.

On the eastern margin of semi-humid climate the average annual precipitation is 65o mm, on the western margin 75o mm. In the growing period, the rainfall amounts to 35o - 4oo mm. The mean annual temperature is between lo and 11° C with the large annual thermic amplitude of 72°C /-32°C up to +4o$^{\circ}$C/, which points to the continental character of the climate.

The precipitation distribution is unfavourable in relation to the growing period, with high evapotranspiration in summer, and with considerable hydric oscillations throughout the year. In this climate, it is important to accumulate autumn and winter precipitation and preserve soil moisture for the hot part of the year. The vital part is played here by soil tillage, for there is practically no irrigation.

Our investigations in eastern Slavonia and Baranja were confined to brown soil on calcareous loess, which is an important soil type for sugar beet, accounting for 3o - 35 % of all arable land.

The solum depth varies from 6o to 12o cm, and calcareous loess mostly appears under 8o cm. The upper solum layers are loamy clay with a somewhat more compacted B-horizon in the profile. In the main zone of root development, the absolute water capacity is 35 - 39 %, the air capacity from 3,5 to 13 %, tending to lower values.

The soil is poorly humous, neutral, and the saturation with bases is high. The content of available nutrints is satisfactory down to 3o cm, and below this depth it decreases in the direction of calcareous loess.

LITERATURE RELEVANT TO THE PROBLEM

Little research has been done into the basic tillage for sugar beet in the semi-humid climate of Croatia.

MUŠAC /1971/ studied the phenomenon of residual effect of basic tillage on brown soil in eastern Slavonia and found out that the basic tillage at 42 cm was the most favourable depth for sugar beet.

BUTORAC, LJILJAK, KULAŠ and VENCL /1977/ and BUTORAC, LJILJAK and KULAŠ /1977 and 1978/ investigated the optimal depth of basic tillage with mineral fertilizing on lessivé pseudogley in eastern Slavonia. The best combination on this soil type was ploughnig + subsoiling with the total tilling depth to 5o cm.

MIHALIĆ, BUTORAC and BIŠOF /1967/ and MIHALIĆ, BUTORAC, LACKOVIĆ, BEŠTAK and FOLIVARSKI /1973/ conducted investigations of deep ploughing on brown soil in Slavonia, and ploughing and subsoiling in Baranja.

In the adjacent, more arid, Vojvodina, ploughing at 35 - 45 cm gave the best results for sugar beet on fertile chernozem soils, especially if successive ploughing per layers was carried out to that depth, or even better if the system of "topsoil formation" by complex fertilizing and ploughing down to 45 cm was applied /DREZGIĆ, 1972 and STANAĆEV, 1973/.

METHODS OF EXPERIMENTAL WORK

These investigations were a part of complex research into the optimal depth of basic tillage on the main soil types in combination with mineral fertilizing in the continental part of Croatia. Complex investigations were carried out in the period from 1961 to 1973.

Trial locations on brown soils on calcareous loess were situated in eastern Slavonia /Nuštar and Andrijaševci/ and in Baranja /Brestovac/. The following trial variants were applied:

I Eastern Slavonia /Nuštar and Brestovac/
The basic tillage was graded at 2o, 3o, 4o, 5o and 6o cm of ploughing depth, while mineral macrofertilizers /NPK/ in three grades of pure nutrients:

FERTILIZING GRADES	PURE NUTRIENTS KG/HA			
	N	P_2O_5	K_2O	TOTAL
low	7o	13o	1oo	3oo
medium	13o	2oo	16o	49o
high	19o	27o	22o	68o

II Baranja /Brestovac/

The basic tillage variants were: ploughing at 2o, 3o,4o and 5o cm, subsoiling at 4o cm + ploughing at 2o cm, and subsoiling at 4o cm + ploughing at 3o cm. Mineral fertilizing was applied in the following grades:

FERTILIZER GRADES	PURE NUTRIENTS KG/HA			
	N	P_2O_5	K_2O	TOTAL
low	1oo	12o	9o	31o
medium	13o	15o	13o	41o
high	16o	2oo	17o	53o

Due to subsoiling and a smaller soil mass included into tillage, fertilizer grades in Baranja were slightly lower than those in eastern Slavonia.

On all locations, sugar beet suceeded stubble cereals /winter wheat/, so that the harvest was followed by shallow ploughing of the stubble field, while further tilling practices were carried out in the course of summer when the soil consistence is favourable /dry - friable/.

Mineral fertilizing and other agrotechnical measures were those considered standard for large agricultural plants.

INVESTIGATION RESULTS

I Eastern Slavonia

a/ Trial location Nuštar[x]

/soil of high effective fertility/

BASIC TILLAGE GRADING	YIELD Q/HA	MINERAL FERTILIZING GRADES	YIELD Q/HA
Ploughing at 2o cm	451,8	Unfertilized /o/	477,2
" 3o cm	49o,8	low grade $N_{7o}\ P_{13o}\ K_{1oo}$	476,6
" 4o cm	484,6	medium grade $N_{13o}\ P_{2oo}\ K_{16o}$	493,2

./.

x - measured in the third year, after the completion of the basic tilling practices and mineral fertilizing

BASIC TILLAGE GRADING	YIELD Q/HA	MINERAL FERTILIZING GRADES	YIELD Q/HA.
Ploughing at 5o cm	489,5	high grade N_{19o} P_{27o} K_{22o}	487,6
" 6o cm	5o2,2	-	-
LSD P = 5 %	14,o4 q		
P = 1 %	29,o5 q		

It is evident that the basic tillage and mineral fertilizing /NPK/ had a significant effect on the yield of sugar beet roots, tillage being stronger than fertilizing in the investigation period. The explanation lies in the high effective soil fertility and correction of the climate /accumulation of the precipitation water/ for sugar beet as a spring crop in a precipitation deficient year.

Table 2. Andrijaševci - Effects of basic soil tillage and mineral fertilizing on the root yield of sugar beet /soil of lower effective fertility/

BASIC TILLAGE GRADING	YIELD Q/HA	MINERAL FERTILIZING GRADES	YIELD Q/HA
Ploughing at 2o cm	536,8	Unfertilized /o/	389,3
" 3o cm	56o,7	low grade N_{7o} P_{13o} K_{1oo}	597,3
" 4o cm	628,6	medium grade N_{13o} P_{2oo} K_{16o}	668,7
" 5o cm	58o,3	high grade N_{19o} P_{27o} K_{22o}	684,3
" 6o cm	617,8	-	-
		LSD P = 5 %	51,4o q
		P = 1 %	77,4 q

II Baranja

b/ Trial location Brestovac

/soil with strongly expressed B-horizon/

Table 3. Brestovac - Effects of basic soil tillage and fertilizing on the root yield and digestion of sugar beet

GRADING OF BASIC SOIL TILLAGE	YI ELD Q/HA	DIGESTION %
Ploughing at 2o cm	482,3	17,2
" 3o cm	486,6	16,3
" 4o cm	481,1	17,5
" 5o cm	488,4	15,8
Ploughing at 2o cm + subsoiling at 4o cm	493,4	14,3
Ploughing at 3o cm + subsoiling at 4o cm	498,2	17,5

GRADING OF BASIC SOIL TILLAGE	YIELD Q/HA	DIGESTION %
LSD P = 5 %	42,8	
P = 1 %	59,2	

GRADING OF MINERAL FERTILIZING	YIELD Q/HA	DIGESTION %
Unfertilized /o/	4o9,8	17,2
low grade N_{1oo} P_{12o} K_{9o}	513,9	16,4
medium grade N_{13o} P_{15o} K_{13o}	5o5,1	16,4
high grade N_{16o} P_{2oo} K_{17o}	524,4	15,9
LSD P = 5 %	8,8	
P = 1 %	11,7	

Basic soil tillage and mineral fertilizing /NPK/ had also at Brestovac a positive effect on the root yield of sugar beet. As regards tillage, the best variant was that of ploughing at 3o cm + subsoiling at 4o cm. In fertilizing, the highest yield was obtained with the high grade. Similar to other locations, ploughing at 2o cm was not sufficient for sugar beet. The effect of soil tillage on the digestion decreased parallel to increased fertilizer grades, probably due to the negative effect of nitrogen in the high grade.

CONCLUSION

Out of the extensive trial material, the most important results were selected and used as the basis for the following conclusions:

- On brown soil on calcareous loess, ploughing at 2o cm was not sufficient for sugar beet, a root crop. The depth of 3o - 4o cm was satisfactory.

- The aim of deep tillage into the pedosphere, over 4o cm, was primarily to accumulate autumn and winter precipitation for sugar beet as a spring crop, which is of utmost importance in precipitation deficient years.

- On the brown soil with more expressed B-horizon /Brestovac/, the best results were obtained by the combination ploughing + subsoiling, but only if the ploughing depth was 3o cm.

- The bringing up of mineral, less fertile, soil to the surface does not suit sugar beet, which requires effective fertility of the upper soil layers.

- On the soil of high effective fertility, the effect of tillage on the root yield of sugar beet was stronger than that of mineral fertilizing, whereas on the soil of lower effective fertility /Andrijaševci/ and on the soil with more expressed B-horizon, fertilizing was a more decisive factor than basic deep tillage in the formation of sugar beet yields.

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SYSTEM OF SOIL TILLAGE AND FERTILIZATION WITH THE AIM OF INTENSIFYING OF PLANT PRODUCTION IN NORTH-EASTERN PART OF YUGOSLAVIA (VOJVODINA)

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ABSTRACT

This report presents the system of soil tillage and fertilization in the north-east part of Yugoslavia - Vojvodina based on a long series of experiments performed previously. Hence this paper is the synthesis of so far obtained and published research results on the base of which, besides other elements, a technology of filed and vegetable crops production has been created in this region.

INTRODUCTION

Vojvodina is in the north-eastern part between $44^{o}38'$ and $46^{o}10'$ north geographic longitude and $18^{o}10'$and $21^{o}5'$east geographic latitude.

The primary production possibilities of Vojvodina are determined by its belonging to the large Pannonia ecosystem and it represents the south part of it with favourable production conditions.

The climate of Vojvodina can be defined as a special variety of semi-arid steppe climate with $10,9^{o}C$ average annual temperature and 600 mm average annual precipitations. The soil of the land is diversified, however, the largest part is chernozem and meadow soil, then alluvial and delluvial soil, and hydromorphic blacki soil. The most fertile soil are meadow soil and chernozem on which the greatest part of experiments have been conducted and which are the base of suggested system of tillage and fertilization.

DISCUSSION AND CONCLUSIONS

Remarkable results in increasing plant production in general and specially in field crops growing have been achieved in the past 22 years in Vojvodina, the base of this increase was as follows: new highyielding cultivars of the main field crops (particularly wheat), and the new technology. (Table 1).

Table 1 - Surface,yield and production of wheat in Yugoslavia and Vojvodina for the period from 1930-1939 to 1977

Period	Yugoslavia			Vojvodina		
	Surface (ha)	Yield (q/ha)	Production (t)	Surface (ha)	Yield (q/ha)	Production (t)
1930-1939	2 144 000	11,4	2 430 000	660 000	13,7	906 000
1947-1955	1 835 000	11,4	2 093 750	489 000	13,6	662 340
1956-1960	1 053 000	15,2	2 976 664	462 800	19,1	883 400
1961-1965	2 002 000	18,0	3 594 800	412 400	21,7	895 600
1966-1970	1 912 400	23,5	4 864 048	406 600	31,3	1 272 200
1971	1 929 000	29,1	5 604 010	441 000	39,4	1 737 460
1972	1 924 000	25,2	4 864 570	458 000	32,3	1 467 670
1973	1 697 000	28,0	4 690 310	381 000	41,3	1 573 440
1974	1 842 600	34,1	6 282 230	433 000	46,3	2 005 210
1975	1 615 000	27,3	4 403 790	389 000	40,6	1 518 020
1971-1975	1 801 600	28,7	5 165 382	420 400	39,8	1 672 360
1976	1 724 000	34,7	5 962 280	404 000	50,0	2 020 000
1977	1 605 000	35,0	5 617 500	419 200	51,4	2 154 688

With the new technology of production beside the highyielding cultivars a decisive role in the increase of production have two basic abiotic factors - tillage and fertilization. New native highyielding cultivars and research results in the field of cultural practice have been to great extent the base for our own technology.

The creation of technology in plant production for particular environmental conditions required a very good knowledge of biological properties of plant material cultivars, then a very good knowledge of climatic and soil conditions of a certain region. On the basis of these elements individual elements of the producing process have been worked out, namely to particular agrotechnical measures with the preliminary investigations to find out the most adequate methods in crops growing under given conditions.

Therefore the research has been aimed to investigate the corresponding system of soil tillage and fertilization in order that soil, as the substratum and ecologic enviroment respectively, offers to the plants the most optimal conditions for the development, and formation of high yields. When such kind of investigation is in question, then it should be pointed out that so far only through soils and tillage respectively and fertilization can be possible to affect the climatic extremities which are very often the limiting factors in plant production.

a) Tillage - There have been several stages in the research of soil tillage problems, such as intensive studies of the effect of deepening the arable layer for all crops, investigations of residual effect of deep tillage, interaction of deep tillage and the intensity of fertilization, periodical deep tillages in a particular crop rotation for a very special production and possibilities of applying reduced and minimal tillage without the traditional plonghing using only tools of surface tillage. These investigations of the reaction of the individual crops on the depth of tillage have been conducted after the method of establishing the arable land the theoretical principles of which were worked out by D. T o d o r o v i ć. On the basis of these results there have been distinguished crops which need permanently deep tillage and crops which need permanently deep tillage and crops which make good use of the supplemental effect of deep tillage. As the crops ehich need deep tillage preoved to be: sugar beet, alfalfa and wheat (at the transiti on from shallow to deep tillage). Other crops, among them maize too, react less to the deep tillage and use very well the residual effect of deep tillage and fertilization after the system of establishing arable land. The investigation of the mutual efect of deep tillage and the intensity of fertilization have shown that the depth of tillage can be compensated by increased fertilization and that satisfactory results can be also obtained without tillage, only by disk harrowing. Research of the tillage problems, within a certain crop rotation, indicated to the possiblity of applying the method of establishing and renovating the arable land as the permanent system of tillage. In the interval between establishing and renovating the arable land, the tillage can be shallow for all crops except for sugar beet and alfalfa. The depth of tillage in this interval depends first of all upon the crop grown, soil condition and amount of harvest residues which should be ploughed in. Within the system of tillage after the method of establishing and renovating the arable land, from to time, minimal tillage and sowing with no tillage can be used. Although there are results which speak in favor of the sowing witout tillage as the system of growing, we consider that in our agroecological conditions this system can be used exceptionally and in a short interval.

b) Fertilization - There have been also several stages in the research of problems of fertilization with mineral fertilizers, from the studies of applying single powder fertilizers to the stage of applying granular high concentrated complex fertilizers and liquid fertilizers. Within these investigations the problems of rates and ratios of NPK nutrients and mode of fertilizers application for all important field crops have been considered.

Most of these research trials have been conducted simultaneously under conditions without irigation and with irrigation. The results obtained showed that the same rates and ratios are suitable for the conditions of irrigation. Higher rates and ratios of fretilizers under conditions of irrigation did not always show greater effect, namely irrigation primarely affected the better utilization of nutrients from fertilizers and from soil reserves.

Research results of the mode of fertilizers application showed that fertilizers should be partly applied in the basic tillage, partly in pre-sowing preparation and partly in topdressing concerned only the nitrogen fertilizers.

It can be noticed from the earlier trial results as well as the fertilizers application in practic that nitrogen has an outstanding and leading role. This has been proved by numerous recent trial results about the uptake and taking out nutritive elements, it means that in the next period there will be changes in the present established rates and ratios of the basic nutritive elements.

On the basis of all research results obtained up to now, practice has been recommended to use the system of tillage after the method of establishing and renovating the arable soil, which shoud be applied in acordance with soil conditions of the individual regions. Within this system the problems of tillage for the main field crops and the outstanding specifities in the tillage for each individual crop have been worked out.

c) General conclusion - Since Vojvodina does not represent a unique region concerning the climatic and soil conditions there are given the producing characteristics of the individual regions and specifities in technology, primarely in the choice of plant species and varieties grown, as well as in tillage and fertilization. The solutions proposed are given on the basis of the accepted system of tillage and system of fertilization. The system of tillage after the method of establishing arable land, as well as the principles of fertilizations accepted, offer a fairly stable basis of applying these measures in production although there are considerable differences in respect to climatic and soil conditions in the individual regions.

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EFFECT OF BASIC SOIL TILAGE AND HERBICIDES USAGE ON PRODUCTIVITY THRE-CROP ROTATION ON CHERNOZEM SOIL

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ABSTRACT: The system of basic soil tillage and herbicides usage have their specific effect on productivity of particular crop rotation. They act mainly through reduction of weeds population and through increased depth of ploughing layer which results in better activation of natural soil potentials. Jn three crop rotation sugar beet, maize and wheat depth of ploughing was investigated as follows: Permanent ploughing at 35 cm deep and 35 cm for sugar beet and 20 cm for maize and wheat. On the half of plots weeds were controled mechanically and on the other half by herbicides. Permanent ploughing on 35 cm gives better productivity of field. Weed controling by herbicides has good effect on maize and sugar beet productivity.

Introduction

Herbicides usage as a method of weed control become more or less part of field crop production. In wheat or maize it has longer period of use and solutions are much better than in sugar beet crop. In sugar beet herbicides may cause some undesired effects like decreased productivity in some cases. This is result of lack of salectivity of herbicides. Some weeds which are wide spread in sugar beet crop are closed relatives of sugar beet. This makes difficlty to kill weeds and save sugar beet plants. Also interaction between nitrogen and some of herbicides play its role in herbicides selectivity. Some demage on sugar beet can be caused by herbicides used in maize. This is quite possible to observe in wheat sown after maize.

Besides of herbicides weeds can be controled by system of soil tillage, first of all, by depth and number of ploughing. Fertilizing and crop rotation as a parts of soil utilization also have effects on weed populations. Postive effect of basic soil tillage on productivity of wheat, corn and sugar beet has been proved in many experiments (Stanaćev (6,7,8,10), Drezgić idr. 1, Marković (4), Jevtić (3), Stanaćev idr. (9,11), Spasojević (5)).

Drezgić at all. (2) have investigate of effectivity of establishment of arable layer and period of its utilizations and concluded that in four field rotation establishment of arable layer for sugar beet enabled shallow or even very shallow ploughing for wheat, maize and sunflower in some rotation, without loss of yield.

Under different systems of soil tillage the weeds populations are altered. It is well known that perennial weeds which have rizomes can be controled by changing depth of ploughing. In agrobiotops herbicides are killing certian weed species because of their selectivity. Weed species which are not under herbicides control become very prolific because they are free from competitions with other weeds. This probeem can be solved by combining two or more herbicides in particular crop.

Weed control and higher productivity of soil can be attained by proper choice of herbicides and system of soil tillage. Those two factors become very important in weed controling but they bear permanent danger for over population some of weeds species if misused.

To solve problems listed above we set an experiment with investigations of effects of systems of soil tillage and weed control on productivity of growing crops in thre-crops rotations.

Methods and materials

In 1974. we established long-term field experiment. The soil was chernozem. Experimental area was divided into three fields with sugar beet, maize and wheat. In this experiment we investigated interaction between systems of soil tillage and herbicides usage in combinations as follows:

1. Basic soil tillage 35 cm for all three crops
   a) Mechanicall weed control
   b) weed control by herbicide
2. Basic soil tillage of 35 cm for sugar beet and 20 cm for wheat and maize

a) mechanicall weed control

b) weed control by herbicides

For weed control we used herbicides as follows:

a) in sugar beet crop - Roneet 4lit/ha + Venzar 0,6 kg/ha

b) in maize - Agelon 3 lit/ha and

c) in wheat - Deherban (2,4 D) 2,5 lit/ha

In every year we sown "NS poly mono" sugar beet variety, "Sava" wheat variety and NSSC-70 hybrid of maize.

The data we are dealing with in this paper are from years 1976. to 1978. This means last year of first and two years of second Rotation.

Climatic conditions

For esteemation of climatic conditions we have recorded data for precipition and average months temperature only. Those data are in table 1.

Tab.1. More important data for weather conditions

Weathers factors	period	1976	1977	1978
Precipitation	X	34	29	16
	XI-III	114	262	287
	IV	39	59	36
	V	31	52	126
	VI-VIII	290	240	166
	IX-X	90	51	74
t^oC	IV	11.9	10.2	10.2
	V	16.2	17.0	14.3
	VI-VIII	19.1	20.2	19.3
	IX-X	13.6	13.0	13.0

For growth of sugar beet the climatic conditions in 1976. and 1977. were more favourable than in 1978. In the first year yield was 545 mc/ha but in third 437,2 only. Amount and distibution of precipitations between winter and growing season and also distribution of rain in growing season have pronounced adventage of permanent deep ploughing. In the year of 1978. conditions were unfavourable for early drilling. The weather was cold in may. Drought in july and august also take are part in slow growth of sugar beet.

Less precipitations in winter period 1975/1976 caused bigger differences in yields of maize between shallow and deep ploughing, according to ours expectations. It is need to say that weather conditions in all three years were favourable for high yield of maize. The conditions in ripenning period of 1978. were poor so the maize was harvested with higher maisture content which makes storage process more difficult.

Weather conditions for wheat were rader satisfactory and in all three years yields of wheat were good. It was also results of high yielding potential of variety.

Lowest yield in 1976. was caused by how moisture content of soil in spring. That year deep ploughing showed better results.

Results of experiment

Productivity of thee crop rotation depending om systems of soil tillage and weed control, through main yields of crops, is showed in table 2.

Tab.2. Yield of beets, wheat and maize karnels

System of basic soil tillage	herbicides usage	Yield q/ha in period from 1976-1978 year of sugar beet	maize	wheat
20/35	yes	488.1	86.2	58.1
	no	501.2	95.3	55.4
	average	494.6	90.8	56.7
35/35	yes	513.9	91.7	59.6
	no	535.8	102.7	56.9
	average	524.8	97.2	58.3
average	yes	501.0	88.9	58.8
	no	518.3	99.0	56.2
LSD 5% - for treatmants		24.16	3.25	3.05
for interaction		38.40	5.20	4.33

In average of three years permanent ploughing of 35 cm gives higher yield of all three crops. For sugar beet, maize and wheat 6,11%, 7,05% and 2,82% respectivelly. Wide rows crops which ripe in atumn wth shorter growing season react better on deeper ploughing than wheat with longer growing season which ends in june. Although for sugar beet ploughing was 35 cm deep in both systems fields with permanent deep ploughing yielded better. Sugar beet as an plant which forms its main yield in the soil needs deep arable layer to provide crops with maisture, good microbiological activity and etc. This can be attained by certain system of soil tillage. Postive effect of deep plounghing on productivity of maize can be explained by better maisture accumulation, better biogenic soil conditions and higher activation of nutrients in the soil.

Herbicides applied in sugar beet and maize have improved yield. This was 3,45% and 11,36% in average for three years for sugar beet and maize respectivelly. In wheat herbicides have decreased yield by 4,43%. When judge effects of herbicides it is necessery to take into acomnt effects of herbicides used for previous two crops. Negative effest of herbicides on yield of wheat can be caused by herbicides used for maize in previous year. After second rotation we shall use for maize herbicides with less residual effects. Herbicide useds in present have good weed control in maize. Yield was increased by 11,36% in relation with yield obtained with mechanicall weed control. In sugar beet herbicides usage gives slightly better yield but-withaut significant differences. This can be explained by facts that herbicides killed weeds but also did some demage in sugar beet. This negativ effects on young plants may be caused by herbicides and nitrogen and by interaction between them.

Effects of herbicides was the same in both systems of soil tillage like it was in average for experiment. Theirs effect on productivity of all three crops can be seen from table 3.

Tab.3. Jncrement of productivity of three field rotation under effect of herbicides usage

System of soil tillage	% yield increment		
	sugar beet	maize	wheat
20/35	2,68	10,56	- 4,65
35/35	4,26	11,99	- 4,53

The systems of soil tillage acted similar in both systems of weed control, as it was in average for experiment. Although there is weak tendency of increasing productivity for all three crop in the system with deeper proughing. Increased productivity of permanent deep ploughed fields in comparison with shallow ones is showed in table 4.

Tab.4. Increment of productivity of thee field rotation under different systems of weed control

System of wredcontrol	% yield increment		
	sugar beet	maize	wheat
mechanicall	5,28	6,38	2,58
chemical	6,90	7,76	2,70

C o n c l u s i o n s

1. Basic soil tillage of 35 cm deep in three crop rotation increased productivity of all crops in relation with differentiated soil tillage which means shallow ploughing (20 cm) for wheat and maize and 35 cm for sugar beet.

2. Chemical way of weed control slightly increased yield of sugar beet but increment in maize was significant. In wheat yield was decreased which partly was due to residual effects of herbicides used in maize.

3. In both systems of basic soil tillage herbicides acted similarly on productivity of rotation.

4. In both systems of weed cotrol investigeted systems of basic soil tillage acted similarly, but with tendency of increasing productivity if soil was ploughed 35 cm deep.

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EFFECT OF PLOWED UNDER ORGANIC MATTER IN GROWING MAIZE AS MONOCULTURE ON SOIL MOISTURE AND YIELD

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Summary

The effect of plowed under organic matter was investigated on a carbonate chernozem type of soil at the Maize Research Institute in Zemun Polje. The study was made on a plot where maize was grown in monoculture over several years.

Maize stalks and stable manure was plowed under into the soil as organic matter.

Variants:

Maize stalks:

a) cut and removed from the field
b) 50% plowed under, 50% removed
c) 100% plowed under

Stable manure:

a) without stable manure
b) 0.5% of the volume of plowed soil
c) 1.5% of the volume of plowed soil

Maize stalks were plowed under every year in the fall during primary tillage. Stable manure was incorporated into the soil every third year also during primary tillage.

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EFFECTS OF DIFFERENT TYPES OF SOIL TILLAGE ON SOIL PROPERTIES AND YIELD PARAMETERS OF WHEAT AND SUGAR-BEETS

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ABSTRACT

In a 4 years field experiment with a crop rotation of high proportion of cereals and crop residue incorporation, 3 tillage systems have been examined in which the tools were plough, heavy cultivator and rotavator. The experiments have been carried out under different soil conditions.

Mainly, the aspects of soil porosity, root development of sugar beet and the yield efficiency of winter wheat and sugar beet have been discussed.

Due to the findings, an attempt has been undertaken to precise the advantages and disadvantages of the investigated tillage systems and to recognise the consequences of their application.

PERFORMANCE OF THE TEST

During the years 1974 - 77, field experiments have been carried out to investigate the influence of different tillage systems in three locations: loamy sand, loamy silt and silty clay-loam. The tillage systems and the implements used are given in table 1.

A 4 years crop rotation with 75 % of cereals proportion: sugar beet - winter wheat - winter wheat - winter barley has been selected. In all cases organic crop residues (straw and beet leafs) have been incorporated with a same mineral fertilizer and herbicide level. The herbicide quantity used was determined according to the plough-system. This level was also used for other tillage systems in order to check the weed infestation.

System	stubble cultivat.	primary tillage	seedbed-preparat.	sowing
1 Plough	rotary harrow	plough + packer (25 cm)	C: - seedbed combin.	seed drill
			SB: seedbed combin.	precision seeder
2 cultivator	heavy cultivat. (10 cm)	heavy cultivat. (20 cm)	C: - seedbed combin.	seed drill
			SB: seedbed combin.	precision seeder
3 rotavator	rotavator (8 cm)	C: -		Rotaseeder
		SB: rotavat. (12 cm)	seedbed combinat.	precision seeder
	C = cereals		SB = sugar beet	

Table 1: Soil tillage systems and the applicated implements (1974 - 77)

The investigations were concentrated mainly on:
- determination of the physical proportion of soils - annually determination of pore volumina and air content at pF 2,0;
- determination of the forked beets;
- annually determination of the plant development especially the yield efficiency.

RESULTS

Influence of different tillage systems on the physical conditions of soils

Changes in soil structure, i. e. pore volume, average of 2 depths, after 4 years of applications of 3 soil tillage systems is given in table 2. The last column represents the limiting values of the "optimal pore volume" according CZERATZKI.

soil	depth (cm)	pore volume (vol. %) tillage system plough	cultivator	rotavator	optim. pore volume (vol. %)
loamy	5 - 10	40,8	43,1	42,0	40
sand	15 - 20	42,0	41,3	37,8	
loamy	5 - 10	47,6	48,6	47,3	45
silt	15 - 20	47,7	46,4	43,9	
silty	5 - 10	47,6	44,3	42,5	47
clay-loam	15 - 20	44,1	43,5	40,0	

Table 2: Total pore volume after 4 years of application of the different tillage systems (1977)

The data indicate significant differences especially in the rotavator-system treatment within the layer 15 - 20 cm in all investigated locations. This is especially true for the silty clay-loam soil in which the pore volume was decreased about 7 % and reached 40 vol.% (air content at pF 2,0 = 3,1 vol.%) instead of 47 vol.% (air content at pF 2,0 about 12 vol.%) which represents the optimum case. No differences could be achieved between the other two systems.

Influence of different tillage systems on percentage of the forked beets

The percentage of the forked beets were determined in order to investigate the influence of the different tillage systems on root development (Fig. 1).

The results indicate very clearly that the proportion of forked beets in the loamy sand soil were two times greater due to the use of rotavator system than those of plough- and cultivator system as a result of soil compaction in the layer 15 - 20 cm. On the loamy silty-soil, the percentage of the forked beets increased with decreasing the primary soil tillage depth (plough — cultivator — rotavator system).

On the heavy, silty clay-loam soil the percentage was generally high. Also the primary soil tillage with plough caused high percentage values. This can be recognised as a result of the existing of rough

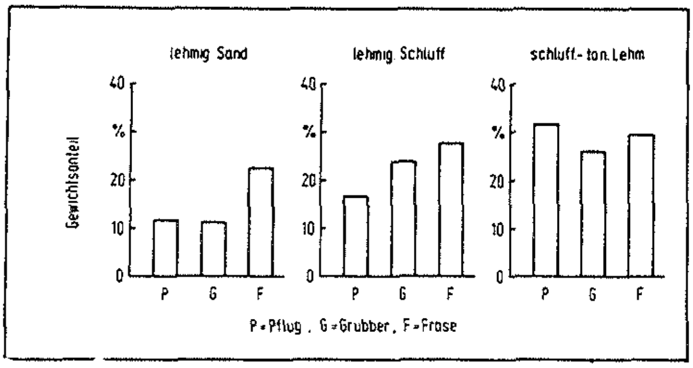

Fig. 1: Influence of the different tillage systems on the percentage of the forked beets
tillage system: P = plough, G = cultivator, F = rotavator
soil: lehm.Sand = loamy sand, lehm.Schluff = loamy silt, schluff.-ton.Lehm = silty clay-loam

cloddy plough furrow, in which the weight percentage of the 80 mm clods and bigger, was 2 - 3 times higher as those of the cultivator. The clods in the deeper layer hinder the development of the beets. The seedbed preparation should be also done intensively, viz. several working operations might be necessary for heavy soils.

Influence of tillage systems on yields of cereals and sugar beet

Yield of sugar beet

Significant differences between the yield efficiencies of the 3 locations could not be recognised in spite of the fact that the low tillage depth of the cultivator- and especially of the rotavator system led to soil compaction of the layer up to 15 cm manifest this fact and demonstrate the sugar beet yield in comparison with plough system treatment during the 4 years period (fig. 2).

This effect of the mechanical and equal chemical weed control was the same in all tillage systems. The long period between the tillage and cultivation has influenced positively the mechanical weed control through an intensive stubble cultivation and straw incorporation. The trend to shallow primary tillage were coupled with a bad quality of the beet as a result of increasing the forked beets proportion (fig.1) through the rotavator system. Further, the beet embedding in the soil was quite differently. The apparent part above ground was rather bigger. Difficulties arise then for mechanisation of the beets uprooting as a result of unaccuracy of beet's topping, which lead to a higher yield loss.

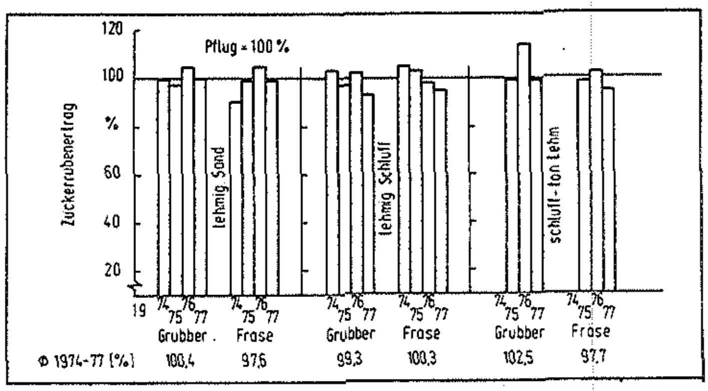

Fig. 2: Influence of the different tillage systems on the yield of sugar beet in relation to plough = 100 %

tillage system: Pflug = plough; Grubber = cultivator
Fräse = rotavator

soil: lehm.Sand = loamy sand, lehm.Schluff = loamy silt, schluff.-ton. Lehm = silty clay-loam

Yield of winter wheat

Essential higher yield differences of the winter wheat were recognised. The figure 3 demonstrates the development of grain yield relatively of winter wheat (after winter wheat) in the crop rotation of the cultivator- and rotavator systems in comparison to the ploughsystem (100 %).
A slight decrease of the yield as a whole on loamy sand and loamy silt soils was recognised as a result of repeated application of cultivator- and rotavator systems. Significant low yields were achieved at 3rd and 4th year after repeated application of the rotavator system and only at 3rd year by means of cultivator system on loamy silt soil.

The uniformity of seeding depth by rotaseeder led to a decrease of the yield efficiency. The yield decrease was proportional to the increasing of weed infestation (grass weed) as a result of repeated cultivation of winter cereals. The germinated grass weed after stubble cultivation was effectively controlled by means of turn over effect of the primary tillage of the plough due to the proper incorporation of weeds in the deeper layer rather than by means of cultivator or rotavator.
A significant low yield has been obtained only one time indeed by using the rotavator system on the silty clay-loamy soil.

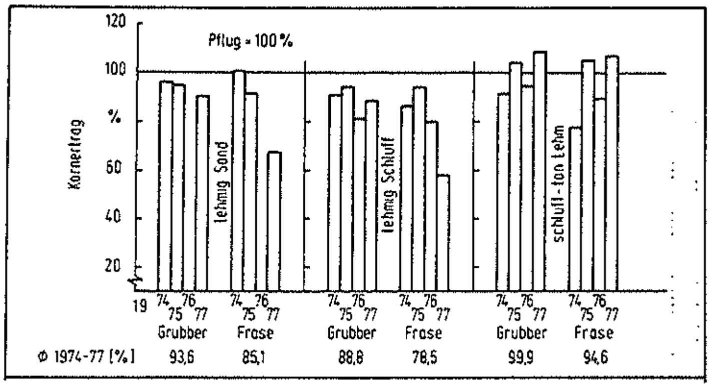

Fig. 3: Influence of the different tillage systems on the yield of winter wheat (after winter wheat) in relation to plough = 100 %

tillage system: Pflug = plough, Grubber = cultivator
Fräse = rotavator

soil: lehm.Sand = loamy sand, lehm.Schluff = loamy silt
schluff.-ton.Lehm = silty clay-loam

CONCLUSION

The experience gained from the 4 years investigation may be concluded as follows:

- Essentially could be said, that plough alternative systems, especially a heavy cultivator can be applicated with success also in a crop rotation with high proportion of cereals.
  The rotavator system is not suitable for sugar beet cultivation.
- The frequency of application of the alternative systems depends on several factors. Not only the climate, the physical soil conditions and crop rotations but also the weed elimination is essential especially a differentiation of weed control should be then made according to the tillage system used.
- By heavier incorporation of organic crop residue, mainly straw, it is essential to ask for a disturbance free sowing technique.

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EFFECT OF MINIMUM TILLAGE AND PRECEDING CROPS ON THE YIELD OF MAIZE

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Abstract

Minimum tillage variants have been investigated: ploughing at the depth of 30 and 20 cm and rotofrasing at the depth of 8 and 4 cm with the preceding crops: winter wheat, sugar beet and alfalfa on chernozem.

On the basis of three-year investigations the following can be concluded: The highest maize yield was effected by ploughing at the depth of 30 and 20 cm. No difference was observed in the yield depending on the depth of ploughing, which indicates that it would be possible to till the soil more rationally.

Application of rotovator caused very significant decrease in maize yield as compared with the application of plough after preceding crops: winter wheat and alfalfa, with the exception of sugar beet in which tillage depth by rotovator application does not affect the yield rate. The highest average yield of maize was obtained after alfalfa, lower after sugar beet and the lowest after winter wheat.

INTRODUCTION

The progress in maize growing by introduction of the high yield hybrids, high quality tillage and proper care is well known. Although most of the innovations have been introduced in maize growing, there are still different opinions on yield increase and productivity.

Development of chemisation, mechanization and intensification affected the investigations of the variants of minimum tillage in a number of countries.

According to some authors this is a progressive direction, therefore, the attention of agricultural sciences and practice is more and more aimed to developing the variants of minimum tillage (Milojić, 1963, 1964; Drezgić, 1968; Milojić-Dakić, 1972; Milojić-Otašević, 1973; Milojić et al., 1976).

From 1963 on, few works related to the problem of minimum tillage for maize have been published in our country.

Our objective was to examine how the variants of minimum tillage by ploughing at 20 cm and rotovator application at 8 and 4 cm depth affect the maize yield on chernozem when compared to the classical and conventional tillage at 30 cm depth after winter wheat, sugar beet and alfalfa as preceding crops.

METHODS OF WORK

The examination of one variant of minimum tillage and preceding crop effect on the maize yield was performed in the period of 1970/1 - 1972/3 on chernozem soil. Chernozem is characterized by lighter mechanical composition (40% physical clay), and according to the standard laboratory analyses, in the ploughing layer it contains 0,17-0,19% N, 3,6 - 4,2 mg P_2O_5 and 18,6 - 20,2 mg/100g soil of K_2O. The examination was carried out by the field experiment method in 6 replications. The size of the basic plot was 59 m^2. The variants in the trial were arranged randomly.

The following tillage variants were investigated:

A. Tillage with plough at 30 cm - conventional tillage - control;

B. Tillage with plough at 20 cm;

C. Tillage with a rotovator at 8 cm;

D. Tillage with rotovator at 4 cm.

The preceding crops were winter wheat, sugar beet and alfalfa.

In individual variants soil tillage varied according to the preceding crop.

1. Ploughing at 30 cm depth /conventional tillage/:

a) preceding crop - wheat: immediately after harvesting of wheat ploughing of stubble field at 10-12 cm and harrowing took place, and at the beginning of autumn ploughing at 30 cm was performed. Immediately after ploughing haevy disc was applied and a month later - a lighter disc in order to destroy weeds;

b) Preceding crop - sugar beet: immediately after taking out sugar beet, ploughing at 30 cm and discing with haevy disc was performed;

c) preceding crop - alfalfa: after the third swath the soil was ploughed at 20 cm and a month later ploughing at 30 cm was performed as well as discing. At the end of autumn a lighter disc was applied against weeds.

Pre-sowing soil tillage after all preceding crops was carried out by:

2. Ploughing at 20 cm depth differed from the conventional tillage at 20 cm.

3. Rotovating at 8 cm depth /LR 80-225/:

a) preceding crop - winter wheat: after wheat harvesting, ploughing of stubble field at 10-12 cm, with harrowing, was performed. Preparation of soil for sowing was done in spring by the application of rotovator at the depth of 8 cm;

b) preceding crop - sugar beet: soil tillage after sugar beet consisted of the spring rotovator application at 8 cm in order to prepare the soil for sowing;

c) preceding crop - alfalfa: soil tillage after alfalfa was the same as after the sugar beet.

4. Application of rotovator at 4 cm depth was performed in

the same manner as in the preceding variant. /var. No. 3/, while the rotovator was applied at 4 cm depth.

Fertilizing system in these experiments was based on mineral fertilizers applied over supplies. Namely, in autumn 1969 280 kg/ha P_2O_5 and 200 kg/ha K_2O was ploughed in in the variants with winter wheat and maize as preceding crops. Nitrogen fertilizers, except for alfalfa as preceding crop were applied in a quantity of 120 kg/ha N (60 kg/ha in pre-sowing preparation, and 60 kg/ha N as top dressing).

Sowing of hybrids YU-NS SK-70 was done by hand in the second half of April at distance of 70 cm x 64 cm + 2(44,642 plants per ha).

During the vegetation period 3 cultivations were performed in 1971 and 4 in 1972 and 1973 in order to destroy weeds. Herbicides were not applied.

Protection of maize from soil pests was done by the application of geoline G-3 (30 kg/ha in the pre-sowing preparation of soil.

Harvesting was carried out by hand when the maize was fully ripe.

The results have been processed by the analysis of variance.

Meteorological conditions

The meteorological conditions - the average monthly temperatures and precipitation amounts are as follows:

	Average monthly temperatures (C^o)			Precipitations in mm		
	1971	1972	1973	1971	1972	1973
I-XII	11,34	12,15	12,10	520	645,5	417,8
IV -IX	18,56	18,93	19,46	349,1	441,8	282,0

Taking into consideration the temperature conditions and precipitation distribution, it can be concluded that, for maize production, meteorological conditions were the best in 1972.

RESULTS AND DISCUSSION

The results of the study of the effect of minimum tillage variant as well as the kind of preceding crop on maize yield are given in Table 1.

The highest maize yield on this type of soil in 1971 was achieced by ploughing after all preceding crops. The depth of tillage did not influence the yield. Namely, the rate of yield is practically the same at both depths tilled with plough. However, tillage by the application of rotovator at 8 cm,when compared with the tillage at 4 cm, lead to statistically significant increase of maize yield after winter wheat and alfalfa as preceding crops (7,18 mc/ha and 7,32 mc/ha, but not after the sugar beet (2,78 mc/ha).

Soil tillage by rotovator at 8 cm depth caused statistically significant decrease of yield after winter wheat (6,80 - 7,38 mc/ha) and very high after alfalfa (12,62 - 13,08 mc/ha) if compared to tillage by plough. However, the decrease of yield after sugar beet was not statistically significant. When the soil was tilled by the application of rotovator at the depth of 4 cm statistically significant decreae of yield was obtained after wheat

Table 1. - The influence of minimum tillage on maize yield (mc/ha) on chernozem

Tillage methods		1971 Preceding crops			1972 Preceding crops			1973 Preceding crops			1971-1973 Average preceding crops		
		Winter w.	sug. b.	alfal.	Win.w.	s. b.	alfa.	win. w.	s.b.	alfa.	win. w.	s.b.	alfa
A		74,94	75,70	88,06	90,96	93,90	104,82	70,28	72,44	76,50	78,73	80,66	89,79
	%	100	100	100	100	100	100	100	100	100	100	100	100
B		75,52	74,86	88,52	93,60	94,32	103,20	62,82	71,32	64,26	77,31	80,17	85,33
	%	100,77	98,89	100,52	102,90	100,44	98,45	89,38	98,45	84,00	98,19	99,36	95,03
C		68,14	70,76	75,44	84,32	83,26	86,96	55,88	60,88	66,20	69,45	71,63	76,20
	%	90,92	93,47	85,66	92,70	88,66	82,96	79,51	84,04	86,53	88,21	88,78	84,86
D		60,96	67,98	68,12	83,00	85,30	82,06	53,90	60,00	56,32	65,95	71,09	72,17
	%	81,34	89,80	77,35	91,24	90,84	78,28	76,69	82,82	86,69	83,76	88,11	80,37
LSD	5%	6,68	7,18	6,91	10,92	10,41	7,78	6,86	6,15	7,79	4,17	4,93	4,78
	1%	9.26	9,97	9,95	15,16	14,45	10,80	9,52	8,54	10,82	5,79	6,84	6,64

(13,98 - 14,56 mc/ha) after alfalfa (19,94 - 20,40 mc/ha and after sugar beet at the significance limit (6,88 - 7,72 mc/ha), when compared with ploughing.

In 1972, as in the preceding year, the highest maize yield was obtained by ploughing at 30 and 20 cm, whereby no differences in yield were noticed in relation to the tillage depth. This year, in contrast with the preceding one, no differences in yield were observed with respect to the depth to the tillage depth by rotovator, i.e. the differences are within the limits of experimental error.

Soil tillage by rotovator causes, statistically very significant decrease of yield after alfalfa (16,24 -17,86 mc/ha at 8 cm and 21,14 - 22,76 mc/ha at 4 cm depth) when compared to ploughing, while the decrease after winter wheat is not statistically significant. However, after sugar beet, when compared with ploughing variants, statistically significant decrease of yield is obtained only by tillage with rotovator at 8 cm (10,64 - 11,04 mc/ha).

In the third year of the experiment the highest yield on chernozem was obtained by tillage with plough at both depths after winter wheat and maize, w ile after alfalfa only by deeper ploughing, which is characteristic for 1973 in comparison with the preceding years. It should be added that after winter wheat, ploughing at 20 cm caused, in relation to ploughing at 30 cm, statistically significant decrease of yield (7,46 mc/ha) and after alfalfa even very significant (12,24 mc/ha). This is the only case in the three-year experiment on chernozem that deeper ploughing in relation to the shallower provided statistically significant increase of yield.

Soil tillage by rotovator application caused decrease in yield if compared to ploughing (20 cm) after alfalfa. However, the application of rotovator caused statistically very significant decrease of yield if compared to the ploughing at 30 cm depth after alfalfa and winter wheat (10,30 - 10,18 mc/ha and 14,40 - 16,38 mc/ha) and after sugar beet if compared to ploughing at both depths - 11,32 - 11,56 mc/ha. Statistically significant decrease of yield was obtained by tillage with rotovator in relation to ploughing at 20 cm after winter wheat,

It should be emphasized that in 1973 the depth of soil tillage by application of rotovator, after all preceding crops, had not affected the yield of maize.

During the three-year experimental period the highest average yield of maize by tillage with plough, after all preceding crops was obtained on chernozem. Whereby the difference accounting for the deeper ploughing has not been statistically proved; neither was the significance of the difference in yield in dependence of tillage depth by the application of rotovator.

It should be pointed out that the average yield of maize by deeper tillage using rotovator was higher for 3,50 mc/ha after winter wheat and for 4,03 mc/ha after alfalfa, as well as that the deeper ploughing had a higher effect on the yield for 4,46 mc/ha.

Soil tillage by rotovator within the three-year period caused statistically very significant decrease of maize yield if compared to ploughing, after all preceding crops. This decrease amounts from 7,66 - 12,78 mc/ha after wheat, from 8,54 - 9,58 mc/ha after sugar beet and from 9,13 - 17,62 mc/ha after alfalfa.

The question of the effect of manner and depth of variant of minimum tillage on maize yield is interesting from both theoretical and practical point of view. There are results that confirm that there are no statistical differences in maize yield by ploughing at 40 and 30 cm, as well as by ploughing at 35 and 25 cm depth (Todorov-Stoinev, 1970) and 45 cm and 23 - 25 cm (Vasilev, 1971).

In our experiments no statistically significant differences were established in maize yield by tillage at 30 and 20 cm.

The conclusions of many authors are that such investigations require a long period of time. If the results of several year investigations would show that the depth of ploughing has no influence on the yield of maize, that would indicate an increase in economy of maize growing.

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EFFECT OF DIFFERENT TILLAGE METHODS APPLIED TO CHERNOZEM SOIL ON SOME SOIL PROPERTIES AND MAIZE YIELDS

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Abstract

In this paper three tillage methods were investigated: zero tillage, rotary tillage and conventional tillage. In addition investigations were made of three methods of disposing of wheat straw after harvesting: burning od straw, baling and leaving the straw on the field. In connection with this, the content of humus in the soil was investigated at the beginning and the end of the maize growing period.

The moisture content of the top layer was observed as affected by the factors mentioned above.

At the end of the paper results of maize yields are given.

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SOIL TILLAGE IN A LONG TERM WHEAT MONOCULTURE.

Incidence on soil, physical soil properties, plant diseases, weeds infestation and wheat yields

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ABSTRACT

In a long term experiment of wheat monoculture established in 1967 on an old grassland, direct drilling was compared to the conventional method. The following observations were made:

The organic matter content of the soil and the aggregate stability decrease more rapidly in ploughed than in untilled plots. No deterioration of the soil structure was observed in untilled plots, even at long term. Eyespot was more severe and the wheat yield lower in ploughed plots.

Introduction and experimental design

A long term experiment was established in a wheat monoculture at Changins in order to investigate the long term effects of reduced cultivation on the soil physical evolution, on plant diseases, on weeds infestation and on crop yields. This experiment was started in 1967 on an old natural grassland.

Soil type: clay 28%, silt 67,5%, sand 4,5%, organic matter in 1967: top layer 4,1%, layer 10 to 20 cm depth 3,2%.

The following treatments were carried out:

1. Direct drilling, wheat monoculture
2. Conventional tillage (discing of the stubble, ploughing at the beginning of October, sowing mid of October): wheat monoculture
3. Direct drilling, wheat monoculture until 1976, then rotation maize - wheat - rape - wheat
4. Conventional tillage, rotation as 3
5. Conventional tillage, wheat monoculture until 1974, then rotation oat - wheat - rape - wheat

Treatments 3, 4 and 5 were used from 1967 to 1974 in order to examine complementary questions related to a reduction of soil tillage and to wheat monoculture (application of fungicides, complement of nitrogen, sowing methods, problems of the straw gathered at the soil surface).

Treatments 1 and 3 were drilled with a triple disc coulter from 1967 to 1971. Since 1972, these plots were regularly sown with a "Rau-Kombi" drill. This implement is based on the adaptation of a power driven rotary cultivator for direct drilling. The seeds are broadcasted. This drill is less impeded by the trash on the soil surface than the triple disc. The working depth was deliberately very shallow, normally 3 to 4 cm. With the exception of this very slight cultivation, when sowing, the soil was not tilled. Paraquat was used systematically to destroy the vegetation in the untilled plots. Complementary treatments with aminotriazole or glyphosate were carried out as circumstances required.

Size of the plots: 160 m^2

Number of replicates: 4

In this paper, we have focused our observations mainly on treatments 1 and 2.

Results

Changes in soil conditions

This trial was carried out on a natural grassland. The initial organic matter content of the soil was therefore relatively high. The introduction of cultivation and cropping caused a marked decrease of the organic matter content (table 1). This decrease is significantly slower after direct drilling.

The reduction of the stability of soil aggregates was particularly evident in the conventional tilled plots (table 1). However, the stability of the aggregates was lower after direct drilling than after grassland. In the plots, which were systematically ploughed, we have noticed a trend to slaking and crusting in the spring, which increased from year to year.

Since 1972, the total porosity and air capacity at pF 2 was checked each year in April at two depths (table 2). In this soil rich in clay and well provided in organic matter, we noticed that the porosity and macroporosity remained much the same during all those years in the untilled plots. Frost effects during winter, soil swelling and shrinkage due to wetting and drying allow to preserve a good soil structure.

In the ploughed plots, porosity and air capacity of the soil, which were checked in April, varied considerably from year to year. When the autumn was wett, as in 1974 or 1977 (313 and 318 mm precipitation in September and October), the soil was tilled in wet conditions and consequently macroporosity of the soil in the following spring was very low. On the contrary, when the autumn was favourable and the winter dry, the increase of porosity caused by ploughing was still evident in the following spring. Some soil profiles carried out in 1975 and 1978 in the ploughed plots showed a deterioration of the soil structure with some marks of gley (pseudogleyfication). Such deteriorations could not be seen in the untilled plots, where the macroporosity varied very little from year to year, in spite of a total pore space which was generally lower in the layer from 10 to 20 cm depth.

Effects on pests and diseases

Eyespot (Cercosporella herpotrichoides) has severely affected this wheat monoculture for many years. Contrary to our expectation, the attack of eyespot was obviously more severe on the ploughed plots (table 3).

According to YARHAM and HIRST (1975), the attack of eyespot in the spring is related to the importance of the infections brought by dead

Table 1 - Evolution of the organic matter content of the soil and of the stability of the soil aggregates

Kind of control	Layer examined (depth)	Year	Conventional tillage	Direct drilling	Grassland* as check plot
% of organic matter in the soil	0 - 10 cm	1967	4,1	4,1	4,1
		1971	3,0	3,6	4,2
		1975	2,4	3,3	4,0
		1978	2,4	2,9	4,2
	10 - 20 cm	1967	3,2	3,2	3,2
		1971	2,8	2,8	3,0
		1975	2,4	2,6	3,0
		1978	2,3	2,6	3,2
Stability of soil aggregates** (method of Henin, 1960)	Index S 0 - 10 cm	1971	0,93	0,66	0,40
		1977	1,61	0,78	0,61
	Index K 0 - 10 cm	1971	5,4	9,5	10,1
		1977	3,0	3,4	4,1

* Grassland around the trial
** The aggregates are all the more stable as the index S is low and the index K high

Table 2 - Evolution of the total pore space in % and the air capacity at pF 2 (0,1 bar) in tilled and untilled plots. Relation to the precipitations during the period of soil tillage

Year	Total pore space in %				Air capacity at pF 2				Precipitations in the autumn of the previous year, in mm	
	Layer 0 - 10 cm		Layer 10 - 20 cm		Layer 0 - 10 cm		Layer 10 - 20 cm			
	ploughed	untilled	ploughed	untilled	ploughed	untilled	ploughed	untilled	September	October
1971	56,7	47,7	-	-	22,7	10,7	-	-	47	73
1972	53,2	48,1	52,5	48,0	18,2	12,6	15,4	11,8	93	82
1973	57,4	51,7	57,1	49,1	25,2	16,1	21,7	14,3	49	20
1974	52,8	53,3	50,3	48,9	15,9	14,8	13,0	12,7	111	100
1975	49,5	53,4	50,6	48,1	10,6	12,2	9,9	12,2	142	171
1976	57,4	51,9	51,5	49,8	26,0	15,7	15,4	13,3	173	38
1977	53,2	53,3	50,5	48,7	15,6	12,9	9,8	10,0	222	71
1978	51,8	52,3	51,2	52,4	12,1	15,5	12,7	14,5	12	116

Table 3 - Effect of soil tillage on the development of eyespot and yield of wheat in monoculture

Year	Yield in q/ha		Index** of eyespot	
	no tillage before sowing	ploughing	no tillage before sowing	ploughing
1968	56,9	58,2	-	-
1969	34,6	34,9	-	-
1970	38,1	35,0	1,8*	2,8*
1971	41,7*	36,6*	1,9	2,0
1972	47,9*	40,2*	1,8*	2,0*
1973	37,0*	26,7*	1,9*	2,4*
1974	54,0*	40,5*	1,3*	2,0*
1975	41,2*	33,0*	1,4*	1,8*
1976	37,3*	33,0*	1,6*	1,8*
1977	47,1*	38,8*	1,7*	2,0*
1978	60,9*	55,2*	1,8*	2,5*
Mean	45,2	39,3	1,7	2,1

* Significantly different (P: 0,05)

** $\text{Index} = \dfrac{\text{(stems sev.att.x3) + (stems mod.att.x2) + healthy stems}}{\text{number of stems examined}}$

plant material on the soil surface. Consequently, wheat should be well exposed to the disease after direct drilling. However, at maturity, the development of eyespot is related to the microclimate inside the culture as much as to the initial inoculum. Ploughing should provide for a more favourable microclimate towards the disease. Furthermore, according to these authors, the survival of the fungus should be better on burried straw than on straw left at the soil surface.

In our trial, it seems that the decrease of eyespot after direct drilling results not only from a consequence of not ploughing, but is also partly due to the broadcasting in untilled plots and to the incidence of this sowing method on the microclimate.

- The infections of take-all (Gaeumanomyces graminis) were very slight and no observations were made. Several authors have quoted a reduction of take-all in direct drilled wheat (BROOKS and DAWSON, 1968; SCHWERDTE and KOCH, 1967). According to PREW (1972), the fungus would be spread in the field by the implements during tillage of the soil.
- In the spring we have sometimes noticed a slight infection of Septoria nodorum on the plantlets of wheat in untilled plots. No difference was observed at maturity.
- Slugs were regularly more abundant in untilled plots, however, without any consequence for the crop.
- Concerning nematodes, our colleague Dr. R. Vallotton has realized in 1976 controls of the population of H. avenae in our trial. The infestation was high. Ploughed plots contained 606 cysts per 100 cm^3 and untilled plots 888. However, it must be said that winter

wheat tolerated this nematode rather well and that the crop was apparently not affected. Spring cereals are much more sensitive to this pest.

These few observations emphasize how the modification of a simple method of soil tillage can have incidences on the intricate relations which exist between a parasite and its host-plant.

Weeds

Treatments carried out during the trial with appropriate herbicides, depending on the weeds present, have allowed to maintain the cultures almost weeds free. However, we have noticed that Convolvulus arvense, Poa trivialis, and annua, Cirsium arvense, Polygonum aviculare and Agropyrum repens are more frequently met in untilled plots. On the other hand, Gallium aparine, Veronica and Papaver are more numerous in ploughed plots.

In the spring 1975, our colleague H. Beuret has checked the seeds stocks of the soil (table 4).

Table 4 - Effect of soil tillage and rotation on the seeds stock in the soil (state in the spring 1979 according to H. Beuret)

Soil tillage	Rotation	Number of seeds per m^2 for a depth of			Number of most important species
		0 - 5 cm	5 - 10 cm	10 cm	
Direct drilling	monoculture	347	903	764	8
	rotation since 1976	1250	1944	1597	15
Ploughing	monoculture	694	1180	1458	13
	rotation since 1976	625	1208	2499	17

We have noticed that direct drilling provides at long term for an obvious decrease of the weeds seeds number in the soil and also for a decrease of the present species. Monoculture causes the same effect.

Yields

During the first three years, the wheat yields were approximatively the same in tilled as in untilled plots. Later on, the untilled treatments provided systematically for better yields (table 3). The severe attacks of eyespot (Cercosporella herpotrichoides) are partly responsible for these differences. Fungicide applications carried out during two years on treatments 3 and 4 have shown that even with a fungicide protection, the direct drilling is more productive than the conventional method (means of two years 11,8%).

The preservation of a good soil structure and of a high level of organic matter accounts also for the good results obtained in untilled plots.

Conclusion

Under Swiss cultural conditions, even at long term, tillage was not necessary to regenerate the soil structure of a heavy soil well provided with organic matter. On the contrary, we noticed a decrease of the organic matter content in the soil and in the aggregate stability at long term, which was due to soil tillage.

Contrary to our expectation, winter wheat was more affected by monoculture in ploughed than in untilled plots; eyespot was particularly more severe.

With the herbicides available today, it is possible to control weeds infestation rather well, even in untilled wheat monoculture.

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PLANT-WATER RELATIONS AND YIELD OF WHEAT ON RIDGES TILLED IN THE EAST-WEST DIRECTION

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ABSTRACT

Winter wheat (Triticum aestivum L. em. Thell.) was grown in rows on ridges tilled in the east-west direction, under irrigated and dryland conditions in the Panhandle of Oklahoma, USA, to determine if yield of plants in south-facing rows was greater than yield of plants in north-facing rows. In addition to yield, measurements of height, leaf temperature, stomatal resistance, leaf water potential, and leaf osmotic potential were taken on plants in north- and south-facing rows. Differences in stomatal resistance, water potential, and osmotic potential of north- and south-facing plants could not be detected. South-facing plants had a cooler leaf temperature than did north-facing plants. South-facing plants grew more than 10 cm taller, and yielded as much as two times more, than did north-facing plants. The results showed that wheat in the Panhandle of Oklahoma should be planted on south sides of ridges for maximum yields.

INTRODUCTION

In the Panhandle of Oklahoma, where wheat is furrow-irrigated, farmers always have noted that wheat planted on the south side of ridges oriented in the east-west direction grows taller than wheat planted on the north side of ridges. The increase in height has never been quantified. Also, it is not known whether or not wheat on the south side of a ridge yields more than wheat on the north side.

There have been few studies of effects of row orientation on plant growth. Day et al. (5) and Erickson et al. (7) review the literature. Studies show that plants (wheat, barley) oriented in east-west rows yield more grain than plants oriented in north-south rows (4, 5, 7). Day et al. (5) attribute the increased yields to warmer soil temperatures on south-facing rows of crops oriented in the east-west direction, which has been observed by several workers (2,3,8,10). This results in faster germination and early growth of south-facing plants compared to north-facing plants. The warmer temperatures also may have effects during later stages of growth when mature, south-facing plants are directly in sunlight. This might result in wider stomatal openings for increased photosynthesis. If stomata were more widely open in plants on south-facing rows, leaf temperatures would be cooler, too, since transpiration rates would be higher.

The objective of this research was to determine if there were differences in leaf temperature, stomatal resistance, plant water potentials, growth, and yield of winter wheat in north- and south-facing rows sown on ridges in the east-west direction. Measurements were taken during the second half of the wheat's growth cycle (from the beginning of spring growth to harvest, 151 to 235 days after planting.

MATERIALS AND METHODS

The field-plot layout, instruments used, and details of procedures already have been described (11). To summarize briefly: The experiment was carried out at the Panhandle Research Station, Goodwell, Oklahoma, during the 1977-1978 growing season. Certified hard red winter wheat (*Triticum aestivum* L. em. Thell.) seed was planted in east-west rows on 13 Oct. 1977. Plants were grown dryland and with furrow irrigation. There were nine beds (nine ridges of plants), six irrigated beds and three dryland beds. Each bed was 142 cm in width and six rows of wheat were planted in each bed. There were 20 cm between rows. In each bed, rows were numbered 1 to 6, with row 1 on the north side and row 6 on the south side. Five cultivars of wheat, commonly grown in the Panhandle, were studied: 'Centurk', 'Scout 66', 'Tam W101', 'Triumph 64', and 'Vona'. The irrigated plots were planted with 30.5 kg seed/ha and the dryland plots were planted with 15.3 kg seed/ha. The soil type was a Richfield clay loam, which is classified as an Aridic Argiustoll. Irrigated plants were given pre-planting and post-emergence irrigations in the fall and not irrigated again until the spring (first spring irrigation was on 20 March).

On four days in the spring (13 March, 12 April, 10 May, 5 June), measurements of height, leaf temperature, stomatal resistance, leaf water potential, and leaf osmotic potential were taken between 08:00 and 10:00 hr on three plants in row 2 (on the north side of a bed) and three plants in row 5 (on the south side of a bed). Rows 1 and 6 were not measured because they were on the sides of the beds. Rows 2 and 5 were on the ridge of a bed.

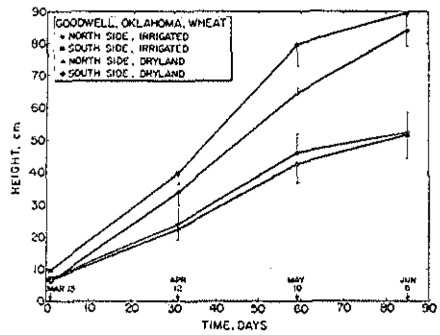
On 5 June 1978, wheat heads were harvested from 30-cm sections in rows 2 and 5. The entire head, including the awns, was weighed and the following four characteristics of the heads were noted: number of spikelets per head (whether filled with grain or not); number of spikelets with at least one grain filled; number of potential grains per head if all grains were filled; number of actual grains filled per head. Ten heads from each 30-cm sample from a row were counted and averaged.

RESULTS

No significant difference in either level or seasonal pattern of leaf temperature, stomatal resistance, leaf water potential, or leaf osmotic potential was found among the five cultivars. Therefore, measurements of each parameter taken during the spring have been averaged.

Height. Under both irrigated and dryland conditions, plants on the south side of a bed were taller than plants on the north side (Fig. 1). Irrigated plants on the south side of rows grew more than 10 cm taller than wheat on the north side. Irrigated wheat on south sides of beds was taller when growth started to resume in the spring (13 March measurements) than other plants. This suggested that the south-facing plants were taller in the fall, too, before winter dormancy set in.

Leaf temperature. Under both irrigated and dryland conditions, leaves of plants on south-facing rows were cooler than leaves of plants on north-facing rows (Fig. 2). Leaf temperatures of south-facing, irrigated plants were as much as 4.5°C cooler than air. Ehrler et al. (6) found leaves of irrigated durum wheat in Phoenix, Arizona, USA, to be as much as 11°C cooler than air just before sunset (see their Fig. 3). Daytime values which they observed were similar to those seen in this experiment. On 5 June, a 2.9 cm rain fell until an hour before measurements were taken. (Reference no.11 gives amounts of rain that fell during the experiment.) Just after the rain, all leaves were the same temperature.



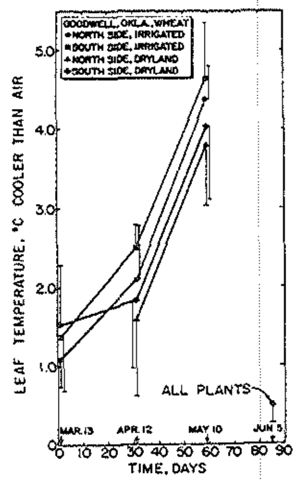


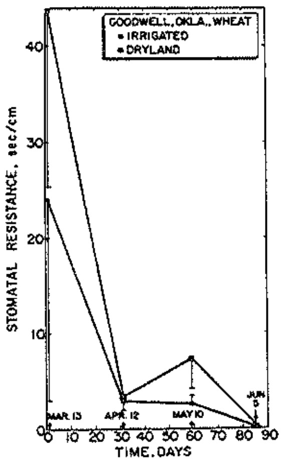
Figure 1. (Left). Height of irrigated and dryland winter wheat in north- and south-facing rows on east-west ridges. Vertical lines indicate standard errors. Only half the standard-error line has been drawn to avoid cluttering the figure. Figure 2. (Right). Leaf temperature of irrigated and dryland winter wheat in north- and south-facing rows on east-west ridges. For vertical lines, see legend of Fig. 1.

Stomatal resistance. Even though leaf temperatures were cooler on south-facing slopes, differences in stomatal resistance of plants in north- and south-facing rows could not be detected. Therefore, leaf temperature appeared to be a more sensitive indicator of water loss from the leaves than stomatal resistance. The stomatal-resistance data from the north- and south-facing rows were averaged together and are presented in Fig. 3. Resistances were high on 13 March because of little rain during the preceding winter. Stomatal resistance of irrigated plants was high, too, because they did not receive the first spring irrigation until 20 March. Rain that fell on 9-10 April and 5 June resulted in low resistances for dryland plants.

Plant potentials. Differences in potentials of plants in rows on north and south sides of beds could not be detected and results have been averaged (Fig. 4). Irrigated plants had a higher water potential, and a higher osmotic potential, than did dryland plants. Dryland plants apparently took up large amounts of salts to adjust to the dry conditions (note the low osmotic potentials in Fig. 4). This resulted in their having a higher turgor potential, after 13 March, than that of the irrigated plants.

Yield. Table 1 shows the yield of the plants on 5 June 1978. Under both irrigated and dryland conditions, plants in south-facing rows yielded more than did plants in north-facing rows. On an average, wheat on south-facing rows under irrigated and dryland conditions, respectively, yielded 1.4 and 1.6 times more than wheat on north-facing rows. In some cases (for example, Centurk, irrigated), the yield was up to two times more when plants were on south-facing rows than when they were on north-facing rows. Day et al. (5) also noted that the south row position on east-west beds of irrigated wheat in Arizona, USA, had a higher grain yield than did the north row position.

The greater yield in this experiment was due to a greater number of spikelets and a greater number of filled grains (Table 2). Except for a few cases (for example, Triumph 64, irrigated; Vona, dryland), plants on south-facing rows had more total spikelets, more spikelets with at least one grain filled, more grains per head, and more potential grains per head.



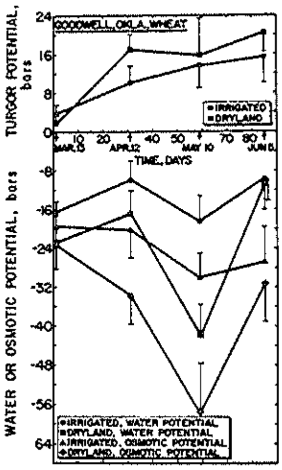


Figure 3. (Left). Stomatal resistance of irrigated and dryland winter wheat grown on east-west ridges. For vertical lines, see legend of Fig. 1. Figure 4. (Right). Water, osmotic, and turgor potential of irrigated and dryland winter wheat grown on east-west ridges. For vertical lines, see legend of Fig. 1.

Table 1. Weight of irrigated and dryland winter wheat heads, harvested 5 June 1978, on north and south sides of east-west ridges. Average coefficient of variation was 23%.

Cultivar	Irrigated North side	Irrigated South side	Dryland North side	Dryland South side
	g/30-cm of row			
Centurk	43.4	84.5	31.2	83.9
Scout 66	40.5	69.1	12.0	27.1
Tam W101	48.6	63.8	23.5	24.3
Triumph 64	61.6	65.3	29.9	33.3
Vona	74.6	81.6	26.9	29.7
Average	53.7	72.9	24.7	39.7

Table 2. Total number of spikelets per head, number of spikelets per head with at least one grain filled, number of filled grains per head, and number of potential grains per head of irrigated and dryland wheat on north and south sides of east-west ridges. Average coefficients of variation for the above four measurements were, respectively, 8%, 7%, 12%, 12%.

Cultivar & treatment	Total spikelets/ head	Spikelets/ head with at least one grain filled	No. of filled grains/ head	No. of potential grains/ head
Centurk				
Dryland				
North	13	10	25	31
South	14	13	31	32
Irrigated				
North	13	11	25	27
South	12	11	26	28
Scout 66				
Dryland				
North	11	5	11	21
South	11	9	18	24
Irrigated				
North	12	7	16	24
South	14	13	31	33
Tam W101				
Dryland				
North	10	7	15	19
South	12	6	11	21
Irrigated				
North	11	9	20	22
South	12	10	20	24
Triumph 64				
Dryland				
North	12	10	19	22
South	12	11	22	24
Irrigated				
North	13	12	28	29
South	13	10	24	26
Vona				
Dryland				
North	14	6	15	32
South	14	6	13	28
Irrigated				
North	13	12	35	36
South	13	12	35	37

DISCUSSION

The results showed that plants on south-facing rows in ridges tilled in the east-west direction grew taller, had a cooler leaf temperature, and yielded up to two times more than plants on north-facing rows in the same ridges. Plants on south-facing rows probably grew and yielded more because they could absorb more of the sun's energy than could plants on the north-facing rows. South-facing plants produced more photosynthate which resulted in more grains per head than north-facing plants. Light, therefore, might have been partially limiting growth of plants on north-facing slopes. However, the major cause of increased growth of south-facing plants might have been due to temperature rather than light. On 12 April, for irrigated plants, the soil temperature at the 20-cm depth, at the base of the south and north slope, was 19 and 15°C, respectively, and for dryland plants, 21 and 17°C, respectively. On 10 May, plants shaded the soil and differences in soil temperature at the 20-cm depth on north and south slopes could not be detected. As wheat-root temperatures increase from about 15 to 25°C, stomatal conductance increases linearly (9). Therefore, the warmer root temperatures probably resulted in the cooler leaf temperatures of south-facing plants, which transpired more water than north-facing plants. It has been known for a long time that growth increases with increase in temperature, up to an optimum (1,12). The results of this study suggested that it might be worthwhile for farmers in the Panhandle to till the ground into east-west ridges and plant only on the south sides of the slopes. The north-facing slope could be steep so a minimum amount of land would not be planted. Fertilizer could be placed only on the south sides of ridges to ensure maximum growth.

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RIDGING FOR POTATOES

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Abstract
Ridging is an important tillage operation in potato cultivation. The quality of the ridge can be characterized by soil texture, tilth, size and shape of the ridge. In view of prevention of capping and clods, soils with 10-25% clay are most suitable for potato production. Clods larger than 20 mm should be reduced to minimum; the presence of aggregates below 1 mm is advantageous for sprouting. The optimum ridge size is 600 cm^2 of loose soil in cross section. A slightly flattened top of the ridge improves the temperature and the moisture content at seed tuber level. Increase of row spacing allows a reduction of working depth at seedbed preparation, but is accompanied by a yield reduction of 3-4% for ware potatoes and 5-6% for seed potatoes.

REASONS FOR RIDGING

Potatoes are generally grown on ridges. There are many reasons to do so: As a prerequisite for mechanical harvesting; to lessen the damage of tubers by tyres; to reduce the amount of green tubers and the infection by P.infestans; to protect the tubers from the tuber moth in the tropics; to keep the good soil on top and to improve the structure of puddled and capping soils; to reduce salt injury; to control weeds and to bury organic matter; to facilitate drainage in humid areas and furrow irrigation in dry zones; for soil and water conservation, especially by tied ridging.
With regard to growing conditions ridge quality can be characterized by ridge size, ridge shape and the tilth of the loose soil in the ridge, aspects that are mainly influenced by soil texture and by tillage operations.

SOIL TEXTURE AND SOIL TILTH

Though p.t.o. driven implements have improved results of seedbed preparation, sufficient crumbling of heavy soils is still often a problem. Therefore ridges on these soils are often relatively small and cloddy and are accompanied by relatively low moisture contents and by a low moisture conductivity.

Clod size distribution influences greatly the germination and growing of potatoes. Especially the fraction < 1 mm (25% in The Netherlands) is accompanied by a relatively high moisture content(Kuipers, 1961).To prevent sealing or capping of the surface, the tilth on the light soils should not be too fine. Ridges with a coarse tilth are drier and the daily mean soil temperature at seed tuber level is lower than in ridges with a fine tilth. Differences in moisture content decrease during the growing season, but increase after long dry periods(Fig.1). Differences in temperature disappear after completion of the ground cover(Fig.2). Emergence and growth can be delayed considerably by a coarse tilth(Table I)(Kouwenhoven,1978).

Table I. Soil tilth, growth and yield

Tilth	Fine	Coarse
Length of stems, cm	69.7	78.4
Number of stems per plant	5.3	4.8
Number of tubers per plant	9.2	8.9
Tuber weight, g	128.3	123.7
Underwaterweight,g	380	375

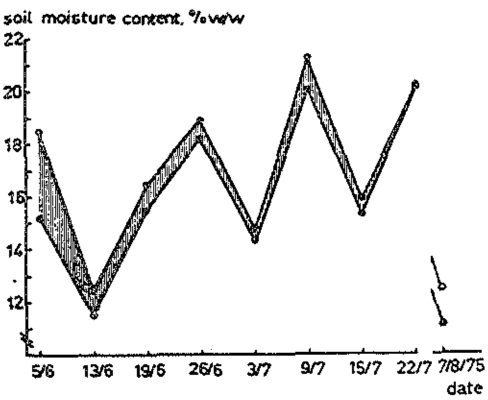

Fig 1. Soil moisture content in the ridge as influenced by coarse (•) and fine (o) tilth on different dates during the growing season.

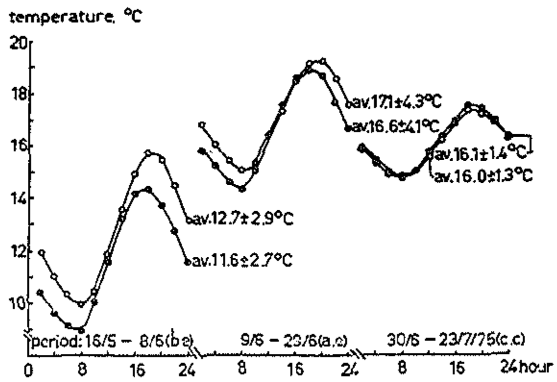

Fig. 2. Average daily course of soil temperature at seed level (11 cm soil covering) over 3 periods: before emergence (b.e.), after emergence (a.e.) and at completion of ground covering (c.c.) with coarse (•) and fine (o) tilth.

RIDGING

Ridging should commence early, sometimes even during planting or just after planting. Surface irrigated potatoes have to be ridged at planting; with sprinkler irrigation ridging can be carried out as the plants appear above the ground. Earthing up should be finished by the time the plants are 25 cm high. As potatoes are very sensitive to root damage and compaction, the number of inter-row cultivations should be reduced to minimum. Without chemicals 3-4 cultivations are sufficient for weed control.

RIDGE SIZE

Especially ridge size can be considered to regulate potato growth. Ridge size is often characterized by its height, but the area of loose soil in cross-section is to be preferred for ridge size indication.

Generally, large ridges have a higher moisture content and hold more water than small ridges(Fig.3). The moisture content within the ridge increases from the top to the bottom of the ridge(Kouwenhoven, 1978). Daily mean temperatures decrease from the top to the bottom of the ridge(Table II). Temperature differences are more pronounced at the beginning of the growing season than later on.

Under conditions where soil moisture content is sufficient for sprouting, increase of ridge size delayes emergence at a rate of 1 day per per 2-4 cm of soil covering.

Table II. Ridge size, planting position and temperature, ^{o}C

Position -top of the ridge, cm	Large ridge	Medium sized ridge	Small ridge
10	19.0	18.7	18.2
15	18.4	18.0	--
20	17.9	--	--

Total tuber yield increases with an increasing ridge size to 600 cm^2 in temperate regions and decreases again with a further increase of ridge size(Fig.4). If the soil is loosened to a depth of 10 cm and 20% is compacted during planting, 8 cm is left, being sufficient for ridges of 600 cm^2 of loose soil in cross section with 75 cm row spacing.

If the ridges contain a considerable amount of clods and stones, the optimum ridge size will be larger(Kouwenhoven &

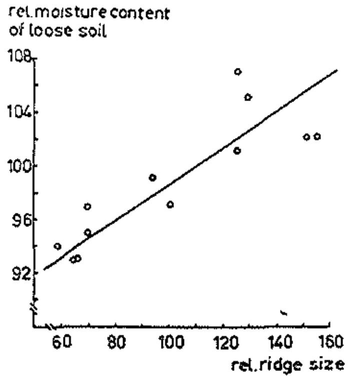

Fig. 3. Relative soil moisture content (100 = 20.7 % w/w) as influenced by the relative size of the ridge (100 = 580 cm²).

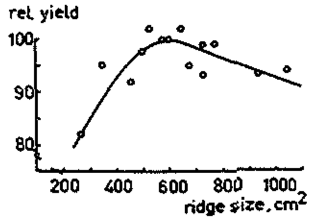

Fig. 4. The optimum ridge size, indicated by the maximum relative yield (100 = 51.1 tons/ha) in field experiments.

Van Ouwerkerk, 1978).

RIDGE SHAPE

Ridge shape should be adapted to the shape of the cluster and to climatic conditions: Under dry conditions a flat top and even a furrow on top to catch water is preferred;under wet conditions ridges are given a sharp top to facilitate drainage. In flat ridges moisture content is higher than with sharp ridges of the same size. Strongest differences are observed before complete ground cover is obtained(Table III).

Table III. Shape and moisture content of ridges of the same size(average 19/5 - 20/8/'76),% w/w

Shape of the ridge	Sharp	Medium	Flat
Moisture content	15.0	16.0	16.2

The daily mean temperature at seed tuber level in the beginning of the growing season and the mean temperature fluctuation increased with an increasing flatness of the ridges. After completion of the ground covering by foliage, the opposite was found(Fig.5). The high temperature and moisture contentat seed tuber level and the shorter way to go for the sprouts to reach the surface, shortens emergence time as the ridge becomes more flat.

Increase of flatness is accompanied by an increasing number of tubers, a slightly increasing total tuber weight per plant, but also by a decreasing weight per tuber, more green tubers and more second-growth(Kouwenhoven, 1978).

ROW SPACING

Row spacings for potatoes vary considerably: From 62.5 cm in Germany(Scholz, 1971) to even 105 cm in England(Anon., 1974). In view of weed control, narrow row spacings are preferred. However, reasons of mechanization and irrigation lead to wide row spacings. Powerful tractors of more than 100 kW are accompanied by wheelspacings of 180-210 cm and tyre widths of 40-70 cm. This requires an increase of row spacing and a widening of the furrows to avoid compaction of the sides of the ridges(Fig.6)

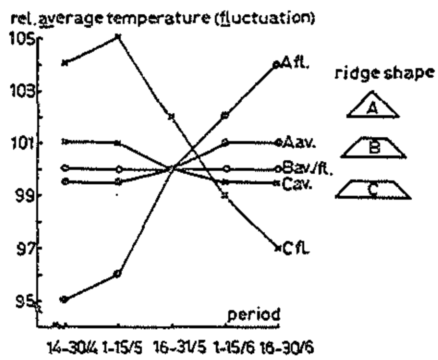

Fig.5. The relative daily average temperatures (av) and average daily temperature fluctuations (fl), as influenced by ridge shape during different periods of the growing season.

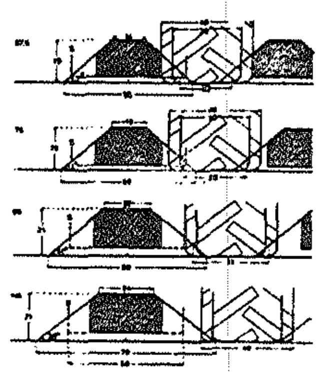

Fig. 6 Ridges, furrows and tractor tyres at various row spacings (a = shape) (shaded = area of potato cluster).

Kouwenhoven & Van Ouwerkerk(1978) found that full ground covering was delayed by 2 to 2.5 weeks when the row spacing increased from 75 to 105 cm. Cluster width increased only very slightly(Fig.6).

The gross yields decreased with 3-4% with 90 cm row spacing and with 5-6% with 105 cm row spacing, compared with 75 cm rows. Row spacing had a much stronger effect on nett saleable yield in a year with many rejects and with seed potatoes, than on gross yield of ware potatoes.

DISCUSSION

The increase of saleable yields with increase of row spacing, reported from England(Jarvis, 1971,1972), may be attributed to the relatively small ridge size(about 540 cm^2, Jarvis, 1972) found with 75 cm rows. Moreover stones and clods reduce the effective size of the ridge. With ridge sizes of 600-700 cm^2 of loose soil, row spacings of 75 and of 90 cm gave similar gross yields(Fig.7).

In trying to overcome the detrimental effects of deteriorating plant arrangement with increasing row spacings,

best results were obtained by heavier nitrogen dressings (Kouwenhoven & Van Ouwerkerk, 1978).
The fact that a ridge size of 600 cm^2 is sufficient for all row spacings(with Bintje) means, that the depth of soil to be loosened in spring decreases with an increase of row spacing(Fig.8). Through that the soil can be worked earlier, with less chance of producing clods.

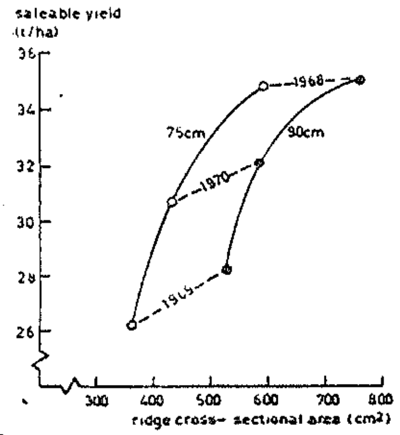

Fig. 7 . Ridge size and saleable yield of ware potatoes grown at two row spacings (according to Jarvis, 1972).

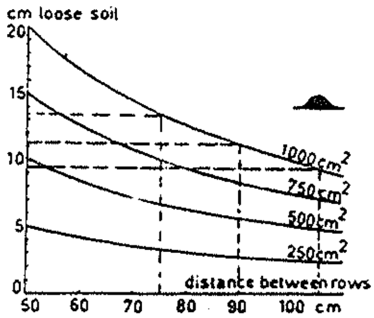

Fig. 8 Loose layer and ridge size in relation to the distance between the rows.

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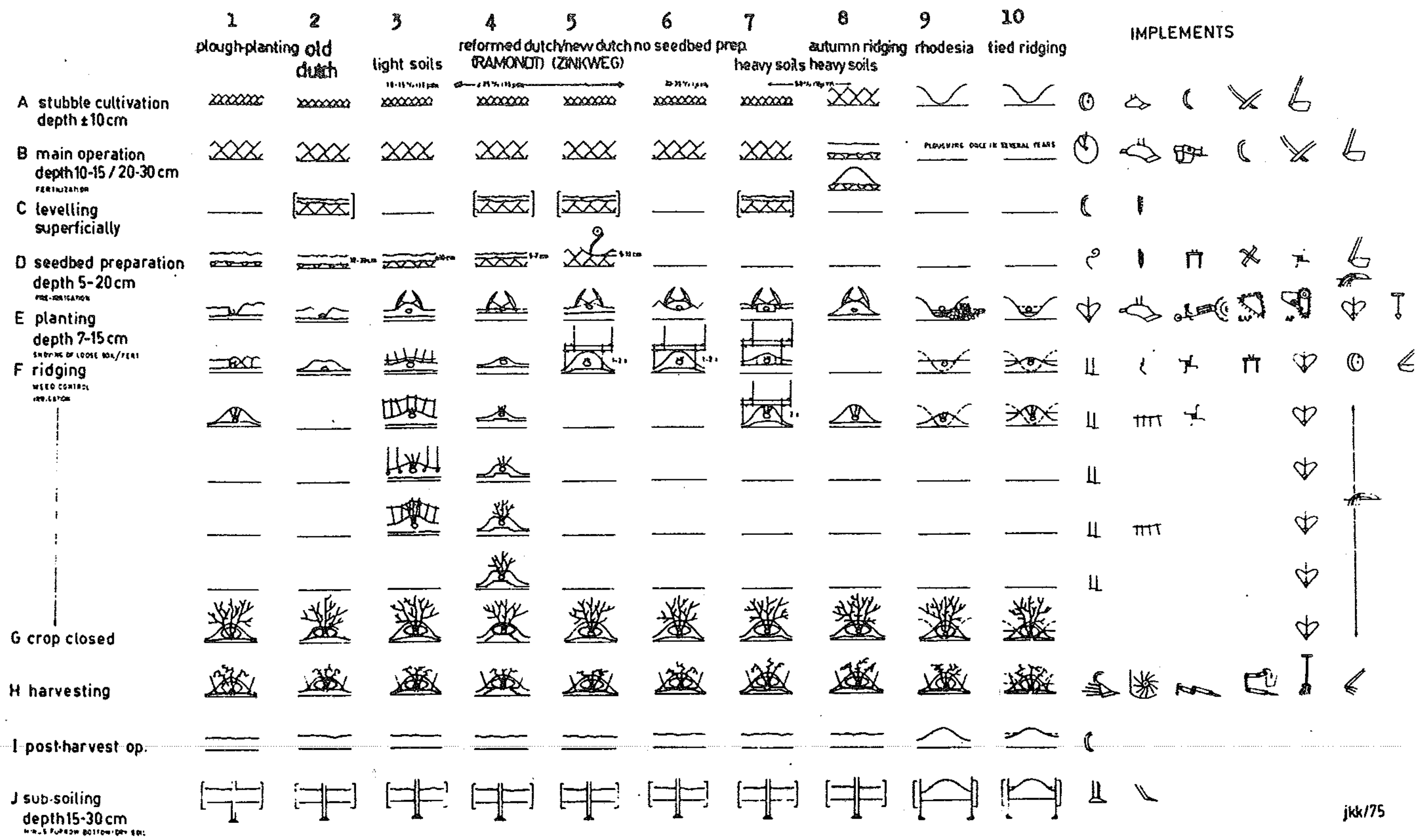
Wageningen, spring 1979

SOIL TILLAGE SYSTEMS FOR POTATOES



The 8th Conference of the International Soil Tillage Research Organization
September, 1979, Stuttgart, Fed. Rep. of Germany

AN EVALUATION OF FOUR TILLAGE SYSTEMS ON PINEVIEW CLAY, A FINE TEXTURED SOIL IN THE CENTRAL INTERIOR OF BRITISH COLUMBIA

by

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INTRODUCTION

The Pineview clay association covers an area of over 100,000 hectares in the Central Interior of British Columbia (latitude 54^{0}). The soil is an Orthic Grey Luvisol (Albic Luvisol) and contains around 55% clay. Its Bt horizon is located between 15 and 35 cm and contains 70% clay. Major problems with this soil are: poor soil structure, shallow rooting depth, presence of a 2-3 cm layer of thatch on top of the soil, and consequently slow soil warming in the spring. Tillage research was undertaken upon request of local agricultural extension people. This paper presents result from tillage research in 1978 which evaluated tillage systems in terms of changes brought about in soil physical properties.

MATERIALS AND METHODS

The site was a 1.1 hectare plot which had not been cultivated nor fertilized for 17 years. Four tillage systems were tried as fall treatments:

1. moldboard plowing using a sod breaking plow (M);
2. rotovating to a depth of 3.5 cm prior to moldboard plowing (R + M);
3. chisel plowing (Ch); and
4. rotovating to a depth of 3.5 cm prior to chisel plowing (R + Ch).

Both moldboard plowing and chisel plowing were carried out at a depth of 10 cm. The plots were harrowed twice during the following spring. They were further fertilized with four nitrogen rates; 0, 56, 112, and 168 kg N/ha in the form of urea (46-0-0). Barley (*Hordeum vulgare*) was seeded in the plots at a rate of 90 kg/ha. Included with the barley seed was a band application of 75 kg/ha of ammonium phosphate (11-48-0). Soil temperatures were measured at 5, 10 and 50 cm depths twice daily using diodes.

RESULTS

SOIL PHYSICAL PROPERTIES

Table 1 lists how various soil physical properties were affected by tillage systems.

Table 1. The effect of tillage treatment on soil physical properties between 2½ and 10 cm depths.
(M = moldborad plowing, R + M = rotovating + moldboard plowing, Ch = chisel plowing, R + Ch = rotovating + chisel plowing)

Analysis		Tillage Treatments				
		M	R + M	Ch	R + Ch	L.S.D.0.05
Aeration Porosity, %						
(pF 1.8)	May 11	20.4	15.6	10.0	9.1	4.0
	Aug 14	22.3	20.7	15.0	15.8	4.1
Bulk Density, kg/m3						
	May 11	897	903	1027	1090	53
	Aug 14	897	907	980	1000	52

The M treatment resulted in substantially higher aeration porosities than the other treatments, particularly the Ch and R + Ch treatments. Rotovation prior to either moldboard plowing or chisel plowing or chisel plowing initially reduced the aeration porosity, but by August 14 there were no significant differences due to rotovation. It should be pointed out that on May 11, one week after seeding, aeration porosities in the Ch and R + Ch plots were at or below the 10% level which is generally considered limiting for adequate crop growth. Aeration porosities increased during the experiment in all treatments. Between May 11 and August 14 precipitation had been scarce (37 mm per month) causing the soil to dry substantially. It is quite possible that soil shrinkage was responsible for the increase in aeration porosity by expanding or creating larger soil pores at the expense of smaller pores. Soil bulk densities in all treatments were quite low and certainly not limiting for crop growth. The M and R + M treatments did however result in lower bulk densities than the Ch and R + Ch treatments. The higher aeration porosities and lower soil bulk densities found in the two moldboard plow treatments can be explained by the mechanics of the tillage operation and by frost action. The moldboard plow treatment is a once-over operation which leaves the bare soil surface exposed to frost action during the winter months. In the chisel plow treatments four passes had to be made before adequate soil break-up had been achieved. This large number of passes may result in soil compaction or plow pan formation. The chisel plow plots also did not leave a bare soil surface but had a mulched soil surface which likely reduced the beneficial effects of frost action during the winter months. The M and R + M treatments thus resulted in a more aerated soil structure than the Ch and R + Ch treatments. Soil temperatures were found to be 1^{o} - $1\frac{1}{2}$ ^{o}C warmer at the 10 cm depth during the first five weeks of the experiment in the M and R + M plots compared with the Ch and R + Ch plots (Figure 1). A better aerated soil structure together with the bare soil surface in the M and R + M plots can explain the higher soil temperatures. By the seventh week of the experiment the barley canopy in the M and R + M plots likely reduced soil warming to a greater extent than the thinner canopy found in the Ch and R + Ch plots.

NITRIFICATION

Nitrification is dependent on soil aeration and soil temperature. Average soil NO_3-N values during the experiment were: 30, 29, 26 and 27 kg/ha (L.S.D. 0.05 = 1.8) for M, R + M, Ch and R + Ch respectively. Barley growing in the M and R + M plots not only benefitted from higher levels of soil NO_3-N but due to better soil physical conditions also reached rooting depths twice as deep, 8 cm, as those in the Ch and R + Ch plots (4 cm).

SILAGE BARLEY YIELD

The effect of superior soil physical environment achieved with mold-board plowing resulted in substantially higher yields of barley (Table II). The M treatment even at zero fertilizer nitrogen resulted in higher yields than the other tillage treatments regardless of nitrogen rate. These results indicate that in terms of crop growth, the beneficial effects of better soil physical conditions outweighed that of the added chemical fertilizer.

ECONOMIC ASSESSMENT

In order to carry out an economic assessment of the treatments, the values of the silage barley yields were expressed in dollars per hectare and the total treatment costs were computed (Table II). Treatment costs include all operations such as tillage work, fertilization and harvesting. The M treatment resulted in the highest yields and the lowest costs, thereby giving the largest profits. The R + M treatment resulted in lower yields and was also more costly than M which substantially reduced profits. The Ch treatment had also lower yields and high costs due to the large number of passes required with the chisel plow. Profits in this treatment were subsequently quite low. Yields with R + Ch were quite similar to those with Ch, however the cost of rotovation caused profits for this treatment to be lowest of all the treatments.

SUMMARY

Moldboard plowing resulted in superior soil physical conditions compared to chisel plowing. Rotovating prior to either moldboard plowing or chisel plowing did not result in any major differences in either the soil physical or chemical properties other than reducing the beneficial action of moldboard plowing. Silage barley yield was substantially higher with moldboard plowing than with chisel plowing. Rotovation prior to moldboard plowing reduced yields compared to just moldboard plowing. Chisel plowing with and without rotovation resulted in similar yields which were substantially lower than those with either moldboard or rotovating + moldboard plowing. Moldboard plowing was also the cheapest of the treatments, followed by chisel plowing and rotovating + moldboard plowing. Rotovating + chisel plowing was the most expensive treatment. Moldboard plowing resulted in the highest profits at all levels of fertilizer nitrogen. Rotovating + chisel plowing resulted in the lowest profits.

Table II. Economic analysis of tillage/fertilizer treatments

Tillage/fertilizer (kg/ha)		Barley yield (t/ha)*	($/ha)**	Treatment cost ($/ha)	Profit ($/ha)
M	0	17.1	263	89	177
	56	19.9	307	109	198
	112	21.9	338	129	209
	168	20.3	313	149	164
R + M	0	10.5	162	113	49
	56	15.6	241	136	105
	112	15.6	241	156	85
	168	15.6	241	176	65
Ch	0	9.7	150	108	42
	56	11.2	173	130	43
	112	11.6	179	150	29
	168	15.6	241	170	71
R + Ch	0	10.5	162	123	39
	56	12.0	185	146	39
	112	13.1	202	166	36
	168	12.1	191	186	5
L.S.D.	0.05	1.9			

* Yields are expressed at 65% moisture content

** Market value for silage barley estimated at $15.42/tonne

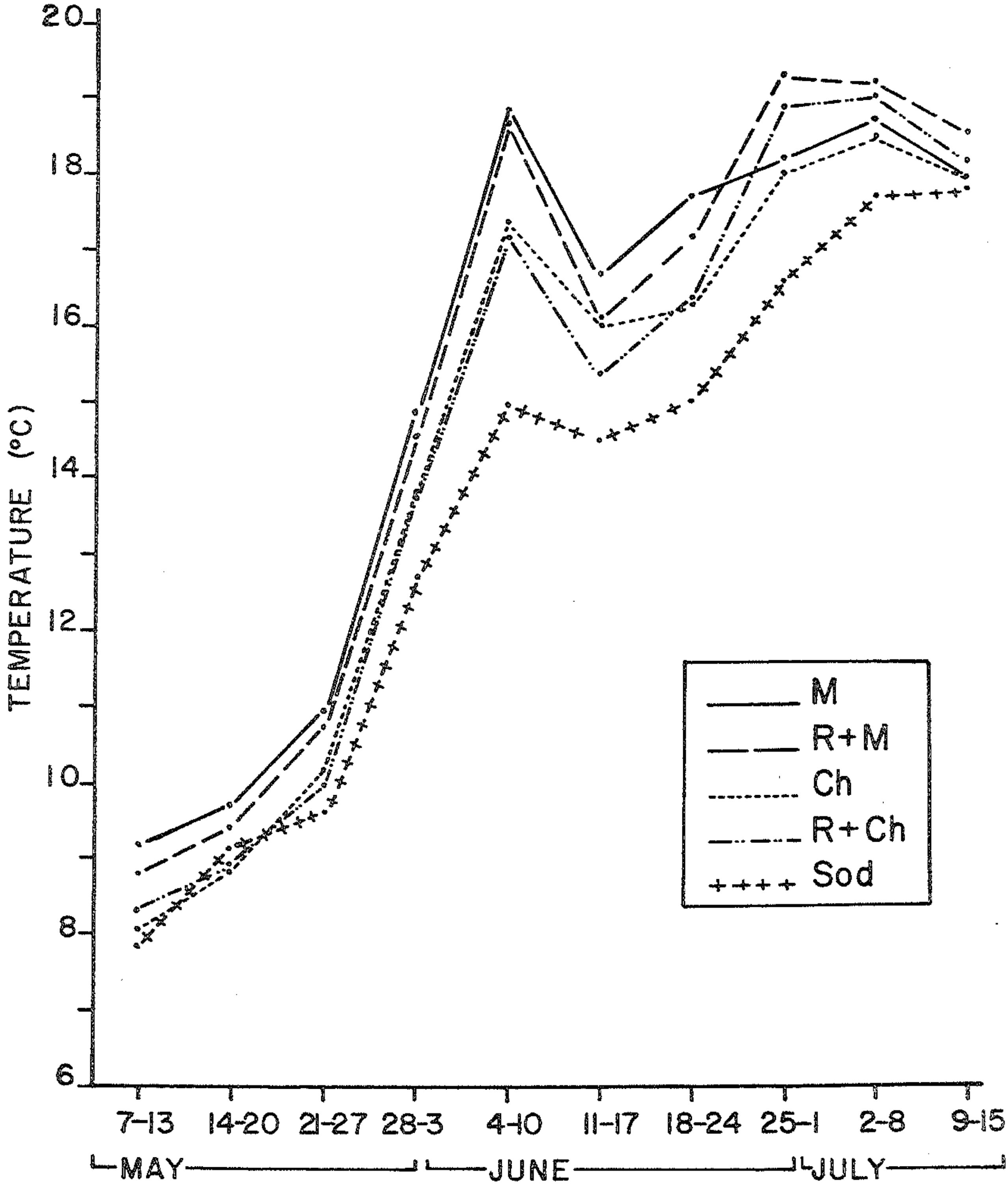

Figure 1. Soil temperatures at 10 cm depth during the 1978 growing season. (Values represent averages from 3 locations)

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THE WORKABILITY OF THE SOIL IN SPRING IN RELATION TO MOISTURE CONTENT AND MOISTURE TRANSPORT

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Abstract

Soil workability in spring is important in view of organization of work and crop yield. This property was evaluated using visual estimation, and measurements of plasticity and water content. The distribution of the water in the top layer greatly affected workability in spring; capillary transport of water plays an important role.

Data were obtained about the ideal situation for seedbedpreparation. It was shown that capillary transport was influenced by several factors. The influence of drainage and actual soil structure was studied, the former by using the results of Rijtema, and the latter by measuring the hydraulic conductivity in samples with different actual soil structure using the Arya-Ehlers method. The distribution of the water content in the top layer could be calculated by a graphical procedure, described by Bouma.

1. *Introduction*

For sowing or planting crops in spring, the soil must be in a condition suitable for the tillage operations desired. This means that it must be possible to crumble the upper 5-10 cm of the soil in such a way that a good seedbed is obtained and also that the whole top layer (0-20 cm) must be stable enough so that implements can be used without harmful compaction.

The earlier the farmer can have a good seedbed ready the better, because that means, certainly in West-European countries, that he has a longer period available to get his crop in and also that in most years crop growth and yields will be better.

If the farmer starts too early, at a moment that the soil cannot be crumbled and is not stable enough to resist compaction, the actual soil structure will not be optimal for good plant growth.

Therefore it is important to know when the soil satisfies the condition of good workability and how to get that condition as quickly as possible in spring.

2. *Workability, moisture content, and moisture tension*

It is well known that workability depends on moisture content or moisture tension. A wet soil is plastic and can easily be deformed, but not be crumbled. A decrease in moisture content results in a more crumbly, less plastic state. The moisture content and moisture tension, at which the transition occurs is an important value with respect to the workability and undoubtedly to the trafficability of the soil in spring. It fairly accurately represents the point at which the soil is suitable for soil tillage in spring. That transition value corresponds with the lower plastic limit, a parameter that was often determined in the past. Together with the moisture content in the field (or at pF 2) it gives a good indication of the workability.

Other methods exist, e.g. the use of the plasticity meter or a visual estimation (fig. 1 and 2) in combination with a measurement of moisture content and moisture tension.

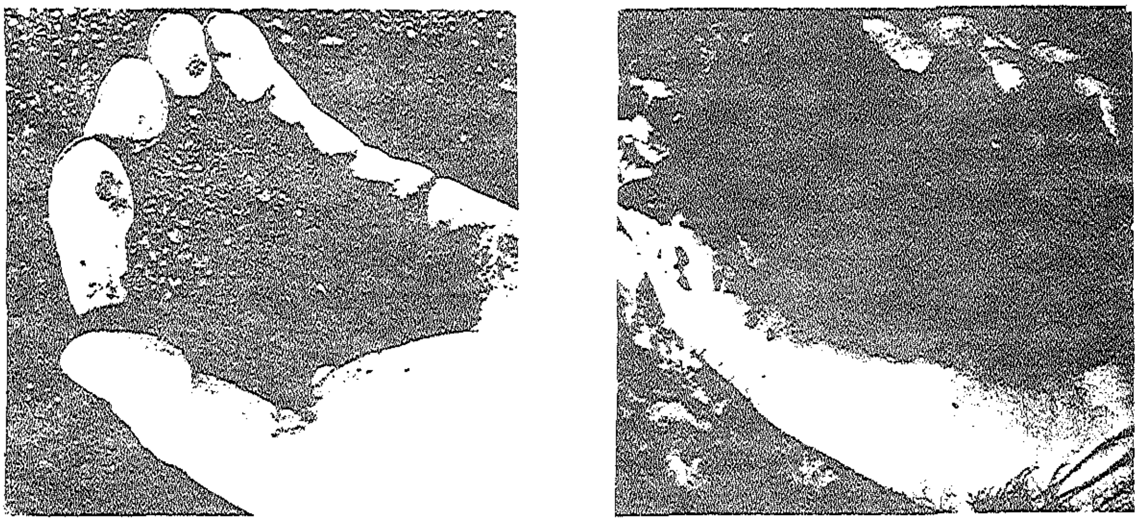

Fig. 1. Estimation of the workability of soil.

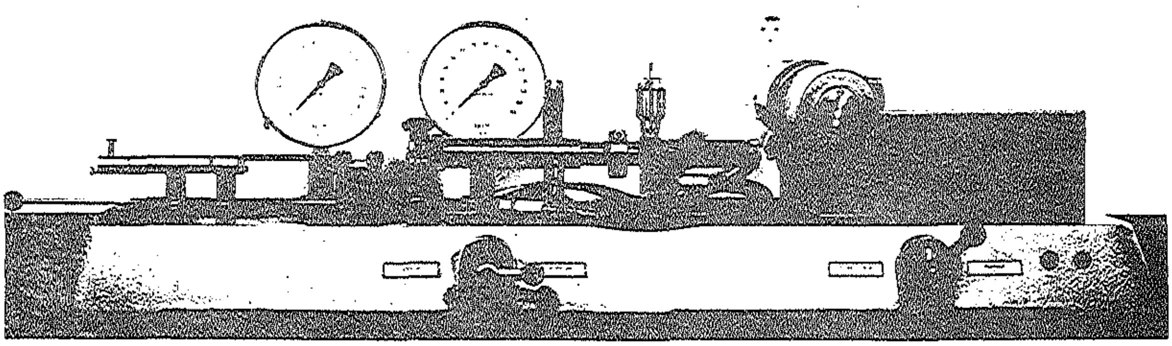

Fig. 2. Apparatus for measuring plasticity

The relation found for a clayey soil is given in fig. 3. It is known that a workability valued at 6, is sufficient for crumbling and gives sufficient resistance against pressure. This corresponds with a pressure potential of about 400 cm (pF 2.6). But what can be done with this result in the field?

3. Moisture content in the field

Most years the moisture content of the topsoil in early spring is higher than the threshold value mentioned before. This water surplus depends on soil type and depth of water table. It must be removed by evaporation. But this results in a situation with an uneven

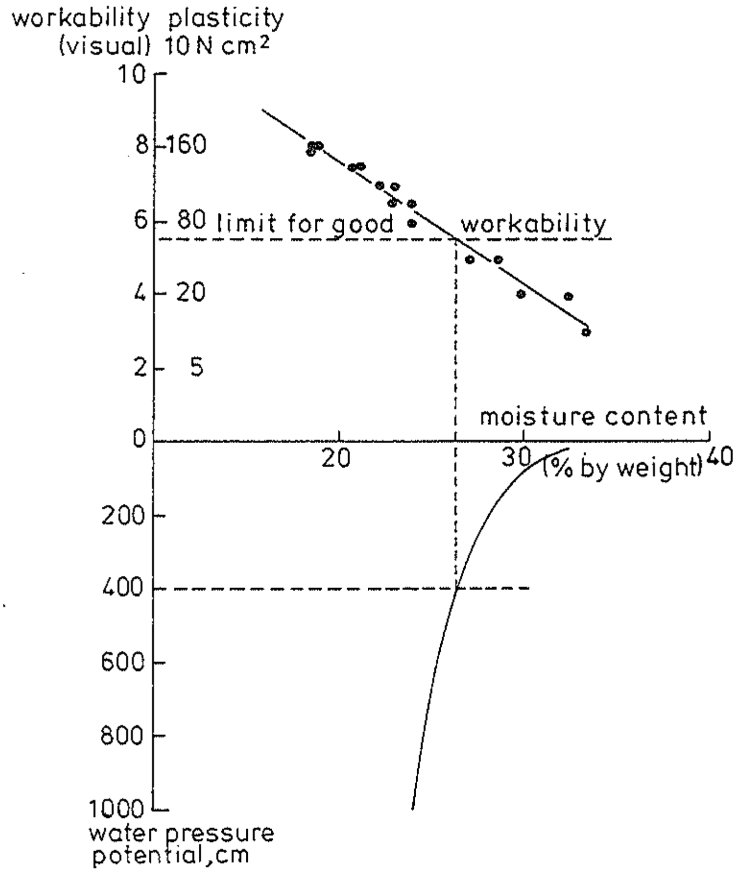

Fig. 3. Relation between workability, water content and moisture tension

distribution of water content and water tension in the top layer. The differences in moisture content in the top layer after a few days of evaporation depend on the possibility of moisture transport in the unsaturated zone. If transport is large, a rather uniform moisture distribution can be expected, if it is low this is not the case (fig. 4).

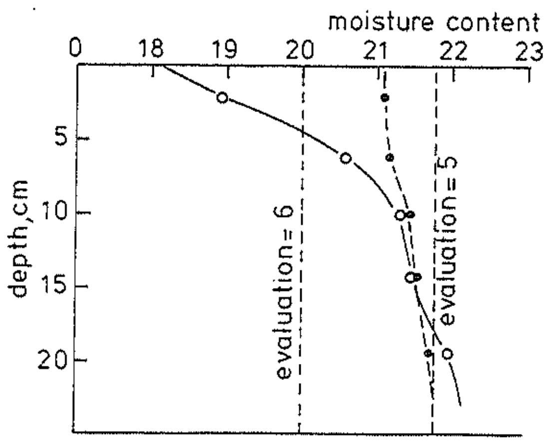

Fig. 4. Moisture distribution in the top layer as a result of differences in capillary water transport.

Then the question arises which moisture distribution is desired or acceptable in spring for the preparation of a good seedbed.

4. Moisture distribution and seedbed preparation

To prepare a good seedbed, the upper 5-10 cm (thickness depending on the crop and the accessory tillage) must be dry enough for crumbling; this means that the workability value must be 6^- or more.
The next 10-15 cm must be dry enough to prevent harmful compaction. The question was which condition was acceptable and which conditions had sufficient resistance against the pressure of the tractor and other wheels and the vibrating action of the tillage implements.
To get an impression about this some measurements were carried out in the field. The compaction of the soil in tracks of tractorwheels was determined. It was done at two points in time, when the moisture distribution in the furrow was quite different.
Results obtained in several cases, are given in table 1.

Table 1. Compaction at two different soil moisture distributions.

Depth cm	Moisture content	Pressure potential	Workability value	Bulk Density g/cm^3 before tillage	after tillage in track	after tillage between tracks
0- 5	21.3	1000	6^+	1.10	1.25	1.16
5-10	30.1	120	5			
10-15	33.3	80	5^-	1.18	1.26	1.23
15-20	33.5	75	$4\frac{1}{2}$			
20-25	35.8	70	$4\frac{1}{2}$			
0- 5	26.6	400	$5\frac{1}{2}$	1.14	1.37	1.18
5-10	29.4	150	5			
10-15	31.8	100	5	1.17	1.39	1.12
15-20	31.6	100	5			
20-25	31.6	100	5			

On a soil with a rather dry top layer of 5 cm - low moisture content and high workability value - compaction in tracks of wheels is much less than on soils with a more uniform moisture content distribution in the top soil but with a higher value in the top 5 cm. This indicates that a dry layer with a more than sufficient workability value ($6-6\frac{1}{2}$) protects the deeper layers against compaction, also when these layers are rather wet and plastic (workability value $4\frac{1}{2}-5^-$). Another advantage of this situation is that only a small amount of water has to be removed (difference is 5 mm) and more water is left in the soil for germination and first growth of the plants.

5. Factors affecting moisture content and moisture transport

It is well known that factors like composition of the soil and drainage have an effect on content and transport of water. Especially drainage was found to be an important factor. From values of moisture content and hydraulic conductivity in table 2 it can be concluded that surplus of water as well as hydraulic conductivity plays a part here.

Table 2. Some values of moisture content and hydraulic conductivity of a silty clay soil with a groundwater table at 30 and 100 cm, K_0= 1.5 cm/day, α= 0.024, according to Rijtema

	with groundwater table in spring at	
	30 cm	100 cm
moisture content in equilibrium with the groundwater table (vol %)	41.0	37.2
workability limit (vol %)	34.5	34.5
surplus of water (vol %)	6.7	2.7
hydraulic conductivity (cm/day)	1.4	0.14

In view of the fact that content and transport of water are affected by the composition of the soil (organic matter and clay content, lime status) it was to be expected that actual soil structure (spatial arrangement of the particles) also affects these properties. It is a known phenomenon in practice, but the question is which situation is needed to get a hydraulic conductivity, which is small enough to prevent replenishment of the loss of water by evaporation in the top 5-10 cm. To get some information about this, the hydraulic conductivity of soils with different actual soil structure was determined. For this purpose the method described and used by Ehlers was used. In this method, a core sample is exposed to a warm air stream, giving a high rate of evaporation. After about 15 minutes the moisture distribution is determined and the hydraulic conductivity at several suctions can be calculated. Fig. 5 shows relationships between hydraulic conductivity, K, the pressure head, h, for the same soil but with a different actual soil structure.

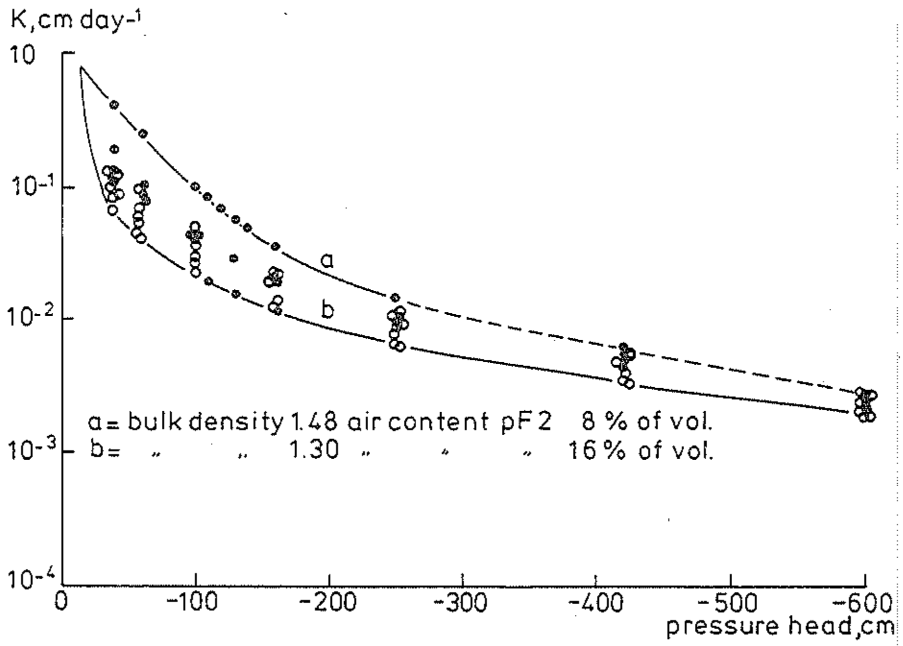

Fig. 5. Effect of actual soil structure on capillary water transport

From these relationships and with the use of a simple graphical procedure described by Bouma and based on the formula:

$$Z_n = -\int_{ho}^{hn} \frac{dh}{1+\frac{V}{K}}$$

in which Z_n is the height above a reference level at which the pressure hn is to be found, K is the hydraulic conductivity, (cm day^{-1}) and V is the flux (cm^3 cm^{-2} day^{-1}), the height above a reference level at which a certain pressure head hn will occur can be calculated.

Taking as reference level the bottom of the top soil layer of 25 cm having a suction of 100 cm water, and choosing a steady flux v. of 0.15 cm (a normal evaporation in spring) the results shown in fig. 6 are obtained.

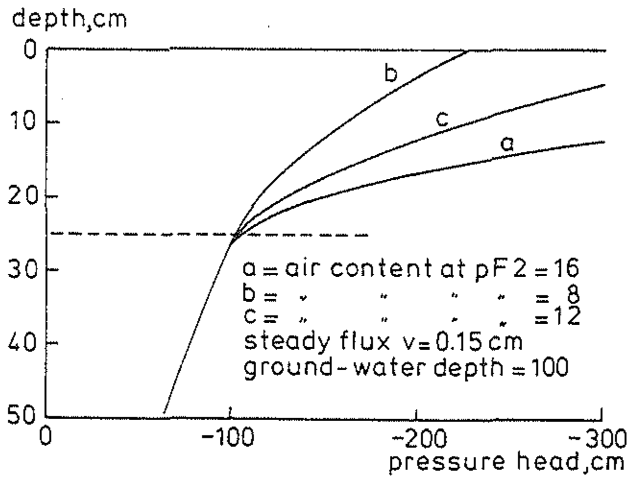

Fig. 6. Influence of actual soil structure on moisture distribution in top layer.

A rather loose soil with a bulk density of 1.32 g cm^{-3} and an air content at pF 2 of 16% by volume reaches the desired situation in a few days of dry weather and an evaporation of a few millimeters, where a dense soil with a bulk density of 1.50 and volumetric air content of 8% gets a pressure head in the top 10 cm of -160 to - 220 cm water. This is much too high for a good workability.

This means that for sufficient and fast drying up of the topsoil in spring, this clayey soil must have an actual soil structure with a volumetric air content of about 15%. There are indications that for sandy soils the same is true. Of course it is not necessery for the whole topsoil of 25 cm to have such an actual soil structure, but this will be sufficient for the top 5-10 cm. Against this background it is an interesting task to determine which soil tillage system must be used to arrive at the required situation.

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ARE YIELDS ON PLOWED LAND DEPRESSED BY PHYSICAL CONDITIONS AND PHOSPHORUS AVAILABILITY AT PLANTING DEPTH?

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ABSTRACT

A single autumn plowing followed by a liquid N-P fertilizer application prior to seedbed preparation of wheat and of cotton in a dryland wheat-cotton-wheat rotation, failed to increase the yields above those obtained on soil disked annually and fertilized at the same rate. Only the first two crops in the rotation were fertilized. The field experiment was carried out with three treatments in four replications on a fine-textured soil with a relatively high water table.

The main reasons for the failure to obtain yield increases of the crops with a single plowing in the crop rotation above those of the crops on only disked soil, were considered to be related to:

a) the deeper average planting depth of wheat in a seedbed prepared after plowing;

b) the lower bicarbonate-soluble P in the topsoil layer of a seedbed prepared after plowing; and

c) the favorable soil moisture conditions for growing dryland cotton in this area, with no cotton yield response to tillage practices.

If this soil has to be plowed in autumn for weed control, more attention should be paid to prepare a seedbed with a finer aggregate structure and to ensure (a) adequate P-availability in the topsoil layer of the seedbed prior to wheat planting at shallow depths of 3 to 4 cm, and (b) optimal conditions for initial growth after the top soil has been wetted by the first rainfall.

INTRODUCTION

Phosphorus fertilizer applied prior to plowing, was found to be unevenly distributed with tilled soil depth after plowing, resulting in a relatively low level of available-P at planting depth and in retarded initial growth of seedlings (2-7). Young seedlings need readily available-P in the topsoil layer; also, P-uptake by roots is more efficient in the early than in the later stages of growth (4). Moreover, P-uptake by plants is dependent on the status of other nutrients in the soil (1). Planting depths for high-yielding wheat varieties have become shallower and the present recommended depth is 3-4 cm.

This paper reports the results of a field experiment in which liquid N-P fertilizer was applied after autumn plowing and prior to

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planting. The yielding potential with this practice was compared with that on only disked soil with the same amount of applied N-P fertilizer (5) under semi-arid climatic conditions.

MATERIALS AND METHODS

The experiment was carried out in the central part of the Yizre'el Valley, where soil (Pelloxererts) has a high clay content of 63% and soil moisture is influenced by a relatively high water table fluctuating between 2.5 m in summer and 1.5 m in winter. Average annual precipitation is 600 mm. Tillage and crops preceding the experiment were autumn plowing in 1968; dryland cotton in 1969; and a fodder crop in winter 1969/70. The experiment consisted of three tillage treatments on 12 x 40 m plots, in four replications in a randomized block design. A dryland-crop rotation of wheat-cotton-wheat was grown from 1970 to 1973. The tillage treatments are shown in Table 1.

Table 1: Experimental setup of tillage and fertilizer treatments.

Year	Tillage treatments			Fertilizer applied on seedbeds of all treatments
	I	II	III	
1970	plowed	disked	disked	liquid N-P
1971	disked	plowed	disked	liquid N-P
1972	disked	disked	disked	—

For the first two years liquid fertilizer (12.5 - 12.5 - 0) was applied at a rate of 500 kg/ha prior to seedbed preparation and disked into the soil. At various times ten soil samples per treatment were taken to a depth of 15 cm to determine bicarbonate-soluble P concentration according to the method of Olsen-Bray. Four 1-m row-length samples of wheat seedlings per treatment were taken to determine dry matter production. Wheat yield was determined from 160 m^2 and cotton lint from 80 m^2 of each treatment. Local spring wheat var. 1177 was planted in autumn 1970, cotton var. C-1517 in spring 1972, and spring wheat var. 2152 in autumn 1972.

RESULTS AND DISCUSSION

The yields of wheat and cotton lint which were obtained in the various treatments are shown in Table 2. Statistical treatment of the yields showed no significant differences (at $p < 0.05$) between the annual yields of the three tillage treatments.

Table 2: Yields (in kg/ha) of the three dryland crops in rotation

Season	Crop	Yields of tillage treatments			C.V.
		I	II	III	%
1970/71	Wheat (grain)*	3641	3754	3763	4.5
1972	Cotton (lint)	763	774	785	5.6
1972/73	Wheat (grain)	4440	4413	4775	5.7

* Wheat yields of 1970/71 were affected by *Septoria tritici*.

The total wheat yield per treatment in the 1970/71 and 1972/73 seasons, showed that the wheat yield of the annually disked plots (treatment III) was not less than that of treatment I or II, each of which had a single plowing included in the rotation. No reduction in yield was thus obtained by continuously disking after the 1968 plowing, that is, 2 years before the initiation of the experiment.

At least two interacting factors influencing the early growth stages of wheat seedlings may be shown to be the cause of low yield response on plowed soil as compared with on disked soil.

In the first place, planting wheat in dry soil at shallow depths of 3-4 cm, as required today for the high-yielding varieties in use, is better achieved on a seedbed prepared by disking alone, rather than on a seedbed prepared by plowing followed by the necessary secondary tillages. An average planting depth deeper than the recommended one on a seedbed prepared by plowing, caused by a coarser aggregate structure, increased the time needed to full emergence after planting; this was more apparent in the differences in early seedling development, as shown in Table 3.

Table 3: Differences in growth of wheat seedlings. (averages with 95% confidence limits)

Seedbed preparation	Planting depth (cm), 12/XI/70	Height of 1st leaf (cm), 6/XII/70	Dry matter weight (kg/ha), 16/XII/70	
			plant	root
Plowing	4.4 ± 0.3	11.3 ± 0.4	26	33
Disking	4.0 ± 0.3	12.0 ± 0.4	38	39

Standcount of seedlings per 1-m row-length showed no significant differences between the tillage treatments. Another important reason for the retardation in seedling growth on seedbeds prepared by plowing may have been the poor seed-soil moisture contact as a result of a coarser aggregate structure; however, this is difficult to determine under field conditions (3).

In the second place, shallow-planted wheat in dry soil requires sufficient available nutrients in the topsoil layer for early growth of seedlings after the soil has been wetted by the first rainfall. Phosphorus uptake by seedlings was previously found to be related to the available soil-P in the topsoil layer (7). The average content of bicarboante-soluble soil-P from residual and applied P fertilizer, as determined at various times, is shown in Table 4.

Table 4: Average content of bicarbonate-soluble P (ppm) in the 0-15-cm soil layer of wheat (1970/71 season).

Time of sampling	Bicarbonate-soluble P (ppm)	
	Plowed plots (treatment I)	Disked plots (treatments II,III)
Before tillage and fertilizing	8	8
After tillage, before fertilizing	5	8
After tillage and fertilizing	17	22
After wheat harvest	4	5

The difference in available soil-P between the plowed (17 ppm) and the disked (22 ppm) seedbeds directly before planting was found to be significant at the 1% level. There was less available soil-P near the planted seeds in seedbeds prepared by plowing as compared with those prepared by disking. Similar results were obtained for plowed treatment II in 1971 prior to cotton planting, and the effect showed up in the wheat yield of this treatment in 1972/73.

Which factor has the greatest influence on the lower yield response of wheat on autumn-plowed soil can be determined only in a simulated laboratory experiment under controlled conditions. However, at present it seems reasonable to recommend (a) a seedbed preparation which gives a fine aggregatestructure for wheat planting, and (b) a sufficient amount of P-fertilizer applied after plowing, taking into account the lower residual P-availability of the topsoil of the overturned soil. This ensures optimal conditions for the shallow-planted seeds to germinate after the first rains wet the upper part of the soil profile.

No significant yield differences were found in the 1972 cotton crop, although this could have been expected, since soil moisture in this area is not the limiting factor for growth of a dryland summer crop. No differences in the vegetative or generative growth of the cotton plants could be observed between the disked and the plowed seedbeds (6).

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NECESSARY FORCES AND QUALITY OF WORK ON PLOWING - WITH DIFFERENT KINDS OF MOLDBOARDS.

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ABSTRACT

Three different kinds of moldboards have been studied, mounted on the same frame, in three different kinds of soils, and varying the speed of work and the conditions of the soil to be plowed, for the purpose of establishing which is the one best suited in each case from the point of view of the energy consumed and the quality of the plowing. A few slight differences were appreciated in favour of one or the other in each case, although the variation is greater- in function of the state of the ground.

INTRODUCTION AND OBJECTIVES OF THE RESEARCH

Taking as a basis a geometrical classification of moldboards - established by HERNANZ, J. L. and ORTIZ-CAÑAVATE, J., 1979, three different shapes have been studied: cylindrical, universal and universal-warped in three different kinds of soil and in different-- humidity conditions for different plowing speeds.

The main objective of the present research work has been to - determine which moldboard shape is the one which best adapts to- each kind of soil from two points of view: the energy consumed and the quality of the plowing.

As antecedents of analogous research works with moldboard - plows we may cite, among others, SÖHNE, W. H. 1960, in Germany, BILLOT, J. F. et M. BINESSE, 1971, in France and REED; J. F. - 1941, in the United States, although each author employs a different methodology and they all devote themselves to those kinds of plow- most used in their respective countries.

MATERIALS AND METHODS

Of the 22 moldboards previously studied (ORTIZ-CAÑAVATE, J. 1976) three have been chosen of the most different kind possible within the range existing in our country: a cylindrical one ------

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(B254-38), a universal (B-1776-2d) and a universal-warped (B-H2-R), as the warped or the general purpose ones are little used in Spain.

The soils where the research has been carried out have been of the sandy-loam, loamy and clay kind, situated in a farm belonging to the Institute of Agricultural Research (INIA) in Alcalá de Henares (Madrid).

As a support of the moldboards a single frame of one body has been used on which the share and the straight coulter were maintained constant.

The measurements carried out during the tests were the following:

a) CONDITIONS OF WORK: In every furrow of 20 m in length the width and depth of the plowing were measured at three fixed points (at 6, 10 and 14 m), and also the angle of turning and the speed of work. The prefixed values were for the width: 35cm (the body of the plow was of 14" width), for the depth: 25 cm established by means of a support wheel and for speeds, the ones used were between 4 and 6.5 km/h which represent the most usual values in our country.

b) RESISTANCE TO PENETRATION

Measurements were taken with a penetrograph of the kind described by HABEGGER, E., 1971, before and after plowing, obtaining a graph of resistance to penetration of the conic point in function of the depth and establishing a "cone index" (IC) as the average value of the resistance to penetration with regards to the depth of work of the plow.

c) UNIFORMITY OF WORK

The rugosity of the ground was established from the data provided by a perfilometer of 2.5 m in width, supplied with a level and rods spaced every 5 cm (fig. 1).

The rate of rugosity is established by means of the expression:

$$R = \log \sigma$$

σ being the standard deviation of the reference point of the ground after plowing with respect to its average value.

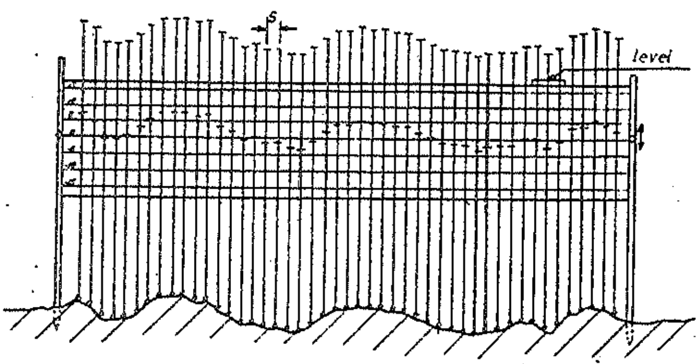

Fig. 1.- Perfilometer to establish the rugosity of the ground and the soil swelling.

d) SOIL SWELLING

With the data taken on the perfilometer an index of swelling of the ground was established, obtained through plowing.

$$e = \frac{b - a}{p} \cdot 100\ (\%)$$

a: average of the reference points of the ground before plowing (referring to a determined level).
b: average of the reference points of the ground after plowing (referring to the same level).
p: average depth of the furrows.

e) DENSITY AND HUMIDITY

With some metal cylinders (of the "Kopecki" kind) samples of earth were taken with a determined volume;they were weighed - and the apparent density of the soil was determined in the arable - area before and after plowing by means of the formula:

$$d_{ap} = \frac{m_{ds}}{V_e}$$, being m_{ds}: mass of dry sample and V_e: volume of the cylinder.

This apparent density "d_{ap}" changes from a value around -- 1,4-1,5 kg/dm^3 before plowing to 1,1-1,2 kg/dm^3 after plowing.

The humidity was established by drying the soil in a stove at 105 ºC during 24 hours and determining the loss of mass which is equivalent to the water lost.

f) LONGITUDINAL FORCE

It was measured with the frame specially designed for hanging implements (fig. 2). On attempting to measure only the longitudinal forces, the objective was to cancel out the vertical and transversal components. In order to do that, the design consisted fundamentally in a longitudinal bar B where the body of the plow was placed, supported on the frame A by means of respective articulated-parallelograms: one vertical with two bars "ab" and the other horizontal with two bars "cd". The longitudinal force was determined-with a dynamometer. The register of these forces refers to the corresponding sections of work, thus obtaining the values of the specific resistance for each plowing.

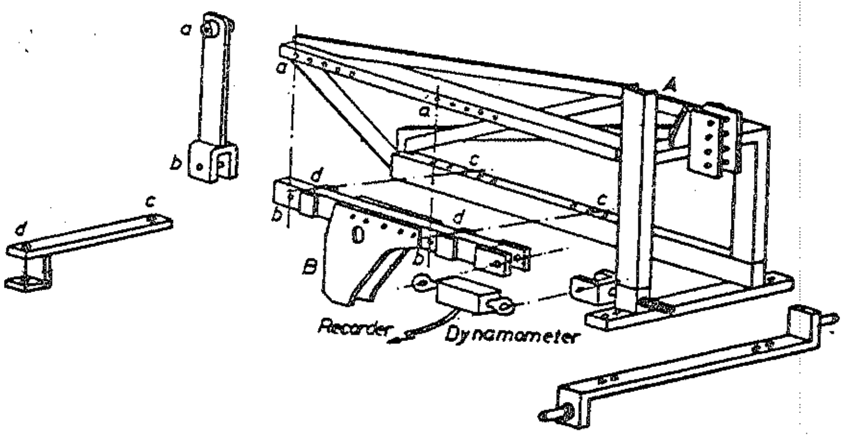

Fig. 2.- Frame to measure longitudinal forces for a one-body mounted plow.

RESULTS OBTAINED

The values indicated have been established from 82 field determinations, but only 50 have been kept, corresponding to a humidity of the earth comprised within 10 and 16 %, which in the soils studied are the best for plowing. In fig. 3 the values of the specific resistance are represented, obtained in each plot and for each moldboard, referring to the speed used.

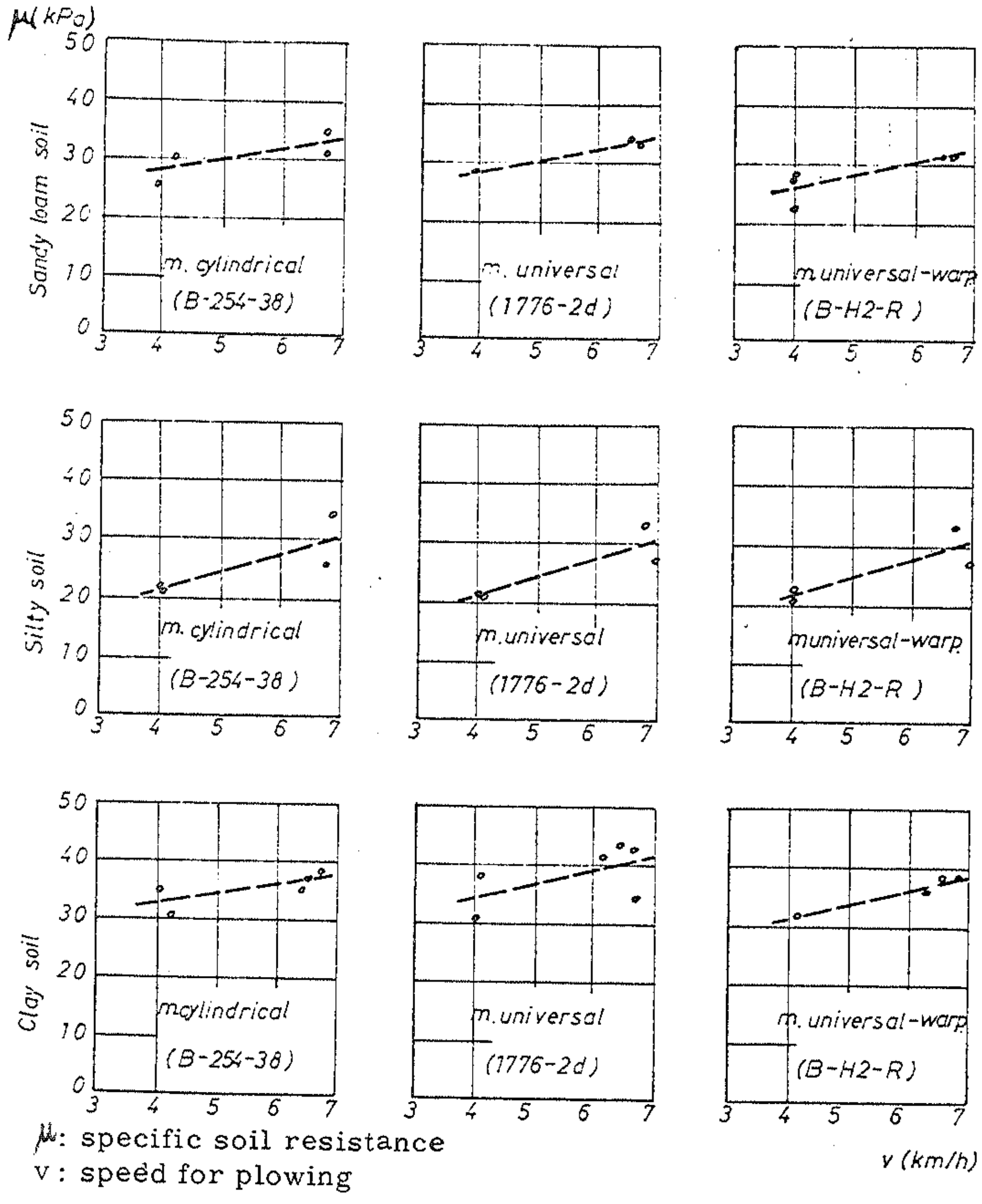

Fig. 3. - Specific soil resistance for plowing with different moldboards in three types of soils.

With respect to the numeric values relative to the quality of the plowing and to the force necessary to plow in different conditions, in Table 1 the average values are expressed of the different indexes: μ, specific force for plowing; IC, cone index, R, roughness and -- e, swelling.

		Cylindrical M. (B-254-38)		Universal M. (B-1776-2d)		Universal-warped M. (B-H2-R)	
	v=	4 km/h	6 km/h	4 km/h	6km/h	4 km/h	6 km/h
	μ (kPa)	25-31	31-35	28	31-38	22-30	30-36
Sandy	IC (kPa)	412	323	558	382	389	524
Loam	R	49	48,5	49	48,5	54	42
Soil	e (%)	18.5	24.5	25.0	22.6	26.0	18.3
	μ (kPa)	20-22	25-35	18-22	22-34	19-24	27-35
Silty	IC (kPa)	363	314	388	294	319	392
Soil	R	43.5	46	49.3	43.7	49	44.2
	e (%)	19.1	35.3	33.2	33.8	34.8	22.5
	μ (kPa)	30-36	34-40	31-38	34-43	31	35-40
Clay	IC (kPa)	578	463	513	310	803	456
Soil	R	58.5	48	53	56.5	54	57
	e (%)	32.8	28.5	29.4	27.5	36.4	30.9

Table 1.- Values obtained with different moldboards in three types of soils μ :specific force for plowing; IC: cone index; R: roughness; e: swelling.

DISCUSSION AND CONCLUSIONS

The fundamental objective of the extensive research project of which this is only a part, is to establis for each kind of soil (in-principle the most usual ones in our country), the kind of moldboard or disk plow which is best suited for the different circumstances.In this work the results obtained until present with moldboard plows-- are given, and at the same time methods of measuring forces of traction and the physical properties of the soil are established to quantify the quality of plowing and the energy necessary to carry it out. -- From this point of view the apparently simple system of measuring the forces of traction has been highly positive and the following conclusions can be deduced:

- For loamy soils the moldboard which carries out appreciably better plowing with the least effort is the universal.

- In sandy loam and clay soils there are not such marked differences, but the universal is inferior to the other two : the cylindrical and the universal-warped.

With regards to the indexes of quality of plowing, that of rugosity gives us a sufficiently good indication of the existence and -- size of the clods which appear.

The cone index, IC, is very useful for knowing the degree of compactation of the soil before plowing, although after plowing the-results are dependable, the average values are in the lower limit of appreciation of the penetrograph used.

The measurement of swelling has been carried out with the same perfilometer used to establish the rugosity, which means a-new usefulness for the data which this apparatus provides. The results show a fairly marked dispersion, which will oblige us in future determinations to make these more numerous and even more precise by means of a perfilometer of greater precision.

To sum up, we may establish that slight differences are appreciated in favour of one moldboard or another in each kind of soil: in loamy soil the universal works better; in sandy-loam soils, the-cylindrical, and in clay soils, the universal-warped, although this variability is much less significant than that which is appreciated - on varying the conditions of the soil, especially the humidity.

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Effects of some soil tillage implements on a Parabraunerde (para brown earth, hapludalf).

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ABSTRACT

The effects of various soil tillage implements on a Parabraunerde (para brown earth, hapludalf) were examined. The variability of yields was more influenced by the factors "years" (resp. weather conditions) and "N-fertilizing" than by the factor "soil tillage". Regarding the yields of the field crops the mouldboard plough and the rotary plough had similar effects; in some parts however, both differed considerably from the effect of the rotary spading machine. Crop residues and green manure were not completely incorporated into the soil by the rotary spading machine. Thereby the plant density of the following cereals was reduced.

According to the favourable soil conditions in the loess soil no remarkable effects of the different soil tillage implements on the soil structure were noticed. A differentiation of the root development in relation to the employed soil tillage implements could not be found. Under these soil and tillage conditions soil loosening with the aid of a rotary spading machine as an alternative to deep ploughing proved to be problematically.

INTRODUCTION

Year by year soil tillage implements are developed or known implements are modified. This is true for the primary and secundary soil tillage. An evaluation of new soil implements should only be done by a direct comparison with known standard implements, if possible in the course of several years to overcome the variation of the weather conditions. In this experiment as a standard the mouldboard plough was compared with the rotary plough and the rotary spading machine.

MATERIALS AND METHODS

These machines differ remarkably in their modes of working. The mode of working of the mouldboard plough is generally known. The rotary plough cuts the soil bar with a small plough share. It is then crushed by a vertical rotor body, situated sidewards behind the plough, and then moved aside. The working of the rotary spading machine reminds of the movements of hand spading, but the topsoil was only loosened. These soil tillage implements were used during the years 1971 - 75 on a para brown earth in the rotation sugar beet, winter wheat, winter barley, winter rye, oats. Except for the year 1972 legumes, especially Persian clover, were grown as green manure before winter rye, oats and sugar beet. Under this tillage system with insufficient incorporation of the cereal stubble the stands of Persian clover tended to be partly heavily invaded by weeds. Therefore Italian ryegrass was sown in the year 1972 as green manure to allow chemical weed control, if necessary. The effect of incorporating the green manure into the soil with the aid of the various soil tillage implements was also of interest.

The soil tillage before the catch crop was sown was done with a heavy cultivator up to a depth of about 12 - 15 cm. Before the main crops were sown the soil was ploughed or loosened to the full depth of the topsoil using the mouldboard plough, the rotary plough or the rotary spading machine. The preparation of the seed bed was uniformly, that is independent of the way of primary soil tillage.

RESULTS AND DISCUSSION

The table of variance for the yields shows a strong influence of the factor "years" on the variability of the yields (Table 1). This influence is not so well marked in the wheat as in the other crops. The variance of the factor "N-fertilizing" is also significant. The significant interaction years x N-fertilizing shows a different effect of the N-fertilizing in the individual years. Obviously this is caused by the very different wheather conditions during the time of experiments. The variance of the factor "soil tillage" shows only significance in the crops winter barley, winter rye and oats. A significant interaction with the other factors can only be noticed in the oats. It cannot be excluded, however, that differences in soil structure, caused by the effect of the tillage implements, had been equalized by an intensive seed bed preparation.

During the years 1971 and 1972 the curves for the yield in relation to the different soil tillage implements had a relatively similar form in winter rye and oats. In the year 1973 great differences in yields occured between the tillage variantes (mouldboard plough and rotary plough compared with the rotary spading machine). These differences could be observed in the following year as well. The mouldboard plough and the rotary plough have a similar behaviour in rye and oats. These differences in yield are caused by the same reason. Both cereals were grown after the green manure with Italian ryegrass in the year 1972. Contrary to the mouldboard plough and the rotary plough the rotary spading machine worked in the Italian ryegrass only incompletely. The result was a partially regrowth of Italian ryegrass in the population of winter rye and oats in the spring of 1973.

The partially remarkable low density of cereal seedlings on the spaded plots could not be compensated by a heavier tillering, so that the lower yields in winter rye and oats in the year 1973 are mainly caused by the low plant density of the cereals (Figure 1). The problems observed in the year 1973 following the use of rotary spading machine were noticed in the same tendency also in the other crops and during all years.

Crop residues and green manure which were only incompletely worked in with the aid of the rotary spading machine, not only caused a decrease of the density of seedlings and plants, but also a partially remarkable regrowth of the cereals in the following main crop. This effect causes problems when ploughing is replaced by soil loosening under this farming system for example for seed growing or by sowing green manure with plants which do not die in winter.

After the harvest of wheat, root investigations were carried up to a depth of 100 cm with the aid of the UTAH Soil Sampling Machine. No differences in root development, caused by the different soil tillage implements, could be observed. In winter wheat physical and chemical soil investigations were carried out. Only in some cases, especially in the medium top soil (10 - 20 cm depth), effects of the different tillage implements on the soil structure were evident. Obviously the better physical soil conditions of the loosened plots (rotary spading machine) have favoured the decomposition of cellulose and the nitrogen release. It must be considered, however, that the partly occuring differences in the chemical and physical properties of the soil had no effect on the yield, because they were in contrast to the remarkable differences in the plant density observed.

A displacement of clay as well as a modification of the C- and N-content of the soil, caused by the primary tillage methods, could not be proved.

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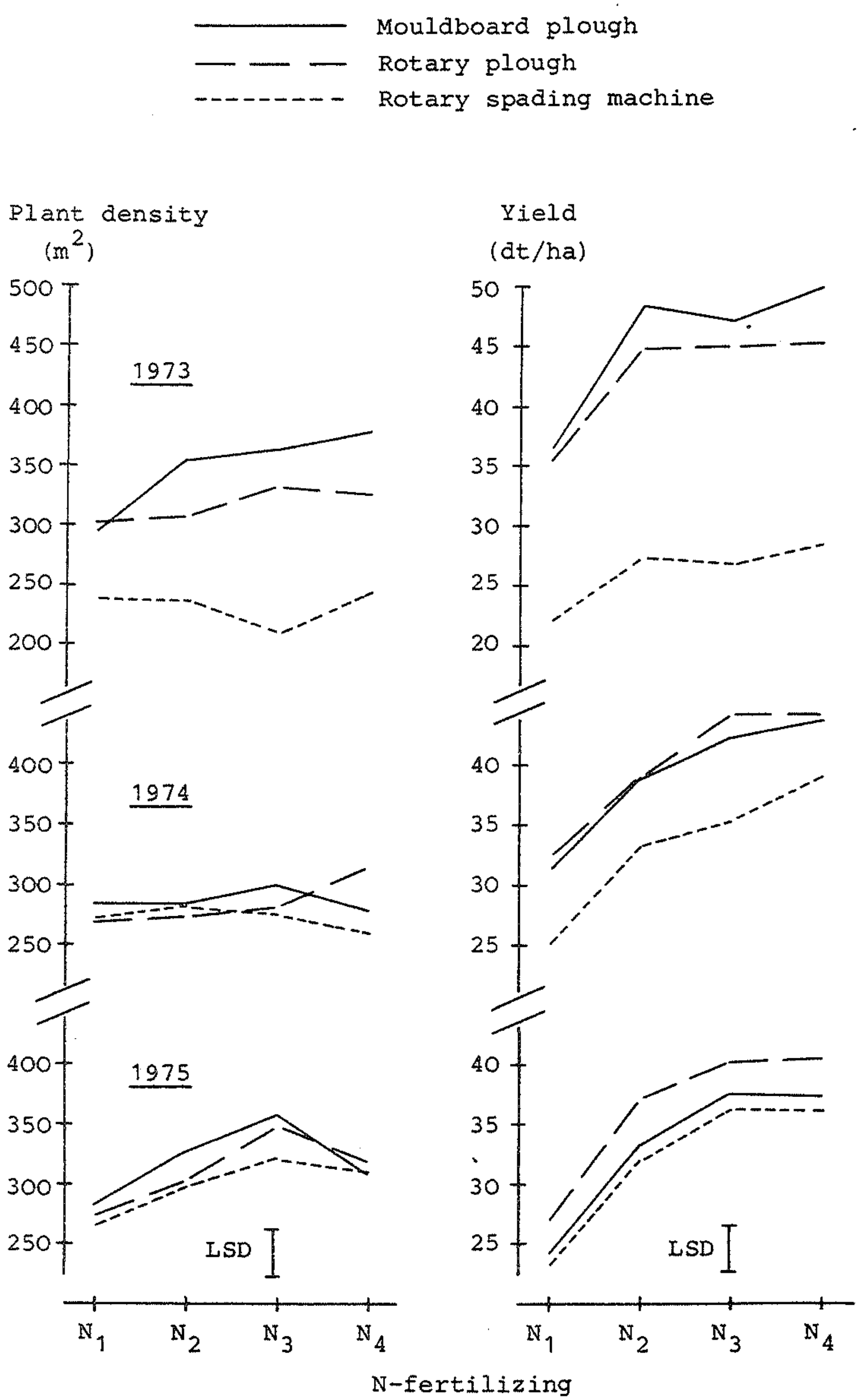
Source of variation	Degrees of freedom	Mean square/F-test				
		Sugar beet	Winter wheat	Winter barley	Winter rye	Oats
Replications(R)	1	$46079,15^{++}$	$230,16^{+}$	$773,79^{++}$	1,94	$200,11^{+}$
Years (Y)	4	$137486,81^{++}$	$121,58^{+}$	$2765,58^{++}$	$3049,61^{++}$	$1060,05^{++}$
Soil tillage(T)	2	2411,92	70,89	$206,77^{+}$	$211,50^{+}$	$304,91^{++}$
Y x T	8	2590,91	11,82	30,35	82,62	170,68
R x Y	4	360,55	41,75	28,39	50,11	14,74
R x T	2	1759,62	2,65	21,88	7,30	10,41
Error (a)	8	2325,82	22,86	41,37	25,83	23,31
N-Fertilizing(N)	3	$52574,63^{++}$	$3751,08^{++}$	$2483,94^{++}$	$613,62^{++}$	$233,98^{++}$
Y x N	12	$5233,34^{++}$	$109,94^{++}$	$118,87^{++}$	$352,17^{++}$	$92,74^{++}$
T x N	6	1614,06	2,15	4,95	3,07	1,37
Y x T x N	24	863,48	1,92	2,75	1,65	$5,98^{++}$
Error (b)	45	822,69	3,23	6,01	2,56	3,24
Total	119					

Table 1 - Table of variance for the yields



<u>Figure 1</u> - Plant density and yield in relation to soil tillage and N-fertilizing (oats)

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THE INCORPORATION OF FERTILIZERS INTO SUBSOIL BY THE WYE DOUBLE DIGGER

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ABSTRACT

Field experiments on a wide range of soils have shown that higher yields of cereal and vegetable crops can be achieved by thorough subsoil loosening with the Wye Double Digger compared with conventional tined subsoiling techniques. Additional yield benefits are also possible from incorporation of fertiliser into the subsoil. Research is continuing to decide on the rate and frequency of fertiliser applications and to optimise machine designs.

Current subsoiling techniques are limited by the need for a dry subsoil to give fissuring and shattering, and a dry soil surface for good traction. Subsoil loosening through direct shear by a rotary tiller can be achieved in moister conditions than is possible through tensile failure (cracking) of soil associated with a tined subsoiler. The development of the Wye Double Digger has been described in a previous paper (Warboys, Wilkes, Gooderham and Wilkins, 1976). This machine rotary tills the subsoil and at the same time ploughs the topsoil. The soil is thoroughly loosened to a depth of 45 cm in one operation, without mixing subsoil with topsoil and without inverting the soil profile. Because of the forward rotating rotor, draught and wheelslip are expected to be less than for conventional ploughing.

There may be further benefit in the use of the Double Digger for mixing materials specifically into the subsoil. On many agricultural soils the concentrations of phosphorus (P) and potassium (K) in the subsoil are very low when compared to concentrations in the topsoil. It is also recognised that subsoils in many regions of the humid tropics are acid (Sanchez, 1976). Therefore, the incorporation of nutrients and lime into subsoils could give increases in crop yield additional to those obtained by double-digging alone. A fertilizer distributing attachment has now been incorporated into the design of the prototype Wye Double Digger.

Effect of deep placement of fertilizer on crop yield

Tined subsoilers have been used in Germany with pneumatic fertilizer dispensers to blow fertilizer into the subsoil behind the subsoiling tine. Because of the relative immobility of phosphorus and potassium, wings and vibrating shares have been used in attempts to improve the distribution and mixing of the subsoil. Despite the difficulty of ploughing and mixing fertilizer in the subsoil with existing equipment, responses to deep placement of fertilizer have been encouraging (Schulte-Karring, 1973).

The Wye Double Digger exposes the surface of the subsoil by ploughing, places fertilizer on the exposed subsoil surface and then incorporates the fertilizer into the subsoil by rotary tillage down to a soil depth of 45 cm. It is thought that this method would give a more uniform distribution of fertilizer in the subsoil than would methods previously used, and that increases in crop yield could be greater.

In the United Kingdom the benefit of incorporating fertilizer into the subsoil was first shown in hand dug trials begun in 1974 at Rothamsted Experimental Station, Harpenden (Table 1).

Table 1 Effects of subsoil loosening and incorporation of P & K (1974-1976)

	Mean yield (tonnes/ha)			
Treatments	1 None	2 Hand Double Digging	3 Hand Double Digging and extra P&K to subsoil	4 Extra P&K to topsoil
Wheat	4.4	5.4	5.2	4.2
Sugar (Sugarbeet)	4.1	4.4	4.7	4.1
Barley	3.5	4.5	5.1	3.4
Potatoes	48	47	56	49

(Source: Woburn Experimental Station Centenary. Guide to Demonstrations, 1977).

All treatments received a standard NPK dressing to the topsoil. An additional large dressing of PK was applied to the subsoil and topsoil in treatments 3 and 4 respectively.

Double digging alone benefitted all crops, except potatoes, with yield increases of 23% for wheat, 29% for barley and 7% for sugarbeet. Furthermore, incorporation of fertilizer into the subsoil when double-digging (treatment 3) resulted in increases in yield for potatoes, barley and sugarbeet of 17%, 46% and 15%.

Experiments using the Wye Double Digger for deep placement of fertilizer were conducted at the National Vegetable Research Station, Wellesbourne in 1977 (Table 2).

Table 2 Percentage increase in yield over controls resulting from double digging (1977)

	Double Digger	Double Digger plus deep fertilizer incorporation (N,P,K)
Potatoes	14.3	23.6
Broad Bean	11.2	14.6
Cabbage	27.8	14.5
Red Beet	33.0	17.3

Source: National Vegetable Research Station, Annual Report, 1977.

Double digging alone increased yield between 14% for potatoes and 33% for red beet. Broad beans and potatoes gave further responses to deep placement of fertilizer, but cabbage and red beet did not.

In 1978, further experiments were carried out at Rothamsted and Woburn Experimental Stations, using spring barley as the test crop. The Wye Double Digger was compared to both standard and winged tine subsoilers. Deep incorporation of PK fertilizer by the Wye Double Digger was compared with that by a winged subsoiler. Yield results are presented in Table 3. Data in parenthesis from the silty clay loam have been adjusted for a diagonal trend across the site.

Table 3 Effect of subsoil loosening and deep placement of PK fertilizer on spring barley yields (t/ha 85% DM) 1978

	Deep P:K kg/ha	Site: Woburn Soil: Sandy loam	Rothamsted Flinty, silty clay loam
Plough (control)	Nil	4.35	4.76(4.39)
Farm subsoiler	Nil	4.95	5.07(4.61)
Winged subsoiler	Nil	3.58	4.21(4.62)
Winged subsoiler	843:382	2.89	4.66(5.08)
Wye Double Digger	Nil	5.27	5.23(5.25)
Wye Double Digger	843:382	5.46	5.99(5.97)
L.S.D. (P = 0.05)		0.98	1.36(0.95)

Double digging increased the yield of spring barley by 21% and by 10% on sandy loam and flinty silty clay loam respectively. Incorporation into the subsoil of very high dressings of PK fertilizer with the Wye Double Digger gave further yield increases, 26% higher than the control on both soils. On the other hand, the winged subsoiler decreased yield substantially on both soils. The poor overall performance of the winged subsoiler could perhaps be attributed to the subsoil not being sufficiently dry when the operation was carried out. It seems probable too that mixing of fertilizer with subsoil by the winged subsoiler was inadequate in spite of the subsoiling runs being made alternately at two depths (30 cm and 40 cm) and at close spacing (30 cm).

In an experiment at Wye in 1978, there were no crop yield responses to deep incorporation of PK fertilizer with the Double Digger (Table 4). Rates of PK fertilizer used, however, were small when compared to those used at Rothamsted and Woburn. Even so, double digging alone increased the yield of winter wheat and spring barley by 15% and 7% respectively.

Table 4 Effect of double digging and deep placement of PK fertilizer on cereal yields (t/ha 85% DM) 1978 (Soil:silt loam)

Cultivation	Plough (control)	Wye Double Digger	Wye Double Digger	L.S.D (P=0.05)
Deep P:K kg/ha	Nil	Nil	38:73	
Winter wheat	3.86	4.44	4.23	0.32
Spring barley	4.08	4.36	4.21	0.24

From these results it is clear that there could be very important additional benefit from the incorporation of fertilizer into subsoil. However, much further research is needed to decide which plant nutrients should be deeply incorporated, appropriate rates and frequency of application. Research is also in progress to optimise machine designs in terms of work rates and power requirement.

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SOME ADVANTAGES OF UNDER-THE-ROW SUBSOILING

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ABSTRACT: Under-the-row subsoiling is a practical technique to increase crop production by piercing man-made soil barriers to good root proliferation in a way to eliminate damage from recompaction.

Soil in the tilled horizon of all fields is susceptible to severe compaction by traffic. Even light implements traveling in dry soil that has been well disturbed can leave soil in a deteriorated physical condition. While the extent and degree of physical deterioration may vary, crop response is highly sensitive and responsive to the soil conditions affecting air and water permeability.

Tillage is performed to prepare a good seedbed and rootbed, and to improve the physical condition of soil. Such benefits do not occur using the conventional plow-harrow-plant system of mechanized agriculture, and a minimum of five concurrent and distinct soil conditions result: (a) Loose, untrafficked soil in the planted row -- frequently the only suitable environment for good root proliferation; (b) a horizon of soil compressed by the harrow in which roots may elongate, but elongate slowly; (c) bands of soil formed by wheel traffic in the interrows that are so densely compacted roots develop only with extreme difficulty; (d) a dense plowpan below the harrowsole that restricts or confines deeper root development, at least temporarily; and (e) subsurface material which is often in good physical condition for normal root development because it is below the depth disturbed by man's tools and traffic.

These soil zones are frequently unrecognized in tilled fields. Three of them (b, c, and d) are responsible for serious agricultural problems, and the subsurface soil (e) is of little use when roots cannot bypass the plowpan. Any band or horizon of compressed soil has an adverse effect on soil air, water, and root permeability. The rate of root elongation and root proliferation within the affected soil also suffers. Not only is plant growth and production severely affected by soil compaction, but such compaction can directly affect the amount of runoff and the chemicals and soil particles that wash from farmed fields. Water washed from a field reduces the amount of moisture stored to nourish the crop. The velocity and volume of runoff concentrated in depressed traffic lanes increases the severity of soil erosion.

It was once commonly believed that subsoiling through plowpans would remedy the soil compaction problem. In practice, hosever, water infiltration and crop production are seldom improved. Rarely will random subsoiling improve a sufficient percentage of a compacted field, even when subsoiling is performed properly, since later indiscriminate traffic usually negates the remedial action.

Where subsoils are conducive to good air, water, and root permeability, our studies indicate that subsoiling can be made beneficial by barely piercing the deepest man-made barrier. Deeper subsoiling only wastes fuel, power, and time, and leaves the loosened soil vulnerable to deeper compaction later on. Our studies also point out that subsoiling can be effective only when performed in locations that will be free from subsequent traffic.

This suggests "hiding" the subsoiled zones from later traffic. The obvious placement for such subsoiling to reduce the chances of recompaction is beneath the planted row. The required operation is called "under-the-row subsoiling." After the field is plowed and harrowed, or merely harrowed, it is subsoiled in the location to be planted just deep enough to assure piercing the deepest barrier. The subsoiler shanks are spaced a row-width apart, and the field is subsoiled in the direction of the next crop to be planted. A ridge is often built over the subsoiled slots by using a ridging device behind each shank. This technique not only marks the location for planting, but provides material for natural settlement into the excessively loosened subsoiler slot. From experience gained in the United States in cool regions, the ridges will drain sooner and warm up faster in the spring, and, although having a dry cap, surface soil can be pushed aside to assure that seeds are planted at the proper depth in moist soil. Equipment wheel traffic is then confined to the furrows when planting so that the soil loosened by subsoiling will not become recompacted. These procedures assure permeable soil beneath the seed for deep, rapid, early root development.

Experimental Results and Discussion

In the southeastern United States, many droughty soils build up "pans" capable of limiting root development to tillage depth. Such soils are then unable to store a sufficient volume of retrievable moisture for ready availability to crops between rains. Many of our studies were conducted on such soil -- in farmers' fields where test strips varied from 4 rows wide and 100 meters long to bands of 20 hectares. Table 1 shows typical results from some of these studies. The yields may seem extreme, but are common in test conditions existing in the soils of the Coastal Plains.

Table 1

COMPARISON OF YIELDS
UNDER-THE-ROW SUBSOILING VS. CONVENTIONAL TILLAGE

Crop	Location	Conventional kg/ha	Under-the-row subsoiled kg/ha
Maize	Clopton, Alabama	2572	5396
Maize	Echo, Alabama	2447	11858
Soybeans	Lily, Georgia	1881	3629
Seed Cotton	Marvyn, Alabama	3184	4372

During years of poorly dispersed rains, it was not uncommon for yields in the under-the-row subsoiled strips to better by more than 400 percent the yields in the conventionally prepared strips. During years with more equitable rainfall distribution, yield increases ranged closer to

50 percent. Results such as those shown in Table 1 are affected strongly by moisture availability. Under conventional tillage practices, much of each high-intensity summer rain is shed from the field, and the moisture storage capacity often is not reached, even after rather heavy periods of precipitation. The higher yields produced where the fields were under-the-row subsoiled can be attributed to the capture of more of each of these rains. However, to obtain higher yields, sufficient fertility must be assured and pest control cannot be neglected. In addition, crops in the subsoiled strips had deep root systems and were able to retrieve the additional moisture stored below the restrictive pans. Where the under-the-row subsoiling technique has been practiced on actual farms, it is common for production to increase from 20 to 30 percent. The reasons for the small increases are many, but the yield improvement is sufficient to increase the acceptance of under-the-row subsoiling.

Even where moisture is ample, root development and growth, and crop yields can be improved by under-the-row subsoiling. Presumably, this is because of the slow rate of root development in dense soils, making roots less efficient in supplying enough moisture and nutrients to the crop at rates needed during peak temperature and sunlight hours. The large and more rapidly developing root system produced by under-the-row subsoiling techniques is capable of meeting the physiological demands of the plant during these periods.

Another study was conducted in well-watered silty clay loam to verify observations made under favorable moisture regimes. One of the large soil bins at the National Tillage Machinery Laboratory, Auburn, Alabama, was prepared with a typical plowpan and harrowsole. One row about 70 meters long was under-the-row subsoiled prior to planting and was compared with a typically prepared seedbed in a row 2 meters away. The three adjoining rows served as guard rows on each side of the two

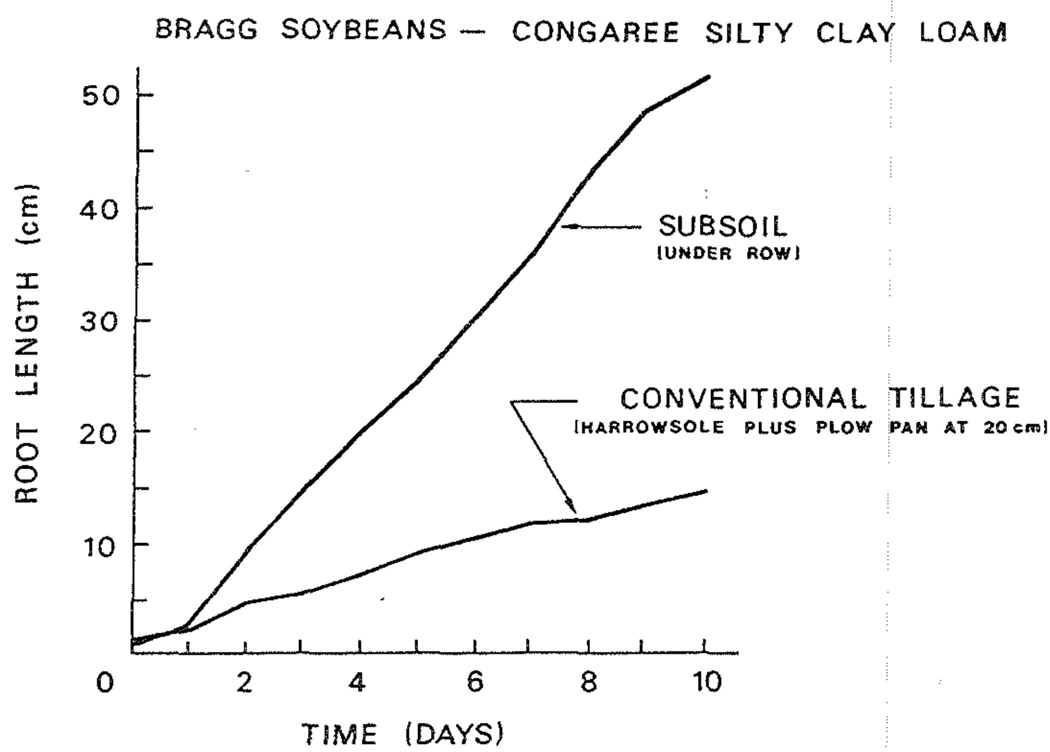

Figure 1. MEAN TAPROOT ELONGATION

test rows. After the subsoiled row had settled, pregerminated soybeans were hand-planted about 1 centimeter deep and 10 centimeters apart in each of the rows. On the following day, and each day for 2 weeks thereafter, 10 seeds were dug up in each treatment and the length of the taproots measured. Figure 1 shows the results of the mean root measurements obtained, and confirms our earlier field observations. Although there were no differences in early growth in any of the well-moistened and fertilized strips, a gain in top growth became obvious in the under-the-row subsoiled row after 3-1/2 weeks, and at maturity its yield was 26 percent higher.

Conclusions

Tests conducted in the southeastern portion of the United States over the past 10 years show that yields can be substantially increased by under-the-row subsoiling in areas where low yields are common due to poor soil or climatic conditions. In situations where moisture capture and storage are normally more conducive to better yields, under-the-row subsoiling can still increase yields, but less substantially. Random subsoiling without restricting subsequent traffic, however, is seldom beneficial.

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Controlled traffic in crop productions

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ABSTRACT

The indiscriminate operation of traffic over the field compacts the rootbed and adversely affects plant growth. Tillage cannot eliminate this compaction adequately; a practical way to control compaction seems to be to control the traffic. Wide-wheel-spaced, automatic guided tractors are used in order to study the various aspects of traffic control i.c. increased root proliferation and yield, better traffic efficiency and reduced tillage. Experiences with respect to machinery executive techniques and impressions concerning soil and crop responses are described.

Introduction

The increased use of agricultural machinery has increased soil compaction. It was once thought,that tillage before planting a crop would eliminate soil compaction adequately. However, in modern intensive crop production many machine operations are used, regardless of soil conditions; this may compact the seed- and rootbed enough to adversely affect plant growth. Conventional crop production systems permit the indiscriminate operation of traffic over the field, consequently covering almost the total area with wheel tracks once or more.
The intensity of soil compaction induced in and below the tilled horizon is evident, the more so as stresses arch out in soil.

Present row spacings, tire widths and inaccuracies in steering preclude an easy solution to the compaction problem when using conventional machinery. A practical way to control compaction seems to be to control the traffic that operates on the field. Dumas et al (1) described the potentials of machinery provided with wide spaced wheels to prevent soil compaction near cotton-plant rows, in the Southeastern U.S.A. Their promising results encouraged us to study traffic control under local Dutch "polder" conditions. The method used to control traffic on our experimental field(s) was to establish permanent traffic lanes on which all wheel traffic passes, with permanent rootbeds in between, freed from undesired mechanical forces. Beforehand, the following aspects have been taken into consideration:
- roots will develop in loosened soil for many years, if the area is not recompacted by wheel traffic
- a compacted (sub-) soil condition may have been developed by the conventional use of farm machinery; subsoiling should be considered before starting the field experiments
- the maintenance of loose soil in the rootbed eliminates the need for costly, time- and energy consuming tillage operations
- the good trafficability of the permanent traffic lanes permits timely conduct of all operations, almost irrespective of weather conditions. Traffic efficiency is improved, owing to lower rolling resistance e.g. (2, 3)
- damage to the tops of the plants by machinery is avoided mainly, using a planting pattern with skipped rows
- on the plots, optimum plant distributions and densities can be selected according to the biological needs, not always well defined so far
- previous experiences learned that traffic can hardly be located on the same spot during the production cycles without using a vehicle guidance system to accurately control the tracks along the center of the traffic lanes
- the system retains permanent wheel paths, hence the field cannot be ploughed unless special adaptions are introduced
- it was not envisioned, that the present system of machines would be an economical system but rather a practical system with which to conduct the experiment.

The controlled traffic studies are carried out in the Netherlands by the Agric.Engng.Institute, IMAG (machinery, soil responses), in cooperation with the Station for Arable Farming, PAGV (cropreactions).

IMAG Fieldlayout

During two years of practical experience, data have been collected; the weal and woe of the executive technique and some preliminary soil- and crop responses are reported in the present article.
Since conventional machinery did not have wheels spaced wide enough to prevent compaction near the rows, available machines were modified to provide 3 m wheel spacings, see Fig. 1.
The total experimental field (on medium textured soil) is subdivided into 4 equal sized parcels (48 x 200 m^2), used for potatoes, wheat, sugarbeets and onions at relatively small and arbitrarely choosen interrow distances of resp. 0.63, 0.16, 0.42 and 0.32 m, on the 2.5 m undisturbed plots. The remaining 0.5 m wide traffic lanes (16.6 % acreage loss) enable the application of wide low pressure tyres.

Traction, automatic guidance

An automatic vehicle guidance system according to Jahns, (see 4) was used to locate this traffic lanes. Therefore an underground insulated copper wire (0.75 mm^2) was installed in the middle of each plot at a depth of 0.5 m below soil surface, with a special subsoiler.
Each 1 ha (crop)parcel has been equipped with 3.5 km cable, forming a closed circuit (5). Through this cable an alternating current is led with a strength of 200 m A and a frequency about 10 kc s, delivered by a battery with oscillator, Fig. 2.
According to the law of Biot and Savart, a concentric magnetic field is created around the wire. The position of the tractor with respect to the cable is determined (and corrected) by means of coils, symmetrically mounted in front of the tractor. An alternating voltage is induced in the coils; in case of side shift an (amplified) voltage difference will appear. This can be used for necessary steering corrections.
The modern tractor (I.H.C. Hydro 826) is equipped with a 88 W electromotor on the steering wheel; the old one (Nuffield 460) is equipped with a hydraulic auxilary cylinder. The installed automatic guidance system is used primarely as a steering aid; the driver can monitor the working elements (of a hoeing machine e.g.) better than before but he cannot leave the vehicle and has to do the turning and lifting at the end of the field.

Tillage

The primary tillage is carried out by a mounted ten furrow, 2.5 m wide skim plough, at a depth of 0.15 - 0.2 m, see Fig. 3.
Because the traffic lanes must remain unimpaired, the first furrow slice is cut at the right side by a disc coulter and is lifted on the path by the (raised) ploughbody. An additional slideboard then lands this slice into the last furrow of the preceding passage.
In order to check soil compaction effects, some plots are being trafficked a single pass in spring (tractor) and in autumn (tractor + trailer), followed by a 0.25 m deep chiselplough, to remove eventual physical barriers just below the plough "sole".
Some other plots have been deep tilled with a rotary digger, at a depth of 0.8 m, in autumn 1978; results are not yet available.

Harvest

Wheat is harvested with a self propelled wide-wheel-spaced combine harvester, with straw chopping device.
Potatoes, onions and sugarbeets are lifted with trailed lifting loaders, working the plots half in one passage, see Fig. 4.

Soil responses

Physical soil properties appear to respond very soon to the different tillage and traffic treatments. Some representative data are given in Table I.

Table I - Some representative data of composite soil properties on different plots

Soil properties	Date	Layer[x]	Untrafficked plots	Trafficked plots	Traffic lanes
porosity ,%	28-10-77	sec.	58.6	50.8	45.8
moisture content (d.b.),%	"	"	36.1	36.1	29.8
air volume ,%	"	"	21.5	3.9	3.0
cone resistance, kPa	25-5 -78	"	750	1450	3500
(60^o, 1 cm^2)	"	sub.	1300	1500	2300
cutting force[xx], mkg	28-10-78	sec.	2.25/3.75[xxx]	10.8	23.0
plough resistance, kPa	25-10-78	prim.	35	42	-

[x] primary, secondary, subsoil horizon

[xx] rotating circular apparatus, 4 knives, 6.5 cm deep, Ø 28.5 cm

[xxx] ploughed/harvested, onions

Soil data, given in Table I, confirm the many aspects concerning controlled traffic, mentioned before.
The traffic lanes have a greater stability than soil conditions, normally encountered, as a consequence of a lower porosity, a lower moisture content and a very low air volume.
The resulting composite soil properties, i.c. penetration resistance and torsional cutting force are on a high level and illustrate the favourable bearing capacity and traction conditions. Owing to this, field operations are permitted from early in spring till late in autumn. Lines of equal porosity and penetration resistance determined show the vertical and lateral pressure distribution under tyres, consequently severely compacting the subsoil under the traffic lanes and parts of the rootbed of the untrafficked plots.
Due to the very low air volume under the lanes, water infiltration and root penetration will be hampered. The untrafficked plots remain very loose, as influenced only by natural forces and superficial hoeing and lifting actions.
Although the trafficked (check-) plots have only been submitted to a single tractor + trailer treatment once, an increase of ca. 20 % in spec. ploughing resistance can already be found!
Secondary soil tillage on the untrafficked plots can be reduced, in view of the results with potatoes. The amount of available loose soil (in 1978) was enough to be formed into ridges without intensive interrow cul-

tivations. The ridges of the side rows and trafficked plots remained small and cloddy, resulting in yield quality losses i.c. more green and damaged tubers.

Crop responses

Because crop responses highly depend on variable weather conditions only some impressions of the passed two years can be reported. On the experimental field the conventional total length of rows/ha was followed. In 1978, plant population density of sugarbeets and potatoes in the side rows was increased, because the roots and aerial parts of these crops were able to utilize apart of the additional air- and soil volume, taken up by the traffic lanes.
The development of the potato plant is favoured by a rootbed being in maximum loose conditions; this stimulates root proliferation, resulting in about 5 % higher gross yield and about 20 % more nett yield (note quality losses !), compared to the trafficked plots.
In 1978 sugarbeets showed about 4 % higher (sugar) yield on the trafficked plots and seem to be stimulated a little by recompaction of the tilled layer, initiated by a single pass of tractor tyres in spring.

Preliminary conclusions, possible applications

Wide-wheel-spaced tractors are useful in controlled traffic research. An automatic guidance system is indispensable for precise following of the traffic lanes. The reliability of the underground leader cable system should be enhanced, especially the stability of the electronics.
The bearing capacity of the traffic lanes increases in favour of the tyre efficiency, resulting in earlier planting etc.
The untrafficked plots show a lower than conventional soil-strength combined with lower tool- and root resistances.
Reduction of tillage activities is feasible, saving time and energy.
Root-proliferation of the potato-crop is improved in loose soil; therefore some fields have been rotary deep-tilled.
Potatoes, w.wheat and onions yielded about 5 % more and sugarbeets about 4 % less on untrafficked plots (1978).
Present farmers practiced already some of the aspects of traffic control. They try to avoid traffic pans under potato ridges by controlling field traffic in spring from secondary tillage through planting.
Onions are planted with irregular interrow space, in behalf of traffic lanes, utilized by up-to-date tractors up and including harvest. The practical interest in automatic guidance systems for farm vehicles is still in an initial stage. Some farmers intend to install a wide spaced underground cable, combined with coils and a dial on the tractor. This steering aid seems useful for spraying etc., when marks are missing.
The experimental controlled traffic fields in the Netherlands will be continued for some more years. Increased yields, higher traffic efficiency and reduced tillage will be the key words previous to the development of an economical system of machines for application of traffic control in agricultural practice.

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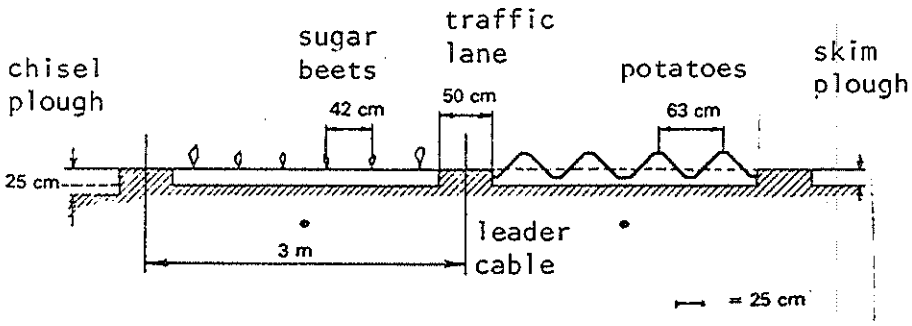

Fig. 1 Cross section of the experimental field

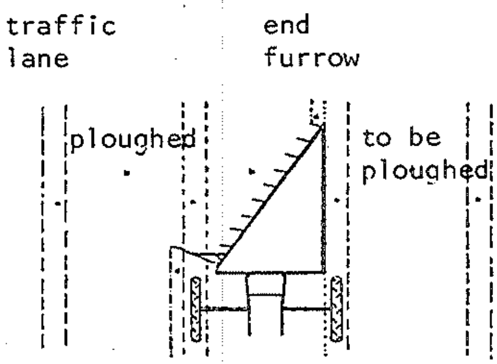

Fig. 3 Top vieuw of mounted skim plough with slide board

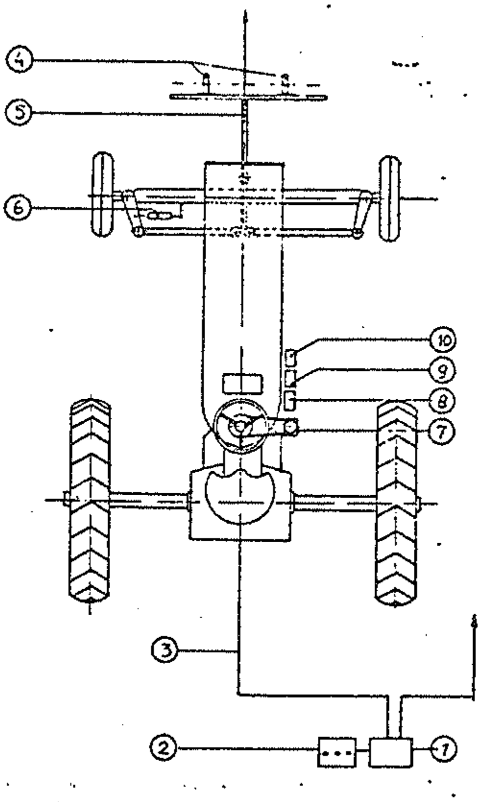

Fig. 2 Automatic guidance system
1. Oscillator; 2. battery;
3. underground cable;
4, 5. detection coils;
6. potentiometer; 7. 88 W electromotor; 8, 9, 10. electronics, according to Jahns

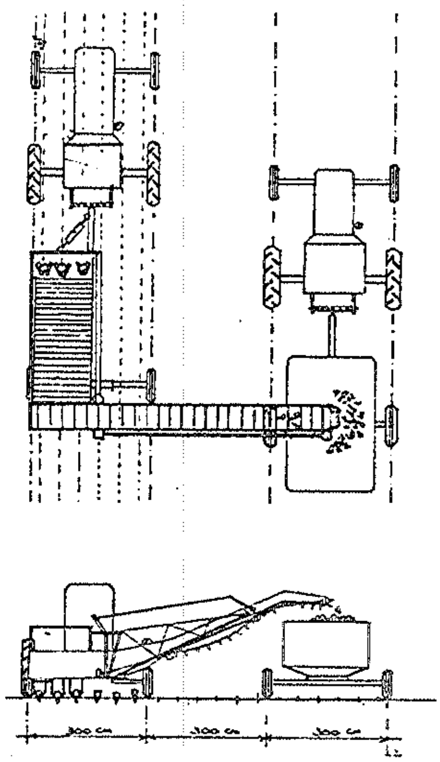

Fig. 4 Top- and rear vieuw of the sugar beet harvest machinery.

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ENERGY ASPECTS OF CONTROLLED WHEEL TRAFFIC IN THE NORTHERN CORN BELT OF THE UNITED STATES.

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ABSTRACT

Controlled wheel traffic, whereby the wheel traffic from all farming operations is controlled to occur only in certain areas of the field, can be an effective way of reducing the detrimental agronomic consequences of soil compaction. Energy needed to till the soil can be significantly reduced by reducing the amount of previously imposed wheel traffic, or by confining wheel traffic to certain areas of the field. Drier corn crop at harvest time can be realized by controlled wheel traffic, thus reducing the energy needed to artificially dry the corn grain.

INTRODUCTION

The modern trend in United States Agriculture is towards larger farm units per operation. One of the contributing factors has been increased size of tractors and farm machinery, thus allowing fewer farm operators to farm more land. While this often allows for more efficient use of the operator's time, larger, heavier equipment may also have some detrimental agronomic consequences in the form of soil compaction. On soils with low organic matter content in areas of high rainfall, excessive soil compaction often occurs for certain types of cropping involving a large number of field operations with heavy equipment. Reduced crop yields under such situations have led to the "controlled traffic" concept whereby all wheel traffic from field equipment is restricted to certain narrow traffic lanes while leaving the remainder of the field in relatively good condition for plant growth. This approach to the compaction problem is most common in the southern United States for cotton production, and in the southwestern United States for irrigated specialty crops.

In the northern United States, where soils are higher in organic matter and are subjected to drier conditions and less intensive field operations, soil compaction from wheel traffic is not a clearly defined problem. There are indications, however, that soil compaction from wheel traffic may be a factor that can be managed to the farmers benefit. Several areas of concern have been identified by Voorhees (1977). One area that is becoming increasingly important is energy conservation. This paper discusses some consequences of wheel traffic-induced soil compaction in terms of energy requirements during tillage operations, and energy required to artificially dry the harvested crop.

Tillage Draft

American farmers have several alternatives with respect to how they manage tractor wheel traffic during a given crop season. By combining several field operations into one, the number of trips across a field can be drastically reduced. By using dual rear wheels, the tractor weight can be distributed over a wider area and thus alter soil compaction patterns. Larger tractors, with 4-wheel drive, enable the use of larger tillage equipment while keeping wheel traffic confined to a smaller portion of the field surface area. However, soil compaction caused by wheel traffic during spring tillage and planting operations persists throughout the growing season (Voorhees et al, 1978) and can be important during fall tillage with respect to draft.

Replicated experiments were conducted on a clay loam (Aquic Hapludoll) soil in southwestern Minnesota to measure the effect of various degrees of soil compaction on tillage draft and rear tractor wheel slippage during fall moldboard plowing. Wheel traffic was imposed with a 7,250 kg tractor in the spring on freshly tilled soil. Soil water content was about 35% by weight, and the bulk density in the surface 30 cm of soil averaged about 1.1 g cm^{-3}. The load applied to the soil by the tractor wheel was estimated to range from about 150 k Pa (~22 psi) during the inital pass in the loose soil, to about 350 k Pa (~51 psi) during subsequent passes.

The various compaction levels consisted of 0, 1, 3 or 5 passes over the entire plot area. The resulting bulk density and penetrometer resistance values are shown in Table 1. Compared with no wheel traffic, just one pass of the tractor wheel increased bulk density to a depth of about 20 cm. Three passes caused further increases to a depth of 30 cm.

Table 1. Bulk density and penetrometer resistance as affected by wheel traffic compaction.

	Bulk density				Penetrometer resistance			
	Tractor wheel passes				Tractor wheel passes			
Depth	0	1	3	5	0	1	3	5
	- - - - - g/cm^3 - - - -				- - - - kg/cm^2 - - - - -			
0 - 7.5	1.11	1.28	1.37	1.46	2.1	11.7	12.3	11.9
7.5 - 15.0	1.25	1.34	1.47	1.45	4.0	8.8	11.0	11.4
15.0 - 22.5	1.21	1.30	1.45	1.43	4.2	7.5	9.3	10.1
22.5 - 30.0	1.29	1.31	1.45	1.42	6.5	7.7	8.1	8.6

Penetrometer resistance, which may be more indicative of tillage draft, was drastically increased in the surface 20 cm (Table 1), and somewhat less to a 30-cm depth. Five tractor wheel passes produced little or no change in either bulk density or penetrometer resistance compared to three passes.

These soil compaction treatments were kept bare throughout the growing season until time of fall tillage. Tillage draft was then measured on a 5-bottom moldboard plow, each bottom being 45 cm wide. Depth of plowing was about 25 cm. A force dynamometer (Johnson and Voorhees, 1979) linked between the tractor and the plow was used to measure horizontal draft. Rear tractor wheel slip was measured with a magnetic pulse counter.

Table 2 shows the measured draft during fall plowing as affected by previously imposed wheel-induced soil compaction. The largest relative increase in draft, 25%, resulted from the first pass of the tractor wheel. Additional amounts of wheel traffic continued to increase draft but at a much lower rate. Statistically, any amount of wheel traffic resulted in significantly higher tillage draft than no wheel traffic, but the only difference within wheel tracked treatments was that five passes resulted in higher draft than one pass.

Effective drawbar power requirements for the above draft values were calculated based on a groundspeed of $\sim$ 4 km/h (2.5 mph). With no previously imposed wheel traffic, a drawbar power requirement of 35.6 k W (47.7 horsepower) was needed to pull a five-bottom plow (Table 2). This power requirement was increased by 25% when the plot was uniformly compacted by one pass of the tractor wheel. Additional passes caused additional, but smaller, power requirements. Estimated energy required at drawbar increased similarly.

Diesel fuel requirements were calculated according to the procedure outlined in footnote No. 4 of Table 2. With no previously imposed wheel traffic, 25.64 liters of diesel fuel were required to till a hectare of land. Fuel consumption was increased to 30.54 L/ha when the land was uniformly compacted by one pass of the tractor wheel. This represents a 19% increase in fuel consumption per unit of land area, even though the draft had increased by 25% (31.8 k N to 39.9 k N). The reason for this disproportionately low increase in fuel consumption with increasing draft was due to decreased rear wheel slip in going from 0 to 1 tractor wheel passes (16.5 to 13.9% slip, Table 2). This decreased wheel slip was likely due to decreased rolling resistance on the firmed soil, thus providing higher tractive efficiency and more efficient use of fuel. Further increases in wheel traffic-induced soil compaction (>1 pass) caused additional fuel requirements more in line with the increased tillage draft.

The data in Table 2 shows that the first pass of a wheel over a loose soil causes the greatest relative increase in subsequent tillage draft and energy requirements. Farmers should therefore delay, if possible, imposing the initial set of wheel traffic on the field when the soil is wet and most easily compacted. Since additional wheel traffic beyond the initial pass has relatively less effect on energy requirements than that caused by the initial pass, the "controlled wheel traffic" concept may reduce energy demands associated with tillage.

Crop Drying

The predominant method of harvesting corn (*Zea mays* L.) in the United States is to combine, or picker-shell, the crop in the field at a relatively high moisture content, rather than waiting for the crop to dry on the stalk and picking the whole ear. While this has the advantage of earlier harvesting, less harvesting loss, and less handling of the crop, it also necessitates artifical drying of the harvested crop if it is to be stored for any period of time. Current drying methods are varied but the most common method involves passage of heated air through the grain. Although solar energy is being considered as a source of heat, the burning of fossil fuels is still the

Table 2. Energy components of tillage as affected by wheel traffic compaction.

Number of tractor passes	Horizontal tillage draft†		Rear wheel slip	Drawbar power‡		Energy required at drawbar§		Diesel fuel required¶	
	kN	(lbs)	%	kW	(hp)	kW-h/ha	(hp-h/a)	L/ha	(gal/a)
0	31.8	(7,152)	16.5	35.6	(47.7)	48.37	(26.24)	25.64	(2.74)
1	39.9	(8,964)	13.9	44.6	(59.8)	60.60	(32.89)	30.54	(3.26)
3	43.1	(9,691)	14.1	48.2	(64.6)	65.49	(35.53)	33.46	(3.57)
5	45.7	(10,263)	15.9	51.0	(68.4)	69.29	(37.62)	34.65	(3.70)

† Measured horizontal draft on a 5-bottom moldboard plow.

‡ Calculated kW = (draft, kN)(speed, km/h)/3.6; based on speed of ∿ 4 km/h (2.5 mph)

§ Based on tillage rate of 0.736 ha/h (1.818 acres/h), with plow 2.3 m wide (7.5 ft), operating at speed of ∿ 4 km/h (2.5 mph) at a field efficiency of 80%.

¶ Calculated based on procedures outlined in Agricultural Machinery Management (American Society of Agricultural Engineers, 1978-1979). Fuel consumption in L/kW-h was calculated from the following equation; $L/kW\text{-}h = 2.64X + 3.91 - 0.2\sqrt{738X + 173}$, where X is the ratio of equivalent PTO power required by an operation to the maximum available from the PTO. The equivalent PTO power was calculated from drawbar power requirements (Table 2) and estimates of tractive efficiency based on soil conditions and rear wheel slip data. Diesel fuel requirements per unit of land area is then the product of energy required at drawbar and the above calculated fuel consumption.

most common source of heat. Thus, any factor that affects the maturity and moisture content of the crop at harvest time can have important energy-related consequences. The controlled-wheel traffic concept was used as an experimental approach to determine effects of soil compaction on growth of row crops in the northern Corn Belt. This approach basically provided three compaction treatments; (1) rows with equal amounts of wheel traffic on both sides, (2) rows with wheel traffic on one side only, and (3) rows with no wheel traffic on either side. In all treatments, there was never any wheel traffic directly over the row. A phosphorus fertility variable consisting of either no added phosphorus fertilizer or 57 kg of P/ha (51 lbs/acre) was superimposed on the compaction treatments. Experimental details are further described by Voorhees et al. (1978).

The water content of the corn at harvest time and the corn yields are shown in Table 3. At both levels of phosphorus fertility, corn in rows with wheel traffic on both sides was drier at harvest time, especially at the low phosphorus level. Thus soil compaction, as imposed in these experiments, hastened crop maturity and resulted in drier grain at harvest time. The amount of energy needed to dry the

Table 3. Water content, yield, and drying energy of corn as affected by wheel-traffic compaction and phosphorus fertility.

	No added phosphorus		57 kg/ha phosphorus	
	No wheel traffic	Traffic both sides of row	No wheel traffic	Traffic both sides of row
Water content at harvest, %[†]	36.5	32.6	31.0	29.6
Corn grain yield kg/ha (bu/a)[‡]	3903 (73.3)	4350 (81.7)	5590 (105.0)	5585 (104.9)
Total drying energy, Mj/kg (k Btu/bu)[§]	2.38 (48.6)	1.94 (39.6)	1.76 (35.9)	1.60 (32.7)
Total drying energy per unit of land, Gj/ha (M Btu/a)	9.29 (3.56)	8.44 (3.24)	9.84 (3.77)	8.94 (3.43)

† Averaged over 1973-1978, with an average annual coefficient of variation of 6.6%.

‡ Averaged over 1973-1978, with an average annual coefficient of variation of 7.2%. To convert from kg of dry matter/ha to bushels at 15.5% H_2O/a multiply by 0.018775 bu/a per kg/ha.

§ Heat energy to burner of high temperature dryer + energy equivalent to generate electricity to operate fan on high-temperature dryer. Based on heating 10°C ambient air at 75% relative humidity to 95°C, and moving the heated air through the grain at the rate of 60 m^3 per minute per m^3 of grain until the corn is dried to moisture content of 15.5% (Morey et al., 1976).

corn to a moisture content of 15.5% was calculated per unit of grain dry matter and is shown in Table 3. At low soil phosphorus levels ("no added phosphorus"), wheel traffic resulted in an energy savings of about 18% per kg of dry matter (1.94 Mj/kg compared with 2.38 Mj/kg) because the grain was 4% drier at harvest time. At high phosphorus fertility, wheel traffic on both sides of the row resulted in about a 9% savings in drying energy per unit of grain. When expressed as per unit of land, the crop drying energy savings due to compaction was about 9% for both levels of phosphorus fertility. Energy savings as a result of a drier crop tended to be offset by a higher total yield per unit of land

The monetary return from reduced drying energy needed for a more mature crop with moderate compaction is difficult to assess because of the economically unstable fossil fuel situation. But based on 1978 prices of propane, the data in Table 3 suggests drying energy savings as a result of compaction with a monetary value ranging from \$9.04/ha (\$3.66/acre) at high phosphorus fertility to \$10.28/ha (\$4.16/acre) at low phosphorus.

SUMMARY

Under row crop culture in the Corn Belt, it is possible with proper selection of machinery size and wheel spacing, to practice complete wheel traffic control with present field equipment. While this represents a departure from common practices, it may not involve any additional direct costs. From the standpoint of energy conservation, this may result in significantly decreased tillage costs and decreased crop drying costs.

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CONTROLLED-TRAFFIC, REDUCED-TILLAGE RESEARCH FOR COTTON PRODUCTION IN THE UNITED STATES

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ABSTRACT *Soil compaction is a common problem in cotton production in the United States. Research at several locations across the U. S. Cotton Belt has shown that tillage that penetrates compacted layers of soil alleviates the problem until the soil is recompacted. Research has also shown that recompaction can be minimized by controlling tractor-wheel traffic in specific pathways, thereby reducing the frequency of deep tillage and saving energy.*

Requirements for fossil-fuel energy for crop production have become a major concern of American farmers. Since the oil embargo of 1973, the cost of products requiring fossil fuel has increased sharply. Although the energy used in agricultural production represents only about 3 percent of the energy consumed in the United States, the increasing energy costs affect farmers' costs for machinery, fuel, fertilizers, insecticides, and herbicides significantly. These cost increases led researchers to investigate ways of reducing energy use for crop production.

In high-energy-input crops such as cotton, land preparation requires more energy than other production operations, and excess tillage often reduces the energy-output efficiency. Therefore, methods of minimizing tillage without reducing crop yields are needed for energy conservation.

Ten years ago American farmers had enough power available for either deep or shallow tillage, depending upon the needs of their particular soil. At that time very few tractors were above the 75 kw class. Now tractors on large farms range from 75 to 185 kw. Although they speed operations and reduce labor, these large tractors contribute to soil compaction that often restricts water and root penetration and reduces production efficiency. Subsoiling and chiseling alleviate compaction problems in many areas of the U. S. Cotton Belt and have replaced some of the operations formerly performed, such as moldboard plowing and harrowing, which led to increased compaction. Deep tillage, however, has often required as much energy as the practices it replaced.

Before 1950, most "deep plowing" for seedbed preparation, except for specialized applications, was only 15-30 cm deep. Since that time, with the availability of large tractors, tillage depth in subsoiling tests has ranged from 38-90 cm.

Grissom et al. (1956) found that subsoiling a fine sandy loam soil containing a compacted layer of soil (hard pan) increased yields of cotton as much as 100 percent in the Mississippi Delta in a

3-year test. Residual effects of 3 years of subsoiling carried over into the fourth year. No yield response resulted from subsoiling a heavy clay soil. Edwards and Coats (1971) found that yield was not reduced when they planted cotton in a heavy clay soil on the previous year's bed and provided no primary tillage for 3 years.

The American Society of Agricultural Engineers, in a symposium in 1960 (Bekker et al., 1961), recognized soil compaction to be a problem in crop production. Trouse (1978, 1979) adequately described the relationship of soil compaction and root growth in these proceedings.

Cooper et al. (1969) showed that cotton plant root proliferation is seriously restricted in soil compacted by tractor-wheel traffic during normal operations in a growing season. They found that traffic compresses as much as 70 percent of the soil surface and that the compression results in increases in bulk density and decreases in crop yield. Also, they showed that 85 percent or more of the total soil compaction can be caused by the first pass of a tractor under certain moisture conditions.

Hendrick and Dumas (1969) found that disk harrowing caused recompaction of deep-turned soil during the first season after turning and that the soil at a depth of 20-25 cm reached a penetrometer reading strength of more than 28 kg per cm^2 after 3 years of disk harrowing alone. They pointed out that the common practice of pulling a moldboard plow with one rear wheel of the tractor in the furrow often develops a hard plow pan.

Problems of soil compaction and energy costs have been researched extensively. After early work at Auburn, Alabama, Carter et al. (1965, 1968, and 1971) experimented with subsoiling to eliminate a compacted zone under the plow depth in fine sandy loam soil in California. After observing that roots responded better to subsoiling when plants were directly over the subsoil slot, they developed equipment which would place the subsoil slot directly under the row of plants. They called the procedure involved "precision tillage." Trouse (these proceedings) calls the procedure "under-the-row subsoiling." Basically, the equipment is a subsoil shank on row centers that has a lister bottom between each subsoil shank on the tool bar. The lister bottom throws up a bed (ridge) over the slot formed by the subsoil shank, and the row of plants is subsequently planted in the center of this bed. The use of precision tillage has proliferated throughout the Cotton Belt, and many commercial tools that will accomplish this operation are now available. Carter (1978) subsequently developed automatic guidance equipment to control the tractor-wheel traffic in the same position from year to year.

Cannon and Stapleton (1977) summarized 8 years of testing in Arizona that included several combinations of list-only and chisel-list (precision tillage) treatments compared with a conventional (moldboard plowed) treatment, on predominantly clay loam soils. They generally concluded that vertical tillage is at least as effective as extensive surface soil manipulation and that fuel consumption with chisel-list tillage was almost 80 percent less than with conventional plowing.

Recent work in Alabama (Dumas and Smith 1975) included several treatments of deep and shallow tillage with controlled traffic (tractor wheels spread to 3 m on center), tricycle tractor traffic with rear wheels on 2 m centers, and tractor plus sprayer traffic on every *interrow. Yields indicated that, if traffic is controlled to reduce compaction in the root zone, deep tillage may not be necessary each year on fine sandy loam soil when preparing a root bed for cotton.*

Wilkes' (1975) studies from 1969 to 1974 in clay loam soil showed that the energy required per unit of yield was less when he reshaped old beds or chiseled and reshaped the old beds, than when he flat broke and bedded or bedded and rebedded.

Mullins et al. (1977) conducted tests from 1973 to 1975 on several levels of traffic control by using 2-, 4-, and 6-row wide implements on a four-wheel tractor and confining traffic on the controlled-traffic plots to the same paths each year. Reducing compaction by using six-row commercial equipment did not increase yields in the three silt loam soils studied.

On a silty clay loam soil in Oklahoma, Batchelder and McLaughlin (1977) found that controlled traffic lowered soil strength in the crop root area early in the season, but its strength appeared to be normal after harvest in the fall.

Fulgham et al. (1973) experimented for 10 years in Mississippi with several wide-bed concepts, including deep and permanent furrows for wheel tracks and a wide elevated bed for the root zone. They concluded that use of the wide-bed system could save about 20-25 percent of the production costs with the conventional system because the average distance between rows would be greater with the wide-bed system and each hectare would have fewer crop rows to be tilled and cultivated. This work was continued by Williford and others (1974, 1978) to thoroughly evaluate a combined controlled-traffic and zone-tillage production system at Stoneville, Mississippi, beginning in 1972. In this system, all wheel traffic is restricted to traffic zones spaced at 2.5 m across the field. Between each of the traffic zones, crops are planted in two rows spaced 1 m apart. Primary tillage is restricted to the production zone which constitutes about 1.5 m of the 2.5 m area between wheels. Traffic zones receive no primary deep tillage and are thus allowed to compact year after year, and primary tillage in varying degrees has been used in the root zone for evaluation. During 5 years of research, yields per land area from the wide-bed plots have been comparable to those from conventional plots on sandy loam soil.

At Mississippi State in 1972 (Colwick et al., 1976), we began comparing 2-m-wide beds with standard 1-m beds for some cotton harvesting research. We observed several advantages, such as better drainage, easier traffic control, earlier planting, easier weed control, and better stripper-type cotton harvesting with the wide beds. Cotton yields were better on the wide beds 3 years out of 4. Based on these observations we superimposed a tillage study on these bed types in 1974 on a silty clay loam soil (Leeper). The objective of our studies was to compare subsoiling with standard shallow chiseling and disk harrowing and to determine how long the residual effects from subsoiling would remain in the root zone of the wide bed if traffic were controlled to avoid recompaction. Treatments are shown in Table 1.

The 1-m-wide beds had one crop row per bed and received random (normal) traffic during seedbed preparation. The 2-m-wide beds contained two crop rows, spaced 1 m apart, and traffic was confined to the same 2-m-spaced wheel patterns as the previous year. Conven-

tional tillage on the 1-m-bed plots consisted of shallow chiseling and tandem disking to a depth of 7-15 cm and disk shaping the rows in the 1-m beds. Conventional tillage on the wide beds consisted of running disk furrowers down the traffic paths and then using a two-row disk harrow to reshape the beds. Deep tillage plots were subsoiled to a depth of 46-56 cm on 1-m centers under the row in the fall or early spring.

The data in Table 1 show that yield differences were significantly in favor of the normal traffic plots in 1 of the 3 years, but yields were slightly higher in the 1-m-bed plots each year.

Readings of typical soil strength measurements made by penetrometer (cone index) are plotted in Figures 1 and 2. Although the tillage treatments apparently have had little effect on yields, the cone index measurements show that subsoiling of all plots before the tests were begun 3 years ago is still evident where the traffic has been controlled from year to year (Figure 2).

Results to date confirm previous reports that subsoiling is of questionable value for increasing yield in silty clay loam soil. However, controlled traffic (minimum tractor wheel spacing of 2 m) maintains the reduced soil strength that results from deep tillage, and such reduction is usually desirable.

Table 1. Cotton lint yields from residual-tillage, controlled-traffic test, Mississippi State, MS--1976, 1977, 1978. 1/

Treatment			Total yield		
Bed width	Type of tillage	Type of traffic	1976	1977	1978
m				kg/ha	
1	Conventional	Normal	130 a	104 a	128 a
1	Deep	Normal	130 a	108 a	128 a
2	Conventional	Controlled	125 a	82 b	123 a
2	Deep	Controlled	132 a	88 b	125 a

1/ Values followed by the same letter are not significantly different at the 5 percent level, according to Duncan's Multiple Range Test.

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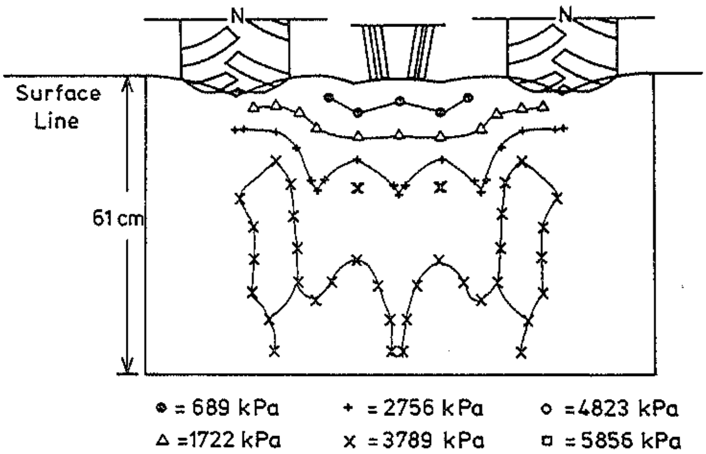

Figure 1. NORMAL BEDS WITH CONVENTIONAL TILLAGE AND TRAFFIC

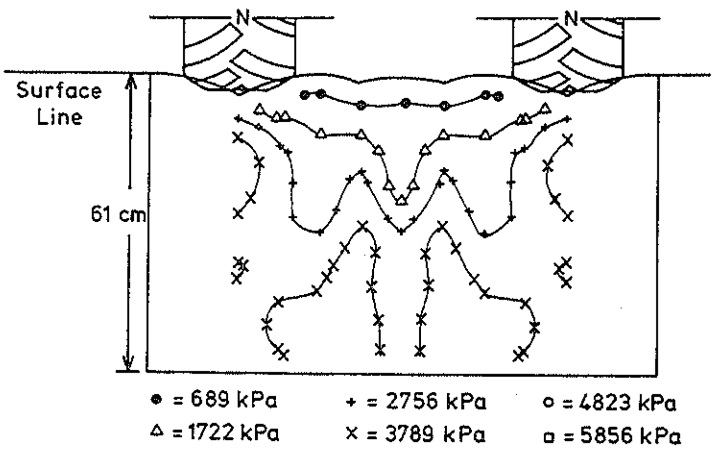

Figure 2. WIDE BEDS WITH CONVENTIONAL TILLAGE AND CONTROLLED TRAFFIC

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SOME OPTIONS FOR REDUCING COMPACTION UNDER WHEELS ON LOOSE SOIL

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ABSTRACT

Measurements of rut depth and bulk density were made following the passage of different wheel systems over loose soil. The use of dual tyres showed a reduction in mid-track compaction and an increase of total compaction compared with single tyres carrying both medium and high loads. Experimental cage wheels mounted alone showed very marked reductions in mid-track compaction. Reductions in the load and inflation pressure for a conventional tyre resulted in a decrease of rut depth and bulk density of the 0-20 cm depth layer.

INTRODUCTION

There is increasing realisation that the compaction and rutting occurring under the wheels of agricultural vehicles exert a marked influence on subsequent crop growth and soil management requirement (Eriksson et al., 1974; Chancellor, 1976; Raghaven et al., 1976). The resulting zones of compacted soil may extend throughout the full depth of the cultivated layer and, in extreme cases, into the subsoil below (Danfors, 1974).

There are two approaches to the solution of the compaction problem. One is to "pile-it-up" which can be achieved by controlled traffic systems, either temporary (tramlines) or permanent (beds). The advantage of this approach is that after the 2nd passage along the same wheel track very little further compaction takes place. The other approach is to "spread-it-out" in which ground pressures are decreased to the point that no appreciable compaction occurs even though the wheel is passed over untracked soil.

Where the draught requirement is low and the payload requirement less than say 1 t (for instance in low volume spraying) ground pressures can be kept as low as 5-10 kPa through the use of low weight vehicle construction and multiple wheel or light weight track systems. In this way rutting and compaction can be virtually eliminated, even on wet soils (Cussans and Ayres, 1978). However for other operations, such as harvesting, limespreading and certain cultivation operations vehicles weighing around 5 to 10 t are likely to be retained. Such vehicles are frequently fitted with tyres requiring inflation pressures in the order of 150-250 kPa which have been observed to cause considerable compaction when running on loose soil.

It is clearly important to know what benefits can be expected from the use of alternatives to the standard tyres generally fitted to agricultural vehicles today. The subject is becoming increasingly relevant in view of the adoption of reduced or zero-tillage systems for which rutting and compaction are likely to be even more damaging than where ploughing is traditionally used to remedy the effects of wheel traffic prior to the establishment of the following crop.

EXPERIMENTAL DETAILS

Wheel Treatments: The wheel treatments used (Table 1) were grouped in three series according to magnitude of the load carried. In

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series A, tests were concerned with wheels carrying about 2 t which is typical of many harvesting and bulk handling vehicles. The option considered was the use of wide section duals. For vehicles having a total weight of about 8 t or more the load is likely to be carried by equal sized tyres on front and rear axles and two passes of such wheels were used in these tests. Further details of these tests are given by Blackwell and Dickson (1978). In series B the wheel loads were medium (between 1.0 and 1.2 t) which is typical of medium sized tractors. The options included the use of conventional dual tyres and cage wheels together with the very unconventional use of cage wheels mounted alone. They were fitted with flat lugs at 90°, 60° and 30° to the tangent of the cage wheel rim. Further details of the series B tests are given by Dickson et al. (1979). Series C tests were concerned with the benefits to be gained by varying the load on a conventional traction tyre between 0.89 and 1.86 t, the inflation pressure being reduced as the load was decreased. Further details are given by Blackwell (1979). The tractors were used at forward speeds of about 1-4 km/h, without draught load.

Measurement of rut and soil characteristics: Prior to the passage of each test wheel the water content, cone resistance, dry bulk density and vane shear strength were measured. Cone resistance was obtained using a 12.9 mm diameter 30° cone and dry bulk density with gamma-ray transmission equipment having a probe spacing of 22 cm (Soane, 1977). Following the passage of each test wheel the maximum rut depth was measured with respect to the original surface. Bulk density was measured in the centre-line of the wheel track including the centre-lines of both wheel tracks for paired wheels.

Initial soil conditions: All tests were undertaken on soils in a loose condition as a result of previous cultivation to a depth of 20 cm. This is reflected in the low mean bulk density values for the 0-20 cm depth which lay between 1.11 and 1.19 g/cm^3 for all series (Table 2).

RESULTS

Series A - High Load Tests: Both rut depth and compaction below the rut were reduced by using wide section dual tyres in place of a single conventional tyre (Fig. 1.). The conventional tyre had 53% lower contact area and 58% greater rut depth than had the duals. With the wide section dual tyres the dry bulk density approaches the initial value at about 36 cm depth whereas the compaction resulting from the conventional tyre appeared to extend to about 45 cm depth. Compaction from wide section dual tyres could therefore be overcome more readily by cultivation to conventional depths. Nevertheless there was still very considerable compaction under the duals which is attributable to the high load carried and the effect of the two passes.

A possible reason for the failure of the duals to make a larger benefit in reducing compaction is their much smaller diameter than the single conventional tyre. Dual wide section tyres of equal diameter would be extremely expensive and not readily accommodated in certain types of vehicles.

Series B - Medium Load Tests

Cage wheels mounted alone: A reduction in rut depth and compaction was found below the mid-line of the cage wheels, the effect being greatest with the experimental cage wheels, especially at high lug angles (Fig. 2). With a 90° lug angle there was virtually no measurable compaction in the mid-line. The commercial cage wheel mounted alone had a greater ground contact area than the experimental cage wheels and this seems to have resulted in a level of

Table 1
Details of wheel treatments

Test Series	Wheel type	Details (ply rating)	Wheel load t	Inflation pressure kPa
A. (2 passes) High Load	Conventional traction tyre	12.4/11-36 (4 PR)	1.86	172
	Wide section duals	18-22.5 (16 PR)	1.87	172
B. (1 pass) Medium Load	Conventional traction tyre	13.6/12-38	1.05	83
	Experimental* cage, mounted alone	90^{o} lugs	1.00	-
		60^{o} lugs	1.00	-
		30^{o} lugs	1.00	-
	Commercial cage, mounted alone	Angled tubular bars	1.00	-
	Conventional dual tyres	13.6/12-38	1.20	83
	Conventional cage mounted next to tyre	Angled tubular bars 13.6/12-38	1.17	- 83
C. (1 pass) Variable load	Conventional traction tyre	12.5/11-36 (4 PR)	0.89 1.21 1.86	84 1.10 1.72

* Designed and kindly loaned by Dr D Gee-Clough, National Institute of Agricultural Engineering, Silsoe.

Table 2
Soil conditions prior to the passage of wheels

Test Series	Soil Series	Texture 0-20 cm depth	0 - 20 cm depth			
			Water content % w/w	Cone resistance kPa	Dry bulk density g/cm^3	Vane shear strength kPa
A. High Load	Threipmuir	Loam	20.0	258	1.11	8.0
B. Medium Load	Darvel	Loamy sand	20.4	98	1.12	6.2
C. Variable Load	Threipmuir	Loam	23.0	600+	1.19	23.8+

\+ Higher values attributed to presence of young rye-grass.

rutting and bulk density which is not much less than that observed for the tyre alone (Fig. 2).

Cage wheel mounted conventionally: As noted previously (Soane et al., 1976) the rut depths and compaction under the cage wheel mounted conventionally were appreciably less than that for the wheel to which it was attached (Fig. 3). It is suspected that this is due to the opportunity of soil to pass upwards through the angled bars of the cage, the slightly smaller diameter of the cage wheel than the tyre to which it was attached and possible flexing in the mounting of the cage wheel when under load. We are examining the contribution of these effects to the observed behaviour of soil under cage wheels.

Dual rubber tyres: Tests made under both the dual rubber tyres showed that the rut depth and compaction below the outer tyre was less than for the inner tyre (Fig. 4) though the difference between them was very much less than that observed for the cage wheel and tyre (Fig. 3). It is possible that some flexing in the dual mounting may have occurred which could reduce the load carried by the outer tyre. Tread wear appeared to be equal on the two tyres though the lug pattern was different. Greater benefit from the use of duals might have been obtained if the inflation pressure had been decreased. Tyre manufacturers will allow deflation when using duals, to a limit appropriate for $\frac{3}{4}$ of the load which would have been carried by a single tyre.

Series C - Variation in load on conventional tyre: Considerable and statistically significant reductions in rut depth and compaction were observed (Fig. 5) as a result of reducing the load from 1.86 to 0.89 t with associated reduction in inflation pressure from 172 kPa. The differences between the highest and lowest load treatments were significant ($P < 0.05$) to a depth of 23 cm below the original surface. At the highest load the rut depth (5.5 cm) and maximum bulk density in the 0-20 cm depth (1.47 g/cm^3) were appreciably less than the corresponding figures (15 cm, 1.67 g/cm^3) found for the same wheel treatment in Series A tests (Fig. 1). This difference is attributed to the higher strength of the soil in Series C tests (Table 2).

DISCUSSION

The use of very wide section single tyres to carry high loads over weak soils without compaction is highly expensive and for agricultural vehicles it is usually necessary to consider cheaper alternatives. Reducing the vehicle weight is clearly an effective approach which should be pursued whenever possible but apart from special applications (e.g. low volume spraying) progress in this direction has been slow. A conventional traction tyre carrying 0.89 t with an inflation pressure of 83 kPa was found to cause appreciable rutting and compaction on soil of low strength. Further reductions in load and inflation pressure would be required to show appreciable benefits for conventional tyres.

The use of duals offers considerable benefits without excessive cost but appreciable rutting and compaction may still occur when high loads are carried. By greatly increasing the contact area there is likely to be a considerable increase in the total compactive response, as indicated by total rut cross sectional area (Dickson et al., 1979), the distributional summation of compaction (Soane et al., 1976), or the total change in air-filled porosity (Blackwell and Dickson, 1978). The change in air-filled porosity per unit length of rut was estimated to be 900 cm^3/cm for the wide section dual wheels carrying 1.87 t compared with 450 cm^3/cm for the single conventional tyre (Series A).

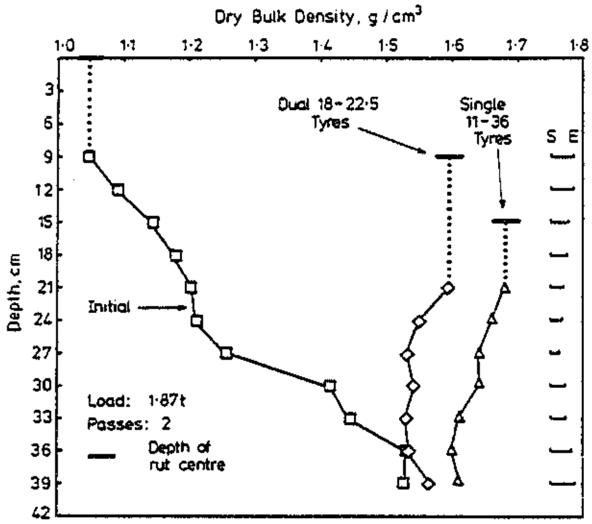

Fig.1. High load, wide section duals compared with conventional tyres (12.4/11-36)

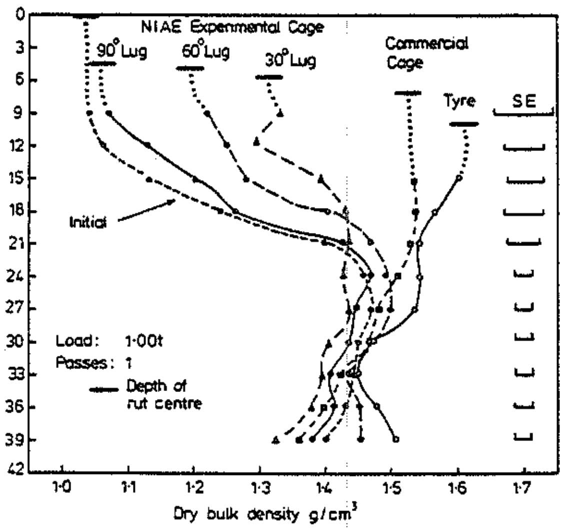

Fig.2. Medium load, experimental and conventional cage wheels mounted alone compared with conventional tyre (13.6/12-38)

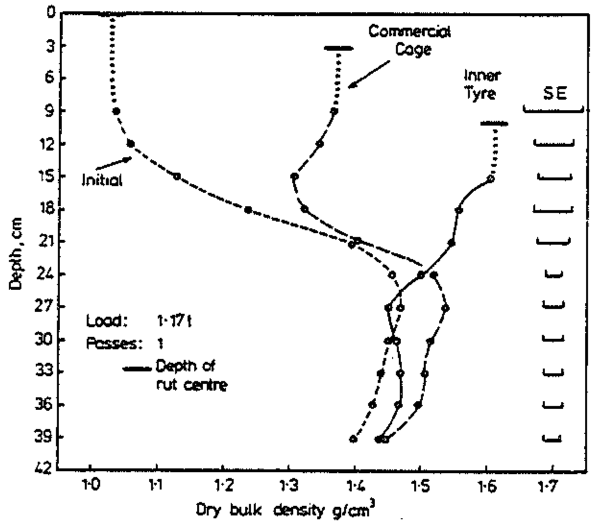

Fig.3. Medium load, commercial cage wheel mounted next to conventional tyre (13.6/12-38)

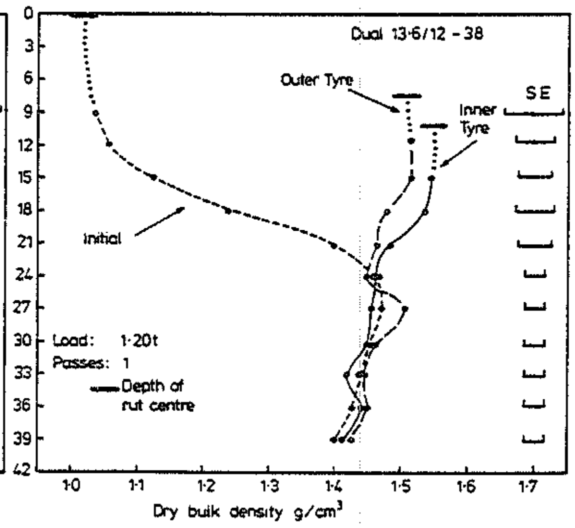

Fig.4. Medium load, dual conventional tyres (13.6/12-38)

<u>Figs 1-5</u>

Rut depth and dry bulk density in relation to original soil surface, measured in the mid-line of tracks of wheels carrying different loads over loose soil.

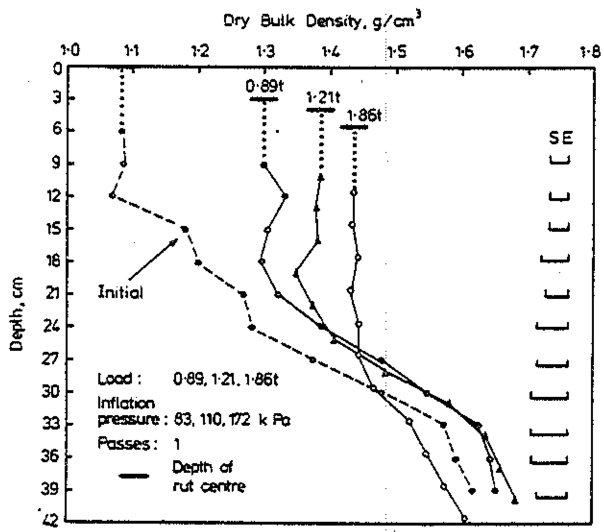

Fig.5. Variable load and inflation pressure for conventional tyre (12.5/11-36)

Although considerable reduction in mid-track compaction appears to be possible by using cage wheels mounted alone there are clearly problems associated with their use on hard roads. The use of an auxiliary wheel system for road work might be justified for certain types of vehicle.

Where vehicles are to be used on soils which have not been recently cultivated it is probable that the higher strengths of such soils will lead to appreciably less rutting and compaction (Pidgeon and Soane, 1978). This effect was also illustrated by the difference in responses obtained in Series A and C tests in this work. Compaction studies should therefore take into account the very wide range of both soil and wheel characteristics which are relevant to agricultural systems.

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THE TITLE OF THE PAPER Effect of tine position on the performance of multi-tined implements

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ABSTRACT The effect on performance of positioning tines on multi-tined implements at different spacings and relative depths is considered. The position is found to have a very significant effect on specific resistance and quality of work in a loosening operation.

INTRODUCTION

Previous studies with multiple tine implements Rathje (1932), Zelenin (1950), Willatt and Willis (1965), Chisholm et al (1970), Ferguson (1970), have shown that the positioning of tines on a tool frame can have a significant effect on implement performance. These workers concentrated particularly on either draught or soil disturbance aspects of tine combinations. They paid less attention to specific resistance (draught/disturbed area) and soil mechanics aspects of soil failure. For efficient tillage, the prime aim when arranging tines on a tool frame should be to maximise the type of disturbance required and minimise the draught i.e. minimise the specific resistance.

Soil disturbance or failure under the action of tines will occur along planes where the shearing resistance is a minimum. These failure planes are regular and predictable in homogenous fine structured soils, but may vary in direction in heterogenous soils where local variations in soil shearing resistance occur. When tines are working close to one another, the soil disturbance created by one tine will change the shearing resistance locally and this may affect the disturbance produced by a neighbouring tine. Therefore in multi-tine systems, the soil failure planes and the forces involved may be very different to those developed by individual tines working in the same soil. This paper considers the influence of tine positioning on the soil failure pattern and the specific resistance.

Experimentation

Tests were carried out under two soil conditions:

a) soil bin tests in a fine structured, compact sandy loam.

b) field tests in an undisturbed clay having a coarse blocky to prismatic structure at depth.

The boundary of the disturbed soil zone was determined by excavating a cross-section after the passage of the tines and was mapped using a profile meter. Forces were measured using a tension dynamometer or by mounting the tine or combination on an extended octagonal ring transducer.

Tine geometries and soil conditions were selected so that the soil failed in a brittle heaving manner over the whole working depth. Spacing comparisons were made for tines working at similar and different depths. Tine positions were chosen on a basis of known soil failure patterns with single tines, to investigate the influence of the disturbed zone created by one tine on the

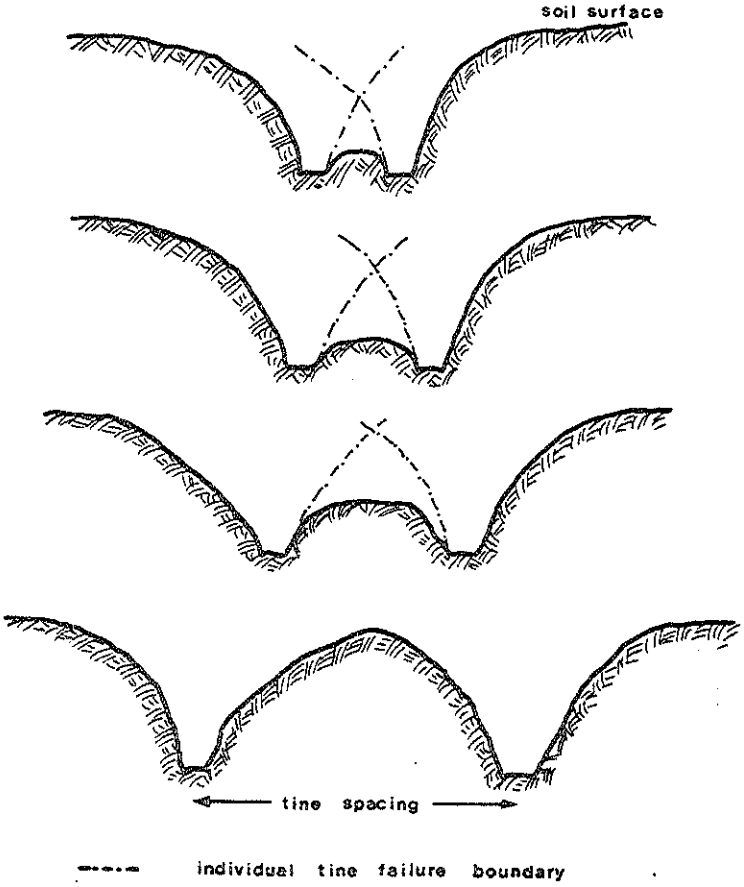


Fig. 1 Profile cross-sections of soil disturbance produced at different tine spacings (tine details 25mm wide 45^{o} rake angle, 150mm working depth.)

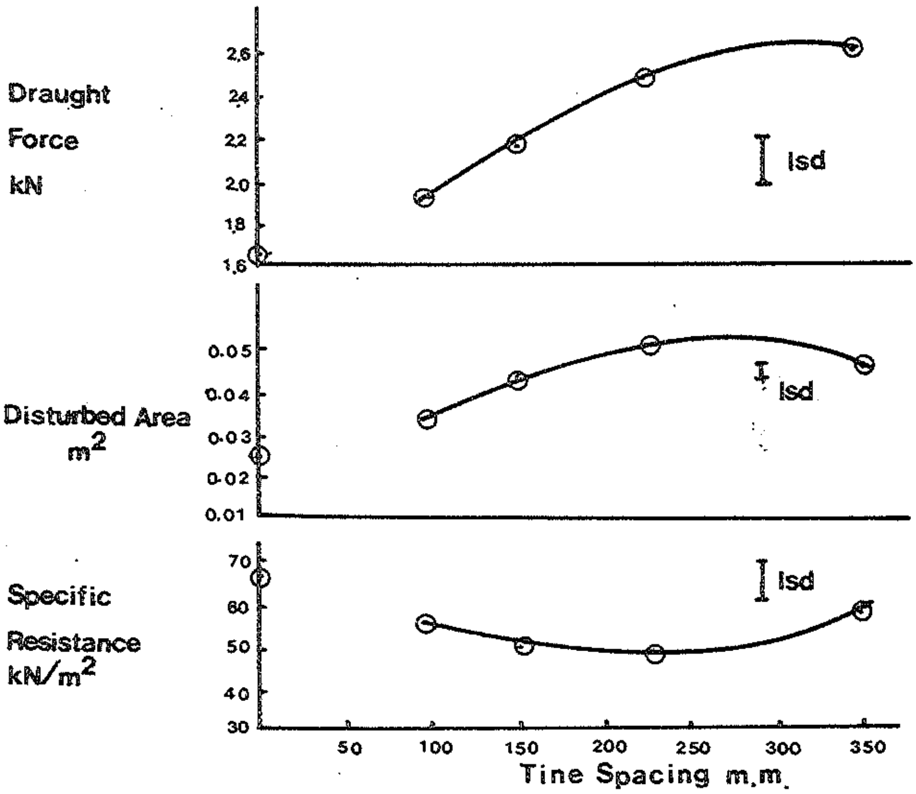


Fig. 2 Relationship between tine spacing and draught force, disturbed area and specific resistance for the tine spacings shown in Fig. 1 (lsd = least significant difference at 95% level).

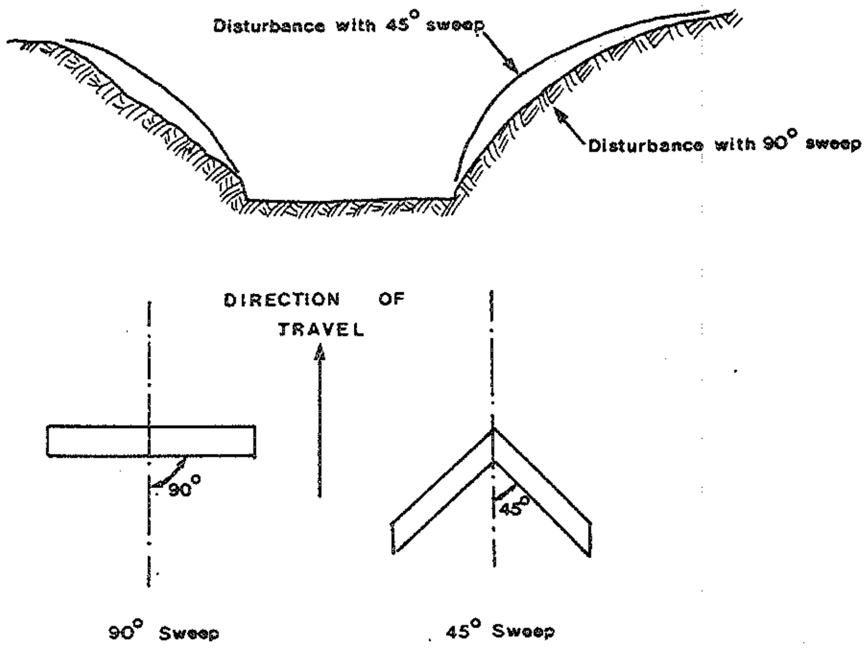
performance of its neighbour.

Results

a) Spacing effects with tines working at the same depth.

Figure 1 shows a cross-section of the soil area disturbed by two narrow tines positioned at different spacings in soil bin tests, Soomro (1977). Superimposed in Fig. 1 is the failure pattern for individual tines, assuming no interaction effects occur. Changes in the direction of the soil failure boundaries can be readily seen, the actual failure planes moving towards the zone loosened by the neighbouring tine. The relationship between the tine spacing and draught force, disturbed area and specific resistance is shown in Fig. 2. The specific resistance tends towards a minimum at a spacing of approximately 1.5 times the working depth, but the change is not significant within the spacing range between 1 and 2 times the working depth. At close spacings in the coarse structured clay soil, the two tines behaved as though they were one wide tine producing significant increases in draught. This effect can be prevented by staggering the tines.

Comparison of the disturbance produced by sweep type tines of 90^{o} and 45^{o} angle of approach, Fig. 3, shows the effect of differential soil failure on the final failure boundary surface, Pillainayagam (1975). Soil failure with the 90^{o} sweep occurs simultaneously across the complete working width and the shape of the side failure boundaries are similar to those of a non-interacting narrow tine in Fig 1. The soil failure is more progressive across the working width with the 45^{o} sweep, the soil in the centre failing first. This initial

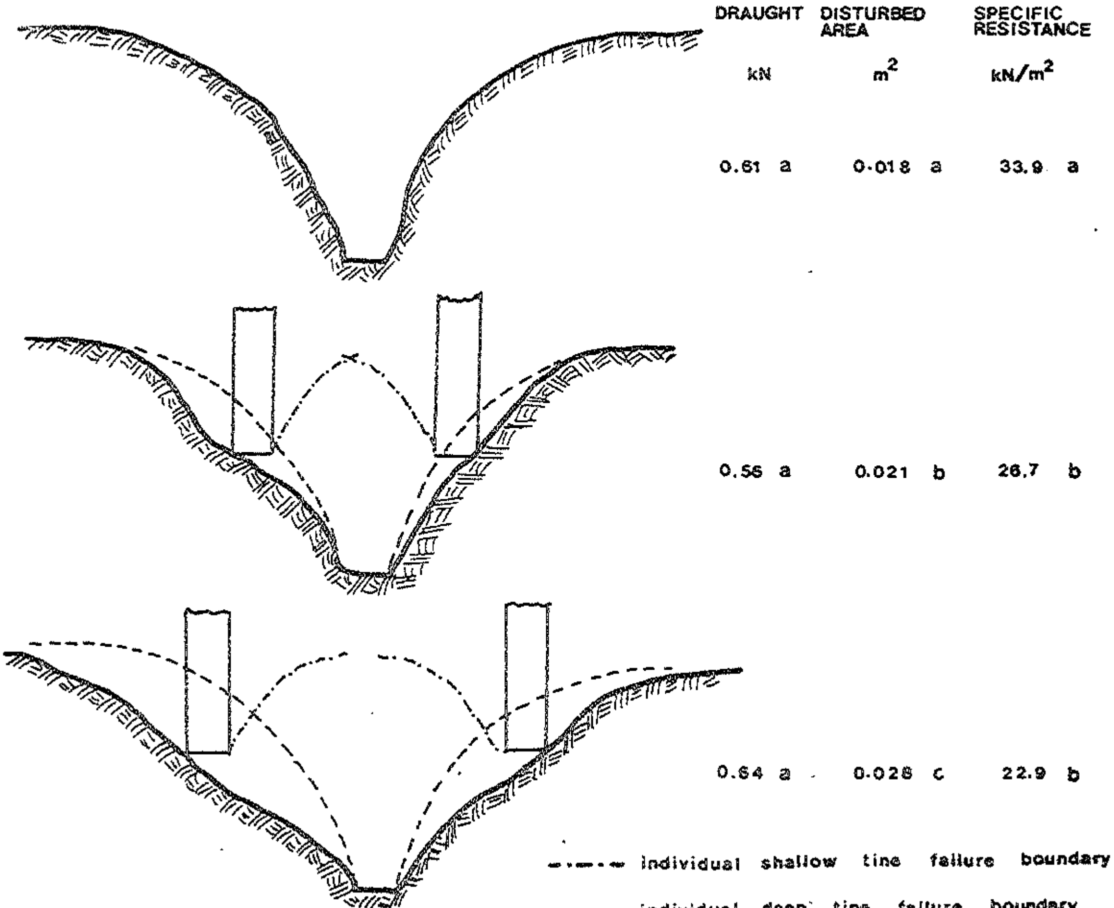


Sweep Dimensions

150 mm deep; 200 mm wide; 25° rake angle

		90° Sweep	45° Sweep
Draught	kN	1·36a	1·43a
Disturbed Area	m^2	0·050a	0·045b
Specific Resistance	kN/m^2	27·20a	31·80b

Fig. 3 The effect of sweep angle on disturbed area, draught force and specific resistance. (Data not followed by the same letter are significantly different at the 95% level).



(Data not followed by the same letter are significantly different at the 95% level)

Fig. 4 The effect of two shallow tines preceding a single deep tine by 300mm (tine details: 25mm wide, 45^o rake angle, 68mm working depth (shallow) and 150mm working depth (deep)).

failure in the central zone has caused the failure planes at the extremities to move inwards towards the loosened zone, reducing the disturbed area and increasing the specific resistance.

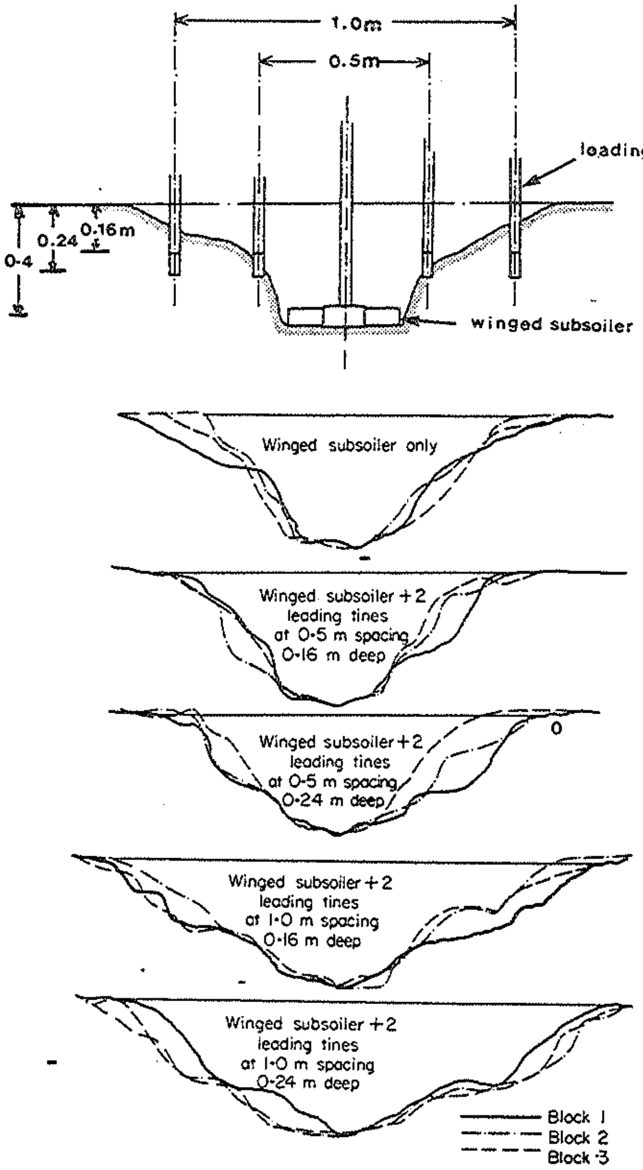
b) Spacing effects with tines working at different depths.

Figure 4 illustrates for a series of soil bin tests the boundary failure planes where the tine combination comprises of two shallow tines preceding a deep tine, the shallow tines working at half the deep tine depth. Increasing the shallow tine spacing changes the position of the deep tine failure planes, increasing the disturbed area and reducing the specific resistance. Fig. 5 illustrates similar changes in a field situation where a winged subsoiler tine was preceded by two shallow tines working at different depths and spacings. Whilst there are again no significant differences in the total draught values between the different tine combinations, there are large differences in disturbed area and hence in the specific resistance. Increasing the number of tines on a tool frame does not mean an increase in draught providing the tines are correctly positioned.

The use of correctly positioned shallow tines working ahead of deep tines can therefore have a very big influence on the efficiency of the loosening operation. Other experiments, Spoor and Godwin (1978), have also shown that loosening the shallow layers prior to the deeper ones not only reduces the specific resistance, but also allows satisfactory loosening to be achieved to much greater depths with given tines over a wider range of soil moisture conditions.

Conclusions

The soil failure boundaries with multi-tine implements is very dependent upon the relative positioning of the tines. Whilst the spacing between the tines working at the same depth influences both the draught force and the disturbed area, its effect on the specific resistance at tine spacings between 1 and 2 times the tine working depth is relatively small. Specific resistance and hence the efficiency of any loosening operation is particularly sensitive to tine positioning with tines working at different depths. Where the soil is loosened in stages from the surface downwards by the same implement, large improvements in specific resistance can be achieved combined with more effective loosening over a wider range of depths and soil moisture conditions.



	DRAUGHT kN	DISTURBANCE m^2	SPECIFIC RESISTANCE kN/m^2
Winged subsoiler only	23.94 a	0.242 a	99 a
Winged subsoiler + 2 leading tines at 0·5 m spacing 0·16 m deep	21.41 a	0.238 a	90 a
Winged subsoiler + 2 leading tines at 0·5 m spacing 0·24 m deep	20.86 a	0.283 b	74 b
Winged subsoiler + 2 leading tines at 1·0 m spacing 0·16 m deep	20.80 a	0.360 c	58 c
Winged subsoiler + 2 leading tines at 1·0 m spacing 0·24 m deep	23.48 a	0.418 e	56 c

Fig. 5 Comparison of disturbed area, draught force and specific resistance with a winged subsoiler tine preceded by two shallow tines. (Data not followed by the same letter are significantly different at the 95%.level).

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INTERRELATIONSHIP OF SOIL TILLAGE AND FERTILIZING IN GROWING MAIN FIELD CROPS ON HYPOGLEY

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ABSTRACT

The objective of three-year investigations on hypogley was to determine the optimal depth of basic tillage, extent of its possible reduction up to no-tillage, optimal fertilizing, interaction of soil tillage and fertilizing, and their mutual compensation in relation to the yields of some important field crops /maize, winter wheat and sugar beet/. The obtained results are positive and point to the possibility of tillage reduction as to the depth, its simplification for winter wheat and maize, but the need for deeper cultivation for sugar beet. The effect of fertilizing was not completely defined, and consequently the effect of combinations of tillage and fertilizing. The research is being continued.

INTRODUCTION

Investigations should show the extent to which the standard soil tillage can be reduced and the role played by fertilizing for maize and wheat, which are traditionally grown in the conditions of the central Drava Valley /North Croatia/, and for sugar beet which is just being introduced.

At a certain level of plant production, the depth of basic soil tillage has to be adjusted to natural conditions but should also be economically justified. Introduction of modern machinery causes great changes in some traditional practices of soil tillage, and also its depth. Thus, the reduction of tillage regarding its frequency, depth and intensity does not weaken only its primary effect but also the residual effect, which in the series of tilling practices should be considered in view of crop-rotation and environmental conditions.

According to some temporary studies, crops can grow and give relatively high yields in less ideal conditions of the soils than it was deemed necessary. Accordingly, it can be concluded that the standard system of soil tillage ensures a more or less favourable seedbed, but very often unfavourable root layer of the soil. Thus, our investigation of reduced soil tillage aims at finding a system that would eliminate these drawbacks and at the same time provide a basis for rational soil tillage in the full sense of the word.

INVESTIGATION METHODS

The trial was set up after the harvest of winter wheat, in summer 1975, on three different soil types. Due to limited space, this paper presents only the results obtained on hypogley.

In the first year four variants of basic soil tillage were investigated, and in the other two years eight variants /Table 1/. In the second and third years, variants of ploughing at 30 and 40 cm were each divided into three subvariants for maize and winter wheat in the following way: a/ herbicides + dead mulch, b/ harrowing with heavy disc-harrow at 15 cm, and c/ ploughing at 2o cm.

When sugar beet was included in the crop-rotation, ploughing at 30 or 40 cm replaced the subvariant of herbicides + dead mulch. The purpose of these practices was to find out if residual effects of deeper tillage would appear, and if its reduction was possible without decreasing the yield. Herbicide application instead of basic soil tillage, in the second and third years, was a substitute for the basic tillage for maize and winter wheat. The chosen variants of cultivation were conditioned by the existing technical potentials, respecting also agrotechnical requirements of the selected crops. Simultaneously, the trials investigated four grades of mineral fertilizing, paying special attention to the fact that in the conditions of reduced tillage it is very important to create nutrient reserves in the soil. Specific requirements of individual crops were thus disregarded in the first year, while in the second and third years, uniform fertilizing was carried out in all variants, but depending on the specific needs of test crops. By creating nutrient reserves in the soil in the first, and by uniform fertilizing in the second and third years, great care was taken to maintain soil fertility and enable tillage reduction, which would have been impossible at low fertilizer grades and in conditions of lesser fertility. The trials have stationary character and have been set up according to the split-block method, in four replications. This paper deals with the results of the first three investigation years. The trials are continuing in order to determine: a/ optimal depth of basic soil tillage, b/ possible extent of the basic tillage reduction up to complete no-tillage, c/ optimal fertilizing, interaction of tillage and fertilizing, and their mutual compensation, and some other important parameters.

BASIC DATA ON THE CLIMATE AND THE SOIL

The region where trials were carried out is rich in precipitation /844 mm per year/ with some oscillations in annual distribution, but also expressed primary precipitation maximum in May, and the secondary one in November. According to the rain factor after Lang /83/, the region is situated transitionally between semihumid and humid climate. According to the hydrothermal coefficient after Seljaninov, the region is in the zone of sufficient humidity /1.0 - 1.3/.

The trial was laid out on a hypogley soil on alluvium, of loamy-clayey texture, averagely gleyed. The compacted and poorly water-pervious layer of heavier structure lies immediately beneath top soil and stretches 90 cm deep. Below 90 or 100 cm there is loamy noncalcareous sand, which may be calcareous in places, depending on the composition of older alluvial deposits. Deeper soil layers are less gleyed due to groundwater.

INVESTIGATION RESULTS AND DISCUSSION

The first test crop in the trials, sugar beet, was preceded by winter wheat in repeated growth, which favoured the spreading of weeds, among which Echinchloa crus galli L. prevailed. The variety Maribo Monova was grown and the results of the analysis of variance showed no significant differences for any of the investigated factors /Table 1/. Absolute differences in root yields were rather expressed. The yield was at more or less the same level in the first two tillage variants, that is the variants of harrowing + subsoiling and ploughing at 20 cm. The yield went up when ploughing was carried out at 30 cm, and the highest yield was obtainted with ploughing at 40 cm. It should be mentioned that this was the first time that sugar beet was grown on this soil type in this region, so that certain production factors are still unknown. The differences in yields between the shallowest and deepest ploughing point to the justification of deeper tillage.

As regards the effects of fertilizing, the situation was rather illogical, which could be explained by the high potential, and also actual fertility of the soil.

As to the combined effect of tillage and fertilizing, there was practically no interaction. It can be partly explained by complete absence of the effect of fertilizer grading.

The second test crop was maize, hybrid Bc SK-418. Tillage had a significant effect on maize yield. The complete advantage was again on the side of deeper tillage, that is ploughing. Still, in relation to harrowing, the differences in yields are not significant. In case of preliminary ploughing at 30 cm, it was even better than direct ploughing at 2o cm for maize. Harrowing, preceded by subsoiling and harrowing rendered a yield which approached that of ploughing. In this case, standard tilling practices /ploughing/ were omitted for two successive years. However, significant differences in the yield occurred only in case of no-tillage by comparison with all other trial variants. Despite this fact, a relatively high yield of maize grain was obtained also in the variants "herbicides + dead mulch". It can be fairly reasonably supposed that in these variants the residual effect was felt of previous ploughing at 30 and 40 cm.

To conclude, soil tillage had advantages over dead mulch, and within tillage ploughing over harrowing. By comparison to standard ploughing at 20 cm, there was no residual effect of ploughing at 30 and 40 cm.

Fertilizing did not have a significant effect, but higher doses were more efficient. As there was no direct effect of fertilizing in the first year, it could be even less expected a year later. Due to favourable precipitation distribution at critical stages of its development, maize had enough moisture for the activation of the soil solution, so that the plants were well supplied with nutrients, even at lower

Table 1-Yield of sugar beet root and grain yield of maize and winter wheat in q per ha according to the variants of basic soil tillage and fertilizing and their combinations.

Basic soil tillage		Fertilizing												$\bar{X}_T$ (Tillage)		
		1st-Year														
		N_{90} P_{80} K_{100}			N_{120} P_{120} K_{140}			N_{150} P_{160} K_{180}			N_{180} P_{200} K_{220}					
		2nd-Year – uniform: N_{160} P_{120} K_{140}														
		3rd-Year – uniform: N_{140} P_{120} K_{110}														
1st Year	2nd and 3rd Year	Sugar beet	Maize	Winter wheat	Sugar beet	Maize	Winter wheat	Sugar beet	Maize	Winter wheat	Sugar beet	Maize	Winter wheat	Sugar beet	Maize	Winter wheat
Discing, 15 cm + Subsoiling, 40 cm	Discing, 15 cm	538,8	90,8	47,9	53,8	90,8	55,8	518,1	93,8	54,3	531,3	91,7	54,8	531,5	91,8	53,2
Ploughing, 20 cm	Ploughing, 20 cm	560,8	93,8	51,3	518,2	92,5	519,4	510,4	98,8	56,0	52,2	95,0	51,1	527,7	95,0	52,6
Ploughing, 30 cm	Herbicides + dead mulch	542,9	80,3	50,0	538,8	83,9	52,5	558,5	87,4	53,9	554,1	84,8	52,8	548,6	84,0	52,3
	Discing, 15 cm		91,8	53,9		91,3	47,4		95,5	50,6		93,8	51,9		93,1	51,0
	Ploughing, 20 cm		89,8	46,9		91,5	52,8		90,4	52,0		91,7	50,3		90,9	50,5
Ploughing, 40 cm	Herbicides + dead mulch	604,7	79,7	50,6	560,4	77,8	50,7	551,3	88,0	55,4	551,7	85,9	51,3	567,0	82,8	52,0
	Discing, 15 cm		86,4	53,2		88,8	48,5		92,8	51,3		90,1	51,7		89,6	51,2
	Ploughing, 20 cm		93,3	50,2		93,2	53,7		96,2	54,0		93,8	50,5		94,1	52,1
$\bar{X}_F$ (Fertilizing)		561,7	88,2	50,5	538,8	88,7	51,7	534,6	92,9	53,4	539,6	90,9	51,8	LSD 5% 6,6 1% 10,0		

fertilizing grades.

It is logical to expect the effect of the combination of tillage and fertilizing to be the result of their individual effects. Thus, there was no considerable interaction of tillage and fertilizing.

Neither in the third experimental year, when winter wheat, variety Zlatna dolina, was grown as test-crop, did any experimental factor have a significant effect on the yield, but significance was most approached by fertilizing. Great uniformity was observed in the yields of winter wheat grain, with relatively high general level of yield in spite of expressly negative meteorological conditions for wheat development. As to the depth of tillage, in some variants wheat was in the most unfavourable situation. Namely, the reduction of tillage (depth) was the smallest for sugar beet, and maize utilised the residual effect of deeper tillage in shallower or no-tillage variants. Therefore, the results obtained with wheat can be considered positive.

Of all the variants, of special interest are those in which tillage was completely omitted and which were named " herbicides + dead mulch ". Herbicide tribunil, which was used as a substitute for basic soil tillage, showed great efficiency in weed control. The obtained yields point to the possibility of not only reducing the basic tillage depth but also of complete omission of the basic tillage, even of pre-sowing cultivation. Wheat is, after all, known as a crop with a poor response to deep tillage. However, no conclusive results are possible after only one year of investigation.

There was practically no effect of fertilizing on wheat yields, though there was a slight tendency towards yield increase at high doses. But as fertilizing was not significant in any of the three trial years, either the differences between fertilizer grades were not big enough or the substratum so fertile that it completely masked the effects of fertilizing. We are in favour of the latter assumption which is confirmed by the general production results, which point to the high production capacity of the soils in question.

In the combinations of tillage and fertilizing there was a rather wide range of winter wheat yields. Still, no combination can be given absolute preference, for no significant differences were recorded. The good effect of no-tillage (herbicides + dead mulch), with almost all fertilizer doses, deserves special emphasis.

When discussing some general questions in connection with these trials, it should be mentioned that reduced tillage hides some drawbacks, one of the basic defects being the restricted ploughing-in of fertilizer into deeper soil layers. In case of soils of good fertility, either natural or technological, these deficits are less important, because plants can take up nutrients from soil reserves at the time of reduced or omitted tillage, which anyway cannot become a universal practice for a longer time period. Thus also from the point of view of soil fertility, the chosen soil type can be taken as suitable for the reduction, or even omission of tillage, that is the restricted fertilizer application would not appear as a more significant limiting factor in periodical reduction of the soil tillage depth. This primarily applies to fertilizing with phosphorus and potassium, the reserves of which should be created at the stage preceding the reduction of soil tillage. As regards nitrogen, due to its behaviour in the soil (leaching) there are practically no greater difficulties in reduced, or even no-tillage systems. On soil types like the one in this trial, well supplied with organic matter, there are considerable nutrient reserves, whose activation depends on other measures applied and also on the current hydrothermal relations of the climate.

CONCLUSIONS

The following conclusions can be drawn on the basis of the climatic and edaphic conditions in the region and the response of test-crops to cultivation and fertilizing:

1. The yields of sugar beet, in the variants of tillage and fertilizing and their combinations, were satisfactory, in spite of considerable climatic aberrations. Besides, it was the first growing of sugar beet on this soil type (hypogley). Differences in the yield between the variants point to the justification of deeper tillage, while fertilizing effects can be explained by high potential, and even actual, fertility of the soil.

2. Tillage had a significant effect on the yield of maize, the second crop in the trial. Tillage had an advantage over dead mulch, and within tillage over harrowing, but without statistical significance in the latter case. Realtively high yields also in the variant " herbicides + dead mulch " are quite logically supposed to be due to the residual effect of previous ploughing at 30 and 40 cm.

Fertilizing had no significant effect, but there was a certain advantage of higher doses. Favourable moisture conditions at critical stages of maize development helped the activation of nutrients from soil reserves, in which respect maize is a very receptive crop.

3. The yields of winter wheat were very uniform in the variants, relatively high despite expressly adverse meteorological conditions for its development. In some variants, the tillage reduction for wheat was the greatest, so the obtained results can be considered positive, because they indicate the possibility of reducing the basic tillage depth, and even its complete omission, as well as the omission of pre-sowing cultivation.

Fertilizing had a poor effect on the yield of winter wheat, but with positive tendencies towards increasing yield at higher doses.

4. Conclusive results can be only obtained after longterm investigations of these problems. Therefore, the trials are being continued, beside those conducted on lessivé pseudogley and lessivé brown soil, the results of which were not presented in this paper due to restricted space, also on hypogley.

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PLOWING DEPTH AND INTENSITY OF FERTILIZATION OF CORN GROWN IN IRRIGATED HEAVY SOILS

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ABSTRACT

The paper presents results of trials on the effects of plowing depth and intensity of fertilization on yield of corn grown on hydromorphic black soil with and without irrigation.

It was found that the effects of cultivation at 15, 25, and 35 cm were similar. The plowing deeper than 35 cm negatively affected corn yield, similarly as a shallower cultivation than 15 cm, i.e., the disking at 10 cm.

Mineral fertilization increased the yields of corn. The medium dosage of fertilizers (256 kg/ha of pure nutrients) brought significant yield increases. Further increases of the dosages of mineral fertilizers brought minimal yield increases. In the case of the largest dosage (342 kg/ha) the yield of corn was increased by 1 mtc/ /ha, on the average for the experiment, in relation to the medium dosage.

Irrigation brought low yield increases because the test years had a high and relatively favorable distribution of precipitation, which does not happen frequently in the region in which the trials were performed.

INTRODUCTION

On the basis of the theory on the establishment and maintenance of arable land established by D. Todorović (1957), and through numerous experiments conducted by P. Drezgić et al. (1964, 1967, 1972), V. Mihalić et al. (1964), Z. Madjarić et al. (1959), M. Stojanović (1971), B. Živković et al. (1966), and others, it was proved that deeper plowing has an economically justifiable effect regarding the yield increases of the crops grown. These experiments were conducted on different types of soil which also had different textures.

The research on different farming systems on various soil types was aimed at the increase of yields of the crops grown. The obtained yields were the basis for the conclusions on the effects exercised by different cultural practices as the depth of plowing, crop rotation, mineral fertilization, plant cultivation, etc.

This specific research should give scientific explanations on the correlations among different farming systems, changes of physical properties of soil, and yields obtained. This will offer a possibility of explaining the effects of different plowing depths and fertilization methods on the increase of corn yields since the increase is the result of conditions created in a certain soil type and the agroecological region.

EXPERIMENTAL PROCEDURES

The experiment was conducted in Vojvodina, the north-eastern part of Yugoslavia, on calcareous hydromorphic black soil of heavy mechanical structure.

The preceeding crop at the experimental plots was the wheat. At the end of October 1974, the soil cultivation and fertilization were performed within the following variants:

a) variants of cultivation:
- disking
- plowing at 15 cm
- plowing at 25 cm
- plowing at 35 cm
- plowing at 45 cm

b) variants of fertilization
- check Ø
- 170 kg/ha of NPK = 71: 59:40
- 256 kg/ha of NPK = 107: 89:60
- 342 kg/ha of NPK = 143:119:80

Some experimental plots were irrigated and some were not. The experiment, which has a stationary character, is conducted according to the split-plot method. The corn (variety NSSC-696) was planted in all cultivation and fertilization variants. The experiment was conducted in the period from 1974 to 1976.

RESULTS AND DISCUSSION

The effect of the tested factors on corn yield varied from year to year in dependance of weather conditions. For brevity, this paper contains only average three-year results.

Mineral fertilization had the highest effect on corn yields. On the average, the lowest dosage (170 kg/ha of NPK) brought the yield increase of 13.34 mtc/ha in comparison with the non-fertilized check plot. The largest dosage (342 kg/ha) brought the increase of about 22 mtc/ha; however, this increase was only 1 mtc/ha higher than the increase brought by the medium dosage (256 kg/ha).

Larger differences among the variants of fertilization were obtained mostly in the third test year, when the extended action of fertilizers applied to the experimental plots before the establishment of the experiment was exhausted. Besides, this soil type is rich in NPK elements - the soil layer to the depth of 30 cm contains 0.20% of N, 22 mg/100 gr of soil of P_2O_5, and 35 mg/100 gr of soil of K_2O. The humus content is 4.5%. It may be concluded that the medium dosage of fertilizers may be considered as ideal for this soil type.

Tab. 1 - Effect of plowing depth and intensity of fertilization on corn yield (mtc/ha), on 3-year average (1974-1976)

Fertilization, kg/ha	Plowing depth, cm					Average
	Disking	15	25	35	45	
Ø	66.84	70.10	70.25	69.62	59.81	67.32
170	77.81	83.60	82.31	84.60	75.01	80.66
256	83.08	90.55	89.46	92.17	84.24	87.90
342	87.32	91.80	90.78	89.80	85.73	89.08
Average	78.76	84.00	83.20	84.04	76.20	81.24

LSD:	Plowing	Fertilization	Plow.x fert.	Fert.x plow.
5%	4.48	3.01	9.37	6.64
1%	6.04	4.00	12.42	8.80

According to the three-year results, the depth of plowing had lower effects on corn yields than the mineral fertilization. The plowing deeper than 35 cm and shallower than 15 cm (disking) brought negative effects. On the three-year average, the disking brought the yields lower by 5.25 mtc/ha than the plowing at 15 cm.

The cultivation depths of 15, 25, and 35 cm brought similar yields of corn (Tab. 1). In other words, the corn may successfully be grown after plowing at 15-25 cm for three years providing that it had been preceeded by the establishment of arable land, i.e., the plowing at 35 cm.

The cultivation at 45 cm brought the lowest yield in the experiment which was even lower than that obtained after the disking at 10 cm. Particularly low yields were obtained in the non-fertilized and non-irrigated variant.

The above results indicate that the depth of plowing should be carefully considered in the case of heavy soils with a shallow accumulative-humic horizon because a deep plowing reaches and plows up the unfertile soil layer, decreasing by the same token the fertility of the entire arable layer.

Tab. 2 - Effect of plowing depth and intensity of fertilization on yield of corn (mtc/ha) grown with and without irrigation, on 3-year average (1974-1976)

Irrigation	Plowing depth, cm	Fertilization, kg/ha				Average
		Ø	170	256	342	
Non-irrigated	Disking	64.76	77.15	82.94	85.45	77.57
	15	66.96	78.70	86.11	88.08	79.96
	25	65.66	81.09	87.36	90.22	81.08
	35	68.19	82.04	86.81	85.02	80.51
	45	56.49	74.68	80.62	82.16	73.48
	Average	64.40	78.73	84.77	86.18	78.52
Irrigated	Disking	68.94	78.48	83.22	89.19	79.96
	15	73.24	88.51	95.00	95.53	88.06
	25	74.84	83.54	91.56	91.36	85.32
	35	72.06	87.14	97.54	94.58	87.83
	45	63.14	75.36	87.86	89.11	78.86
	Average	70.44	82.60	91.03	91.95	84.00

LSD:	Irrigation	Fert.x irr.	Irr.x fert.	Pl.x irr.	Irr.x pl.
5%	5.36	4.24	6.22	6.34	9.37
1%	9.83	5.64	8.25	8.54	12.61

In this experiment, the irrigation had the lowest effect on corn yields. On the three-year average, the irrigation brought the increase of 5.5 mtc/ha. This occurrence is the result of high and favorable distribution of precipitation, which does not happen frequently in this region. The corn was irrigated two times in 1974. Both irrigation, totaling 100 mm of water, took place in August. The irrigation brought yield increases of about 13 mtc/ha in 1974. In 1975 and 1976, the corn was irrigated only once, with 50 mm of water. Effects of irrigation in these two years were low.

The interactions among the tested factors are shown in Table 2. The highest yield in the experiment (97.54 mtc/ha) was obtained with the plowing depth of 35 cm, fertilization with 256 kg/ha of NPK, and irrigation, the lowest (56.49 mtc/ha) with the plowing depth of 45 cm, without irrigation and fertilization. The difference of almost 41 mtc/ha resulted from the combined action of the three tested factors.

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CONCERNING THE STRUCTURE OF IRRIGATED SOILS IN THE NORTH-EAST OF MOROCCO .

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Summary - the authors study the transformation of the structure of clay-soils which have undergone perennial infiltration irrigation, using field-studies, measures (at different levels) of soil porosity, and micromorphological analysis. They describe the evolution of these soils and present hypotheses concerning the mecanisims and the agents of this evolution.

I.- Introduction

Our observations are limited to an irrigated perimeter situated in an arid and semi-arid area in the north-eastern corner of Morocco. (Currently 55,500 ha are under perennial infiltration irrigation; I4,225 ha will be under sprinkler irrigation starting this year.)

In French classification, the majority of soils are isohumic with a moist soil-climate during the raining season, and within this isohumic class are maroon soils and sierozems. In U.S.Taxonomy, they are xerochrepts, calciorthids, paleorthids, calcirhodoxeralfs and calcixerolls.

Certain of these soils have been under perennial infiltration irrigation for I5 or 20 years, and we have noticed that these soils have undergone important morphological transformations, chiefly within the tilled horizons which are later irrigated. Certain studies (RUELLAN I962, I964a,b; Avant-projat, I964; MATHIEU and DANGIS, I976; MATHIEU, I977, I978) have already shown the important consequences for agriculture of these transformations, which are chiefly at the level of basic structure and its porosity. It becomes a question, then, of investigating :

- those soil-properties which have been changed from the non-irrigated state,
- those agriculture practices responsable for the changes.

We have approached this by a detailed examination of soil-structures and their porosities.

2.- Methodologies and Techniques chosen

The field-study at various levels (plot, profile, horizon, clod) was later completed in the laboratory with structural analyses using the following methods :

- apparent density of earthy agglomerates (MONNIER and al., I973)
- micromorphological analyses (morphology and micromorphometry)

We are presenting here an example of those transformations which have come about, comparing one soil-population which never has been irrigated with a population under perennial infiltration - all studies using deep clay soil.

3.- Preparation for planting in irrigated soils

. Tillage is accomplished, almost exclusively, by tractor carrying ploughs having three non-reversible discs.

The first tillage of a new irrigated sector often penetrates to a depth of 25 cm. But this depth rapidly diminishes to the extent that a compact horizon is formed underneath the irrigation furrows.

As soon as this compact horizon is formed in the inferior part of the Ap horizon, tillage remains superficial (IO to I5 cm); and there is no subsoiling accomplished whatsoever. (MATHIEU and DANGIS, I976)

Tillage in summer or autumn (after the cultivation of sugar beets or cereals) is always done in a soil which is too dry and without pre-irrigation. At this time of the year, the soil has only 5 to 7 % humidity in its first few cm, then I2 % between IO and I5 cm. When tillage occurs in winter, spring, or after truck gardening, the soil is moister and more easily penetrated by the plough.

This tillage of a soil which is too dry produces large cubic clods and a great deal of fine powder. The clods must later be broken up by other machines.

. Post-tillage is intended to break-up the soil; and currently the only machine used in a systematic fashion in Easten Morocco is a harrow with discs.

Generally this harrowing takes place in a hard and dry material (soil tilled too dry or soil left too dry after tillage); therefore, the disc harrow grinds the clods into very fine particules. After this operation the tilled horizon becomes a kind of flour with a certain quantity of very hard clods of varying size.

4.- Irrigation

On the plains of the Moulouya, cultivation on ridges is accomplished by infiltration irrigation using short furrows(in Arabic "Robta") with long transversal furrows every 6 meters (see photo). We note numerous defects in this system - especially its inefficiency and its destruction of the soil : large labor force needed to accomplish irrigation, loss of 8 to I2 % of surface area by transversal furrows, impossibility of mechanizing upkeep and harvest, enormous consommation of water, destruction of initial levelling, and rapid transformation of soil structure with appearance of a thick compact horizon.

Border irrigation is used for grain and lucerne.

5.- General characteristics of pedological profile

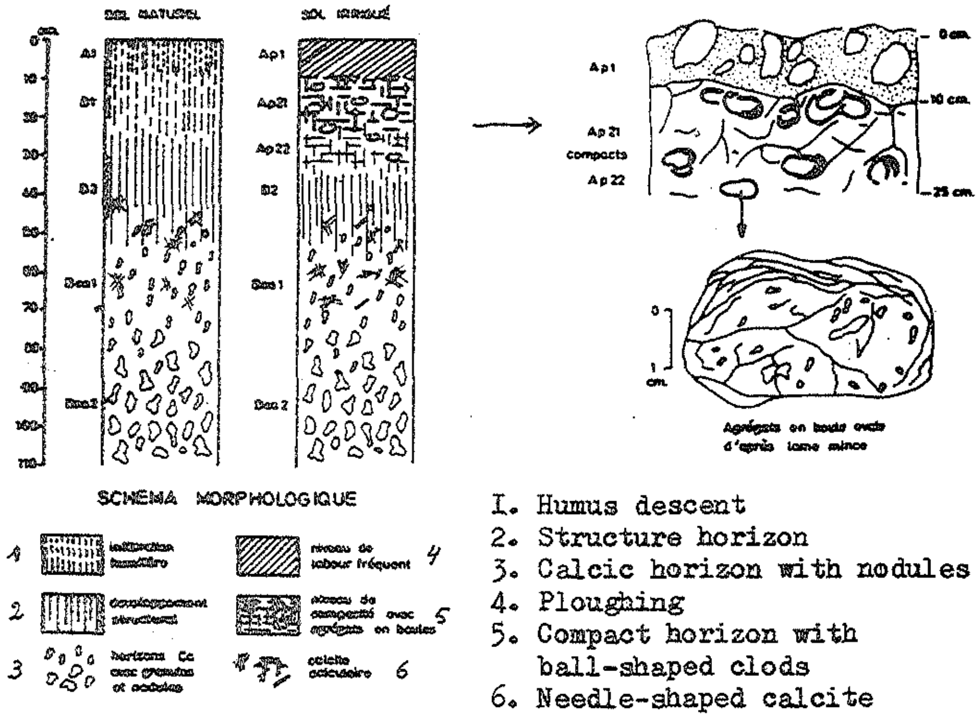
The dominant characteristic of soils of the Moulouya plains is the differentiation of calcium carbonate under the profile (RUELLAN, I97I). In deep clay soils, Bca horizon of calcareous accumulation is formed by soft or hard concentrations (nodules), in variable quantities. The surface of these soils is slightly or not at all calcareous.

Starting at the top of the profile, the clay content gradually increases as one penetrates to a greater depth; and, at a certain depth, depending on the soil, a maximum clay content is reached. In slightly or non-calcareous soils, the clay content is from 30 to 40 % at the surface, and 60 % or more between 40 and 80 cm. The sand content is generally between IO and 20 %.

The most frequent colours are red and red-brown, 2,5 and 5 YR (Munsell Soil Color Charts) and on the surface of the most rainy areas(more than 400 mm/year) the soils may present a mollic epipedon.

Table 1.- Macromorphological organisation

depth cm	Non-irrigated soil	Irrigated soil	depth cm
6/7	- A1 horizon: moderate subangular blocky structure in the wet state with crumbly and granular struct; dry;strong cohesion,when one tries to break up the clods,one obtains a significant quantity of micro-granular elements;crusty at the surface - highly heterogenious structural ensemble with very small and medium-sized elements,important biological artifacts(faecal pellets),high total porosity and some compacted clods	- Ap1 horizon;tilled horizon;massive structure constituted by the massing of granular and crumbly elements and compacted clods;moderate porosity;crusty - in the case of lucerne:0-5cm,parallelipiped blocks with fine laminar substructure; 5-15cm,massive structure with wide desiccation cracks;and,at this time,appearance of ovoïd aggregates just as in Ap21 horizon	10/15
20/25 45/50	- B horizon:more homogenous structure;very clear angular structure in the wet state;if the soil is tilled,the top of B horizon is compact and often presents the begining of laminar structure (plough pan) - gross prismatic structure,prisms have about a ten cm height;dry,they break up into strong very fine angular blocky structure.This structure can continue into Bca horizon	- Ap21 horizon;structure with a tendance to massiveness which breaks down into large clods(sup. to 10cm)by action of desiccation cracks.Appearance of extremely dense structural elements in the form of flattened spheres from 3 to 5cm in length with scaly surface,with weak porosity : very compact zone - sometimes,gross laminar structure at the top of horizon.	25 35
	- Bca horizon:small to moderate-sized strong angular blocky sturcture,calcareous granules and nodules	- Ap22 or B2 horizon:moderate angular blocky structure with a tendance to massive structure; spherical elements are always present : weak porosity,compact zone	



I. Humus descent
2. Structure horizon
3. Calcic horizon with nodules
4. Ploughing
5. Compact horizon with ball-shaped clods
6. Needle-shaped calcite

6.- Evolution of the irrigated agricultural profile

Morphological transformations in the irrigated agricultural profile essentialy concern :

- macroscopic organization
- volume of porosities
- microscopic organization

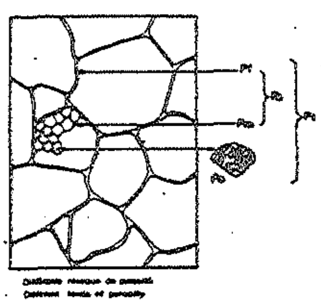
6.I.- Macroscopic organization

Soils which have been irrigated for nearly I5 years show important morphological transformations in their organization structures (see table I) and these new macroscopic organizations of surface horizons have the following characteristics :

- appearance and development of new forms: on one hand, a continous, massive ensemble with lamellar elements in which initial polyhedral elements disappear; on the other hand, appearance of large nutty aggregates in the horizons under the tilled horizon.
- appearance of macroporosity of planes in a continous ensemble
- modification of porosity with increase of compactness of these horizons

6.2.- Volume of porosities

The analyses of systems of porosity of non-disturbed soil requires measurements at several levels of organization in order to distinguish the different forms. These forms are defined in terms of complete porosity, structural porosity and porosity of elemental aggregates (MONNIER and al.,I973)



- Complete porosity (Pt):total voids of soil, including voids between clods, in clods and in elemental aggregates.
- Structural porosity (Ps):includes porosity between clods (Pf) and in clods (Pm)

. Porosity of elemental aggregates (Pa):is tied to elementary fabric and depends on granulometric composition, mineralogy and fabric plasma of the material.

Complete porosity %

Depth cm	0-5	5-15	15-25	25-35	35-45	45-60
Natural Soil	50,35		49,62	49,62	47,31	46,92
Irrigated soil						
- (1)	60,27	[illegible]	47,66	[illegible]	[illegible]	[illegible]
- (2)	45,75	43,85	45,13	45,13	47,69	48,46

(1)-after annual cultivation ; (2)-after cultivation of four years (Lucerne with border strip)

Clod porosity %

Natural Soil	44,56		39,62	39,25	36,15	35,77
Irrigated soil						
- (1)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
- (2)	35,09	34,22	35,77	37,34	38,08	-

Porosity of elemental aggregates, %

Natural Soil	32,41	34,08	32,46	30,42	29,42	29,32
Irrigated soil						
- (1)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
- (2)	27,34	26,80	27,8[illegible]	29,90	29,35	-

The analyses of porosities show the following variations from non-irrigated soils (in relative pourcentages)(see table 2):

. Complete porosity (Pt)	depth: 0-5	5-15	15-25	25-35 cm
- annual cultivation	+19,7	+9,9	-3,9	-3,1
- cultivation of lucerne during 4 years with border strip	- 9,1	-13,6	- 7	- 7
. Clod porosity (Pm)				
- annual cultivation	+ 1,9	-1,0	-8,8	-6,9
- cultivation of lucerne	-21,3	-23,2	-9,7	-4,9
. Porosity of elemental aggregates (Pa)				
- annual cultivation	-10,8	-9,5	-8,0	-2,1
- cultivation of lucerne	-15,8	-15,8	-8,7	+2,6

6.3.- Microscopic organization

6.3.1. in non-irrigated soil

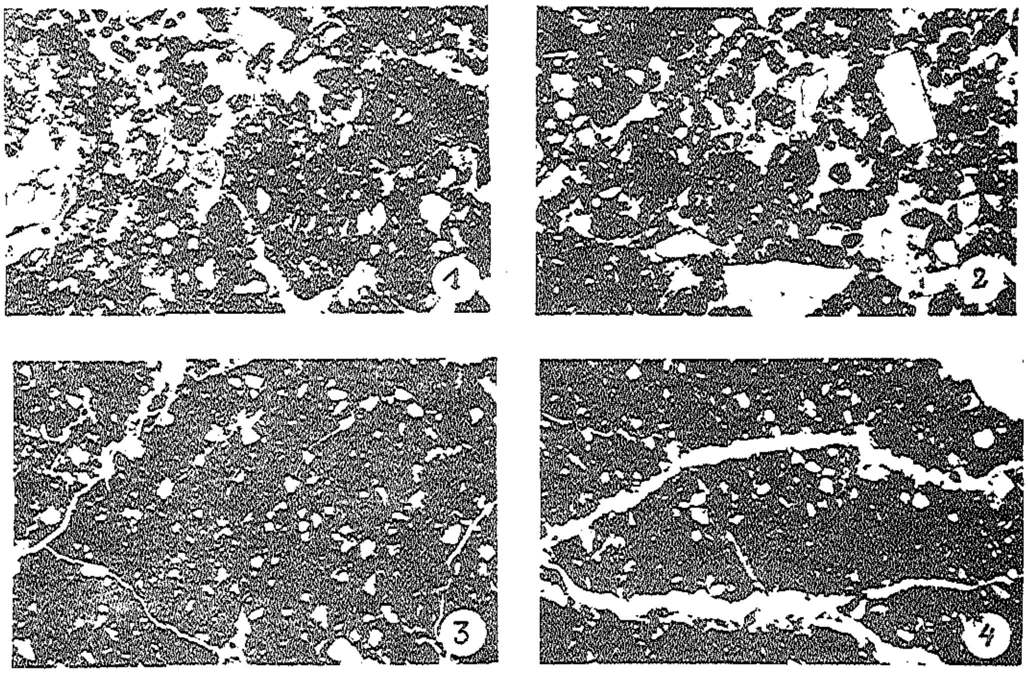
The principal micromorphological characteristics of the clay and clay-silt soils of these plains (MATHIEU,1978) can be summarized as follows :

Plasma

In A1 horizon, the plasma is clayey and homogeneous, without plasma separations (argillasepic)(BREWER,1964).

In B1 and B2 horizons, we have an ensemble with thin plasma separations characterized by striated orientations as islands (insepic) with some aggregates characterized by plasma separations on walls of voids,on surface of skeleton grains, and in elongated zones (maskelvo-insepic).

In Bca horizons, plasma remains clayey but with important calcitic microcrystalline interflorescences.



I and 2.- Non-irrigated soil

I. AI horizon : spongy structure with faecal pellets
2. BI horizon : spongy to crumbly structure, also with faecal pellets

3 and 4.- Irrigated soil

3. ApI horizon : regular joint structure with planes and fissures
4. Ap21 horizon : a sub-parallel external irregular joint structure of a ovoïd aggregate

(plain light ; 26 x)

Structure and voids

In AI and BI horizons, microstructure (according to BEKMAN and GEYGER, 1967) is spongy, crumbly with irregular vughs and rough-walled.

In B2 horizon, microstructure is of the irregular joint type with numerous planes, numerous channels and less irregular vughs, spongy in places. There are no cutans on the surfaces of the aggregates.

In Bca horizons, it is primarily of the irregular joint type with numerous planes; but in the interior of aggregates, it is sometimes very porous and, in places, spongy.

Calcite accumulations

One of the particularities of these soils is, without doubt, its multi-variant calcite accumulations. The following forms can be distinguished : microcrystalline interflorescences, neocalcitans, spongy nodules (orthic nodules), compact nodules (disorthic nodules) and needle-shaped calcite efflorescences("Lublinite").

6.3.2. in irrigated soil

Fabric plasma and plasma concentrations

In B2 and Bca horizons, development of thin cutans (ferri-argilans) is observed in the vughs
In Ap2 and B2 horizons, development of clear masepic fabric plasma is observed, giving the whole a fluidal structure.

Structure and voids

Voids are the part of the soil having undergone the most obvious transformations.

In A horizons and in subjacent horizon with a spongy and crumbly microstructure in non-irrigated soil, the change is to a joint structure in irrigated soil; the number of vughs declines and they are replaced by planes and fissures.

In compacted Ap2I and Ap22 horizons, the joint structures have obviously replaced the spongy and crumbly structures. At this level, the new isolated ovoïd aggregates have a sub-parallel external irregular joint structure. For this reason, the Ap2 horizons are the levels of rupture and rearrangement of micro-aggregates and vughs.

In the remaining part of the B2 horizon, the planes remain numerous and the structure is still dominated by an irregular jointed form. In the Bca horizon, the structure does not change its characteristics from those of a non-irrigated soil.

7.- Interpretations

Our initial analyses seem to indicate a particular agro-pedological evolution in soils subjected to a perennial infiltration irrigation.

7.I.- Transformations

- new macrostructural organization of massive character appears with a macroporosity of planes and a high degree of compactness.
- transformation and diminution of porosity in almost all organisation sturcture to a depth of 35 cm.
- transformation of biological porosity (biological vughs and channels) into mechanical porosity (dessication voids: i.e.,planes)
- evolution of fabric plasma of soil with the appearance of thin cutans and the development of plasma in striated orientation(masepic)

7.2.- Mechanisms

- the alternating soaking and dessication provokes :
  the formation of new types of voids (MATHIEU,I978)
  the diminution of biological activity
  the development of oriented clayey separations (Mc CORMACK and al. I973)
- clay leaching with formation of thin cutans (MATHIEU,I978)
- soil compaction
  - elementary aggregates are compacted with modification of elementary fabric. This compaction is noticed to a depth of 25 cm, having no relation to mode of cultivation - but aggravated by cultivation of lucerne.
  - structural compaction(related to macrostructure). There is a gradual decrease in the size of planes between clods and within clods ending in coalescence,i.e.,jointure of clods which had originally been separate.This compaction is especially noted starting at the top in fields of lucerne and to a lesser extent under the tillage horizon with any sort of cultivation.

7.3.- New factors of genesis

- Working the soil
  - tillage increases total porosity in worked horizon
  - tillage in a too dry soil produces a powdery microstructure incompatible with the perennial infiltration irrigation

- agricultural machines probably contribute to compaction at all levels of organization.

. Irrigation

- a significent infiltration of water can provoke the formation of clay colloïdal suspensions, their migration and the formation of cutans

- alternating states of saturation and dessication which are more intense than in non-irrigated soil causes formation of planes and fissures as well as the modification of fabric plasma.

- submersion of surface horizons leads to a saturation of material and to a state of near liquidity at the extreme surface. This probably modifies elementary fabric of the aggregates, especially the micro-granules. Intense dessication provokes a transformation (and especially a diminution in porosity) of aggregates but also a transformation at all levels.

- the conditions of irrigation of lucerne (i.e. border strip) and abandonment of all working of soil for 4 years are extremely injurious to the structure of the soil at all levels of organization and principally at the horizon with is first tilled, then completely submerged.

7.4.- Suggestions to better agricultural and irrigational methods

. Working of soil

- stubble ploughing and tillage at correct water content, with pre-irrigation

- refining tillage after initial tillage, without drying of soil, and an absolute prohibition of any machine which grinds the soil (i.e. disc harrows) and instead introducing harrows using teeth (e.g., spike harrows)

- to increase deep ploughing tillage plus subsoiling in order to break up the compacted horizon (MATHIEU and HMAMOU, 1979)

. Irrigation

Modifying infiltration irrigation methods in this way : reducing to a strict minimum the area of contact between irrigation water and the soil surface (RUELLAN, 1962) :

- desiminating information on methods of corrugation in order to replace border strip irrigation (e.g. with cereales, lucerne)

- with furrow irrigation, giving the ridge a flater profile and reducing the width of the furrow

. Biological activity

Encouraging the use of the green manure to enhance a maximum of biological activity indispensable to restructuring of soil.

Acknowledgement

Grateful acknowledgement is made to Professeur A.RUELLAN of the Ecole Nationale Supérieure d'Agronomie in Rennes(France) for his generous and wise counsel throughout the study.

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Tillage in irrigated crop production of semiarid and arid regions

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Soil cultivation and management has a basic function in irrigated crop production. Proper timing, decisive for a high productivity, is related closely to the workability and trafficability of soil. The efficiency of tillage equipment is increasing with the level of mechanization but the energy input related to the yields is increasing at the same time. Plot size and accessability of fields are preventing an efficient use of four wheel tractors.

About 220 Mio. ha or 15 % ot the world arable land are under irrigation. Most of this area is in the semiarid and arid regions of the world, more than 50 % (mainly surface irrigation) in developing countries with a high population pressure and a general shortage of arable land. The irrigated area is still extending inspite of severe problems in many of the existing systems and an increasing shortage of suitable water.

The high investment of the irrigation system itself and the operation costs can be justified only by a high productivity, that means high yields and a close crop rotation. To gain that target generally a relatively high level of inputs (seed, fertilizer, plant protection, energy, equipment and management) is necessary.

Because the soil itself is an integral part of the irrigation system and most of the problems of irrigation systems are caused by high water losses and inappropriate soil management soil cultivation has a basic function in irrigated crop production.
Whereas the general aims of cultivation are equal to those of rainfed agriculture here priority must be devoted to tasks caused by the <u>specific conditions of the irrigation systems:</u>

- application of high rates of water, often far beyond field capacity;
- application of high rates of salt with irrigation water;
- continuous wet-dry-rhythm of the soil by water application, combined with swelling and shrinkage of soil with high clay (montmorillonit) content;
- small plots according to the water delivery, infiltration rate, levelling and inclination of plots;
- increased weed pressure;
- close crop rotation;

- additional labour demand (maintenance and operation of the irrigated system).

So main targets of soil cultivation are:

- equal water distribution (bordering, furrowing, levelling) to guarantee sufficient water for all plants;
- high take up rate and water holding capacity to minimize water losses;
- suitable internal drainage of soil to prevent logging of superfluous water, prevention of compacting and hardpans;
- reduction of upwards directed water movement and evaporation causing salt concentration in the top layer or guiding not to be prevented salt concentration to specific areas of the dam, far from the plant;
- controlled water flow to prevent erosion;
- creation of stable soil aggregates of suitable size (5 - 15 mm);
- breaking of crusts.

For surface irrigation systems a number of partly additional field operations before, during an after planting thus is needed:

- levelling dams after harvest of preceding crops, incorporation of plant residue, mechanic weed control;
- subsoiling and leaching if needed (hardpan, compaction, salination);
- primary tillage (deep cultivation) and secondary tillage including weed control;
- levelling of surface;
- bordering (dams in direction of water flow);
- cross checking (dams transverse to the direction of waterflow);
- furrowing (in case of furrow or corrugation irrigation) in direction of water flow;
- shaping of dams;
- crust breaking.

In wet rice (paddy) production the aims of cultivation and therefore also the operations are different. Here the main operation is the puddling of the flooded soil to destroy the soil structure and to create a compact layer for minimum water loss during the field is permanently flooded.

For all operations suitable tools and implements are available from the multipurpose hand hoe and the wooden animal drawn plow to sophisticated tractor and implement systems. But nevertheless the choice and proper use is still difficult.

Basic problems of cultivation are:

- proper timing of operations,
- availability of energy,
- depth, intensity, frequency and accuracy of cultivation,
- accessability of plots (size of farms and plots, roads);
- management, especially in case of multifarm use of machinery.

Proper timing and energy demand

Proper timing when water is available means cultivation immediately after harvest, loosing as little time as possible for the next crop. In Egypt for instance so an average of nearly two crops per year (cropping intensity 1.9) is possible, in Taiwan up to four crops per year (sweet potatoes, rice, vegetables, rice).

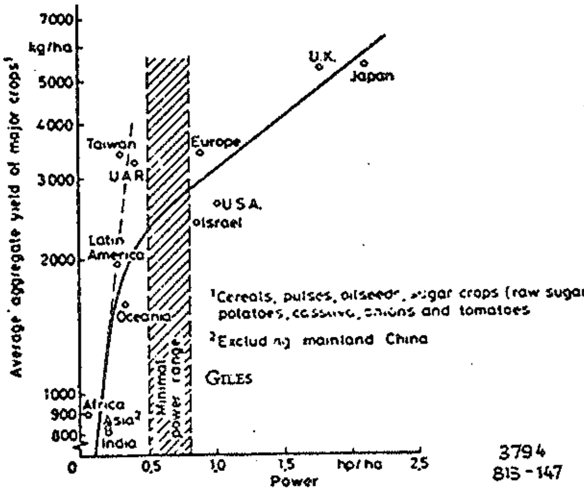

Figure 1: Energy input and yields in different countries.

Crucial especially for the bottleneck soil cultivation is the available power (human, animal or engine) related to the arable land which in most of the developing countries is still far below the demand identified by FAO as 1.5 kW/ha for fully mechanized irrigated crop production or the minimal demand of 0.5 to 0.75 kW/ha as we can see from the graph of Giles (Fig. 1).
The capacity of the different sources of energy is very different as we can see in Fig. 2.

One man can cultivate 0.02 up to 0.1 ha per day by hand-hoe. Additional seasonal labour to break the labour peak of tillage is rare even in overpopulated countries.

So the area to be cultivated by a family of 2.5 active workers is limited to about 1 ha.

With a pair of bullocks the dayly ploughed acreage is about three times as high, 0.03 up to 0.3 ha and the quality of tillage is better. The farm area can be extended to 2 to 2.5 ha. In most of the developing countries the number of draft animal is decreasing, especially in irrigated areas because fodder production for draft animals is too expensive in irrigation schemes and grazing area is not available.

The powertiller is mainly used for puddling in paddy fields of South and South East Asia. The effeciency is 0.15 to 0.5 ha per day, nearly double as high as of a pair of bullocks and five times as a man with the hand-hoe. Furthermore the powertiller can be used in two or three shifts per day with two or three operators so that the daily acreage can be easily doubled once more.

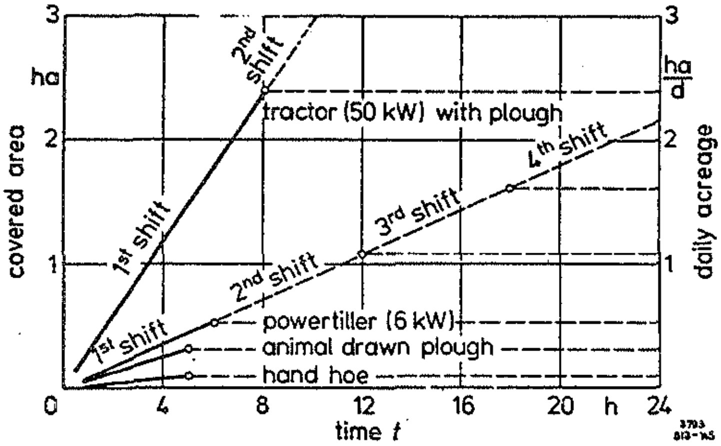

Figure 2:

Tillage effeciency with different power sources.

The four wheel tractor (50 kW) has the highest efficiency with 1.0 to 2.4 ha/day in one shift under comparable conditiones, that means nearly 25 times the human efficiency. 25 ha of land can be cultivated by one tractor. But the average size of irrigation farms in the developing countries is 1 - 2 ha only.

Proper timing besides the available power is closely related to the trafficability and workability of soil. Many of the soils of semiarid and arid zones (esp. with a high content of fine sand and silt) have only a very limited range of suitable water content (Fig. 3)

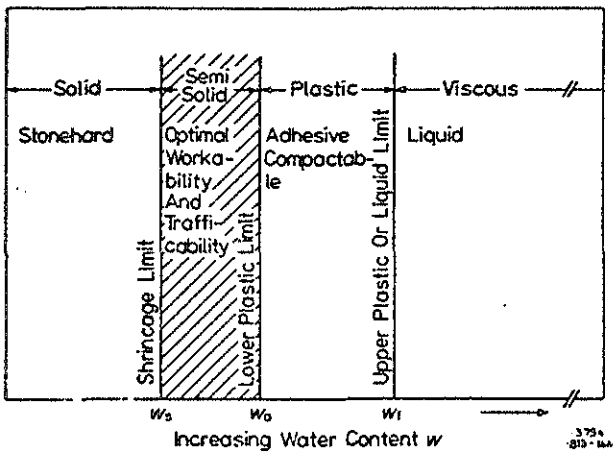

Figure 3:

Consistency limits of soil.

The lower plastic limit is exceeded already after small water gifts, but after the usual high gifts or after heavy rains (in semiarid zones) especially in areas of winter rain with low evaporation rates and poorly drained soils a lot of time (up to two or three weeks) is lost until cultivation is possible.

At high moisture content, where the strength is mainly due to the organic bonds, the clods are very weak because of the very low organic matter content of most of the tropical soils. Thus the clods are very susceptible to deformation and compaction which because of the risk of salination is the basic threat to irrigated soils, especially when tractors and heavy equipment are used.

After a narrow zone of water content with optimal workability (often only a few days or even hours due to high evaporation rates) soils with a high content of fine sand and silt become hard like concrete (up to 20 N/cm^2 of ploughing resistance) and cannot be cultivated by hand or animal. To treat these clod forming soils with heavy tractors and implements seems to be waste of energy and material. So besides the attempt to improve the soils by increasing the organic matter content two alternatives must be discussed:

- cultivation with high efficiency between shrinkage - and plastic limit of the soil or
- technical irrigation to keep the water content in between shrinkage and plastic limit during cultivation if water is available.

In both cases besides the necessary hardware of tractor, implements, equipment and fuel a sufficient know how and management is needed. Singh and Chancellor show that an increased level of mechanization can increase the level of yields considerably but increases also the level of energy input related to the unit of crop. The total costs of production are reduced, the farm income is rising, but the availability and cost of energy will have an increasing influence on highly mechanized production systems. But even for mechanized rice production the energy input-output-relation is far below one (1 to 5 according to Steinhart).
Facing the general energy situation the idea of maximal input to gain maximum yields which is typical for irrigation schemes has to be reviewed.
Egypt for instance with 100 % of irrigated agriculture shows that high yields are also possible with low energy input (0.4 kW/ha, 50 % human and animal). So new approaches have to be investigated. One amongst these is zero tillage, once started for extensive rainfed agriculture (to prevent erosion) which is tested now also for instance for irrigated rice in the Philippines. The yields are comperable with those of puddled plots but weed control is still a problem, even with paraquat which is also rare and expensive. Furthermore water losses are high because there is no water logging layer.

Reduced tillage ?

Energy as well as time and material can be saved by decreasing:

the depth of cultivation
the intensity
the frequency
the accuracy (homogenity, evenness).

The choice of the site and proper irrigation system is decisive for the difficulties of soil management in an irrigation scheme. As well as the availability of suitable water and the hydrologic aspects the characteristics for soil management have to be considered.

The internal drainage of superfluous water is the limiting factor for reduced tillage because any local or general waterlogging causes salination and shortage of oxigen for the plants. Vertisols for instance or saline and alkaline soils have a poor internal drainage and are sensitive to compaction so that they need frequent deep and intensive tillage. Especially where nutrients and water are rare deeper cultivation can increase and stabilize yields. Capillary water ascension causing evaporation and salt concentration at the surface has to be reduced, especially when the water table is high. Hardpans, often created during grading, have to be broken as well as crusts, often after every irrigation. Accurate cultivation creating well levelled and homogenious fields can also improve water distribution, save water and allow bigger plots.

Generally speaking new high yielding crops introduced with a new irrigation systems like cotton for instance or suggar beet have an higher claim of deep and intensive cultivation because they are much more sensitive to compaction as native rainfed crops. The chance to reduce tillage in irrigated crop production seems to be very limited. Because of losses of organic matter and water the use of the mouldboard plough should be restricted to cases where it is needed for weed control, incorporation of organic matter or lifting of fine material and nutrients. In many cases the tine cultivator or chisel plough proved to be sufficient.

Plot size and access

Depending on the irrigation system, the water delivery, the slope and levelling of the field and the infiltration rate the plot size is limited. For basin irrigation on sandy loam for instance the plot size can exceed 0.5 ha only with a high water delivery rate (> 250 l/s). For strip irrigation the proposed width is between 5 and 20 m only, furrow irrigation on the contrary allows furrows up to 500 m length. Farm holdings with a total area of 1 ha only, three or four different crops and scattered fields have plots often not more than 100 m^2. Furtheron because of the lack of roads, dams and the whole irrigation system (mains and submains as well as drainage canals) the field access with tractors is impossible or at least very time consuming.

The efficiency of field operations generally and of four wheel tractors in particular is related to size and shape of field as well as to the distance from farm to field and field to field.

Model calculations of Gindele show that working time is increasing strong progressively with decreasing plot sizes below one hectar especially for large implements, that the most adequate shape of field is rectangular and that the optimal ratio between length and width of field is between 20 for a one hectar plot (500 m furrow length) and 16 for a 0.1 ha plot (62.5 m furrow length).

So most of the irrigation systems of the developing countries are not suitable for the use of four wheel tractors. In rice cultivation tractors have to climbe over the permanent dams but in other crops dams and submains often can be removed for tillage of neighbouring plots (even of different owners) and rebuilt before or even after planting.

For small plots mounted implements have to be preferred and the reversible plow for instance has up to 50 % more efficiency as the one way plow besides the good levelling effect.

Transport time is decreasing the efficiency considerably. For a 0.5 ha plot Gindele shows a 2 % increase per each 100 m of distance between field and field, that means 100 % increase for 5 km.

So the field layout has to be a compromise between irrigation and mechanization system, to be discussed already in the phase of planing of the irrigation scheme. The proper road system is a major problem in the development countries, especially in old irrigation systems, once planned for hand operation and animal use and now to be tractorized.

Summary

Proper timing of soil cultivation is related closely to the available power at hand, especially when the workability of soils is confined to few days only. The reduction of tillage is limited due to the necessary even distribution and internal drainage of water. The efficient use of tractors is impossible as long as the plots are too small and the access is difficult. Unfortunately the degree of mechanization of field operation normally is not discussed in the planning phase of irrigation systems.

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Some Experimental Results of a Newly - designed Soil Tillage machine

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One of today's most difficult problems of soil tillage yet to be solved is the incorporation of plant residues particularly straw into the soil in such a way that, on the one hand, a complete decay is guaranteed, and on the other hand, seedbed-preparation equipments and sowing-machines can still be used without blockages. With ploughless tillage systems, the incorporation of organic materials influences soil loosening and crushing. For these reasons straw incorporation is of special interest in the technology of grain production. Such interest has led to the development of a soil-cultivating machine which is able to incorporate straw into the soil at the same operation as the soil is loosened and crushed. This machine (design, function, power requirements) has been described in the ISTRO-Proceedings of 1976 (1).
In this report results of field experiments with this machine can be found.

Technology's main task with regard to an optimum effect of straw manuring is to insert it evenly into the soil to assure sufficient contact between straw and soil.
This task is not always fulfilled by the machines used in practice. This may be due to an unsatisfactory chopping and an uneven incorporation of the straw.

Therefore, when a new test machine is developed, it must not only have to meet the demand for a uniform insertion of straw in the soil but also the conditions for a satisfactory chopping and distribution has to be fulfilled.

The objectives of this study were the following:

1.) preparation of ideal conditions for straw decay in the soil

2.) reduction of straw concentration on the soil surface to enable the application of conventional seedbed-preparing implements and sowing-machines in ploughless tillage systems.

Figure 1 is a schematic diagram of the test machine.

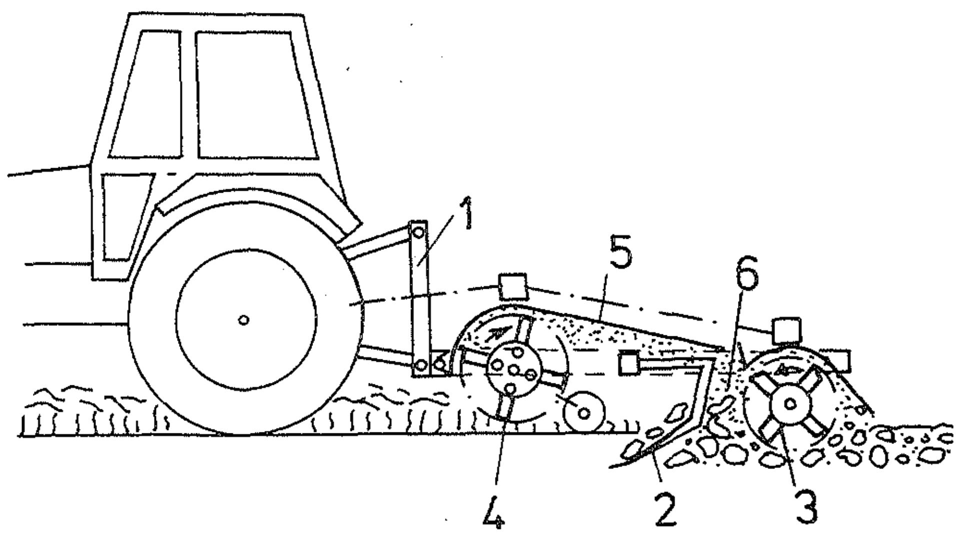

Figure 1: Schematic diagram of the test machine (1: basic frame; 2: chisel tines; 3: rotary cultivator; 4: straw chopper; 5: guide plate; 6: mixing space)

This method of incorporating straw into the soil with the new test machine differs from conventional methods as they are used thus far. The most important difference lies in the combination of chopping and incorporation of the straw. The unchopped straw is spread by a straw distributor at the combine harvester. Thus, unchopped straw is more evenly distributed on the field surface than it would be if it were chopped before spreading, which satisfies the main requirement of uniform mixing in the soil.

Besides an intensified chopping of the stubble, the chopping of the straw in connection with its incorporation offers the additional advantage of eliminating possible blockages of the incorporational implements.

The new machine, described in the ISTRO-Proceedings of 1976 (1), has been tested on the field for three years. The testing took place on a loam soil with a crop rotation consisting of maize, winter wheat and spring barley.

After the harvest of these crops, the straw was inserted into the soil within one pass of the new machine.
The chisel tines worked at a depth of 20 cm, the rotary cultivator at 10 cm with a working speed of 5 km/h. When the straw had been inserted, winter wheat was planted after maize. Three weeks after the straw incorporation a springtine harrow was used to subdue previous crop and weeds on the wheat-barley-plots respectively.

The fields remained unworked until spring sowing. In spring, the seedbed was harrowed conventionally and sown with a seed-drill or a spacing drill.

Here, test results of this new method are compared with the results which had been found under the same conditions, at the same time and on the same site by application of a plough.

In the ploughing system, the straw was chopped and distributed after the harvest by a tractor-mounted chopper, inserted by a rotary cultivator (depth 10 cm), then harrowed for weed-controlling and ploughed in autumn (depth 20 cm). During the ploughing, the tilled straw was mixed in over a depth of 20 cm and the uniformity of the destribution in the soil was determined to compare it with that of the new method. For seeding, a springtine harrow was passed twice and then the seeds were sown with a seed drill or a spacing drill.

Test results:

straw incorporation:

An even insertion into the soil layer from 0 - 20 cm and a maximum quantity of remaining straw on the soil surface of 10 percent (by presumption of straw quantities up to 12 t/ha) was expected.

The actual evenness of straw distribution is compared with the ideal distribution within the mentioned limits.

One index for evaluating the quality of straw insertion may be the deviation from the ideal distribution. In this study the standard mean deviation was used as a parameter for evaluating the straw incorporation. The more σ decreases, the better is the efficiency, and the more σ increases, the worse the insertion effect.

Table 1 summarizes the results of straw insertion by the new method in contrast to the ploughing system.

	straw from				
	barley		wheat		
	1976	1977	1975	1976	1977
test machine	4,6	5,8	9,0	8,5	5,0
plough	24,2	11,1	37,8	19,5	18,8

table 1: index of a straw insertion σ (%) of different methods.

A far more even insertion of straw (by equal quantities of straw) was obtained with the new machine. The reasons for this result, obtained by the new machine are based on a more effective chopping (additional chopping of the stubble) and distribution (spreading of the unchopped straw by the distributor).

These results are shown in Tables 2 and 3.

	straw from				
	barley		wheat		
	1976	1977	1975	1976	1977
test machine	4,1	4,1	4,9	3,9	3,9
plough	6,6	7,4	4,1	5,2	5,2

Table 2: mean length of chops (cm) of different methods.

	straw from				
	barley		wheat		
	1976	1977	1975	1976	1977
test machine	15,8	10,1	4,6	7,2	4,4
plough	21,3	27,4	33,4	34,7	31,8

Table 3: distribution of straw (standard deviation in %) on the field before insertion

soil loosening

The soil loosening effects of the test machine and the plough were investigated at different times of the year and for different depths of the soil with the help of a penetrometer.

Figure 2 shows the measured values for the years 1976 and 1977.

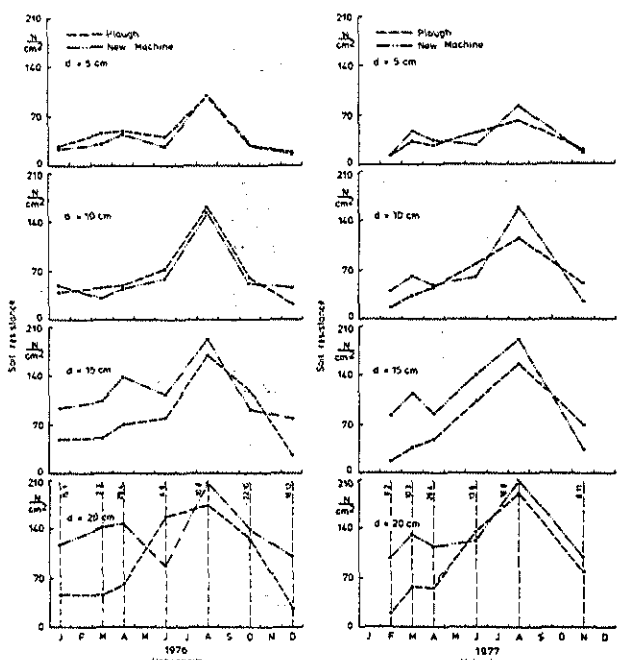

Figure 2: Soil resistance after different tillage

Each point is an average of 10 tests. The values turned out to increase with increasing depth and reached a maximum in summer for both methods.

If the measured values are differentiated to the depth, no differences between the ploughing and the test system can be found within a depth of 0 to 10 cm. At 15 cm, higher indexes of the test machine indicate a better loosening effect of the plough which is significantly more evident at a depth of 20 cm.

Concerning the soil loosening effect, the plough and test machine were egual down to a depth of 10 cm. Deeper layers were loosened more efficiently by using the plough. The spacing of chisel tines of 45 cm gave a reason for the reduced loosening capacity of the test machine as the soil is merely broken up incompletly under wet conditions.

Seedbed-preparing

One important criterion for evaluating a seedbed is the aggregate size of a soil.

Table 4 shows the aggregate sizes of the soil after working on it with the test machine and a plough. They had been determined before the seedbed had been prepared for the crops mentioned in spring and autumn and are represented as mean weight diameters (mm).

	winter-wheat			spring-barley			maize		
	1975	1976	1977	1975	1976	1977	1975	1976	1977
test machine	56,7	39,4	34,2	48,2	8,4	44	31,6	9,4	49
plough	86,1	75,1	74,1	-	73,2	55,3	-	77,8	82

Table 4: mean weight diameters (mm) from different methods before the preparing of the seedbed.

It is shown that the crushing effect of the test machine is evidently superior to that of the plough. The advantage of this fact is given by a reduction of at least one pass to prepare the seed-bed by using traditional harrows.

Yields.

In table 5 yields of different crops after application of both systems are given.

	spring-barley			maize			winter-wheat		
	1976	1977	1978	1976	1977	1978	1976	1977	1978
test machine	90	102	96	79	92	-	103	110	95
plough	100	100	100	100	100	-	100	100	100

Table 5: yields % obtained by using different methods.

The differences in the yields of all crops lie within the limits given by differences of the soils, errors in sowing, fertilizing, plant protection operations, harvesting and the choice of the samples.

The low yields of spring barley and maize of the year of 1976 are to be blamed upon erosion losses, caused by an inclination of the field where the test machine had been working.

With conditions as they were discribed, the application of the test machine does not reduce the yields. Yield losses are not to be attributed to faults of the machine itself. Special advantages are to be expected under climatically unfavourable conditions on heavy soils (complete decomposition of straw, sowing in time, lower energy and labour requirements).

As the insertion of straw, the loosening of the soil and the preparation of the seedbed have to be effected within the shortest possible time under these conditions, and especially in connection with the cultivation of winter crops, the possibility of carrying out all working steps in only one pass is to be favoured.

References:

(1) Stroppel, A.: A new Machine for the Insertion of Straw into the Soil and for deep Tillage in ploughless Tillage Systems. ISTRO-Proceedings 1976, Uppsala, Sweden

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THE PERFORMANCE OF TILLAGE MACHINERY IN LONG TERM CEREAL EXPERIMENTS IN U.K.

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1. Experiments

During the period 1971-77 long term experiments were carried out to study the effectiveness and operating costs of a range of cultivation machinery for reduced cultivations and direct drilling compared with traditional cultivations. Other research staff monitored weeds, diseases, pests and soil aspects.

1.1 Measurements

The experiments were done on replicated plots using plant establishment and crop yield to gauge the suitability of the cultivation technique. To provide information on treatment costs, power and labour requirements, measurements were made of width of work, depth of work, forward speed, wheel slip, draught and power take-off torque.

Observations and measurements were carried out in the soil and on the crops to provide information on the numerous non-engineering aspects.

1.2 Sites

The work was undertaken at three sites where cereals were grown continuously for six years:

a) M.A.F.F. Experimental Husbandry Farm, Boxworth, near Cambridge, where winter wheat was grown on a clay loam soil.

b) Rothamsted Experimental Station, Redbourn, near Harpenden, where winter wheat was grown on a silty loam soil.

c) N.I.A.E., Silsoe, where spring barley was grown on a silty clay loam soil.

1.3 Cultivation equipment and operations

The primary cultivations were pre-determined for each site and generally remained the same throughout the period of the experiments.

The implements for the secondary cultivation, whether in separate passes or in combined operations were chosen according to soil conditions at the time of working the land. All plots on each site were normally cultivated or drilled on the same date when soil conditions were similar.

The straw was baled before the start of the experiments at all sites in 1971. At Silsoe, where spring barley was grown, baling was continued until 1974/75 when the whole area was burned due to weed infestations; in succeeding years baling was carried out. At the two winter sown sites, the stubble was burned each year following 1971 until 1975, when the straw was baled.

Stubble cultivations and/or spraying to control weeds before the primary cultivation was only carried out where necessary and rolling after drilling was done where required. Routine top dressing of the crops with fertilizer and spraying was done according to crop husbandry requirements.

2. Results and discussion

2.1 Soil conditions

The soil at Silsoe (silty clay loam, Wicken series) was generally the most difficult to work and timing of machinery operations was most important to minimise soil compaction and produce a suitable soil tilth.

The soil at Boxworth (calcareous clay loam, Hanslope series) was a little easier to work except in the extremes of weather conditions.

The soil at Rothamsted (silty loam, Batcombe series) was generally easy to manage and it was possible to carry out cultivation operations under relatively wet conditions.

2.2 Primary cultivation implements

Throughout the experiments the conventional plough performed at low work rates compared with the chisel plough, shallow plough and rotary digger (Table 1); the fact that the chisel plough normally required two passes meant that output was intermediate between the plough and shallow plough.

The draught implements performed poorly on wet soils whereas the p.t.o. powered rotary digger led to negligible wheel slip even in the most difficult conditions. Under dry conditions some penetration problems were experienced with the shallow plough and also, when the conventional plough and chisel plough were operated at greater depths (approx 200 mm), a rather cloddy tilth was produced.

The best degree of inversion was produced with the conventional mouldboard plough but this did not appear to be of great importance for cereals in the conditions experienced in the experiments. The shallow plough produced a good degree of inversion and the rotary digger was effective on the heavier soils.

2.3 Secondary cultivation implements

The spring tine cultivator and disc harrow were particularly suited to the lighter soils or preparing a seed bed on the heavier soils where a degree of weathering had occurred. The disc harrow was effectively used to incorporate straw on some non-ploughed treatments. A finger tine harrow had particular application on the heavy soils in the spring where it was important not to bring up unweathered wet soil from beneath the surface.

The p.t.o.-driven rotary harrow and spiked rotary cultivator were suitable for producing a tilth for a winter cereal seed bed from cloddy soil and weedy conditions.

Table 1 Work rates, costs and energy requirements: Cultivation implements and systems

Cultivation system	No. of years	Crop and site*	Primary cultivation, e.g. plough						Complete cultivation system			
			Depth, mm	Overall work rate ha/h	Net energy requirement MJ/ha[⊙]	Net energy requirement kJ m^{-3}	Wheel slip %	Cost, £/ha	Overall work rate ha/h	Net energy MJ/ha[⊙]	Cost, £/ha	Area capability, ha
Plough, Cultivator Drill	6	1	220	0.39	245	117	22	17.00	0.25	320	32.00	88
	6	2	220	0.62	118	56	12	11.00	0.39	180	20.00	132
	6	3	205	0.34	307	146	21	19.00	0.24	324	31.50	99
Plough, Combined cultivator/Drill	6	1	220	0.39	245	117	22	17.00	0.29	324	29.00	103
	6	2	220	0.62	118	56	12	11.00	0.44	178	19.00	147
	6	3	205	0.34	307	146	21	19.00	0.27	328	30.00	99
Chisel plough (2 passes), Cultivator, Drill	6**	1	130	0.58	203	103	15	9.00	0.30	286	23.50	107
	6**	2	145	0.77	147	75	14	7.00	0.42	194	16.50	142
	3	3	130	0.47	213	108	20	10.50	0.30	308	26.50	137
Shallow plough, Combined cultivator/Drill	6	1	110	0.88	115	108	18	7.00	0.50	187	16.00	178
	6	2	105	1.12	68	74	12	6.50	0.63	108	16.50	214
	6	3	105	0.78	133	122	22	7.00	0.46	203	16.50	226
Rotary digger, Combined cultivator/Drill	4	1	100/200	1.02	117	117	2	9.00	0.55	176	21.50	197
	4	2	100/200	1.33	88	61	0	7.00	0.70	144	17.50	235
	5	3	105/205	0.90	156	156	3	8.50	0.49	201	16.00	244
Sprayer, Direct Drill	5	1	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	0.99	38	20.50	353
	4	2	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	1.09	43	20.00	368
	3	3	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	1.01	54	17.50	349

N.A. = not applicable

* 1 = Boxworth, winter wheat
2 = Rothamsted, winter wheat
3 = Silsoe, spring barley

** In 1976/77 only 1 pass of chisel plough required
⊙ Energy at the implement connection

2.4 Combination implements

Compared with traditional cultivations, combination implements considerably reduced labour requirements and soil compaction. Bridging links enabled a choice to be made of different secondary cultivation implements according to the soil conditions. Due to a number of factors including reduced costs and labour requirements, greater weed control, and the action of natural weathering, the minimum number of passes for cereals following cereals was two.

2.5 Direct drilling

The main advantage of this technique was the high work rates (Table 1) possible for both spraying and drilling, which enabled a very large area to be covered by one man and tractor. Whilst in many conditions performance was satisfactory the direct drill used in the experiments was restricted by, wet soil conditions particularly on heavy soil for spring barley, an uneven stubble surface, the presence of cereal stubble or chopped straw and a lack of tilth under hard and dry soil conditions.

2.6 Costs

The primary cultivation absorbed the major part of the cost of the tillage process with the conventional plough the most expensive. (Table 1) Two pass cultivations based on the chisel plough, shallow plough or rotary digger which are capable of satisfactory weed control were the cheapest. Costs for direct drilling were generally higher than the best reduced cultivations but this depended on the concentration of spray material and frequency of use.

2.7 Straw burning

Burning the straw and/or stubble is essential to the success of present direct drilling techniques and it reduces the problems of reduced cultivation systems. The main advantages appear to be a reduction in volunteer cereal and weed seeds, increased crop production, fewer mechanical problems at drilling and a saving in time and labour.

2.8 Crop yields

When considering overall crop yields for a period of years the only treatment which was significantly lower than mouldboard ploughing was direct drilling at Rothamsted and Silsoe. (Table 2) The main reasons for this were the restrictions described in section 2.5.

However, the 1973/74 season produced unexpected results at Boxworth where the yields from most of the treatments were significantly lower than mouldboard ploughing; this may have been due to higher crop lodging on non-ploughed plots. In the very dry year of 1975/76 the direct drilling and rotary dug plots produced significantly higher yields than mouldboard ploughing at Boxworth due probably to a greater conservation of moisture.

2.9 Weeds, soil fauna and diseases

Weeds were in almost every case suppressed adequately so that weed competition was not a factor in determining yield. Exceptions may have occurred at Rothamsted in 1976 and at Boxworth in 1973, particularly on the direct drilling; it is important to maintain a high level of management of herbicides for direct drilling.

Table 2. Crop yields
(tonnes/ha, 85% dry matter)

Cultivation system	Site*	1971/72	1972/73	1973/74	1974/75	1975/76	1976/77	Mean last 4 yrs	Mean 6 yrs
Plough, Cultivator, Drill	1	6.83	6.24	7.46	5.24	3.81	6.55	5.77	6.02
	2	3.58	5.39	5.61	5.98	4.01	5.24	5.21	4.97
	3	5.02	4.30	5.21	5.98	4.99	5.58	5.52+	5.18
Plough, Combined cult./ Drill	1	6.64	6.43	7.10	5.15	3.77	6.57	5.65	5.94
	2	3.56	5.27	4.98	6.05	3.93	5.18	5.04	4.83
	3	4.90	4.46	4.85	6.27	5.02	5.56	5.62+	5.18
Chisel plough++ (2 passes) Cultivator, Drill	1	6.71	6.09	6.93	5.34	3.83	6.49	5.65	5.90
	2	3.38	5.73	5.41	5.49	4.05	5.04	5.00	4.85
	3	5.10	4.36	5.29	6.04	5.03	5.55	5.54+	5.23
Shallow plough Combined cult ./ Drill	1	6.59	6.12	6.64	5.25	3.94	6.66	5.62	5.87
	2	3.35	5.14	5.00	5.67	4.08	5.35	5.03	4.76
	3	4.99	4.59	5.21	6.40	5.05	5.66	5.70+	5.32
NIAE rotary digger Combined cult./ Drill	1			6.46	5.16	4.19	6.47	5.57	
	2			4.84	5.80	4.22	5.02	4.97	
	3		4.51	4.89	6.38	5.11	5.63	5.71+	
Sprayer Direct Drill	1		5.96	6.92	5.17	4.78	6.03	5.72	
	2			5.13	5.52	2.94	4.49	4.52	
	3				4.21	4.76	4.61	4.53+	
S.E.	1	0.11	0.14	0.13	0.14	0.10	0.16	0.06	0.13
	2	0.14	0.21	0.25	0.20	0.20	0.14	0.12	0.11
	3	0.11	0.12	0.14	0.39	0.10	0.17	0.17+	0.11

\+ Last 3 yrs ++ At Silsoe the treatments consisted of ch.pl (1 pass) followed by spraying
The figures underlined are significantly different from the conventional plough treatment ($p \leq 0.05$)

* The sites are as in Table 1. S.E. = Standard Error

Numbers of most species of invertebrates were greater in the soil in which direct drilled crops were grown. (Table 3) Attacks by slugs were much less serious after ploughing and other cultivations than after direct drilling. Attack by stem-boring fly larvae tended to be greater in crops in ploughed soil than those direct drilled. Numbers of L. terrestris were $1\frac{1}{2}$ to 5 times greater with direct drilling (except at Silsoe where there were consistently more L. terrestris in ploughed plots) than with ploughing but numbers of other species differed much less.

There were no direct correlations between diseases and cultivation treatments at any of the sites. The take-all infestation at Rothamsted in the early years of the experiment was considered to be due to the run of previous cereal crops grown on this land.

Table 3

Numbers of soil-inhibiting invertebrates sampled at Boxworth, 1974-78

Fauna	Cultivation			
	Direct drill	Chisel plough	Rotary digger	Plough
Earthworms				
L. terrestris	72	66	37	14
Other species	1472	874	1191	1023
Soil Arthropods				
Mites	2434	1926	2462	1866
Springtails	1315	1344	1730	856
Insects	66	44	68	68
Surface Predatory Beetles	556	948	842	927
Shoot Boring Fly Larvae	62	75	-*	123
Slugs	33	15	-*	19

* Not sampled in 1974

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Development and Performance of a New High Speed Rotary Digger

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Abstract

The benefits of a power take-off driven primary cultivator are identified and the development of a high output machine is described. Bite length was found to be the most important variable since this restricted other parameters to certain values.

1. Introduction

The idea of a rotary digger is nothing new. Several of these machines have been made but they have all worked deep (200 mm) and have employed large blades on a large radius rotor (approx. 0.5 m). They have produced a very coarse tilth and their work output has seldom exceeded that of the plough.

Work on a rotary digger started at the N.I.A.E. when results from a long term tillage experiment on cereals[1] highlighted the shortcomings of more traditional methods of cultivation. These were:

1. 200 mm deep ploughing had a low output (approx. 0.5 ha/h) and often produced cloddy seedbeds.

2. Providing tractive power on heavy soils could be inefficient and often led to soil compaction and smear.

Although rotary diggers could not completely invert the soil, they had great potential for eliminating these problems. Work was therefore aimed at developing a machine with improved output and ability to produce a medium to coarse tilth on a range of soils but particularly on the heavier clays.

2. Design Approach

Development of the machine was approached in two ways:

1. Construction of an experimental machine.

2. Study of previous work on similar machines to provide information on particular aspects of design.

The experimental machine consisted of a horizontal rotor with L-shaped blades (on one side of the flanges only) working to a depth of 100 mm. A bite length (Fig. 1) of 200 mm was selected initially and chisel tines were introduced behind the rotor to stabilize the machine.

Study of earlier work provided information on blade mounting angle and the relationship between rotor variables. Work by Söhne[2] and Bernacki[3] suggested that the optimum mounting angle of the blade, (Fig. 1) should provide a 20° cutting angle after about 10° of rotation in the soil. When work with the experimental machine provided information on the bite length required, the blade mountings were modified to achieve the appropriate angle.

2.1 <u>Rotor Variables Investigated</u> The main variables investigated to give the type of work required with the minimum power input were:

Bite length; 150, 170, 200 and 240 mm

Rotor radius; 0.25, 0.30, 0.33, 0.36 and 0.38 m

Number of blades per flange; 2, 3, 4 and 5

Blade design; L-shaped, C-shaped and extended span blades

Configuration of blades on the rotor

3. Measurements and Field Procedure

Detailed field measurements were carried out on a 1.8 m wide machine at a number of sites to assess the effect of the above variables. Runs 50 m long at various forward speeds were set out in a randomised plot experiment having 3 replicas of each treatment. Depth was controlled by a single depth wheel and the tractor linkage; depth was also checked after each run to ensure valid comparisons could be made between treatments.

Draught and p.t.o. power were measured by a three point linkage dynamometer[4] and a p.t.o. torque/speed transducer respectively. Digital recordings on magnetic tape were then analysed by computer, and regression lines, significant at the 95% level, were fitted to the data. Statistical analysis of the results provided information on the confidence with which one could consider the data from one setting having come from a different population from that of another.

To ensure a common basis of comparison between treatments, bite length and depth of work were kept constant except where these parameters were themselves being investigated.

4. Results and Discussion

4.1 <u>Bite Length</u> Results showed that for a particular set of rotor variables, power decreased with increase in bite length (Fig. 2). In most cases the difference was significant even with small increases of 20-30 mm. Thus the 250 mm bite, selected by subjective field assessment as the optimum for the tilth required, was also ideal in terms of power requirement. The main reason for the reduction in power was almost certainly the reduction in rotor speed with increase in bite.

4.2 <u>Rotor Radius</u> An increase in radius caused an increase in power requirement. This was of the order of 8% at 5 km/h when the radius was increased from 0.33 m to 0.38 m with a given number of blades. The increase was the combined effect of a 15% increase in radius arm, a reduced value of average torque (at the same angular velocity the cutting time per blade is reduced) and an increase in the cross-sectional area of the clod.

4.3 <u>Number of Blades per Flange</u> An increase in number of blades per flange for a given bite length and rotor diameter reduced power requirement. Fig. 3 shows the results for 3, 4 and 5 blades, all of which required a significantly different level of power input. Rotor speed is probably the main factor in the reduction although in this case as blade numbers increase, the cutting path length of the blade is reduced and also the cross-sectional area of the clod removed.

4.4 Blade Design Experiments showed that for our particular application it was preferable to use the L-shaped blade. The C-shaped blade, although requiring about 10% less total power, moved 10% less soil and increased the draught requirement considerably.

Extending the span of the blade generally increased power requirement, and this was still the case where the increased span was accompanied by a reduction in the number of flanges. No reasonable explanation can be attributed to this latter case.

4.5 Flange Spacing Soil movement in the lateral gap between the tip of the blades on one flange and the shank of those on the next needed improving. This improvement was brought about by two factors, increased bite length from the initial 200 mm to 250 mm and reduced flange spacing from 255 mm to 240 mm. Increase in the span of the blades, as mentioned above, resulted in an unacceptable increase in power requirement while reduction in flange spacing did not.

4.6 Configuration of Blades on the Rotor This aspect was studied to improve penetration of the machine in very hard conditions. The rotor was designed so that there was an equal angular distance in the radial plane between each blade on the rotor. This requirement had to be reconciled with a scroll which was selected for each width of rotor and provided for interaction between blades in the soil.

4.7 Soil Blockages in the Rotor This occurred on heavy soils which were in a moisture condition between the plastic limits. The best solution to the problem was found to be a simple sprung tine inserted in the radial plane from the rear of the machine to a point just clear of the rotor tube and in the gap between sets of blades (Fig. 4). This largely prevented soil from starting to build up on the tube and thus for all practical purposes overcame the problem.

5. Specification of Rotor Variables

Consideration of all the factors involved in the performance of the machine led to the following design: (i) 4 L-shaped blades per flange; (ii) Rotor radius 0.38 m; (iii) Flange spacing 240 mm; (iv) Bite length 250 mm; (v) Depth of work, 100-150 mm (rotor); (vi) Chisel tines, 1 per 3 flanges, 150-300 mm deep. Some compromise was necessary between the power requirement, the tilth required and the torque loading on the transmission, but overall the specification did allow the machine to work in as wide a range of conditions as possible.

6. Field Performance

Table I shows the results of experiments where different tillage techniques were compared at 3 sites on the same plot for 4 years. Comparison of the yield of cereals over the 4 years and between the plough treatments and rotary digger showed no significant difference. Measurements of soil structure and cone resistance were also taken and results from the three treatments were very similar.

Table I Machine and crop performance

Cultivation system	Site	Depth, mm	Net* work rate ha/h	Net energy+ requirement		Mean yield, tonnes/ha	
				MJ/ha	kJ/m^3	Cereal 1974-77	Sugar beet 1976-77
Plough + cultivator + drill	B	219	0.45	198	117	5.77	
	R	216	0.70	118	56	5.21	
	S	203	0.38	245	146	5.44	
	S	213	0.24	495	N.R.		38.2
Shallow plough + combined cultivator and drill	B	108	0.93	106	108	5.62	
	R	102	1.11	63	74	5.03	
	S	104	0.74	136	122	5.58	
Rotary digger + combined cultivator and drill	B	100/200●	1.02	117	117	5.57	
	R	102/203●	1.33	88	61	4.97	
	S	105/205●	0.93	145	156	5.50	
	S	100/200●	0.33	313	N.R.		40.5
	S	150/250●	0.29	351	N.R.		40.6

* Spot rate of work reduced by field efficiency factor

● Chisel tine depth

\+ Measured between tractor (56 kW DIN engine) and implement

Sites:- B, Boxworth, W. Wheat, clay loam; R, Rothamsted, W. Wheat, silty loam;
S, Silsoe, S. Barley and S. Beet, silty clay loam.

Work rates were of the order of 1 ha/h, while energy applied to the soil was no different from that for ploughing. Energy per hectare was less for rotary digging than for conventional ploughing but only 70% of the soil was moved to chisel tine depth with the rotary digger.

Experiments with sugar beet over a period of 2 years showed there to be no significant difference in yield (Table I) or quality of the beet following rotary digging and ploughing.

Performance in a wide range of crop residues, including cereals, maize, oilseed rape, grass, potatoes, sugar beet, lucerne, peas and brussels sprouts, has been satisfactory. Some difficulties occurred in certain conditions when residues wrapped around the cutting edges of the blades, but this occurred infrequently.

Experiments to measure the wear of the blades showed that they would cover between 5 and 15 ha/flange. The blade was assumed to be worn out when 20 mm had been lost from its 130 mm span. Calculation of the specific wear of the rotor blades was similar to that found on chisel tines.

7. Conclusions

A power take-off driven machine was developed[5] which has an output about double that of earlier designs of rotary digging or spading machines. Although only about 70% of the soil was moved to the working depth of the chisel tines (approx. 200 mm) performance of sugar beet and cereal crops were equal to those following the conventional plough.

Complete inversion of the soil has not been achieved but a good degree of crop residue incorporation has provided few problems with following operations. The design, based on a 250 mm bite length, has 4 L-shaped blades on a radius of 0.38 m. The provision of rotor cleaning tines and a suitable blade configuration allows the machine to work in a wide range of conditions.

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Fig. I

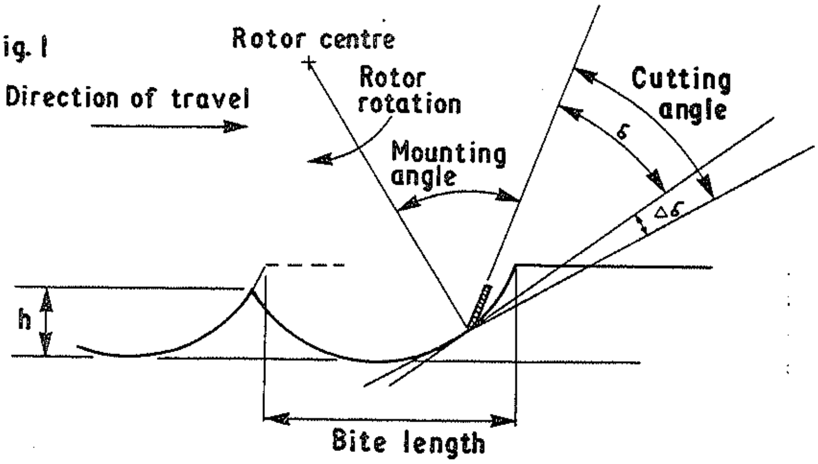


Fig.2. Effect of bite length

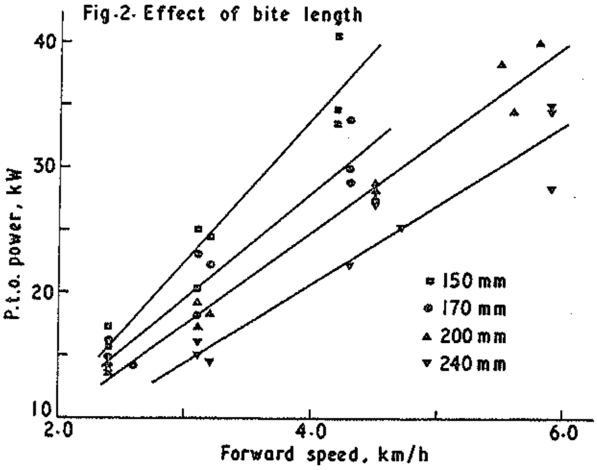
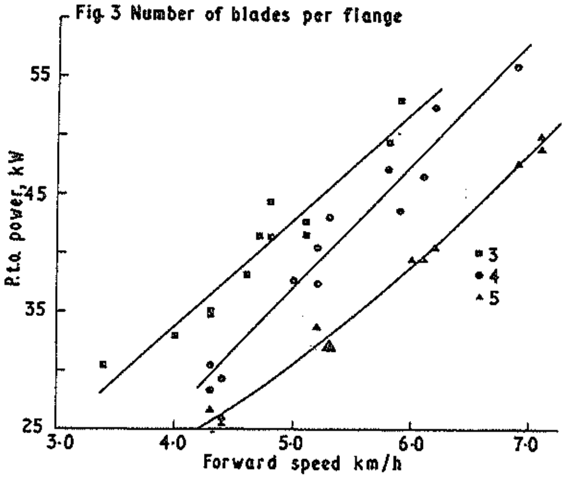


Fig. 3 Number of blades per flange



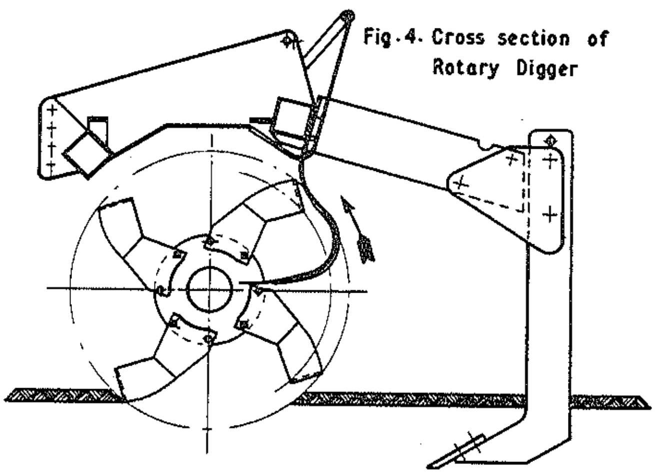


Fig. 4. Cross section of Rotary Digger

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GEOMETRICALMETHOD FOR CLASSIFICATION OF MOLDBOARDS

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ABSTRACT

In this work a method of measuring is established for determining the coordinates of a series of points of the moldboard distributed uniformly over its surface and outline. Taking them as a starting point, a series of functions are asigned them by minimum-square numbers where the dependent variant is explicit. The one whose residuals are minimum is defined as the Equivalent Equation.

With this function a series of parameters are determined which serve to establish a geometrical classification of the moldboards, by means of a coefficient called "rate of warping", obtaining the following kinds of moldboards: cylindrical, semicylindrical, universal, universal-warped and warped.

INTRODUCTION

This research work is centred on the characterization of the shapes of moldboards used in Spain, in order to establish a classification of the same. The following considerations were taken into account:

1) From the purely geometric point of view moldboards are pieces whose macrosurface or body is contained in another, defined in this work as the Equivalent Surface which in the majority of the cases is unknown.

2) Until now neither the body nor the edge have been defined in a constant way in view of the complexity of their shapes, in which many manufacturers and even researchers follow subjective criteria for their determination.

3) Most of the studies carried out are based on graphic methods (SÖHNE, 1959), (REED, 1941), (ASHBY, 1931), in which the piece is partially defined by contours, or shape lines in one or several directions, and also by isolated points which give us a complete idea of their geometric characteristics.

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4) The analytic studies are limited generally to establishing some of the shape lines previously mentioned, deduced from experimental studies. Also in some of them they presuppose that the equation which defines the moldboard is known, the latter being simple in order not to complicate too much the theoretical studies of the behaviour of the soil on its surface.

5) There is great dispersion with regards to defining the surface of the body by means of analytic expressions, these being based on observation and even on personal intuition. In this way surfaces are specified as hyperbolic paraboloids, elliptic paraboloids (ORTIZ-CAÑAVATE, 1976), and as far as the shape lines are concerned, one talks of arcs of circle, catenaries, exponentials, helical arcs, etc.... (NICHOLS and KUMMER, 1932).

6) A complete theory of the behaviour of the soil on the body of the plow is lacking from which the ideal shapes of moldboard can be obtained based on some final objectives for a known kind of soil and climate.

Consequently this research is situated in the ambit of analytical quantification, for moldboard surfaces designed on the basis of subjective, intuitive criteria which have given rise to different shapes, used in almost 90% of the moldboard plows in Spain.

MATERIALS AND ANALYTIC METHOD

To start with the coordinates of the body points were determined by means of an apparatus called a "Coordinatometer" (fig. 1) which, by means of a system of boards, perforated with holes spaced at intervals of 25 mm, is crossed by some steel rods which allow the displacement with respect to the board, once the rods have touched the inner surface of the piece. The situation of the hole gives us the coordinates x_1 and y_1, whilst the displacement of the rod gives us z_1.

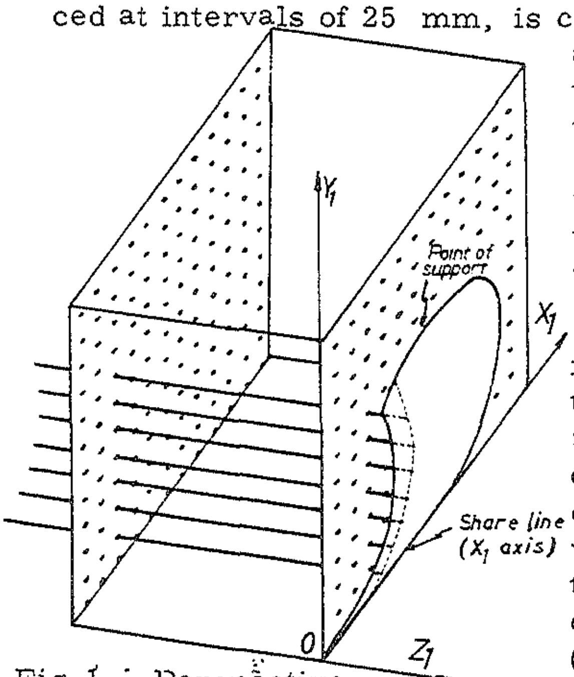

Fig. 1. - Perspective of the Coordinatometer.

Afterwards the points of the profile are measured in the same position as for those of the body, but using a different system which is quicker than the previous one. In order to do so, a square is used which serves to mark the projection of the said profile on a sheet of paper divided into milimetres (fig. 2), a series of points being fixed along the outline. The coordinate z is measured on the square by means of a rule which one leans on the point to be measured and on the corresponding one to that of the projection. The other two coordinates are determined directly on the milimetred paper.

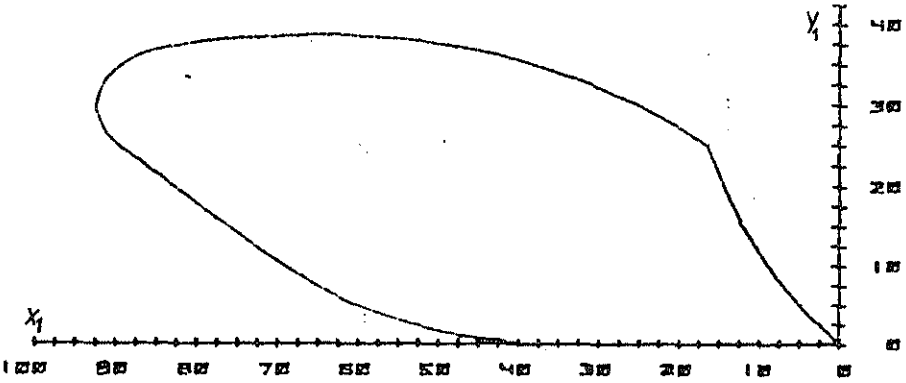

Fig.2.- Projection of the moldboard - into the plane X_1Y_1

(At the present time we are using photogrametrical methods to determine in a quicker way the coordinates of the moldboard surface).

Once the points of the body and outline have been obtained, - approximately the same in number, they are given a series of functions by minimum squares with the explicit dependent variant.

$$z_1 = b_1x_1^3 + b_2x_1^2y_1 + b_3x_1y_1^2 + b_4y_1^3 + b_5x_1^2 + b_6x_1y_1 + b_7y_1^2 + b_8x_1 + b_9y_1 \qquad (1)$$

$$z_1 = b_5x_1^2 + b_6x_1y_1 + b_7y_1^2 + b_8x_1 + b_9y_1 + b_{10} \qquad (2)$$

$$z_1 = b_6x_1y_1 + b_7y_1^2 + b_9y_1 \qquad (3)$$

From the analysis of the remainders we establish as the -- EQUIVALENT EQUATION (fig. 3) the first of these functions as the values which these present are inferior to those of the other two equations, in fact even its distribution is more homogenous.

$$z_1 = 0,157\ x_1^3 - 1,769\ x_1^2y_1 + 2,022\ x_1y_1^2 + 1,176\ y_1^3 + 0,288\ x_1^2 + 0,220\ x_1y_1 - 2,953\ y_1^2 - 0,093\ x_1 + 0,797\ y_1$$

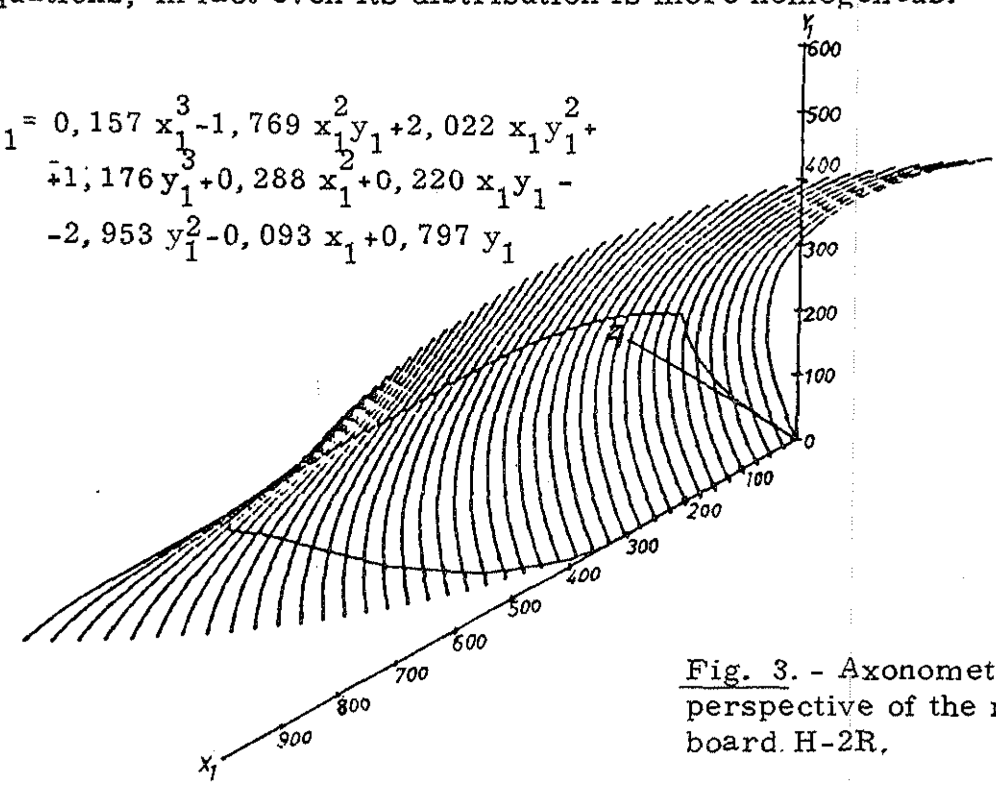

Fig. 3. - Axonometric perspective of the mold board. H-2R.

Afterwards, to each of the parts which make up the projection of the profile a kind of curve is adjusted, according to its shape, obtaining:

For the upper edge: $y_1 = c_1 x_1^2 + c_2 x_1 + c_3$ (4)

For the furrow edge: $y_1 = d_1 x_1 + d_2$ (5)

On the edge of the furrow wall a plan is added of the form $Ax_1 + By_1 + Cz_1 = 0$, which on placing the moldboard in the working-position obliges it to coincide with the furrow wall, that is $z=0$. From here the angles of turning θ and φ are obtained, necessary to carry out the changing of axes.

The equations of change are given by:

$$\begin{pmatrix} x_1 \\ y_1 \\ z_1 \end{pmatrix} = \begin{pmatrix} \cos\varphi & 0 & \operatorname{sen}\varphi \\ -\operatorname{sen}\theta \,.\, \operatorname{sen}\varphi & \cos\theta & \operatorname{sen}\theta \,.\, \cos\varphi \\ -\cos\theta \,.\, \operatorname{sen}\varphi & -\operatorname{sen}\theta & \cos\theta \,.\, \cos\varphi \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad (6)$$

By substituting and identifying coefficients one obtains:

$$\theta = \operatorname{arc\,tg} \frac{B}{C} \quad (7) \; ; \qquad \varphi = -\operatorname{arc\,tg} \frac{A}{A\cos\theta} \quad (8)$$

Starting out from these values the parametrical equation of the surface may be deduced referring to the axes of the soil(X,Y,Z), that is:

$$x = x(\lambda, \mu) \;;\quad y = y(\lambda, \mu) \;;\quad z = z(\lambda, \mu) \quad (9)$$

establishing for the various profiles a relationship between μ and λ as from:

$$\mu = c_1 \lambda^2 + c_2 \lambda + c_3$$
$$\mu = d_1 \lambda + d_2$$

RESULTS OBTAINED

With the Equivalent Equation we establish a series of parameters from which a classification is established, taking as a basis the following considerations:

1) One starts out from that surface which best adapts to the shape of the moldboard, without considering the influence of the kind and conditions of the soil.

2) The classification refers to the body of the moldboards without the outline being taken into account.

3) It allows for comparaison of moldboards of different sizes. In basis on this we define the following parameters (fig. 4)

- maximum length (l_m), on the axes of measurement.
- maximum height (h_m), on the axes of measurement.
- point of reference (z_1) corresponds in (figure 4) to the distance AG, being defined by the expression:

$$z_1 = \frac{f(x_1 y_1)}{l_m} \cdot 100 \quad (10) \quad ; \quad x_1 = l_m \ ; \ y_1 = 0$$

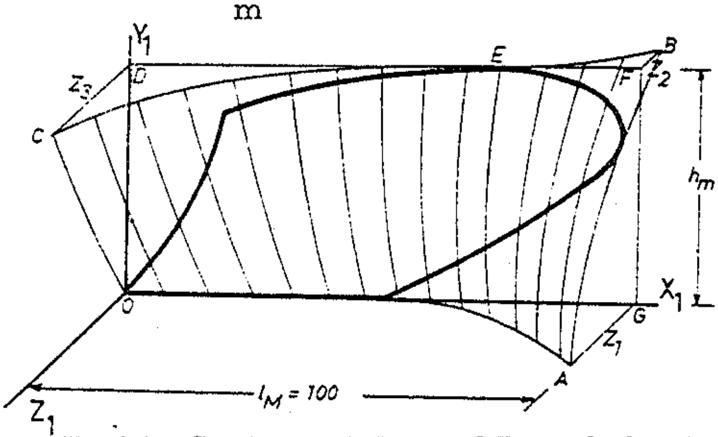

Fig. 4. -Surface of the moldboard shape and dimensions z_1, z_2 and z_3.

- point of reference (z_2) corresponds in (fig. 4) to the distance FB, being defined by the expression:

$$z_2 = \frac{f(x_1 y_1)}{l_m} \cdot 100 \quad (11);$$

$$x_1 = l_m \ ; \quad y_1 = h_m$$

- point of reference (z_3) corresponds to the distance CD, and is defined as:

$$z_3 = \frac{f(x_1 y_1)}{l_m} \cdot 100 \quad (12) \ ; \quad x_1 = 0 \ ; \quad y_1 = h_m$$

z_1, z_2 and z_3 are expressed in %.

If, moreover, we establish that $y_1 = h_m$ is the same as 100 and we project on the plan $Y_1 Z_1$ (fig. 5), the relative position of the two extreme curves gives us an idea of the warping of the moldboard.

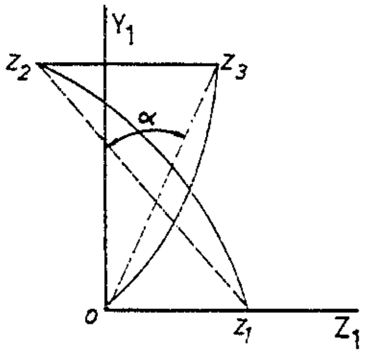

Fig. 5. - Projection on the plane $Y_1 Z_1$.

Starting from Z_1, Z_2 and Z_3, we also define:

- Angle α. It is that which is formed by the straight lines OZ_3 together with $Z_1 Z_2$, it is expressed by:

$$\alpha = \left| \text{arc tg} \frac{(Z_2 - Z_1 - Z_3)\ 100}{Z_1(Z_2 - Z_3) + 10000} \right| \quad (13)$$

As the denominator differs relatively slightly from 10.000 we may consider that :

$$\alpha = \left| \text{arc tg} \frac{Z_2 - Z_1 - Z_3}{100} \right| \quad (14)$$

- Relation i: This is defined as:

$$i = \frac{Z_1}{Z_2 - Z_3} \quad (15)$$

in which the sign tells us if the straight lines OZ_3 and $Z_1 Z_2$ intersect or not at the interval (0.100) of the axis Y_1, which we are considering. On the other hand, if $i > 1$ it indicates to us that on the surface adjusted the external part of the moldboard predominates, that is, that which does not enter into contact with the soil during turning.

If, on the contrary, $i < 1$ it indicates that the lower part predominates. The minimum value of the difference of reference points - $Z_2 - Z_3$, is made to be 1 mm so that "i" doesn't become infinite...

On the basis of these last two parameters we define the RATE OF WARPING as:

$$K = \ln(100 \cdot i \cdot \alpha) \qquad (16)$$

i and α (rad) being given in absolute value and it occurring that -- warping increases with K.

The classification proposed after studying various coefficients in which i is related with α the following groups are established:

CYLINDRICAL .... $K \leq 1,5$
SEMICYLINDRICAL .... $1,5 < K \leq 3$
UNIVERSAL .... $3 < K \leq 4,5$
UNIVERSAL-WARPED .... $4,5 < K \leq 6$
WARPED .... $6 < K$

Table 1. Classification of mold boards in accordance with the "rate of warping K".

	$l_{máx}$ (m)	$h_{máx}$ (m)	$Z_{máx}$ (mm)	Z_1 (%)	Z_2 (%)	Z_3 (%)	i –	α (rad)	K	Classification
254-38	0,885	0,423	88,0	-0,4	2,56	-0,5	-0,13	0,0345	-0,800	Cyl.
David	0,786	0,390	119,0	0,7	-0,28	18,09	-0,088	0,188	-0,336	Cyl.
CC-29-T	0,862	0,327	89,0	2,23	-1,53	11,90	-0,166	0,155	0,945	Cyl.
1753-2	0,692	0,354	93,6	6,07	-7,70	11,4	-0,317	0,249	2,054	Semicyl.
1781-2	0,7635	0,3615	83,0	6,8	-9,08	7,95	-0,399	0,236	2,242	Semicyl.
1781-3	0,8085	0,3798	106,2	7,14	-7,07	11,3	-0,388	0,252	2,280	Semicyl.
1753-4	0,8022	0,425	90,5	6,42	-3,31	8,25	-0,555	0,179	2,292	Semicyl.
1753-3	0,757	0,3775	110,1	9,20	-10,2	10,38	-0,447	0,294	2,575	Semicyl.
1753-0	0,6065	0,310	76,0	10,3	-7,75	11,8	-0,526	0,295	2,741	Semicyl.
Chiriaque	0,699	0,338	96,5	10,96	-1,46	26,06	-0,445	0,350	2,745	Semicyl.
1768-2	0,857	0,450	97,2	10,54	-6,36	3,98	-1,019	0,208	3,053	Univ.
1776-0	0,755	0,331	75,9	11,17	-1,58	6,25	-1,426	0,189	3,294	Univ.
1776-2	0,835	0,375	78,7	11,63	-5,11	3,42	-1,363	0,200	3,305	Univ.
1780-3	0,8445	0,3885	79,5	12,62	-4,79	5,33	-1,247	0,226	3,338	Univ.
1776-2b	0,831	0,380	76,5	10,84	-4,34	2,12	-1,678	0,172	3,362	Univ.
261-53	0,823	0,344	81,5	12,38	-2,11	7,04	-1,353	0,214	3,365	Univ.
1776-1	0,804	0,367	78,0	12,59	-4,20	3,17	-1,708	0,201	3,536	Univ.
1755-4	0,792	0,4214	93,1	16,22	-4,72	7,8	-1,2955	0,274	3,571	Univ.
1776-2a	0,835	0,375	78,3	12,68	-4,99	0,5	-2,309	0,180	3,727	Univ.
Melotte	0,920	0,385	136,1	30,77	-0,69	-6,9	4,954	0,236	4,761	Univ. W.
H-2-R	0,925	0,385	132,5	30,27	-0,45	-5,2	6,372	0,249	5,066	Univ. W.
Kneverland	1,135	0,421	242,0	77,0	-0,3	-1,4	70,0	0,645	8,415	Warped

In Table 1 the values obtained are presented for the 22 moldboards considered, ordering them for values of K from least to greatest. One is able to appreciate that this classification adapts very well to the reality, as the groups obtained correspond to the denomination used by the manufacturers and their action in the soil is equivalent between moldboards of the same type.

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ENGINEERING CHARACTERISTICS OF ROTARY TILLAGE RESISTANCES OF JAPANESE ROTARY TILLERS WITH TRACTORS

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ABSTRACT

It is explained that the rotary tillage resistances, as the external forces to the machine from soil, consist of the radial suction force, centripetal force, turning resistance and lateral force. The turning resistance can be also divided into two resistances acting on the longitudinal portion and tip of the blade. With these principles, it is reported there is an analytical way to obtain the acting centre of all the rotary tillage resistances acting on the tiller. The experiments and theories are analyzed with Japanese rotary blades and tillers mainly, in consideration of European blades and plough dynamics also.

I. FOUR ELEMENTS OF A ROTARY TILLAGE RESISTANCE

There are many achievements of tillage torque resistances on a rotary blade or a rotary tiller with the parameters of tillage depth, travel speed, rotation speed and soil condition. It is, however, necessary to make the loading characteristics of the external forces acting on the rotary tiller clear, in the case of the rotary tillage resistances used for the dynamic analysis on machine motion. It is defined that the external forces, as the tillage resistance of the rotary tiller, consist of four elements as follows:

1) Radial Suction Force, Δs: There is a soil tilling phenomenon at the tip of the blade, similar to a plough, as shown in Fig. 1. The external force to the blade tip is divided into two component forces of Δs on the radius direction and a turning resistance $\Delta\tau_1$. The author calls the Δs " Radial Suction Force".[1] This force has the effect of the sinking phenomenon of the tiller blade into soil.

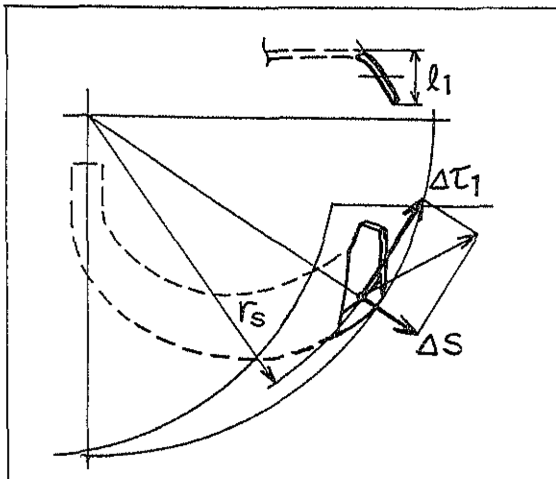

Fig. 1 $\Delta\tau_1$ and Δs

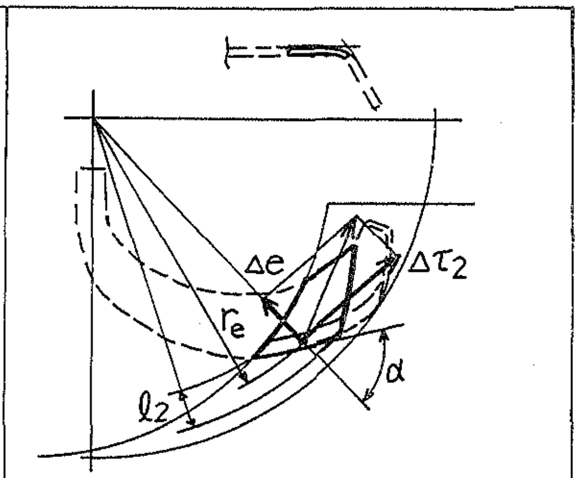

Fig. 2 $\Delta\tau_2$ and Δe

The coefficient of the radial suction force is defined as follows:

$$\Delta s \overset{D}{=} \Delta k_1 \Delta\tau_1$$

The value of Δk_1 for the blade-tip can be presumed with the principle of the line of draft for plough dynamics. This value differs with scoop-angles of the blade-tip.

2) Centripetal Force, Δe : As shown in Fig. 2, the edge-curve of the longitudinal portion, similar to the shank of an European blade, intersects the radius direction. The angle α between the radius direction and the tangent of the edge-curve is named " Edge-curve angle " of the rotary blade.[2) 3)] This portion ought to receive a turning resistance $\Delta\tau_2$ and a component force Δe to the centre of rotation. The author's group calls it "Centripetal Force" of the rotary tillage resistance. This force has the effect of the pushing phenomenon of the tiller blade off the soil.

The coefficient of the centripetal force is defined as follows:

$$\Delta e \overset{D}{=} \Delta k_2 \Delta\tau_2$$

Δk_2 for the longitudinal blade differs with edge-curve angles.

3) Turning Moment Resistances, $\Delta\tau_1$, $\Delta\tau_2$ and $\Delta\tau$: The resultant force of $\Delta\tau_1$ and $\Delta\tau_2$ is $\Delta\tau$ which is the total turning resistance of a blade at the moment. This resistance $\Delta\tau$ was studied by many scientists in the past, as mentioned above.

Triangle-like patterns were reported in the case of the tillage resistance of an European blade. The resistance pattern of one blade should be effective to the simulation of the total torque resistance of a rotary axle installed with multiple blades.

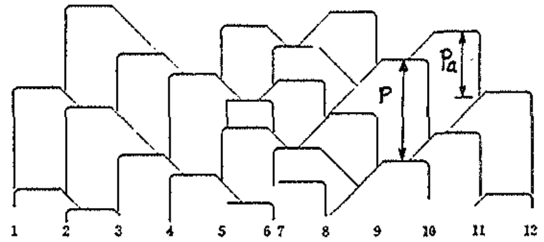

Fig. 3 [5)]

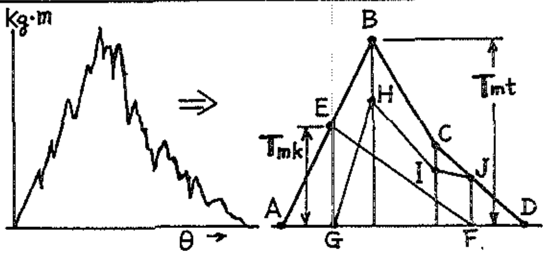

Fig. 4

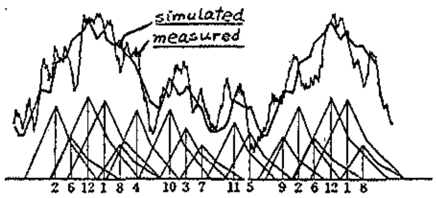

Fig. 5 [5)]

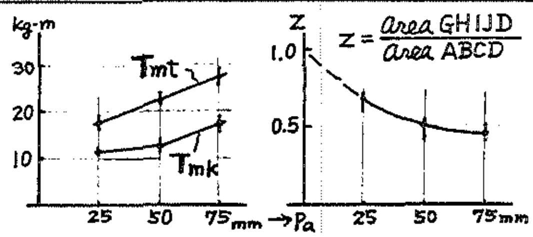

Fig. 6

It is necessary to formulate the basic equation available to all cutting patterns on the soil surface, as shown in Fig. 3. The quadrilateral patterns like ABCD in Fig. 4 are useful for good simulation as shown in Fig. 5, in the case of a maximum depth of cut and hard soil, 7 to 10 kg/cm^2, with a Japanese blade.[4) 5)] Area AEF and GHIJD mean the work of the longitudinal portion and tip respectively. Their ratio differs with actual tilling pitches, P_a, (Fig. 3) and the relative location of adjacent blades. P_a should be called "Actual Pitch", while P is "Apparent Pitch". It is important for the actual pitch to be one of the parameters in the equations of torque patterns. Fig. 6 shows the peak torques and work characteristics of the quadrilateral portion and the tip of a blade. When the actual pitch is about the same length as the tip width of a blade, the total tillage work is equally divided to the longitudinal and tip portions, as $Z \fallingdotseq 0.5$ (Fig. 6).

4) Lateral Force, $\Delta\ell$: A generating mechanism of the lateral force $\Delta\ell$ acting on the blade differs with types of the blade edge, a single-edge or a double-edge.[6)] However, the lateral forces on many blades can balance and deny each other. This means the rotary tiller can till and travel straight in general.

THE IMAGINARY ACTING POINT OF THE ROTARY TILLAGE RESISTANCE

The tractor motion analysis of ploughing can be done on the basis of the acting centre point of ploughing resistances. It is

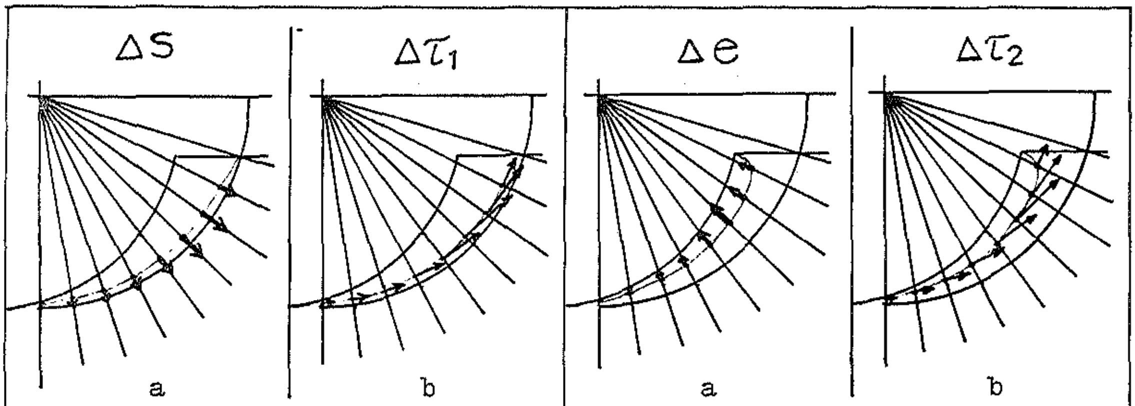

Fig. 7
External Forces acting on Blade-tip

Fig. 8
External Forces acting on Longitudinal Portion

possible to develop a better analysis on the machine dynamics and design theories of tractors and rotary tillers, if the location of the acting centre is determined for the resultant force of all the tillage resistances which are produced by the multiple blades on a rotary axle at the same moment in the soil.

1) Turning Resistance acting on the Blade Tip, $\Delta\tau$: Fig. 7-b shows the locations and sizes of $\Delta\tau_1$ in two dimensions. The approximate location of the acting point is presumed to be at about the middle of the tip width ℓ_1 (Fig. 1) and around the base of the edge. The size of vectors is obtained from the GHIJD pattern of Fig. 4.

2) Radial Suction Force, Δs : As shown in Fig. 7-a, Δs is distributed along the radius directions, and the size is presumed from the GHIJD pattern, on the basis of Δk_1.

3) Turning Resistance acting on the Longitudinal Blade, $\Delta\tau_2$: The location of the acting point is presumed to be at about the centre of ℓ_2 (Fig. 8-b) and at about the middle of the edge width. The size of vectors is obtained from the AEF pattern of Fig. 4.

4) Centripetal Force, Δe : As shown in Fig. 8-a, Δe is distributed along the radius directions, and the size is presumed from the AEF pattern of Fig. 4, on the basis of Δk_2.

5) Resultants of These Forces : The resultant forces, τ_1 from $\Delta\tau_1$, τ_2 from $\Delta\tau_2$, S from Δs, and E from Δe are obtained through computer calculation. One example is shown in Fig. 9. At the next stage, the resultant force T from many cases of τ_1, S, τ_2 and E is also calculated. Fig. 10 shows one of them, and the location

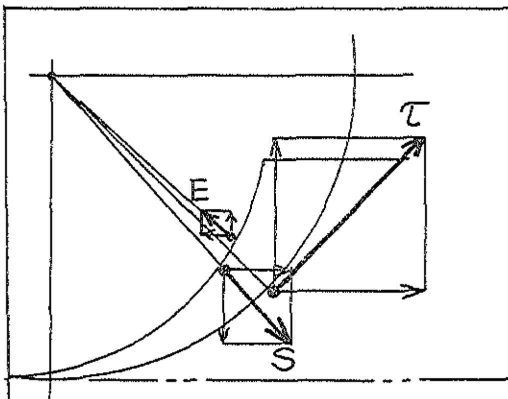

Fig. 9
An example of Resultant Forces: S, E and τ

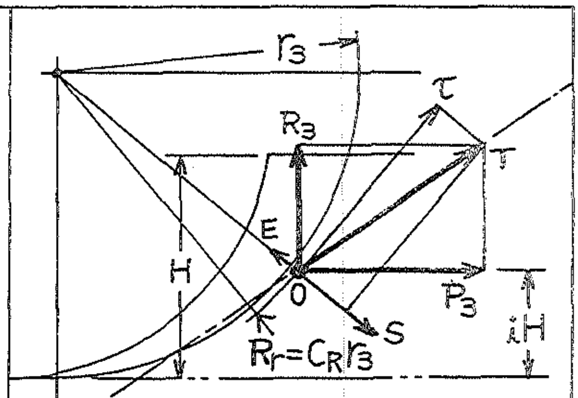

Fig. 10
Imaginary Acting Point of Resultant Forces

of the acting point O of T is expressed as follows :

$$R_r = C_R r_3$$

The analyzed data on C_R for many kinds of τ_1, S, τ_2 and E under a maximum depth of cut show that C_R is in the range of 1.01 to 1.04. In the case of a standard tillage condition with a Japanese rotary blade, C_R is about 1.02. C_R has a tendency to be larger value, when the number of blades in the soil decreases.

iH of Fig. 10 shows height of the acting point. i for a Japanese blade is from 0.3 to 0.5, usually 0.4. Fig. 10 shows also the conceptional conclusion that the resultants, τ from τ_1 and τ_2, S and E are acting on the imaginary acting point. Namely, the acting point of the resultant from all the rotary resistance locates a little outside the peripheral circle of the blade.

The acting point O is named "Imaginary Acting Point" of the rotary tillage resistance in English. C_R is a "Radius Coefficient" of the acting point. (The author's group is still studying on this C_R. Appendix shows the calculation including Söhne's assumption.)

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Appendix

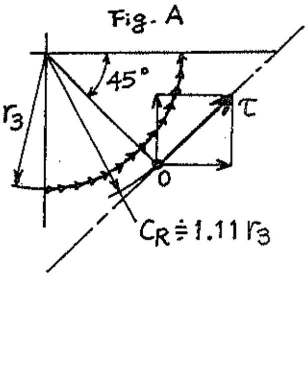
1) If the unit vectors $\Delta\tau$ act along the circumference of a quater circle of r_3 radius, the resultant force τ locates on the acting line outside the circumference as shown in Fig. A, and:

$$C_R = 1.11\, r_3$$

2) If the vectors $\Delta\tau$ act along the circumference of $0.95\, r_3$ (Sohne's assumption, 1957), the resultant force locates on the acting line of:

$$C_R = 1.05\, r_3$$

Fig. A



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EFFECT OF DIFFERENT TILLAGE METHODS APPLIED TO CHERNOZEM SOIL ON SOME SOIL PROPERTIES AND MAIZE YIEZDS

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ABSTRACT

In 1977 and 1978 a field experiment was conducted on a chernozem type of soil in a semiarid region with three methods of tillage and three methods of straw disposing.

The following treatments of tillage were investigated: No-tilage, rotary tillage and conventional tillage. The straw was burned, removed from and left on the plot.

Results of two-year investigations show that soil moisture to a depth of 40 cm was higher by 3.23% on the part of the plot where straw was left as mulch, while tillage had practically no effect on changes in moisture content. The percentage of humus was slightly increased (.13%) on that part of the plot where conventional tillage was performed, and the straw left on the plot. Yield was statistically significantly higher with conventional tillage in relation to the other two methods of tillage.

INTRODUCTION

Today in the world maize is grown on quite different systems of tillage: from notillage to systems which employ numerous tools for primary tillage and seedbed preparation.

Reduced tillage, minimum tillage and no -tillage have found their place in certain regions in maize growing. Each of these systems has its advantages and disadvantages. One of the many factors encouraging the use of any of these systems of tillage, wherever possible, is certainly a cheaper maize production.

In Yugoslavia different methods of minimizing tillige in maize growing as affected by climate and soil conditions were investigated earlier also (Drezgić et al 1966. Milojić et al 1964, 1971,1976; Kolčar 1964, Butorac et al.1976; Kosovac 1972, etc.).

The aim of our investigation of the effect of tillage on some soil properties and maize yield is a contribution to solving this problem in the semi-arid region of our country.

MATERIAL AND METHOD

The investigation was conducted in 1977. and 1978. on the experimental field of the Maize Research Institute in Zemun Polje on a chernozem type of soil.

The trail was set up as a three-factorial experiment accordding to the Split-plot design in four repliacations.

Two factors were investigated:

I Tillage

P_1 No-tillage

P_2 Rotary tillage

P_3 Conventional tillage

In the treatment no-tillage planting was carried out with a planter in the stubble field without any preceding tillage. The second treatment was made with the rotary hoe in the fall to a depth of 10-12 cm. Planting was performed with a planter. Conventional tillage consisted of the following. Shallow ploughing under of the stubble field:(15 cm) immediately after harvesting of wheat (month of July), primary tillage (30 cm) with a 2-bottom plow in the fall (month of September), seedbed preparation with a RAU-COMBI system in the spring and planting with a planter as in the preceding two treatments.

II Straw disposal

S_1 Burning on the plot

S_2 Baling and removing from the plot

S_3 Leaving it on the plot

Fertilizers were applied in the fall N,P, and K with 150, 105 and 75 kg/ha, respectively.

Between planting and emergence of hybrid ZP SC 1 the plot was treated with the herbicide Lasso-Atrazin in a dosage of 6 kg/ha.

During the growing season an interrow cultivation was performed in all treatments.

Soil moisture content was observed every 15 days using the standard method of drying samples at 105°C. Humus determinations were made according to the method of Kotzman.

Yield results were evaluated using the factorial analysis of variance.

PRINCIPAL CLIMATE AND SOIL CONDITIONS

Long-term observations (1953-1977) at the Meteorological Station in Zemun Polje, the following data were obtained for the maize growing season (April-October): Mean monthly air temperature for 1953-1977, 1977 and 1978 was 17.8°C, 17.2°C and 17.0°C, resrectively. At the same time the sum of rainfall for 1953-1977, 1977 and 1978 was 356.2mm 360.0 mm and 399.8 mm.

For the growing seasow the average sum of effective temperatures over several years, 1977 and 1978 was 1613°C, 1327.2°C and 1295.3°C.

These data show that the average sum of effective temperatures in the years of investigation was lower and rainfall higher in comparison to the several years average. This speaks of more favourable years for maize growing in respect to rainfall and less favourable in respect to temperature conditions.

The soil was a weak carbonate chernozem with a high production potential. The humus accumulative horizon (A) was 50 cm deep. The horizon AC was 50-80 cm deep, and strongly carbonate. Below this was horizon C loes.

The soil was weakly alkaline (pH 7.6 and H_2O at a depth of 0-40 cm). Humus content was 3.5% and of nitrogen .17%. The content of available P_2O_5 and K_2O ranged from 9-12 mg/100 g and 2o-28 mg/100 g of soil, respectively.

These analyses led to the conclusion that the soil was medium supplied with humus and nitrogen, abundant in potasium, but poor in phosphorus.

RESULTS AND DISCUSSION

A. Dynamics of soil moisture content

The two-year average soil moisture content during the growing season in respect to tillage and straw is given in Tab.1.

Tab.1. Soil moiture content (% weight) during the growing season (Two-year average)

Straw Disposal	Tillage P_1	P_2	P_3	$\bar{X}$	Relat
S_1	18,7	18,7	18,4	18,6	100,00
S_2	18,9	18,8	18,7	18,8	101,07
S_3	19,3	19,3	19,1	19,2	103,23
Average	19,0	18,9	18,7		

From results in Tab.1. it can be seen that tillage in the two-year average had practically no effect on soil moisture content. For the treatment no-tillage, soil moisture was higher by .3% compared to conventional tillage. Teunis van der Sar Ir. (1976) determined soil moisture content at a depth of lo-25 cm on the plowed part of the plot at 17.3% and with minimum tillage 17.2%. Van Doren and Triplett (1969) investigated soil moisture content and found that in the no-tillage treatment moisture content was 7.4 cm and in conventional tillage 5.2 cm.

Although the method of straw disposal did not significantly affect soil moisture content, still it was .6% higher in the soil with the treatment where straw was left on the plot (S_3).

During the critical period of the maize growing season in Yugoslavia (July-August) straw left on the field increased soil moisture content by 1.3% in comparison to burning the straw (Tab.2.). Van Doren and Triplett (1973) established as well that the moisture content was higher on the mulched part of the plot, while Triplett et al (1968) found that the total infiltration after one hour was 2.5 times higher on no-tillage with 80% residue than on plowed bare.

During this critical period, too, tillage did not affect moisture conten (Tab.2). A somewhat higher percentage of moisture occurred in 1978 in comparison to 1977 which received in the growing season almost 40 mm more rainfall.

Tab.2. Soil moisture content during the critical period of the maize growing season (July-August)

Straw Disposal	P_1		P_2		P_3		
	1977	1978	1977	1978	1977	1978	X
S_1	16,6	16,4	15,8	16,8	15,2	16,9	16,1
S_2	15,3	16,2	15,4	16,4	15,7	16,7	15,9
S_3	16,6	18,4	17,1	17,3	15,1	17,8	17,4
X	16,2	17,0	16,1	16,8	15,3	16,8	
Two-year average	16,6		16,4		16,0		

B. Content of humus

The average soil humus content on the experiment plot to a depth of 20 cm was 3.5o-3.62%

Results of the average humus content at the end of the maize growing season are given in Tab.3.

Tab.3. Effect of plowing and straw on soil humus content (in %, 0-40 cm deep)

Straw disposal	Tillage				
	P_1	P_2	P_3	X	S_1
S_1	3.61	3.69	3.64	3.65	-
S_2	3.68	3.61	3.71	3.67	0.02
S_3	3.78	3.78	3.80	3.78	0,13
$\bar{X}$	3.69	3.69	3.72	3.70	

The method of tillage did not affect the soil humus content although it was slightly higher in conventional tillage in comparison to the other two (.03%).

Straw showed a greater effect on humus content. In the treatment where straw was burned (S_1) the humus content was on the level of the control. The stubble field increased humus content by .02%. Straw left on the plot, particularly with conventional tillage, also increased the humus content by .18% in relation to the control and .13% to treatment S_1.

Straw as organic matter increases soil humus content and affects other soil properties and should, therefore, not be burned, but plowed under.

C. Yield

Results of yield are givenin Tab.4.

Tab.4. Effect of the method of tillage and straw disposal on yield of maize hybrid ZP SC 1 (mc/ha)

Straw Disposal	P_1			P_2			P_3			Average
	1977	1978	X	1977	1978	X	1977	1978	X	
S_1	82,54	90.77	86.66	87.06	103.66	95.36	108.72	105.18	106.95	96.32
S_2	82.45	89.23	85.45	96.96	101.21	99.08	104.28	102.16	103.22	96.05
S_3	85.21	98.60	91.90	102.56	104.21	103.38	106.05	105.60	105.82	100.37
$\bar{X}$	83.40	92.88	88.14	95.52	103.02	99.27	106.35	104.31	105.33	97.58
R			100.00			112.63			119.50	

LSD		For straw 1977	For straw 1978	For tillage 1977	For tillage 1978
	5%	4.70	3.13	5.43	4.03
	1%	6.33	4.13	7.31	5.33

Maize yields were higher on conventional tillage (P_3) and rotary tillage (P_2) by 19.50% and 12.63%, respectively in comparison to no-tillage (P_1).

In conventional tillage, favourable conditions were created for germination, emergence, growth and development of plants. Yields varied less within different methods of straw disposal. Greater differences in yield for the two-year average were shown in no-tillage and rotary tillage.

The success of no-tillage depends on the type of soil and on environmental factors. Lal (1976) established by analysis that maize yields on different types of soil in Africa with no-tillage compared to tillage ranged from 72% to 233%. In semi-humid regions of our country, Butorac et. al. (1976) obtained on lessive brown soil by planting directly without seedbed preparation almost the same yield as with reduced or conventional preparation for planting. Drezgić (1976) obtained on chernozem yields similar to ours, 13.9 mc/ha less with discharrowing in comparison to the treatment where the soil was plowed to a depth of 25 cm. 16% less yield with minimum tillage compared to plowing was obtained by Teunis van der Sar (1976), and Van Doren and Triplett (1973) with no-tillage 30.6% less yield than with full tillage. If on the same soil 70% of the area was mulched with maize stalks yield was higher with no-tillage by 9.7%. The same authors obtained a higher yield with no-tillage than with conventional tillage in monoculture in all treatments where nitrogen was applied. Van Doren et al (1976) found that maize is not very susceptible to soil tillage. On a certain type of soil maize was grown 10 years in monoculture with no-tillage, yield was less by 13% in relation when the same soil was tilled. On another type of soil an 11-year average on no-tillage. The yield was by 10% higher than with plowing where maize was grown either as monoculture of in rotation with soybean.

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TITRE : TILLAGE IN THE WEST AFRICAN TROPICAL ZONE

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ABSTRACT

IRATS' work in the West African tropical zone has shown that tillage can be of considerable importance to crop yield improvement.

However, for each type of environment, each type of crop there is a corresponding tillage which may according to circumstances be either very deep or minimal.

We must then avoid making hasty generalizations in favour of one alternative or another.

Soil tillage in the tropical environment is a frequent topic for agronomists' discussions. It is felt by some that tillage is indispensable, whereas others maintain that it is useless, indeed dangerous, at the very least it is considered uneconomical.

The problem is a complex one and no definite solution can be offered by either of the two factions. This is demonstrated by the numerous results obtained by IRAT in the West African tropical zone.

1. - EFFECTS OF SOIL TILLAGE IN THE TROPICAL ENVIRONMENT

Generally speaking, tillage can be seen to produce three main effects :

1.1. - Changes in the soil's physical state

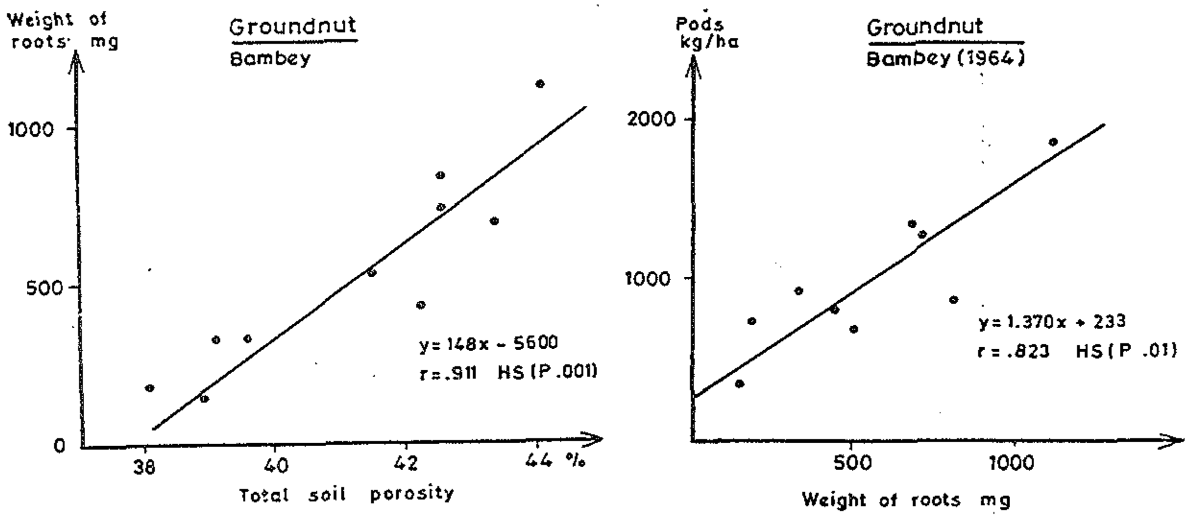
The first effect of tillage is upon the structure of the superficial layers of soil. Various features may be modified.

Porosity

There is an increase in total porosity but at the same time the distribution of the pore size is altered. Cultivated plants take root more quickly and more deeply.

Many results obtained in West Africa (Senegal, Mali, Ivory Coast) all demonstrate the favourable effect of soil cultivation upon the principal characteristics of root systems, features such as : maximum depth, total weight, density at depth, total length, diametrical area and average distance between roots.

By way of example, the attached graphs demonstrate the relation ship obtained between porosity and rooting on the one hand and between rooting and yield on the other.



Water regime

Tillage :

- Improves water seepage into the soil (by increasing porosity and creating microrelief features),

- Reduces evaporation and improves the soil's water retention in dry periods by creating a surface of earthy mulch. This effect is especially important in dry tropical areas in that water reserves can be carried over from one year to the next,

- Allows greater exploitation of the soil's water reserves because of greater root system depth.

Erosion susceptibility

When correctly performed, it yields microrelief features, clods for instance, which restrict run-off and it may therefore be considered an effective weapon against erosion. Significant results have been achieved in this domain in Senegal, Upper Volta and Ivory Coast. However in cases where the slope is very steep, where the rainfall is too intense or where the tillage has been performed inadequately - and in particular with a disc plough - these circumstances do not always occur.

Microbial activity

By increasing soil aeration it influences the life of micro-organisms. One particular effect is that upon the fixation property of rhizobium which is increased in sandy soil, thus playing a considerable part in improvement of groundnut yield in Senegal and in the nitrogen balance.

1.2. - Seed-bed preparation

The aim is to prepare a favourable environment for the seeds to emerge in; good seed-soil contact must therefore be established to ensure efficient moistening-a very important consideration in dry tropical zones. At the same time however, the soil must not be compressed too much, otherwise the upper layers will be pulverised and the very beneficial effects upon porosity will be lost.

Superficial tillage after ploughing is, then, a rather delicate problem to solve.

1.3. - Weed control

It has been demonstrated in numerous tropical countries that turning the soil by plough reduces the amount of weed control necessary.

With the use of herbicides the situation is somewhat altered. However, besides the fact that their cost does not permit their general use, it has been proved that herbicides are not totally effective in all circumstances (e.g. Ivory Coast, Togo). Let us avoid generalizing then ; there remains a great deal of progress to be made in the tropics in this domain. Indeed, even now, manual weeding remains all too often the most widespread weed control method.

2. - CROP YIELDS

Table one below illustrates the results of experiments carried out by IRAT and ISRA in Senegal. The experiments concern the effects of ploughing on the yields of a certain number of crop. The soils concerned are sandy and sandyclay soils (in general tropical ferruginous soils) and the results are representative of the whole of the Sahel - Sudan area of Western Africa.

	Number of annual results	Control Traditionnel yield Kg/hc	Ploughing yield Kg/hc	% gain due to ploughing
Millet	36	1638	1944	+ 19
Sorghum	54	2033	2523	+ 24
Maize	20	2439	3666	+ 50
Rain-fed rice	20	1164	2367	+103
Cotton	16	1576	1840	+ 17
Groundnuts	46	1259	1556	+ 24

Table 1 : Effect of ploughing upon major crops in Senegal

However during recent years IRAT has been developing research towards the replacement of ploughing by minimum tillage connected most often with crop-remnant mulching. In the majority of cases, weed-control is effected by the use of herbicides.

Table 2 : Tabulates the yield figures for crops in Senegal (ferruginous tropical soil), in Togo (ferralitic soils slightly desaturated) and in Ivory Coast (ferralitic soils).

	PLOUGHING	MINIMUM TILLAGE	MINIMUM TILLAGE % PLOUGHING
SENEGAL			
Groundnuts	2029	1536	76
Millet	1635	1546	95
Maize	3014	1515	50
Rice (rain-fed)	3417	1765	52
TOGO			
Maize	1991	608	31
Sorghum	3392	1259	37
Groundnuts	1111	666	60
IVORY COAST			
Maize			
Class 1 soils			
Variety IRAT 81	4355	4510	104
CJB	3125	2920	93
Class 2/3 soils			
IRAT 81	3340	2740	82
CJB	2180	1800	83
Rainfed rice			
Class 1 soils			
IRAT 13	3240	3340	103
Moroberekan	1700	1850	109
Class 2/3 soils			
IRAT 13	2200	1900	86
Moroberekan	1240	1560	126

Table 2 : Comparison of results between ploughing and minimum tillage in varying situations.

Class 1 soils : soils with good water retention properties

Class 2/3 soils : soils with gravel content, poor water retention properties

From these results, it is seen that the need for soil tillage is not the same in all circumstances. For a given situation the results may fluctuate according to the crop and even the variety. The crucial factor is most often the crop's ability to adapt to its physical surroundings.

3. - FACTORS WHICH MAKE SOIL TILLAGE NECESSARY IN A TROPICAL ENVIRONMENT

3.1. - The soil

Soil preparation is of considerable importance in a situation where the physical properties of the soil are poor. This is notably the case when the soil structure is under-developed, when porosity is low and when pore size does not allow adequate root penetration.

Now the structural character of a given soil depends upon its texture and upon the mineralogical nature of its fine fraction. Indeed it is in the capacity of swelling and shrinking that the origin of a natural structure lies. In tropical soils there is a kaolinitic dominance associated with iron sesquioxides in a fraction lower than two microns.

Moreover if soil structure is to develop under good conditions a certain clay content is indispensable. However in most cases the West African tropical zone has upper soil horizons with a clay content of less than 20 per cent. They can therefore be considered as structurally inert.

Coarse soil elements can play a decisive role. Elements such as coarse sand, grit and fine gravel do allow a certain soil aeration and create favourable root penetration conditions but they also increase the speed at which water permeates to the lower horizons.

3.2. - Climate and vegetation

- Rainfall pattern which controls alternating periods of wetting and drying out,

- Season periodicity and length, particularly a long dry season which severely limits any permanent presence of active soil fauna such as earth-worms,

- Rainfall intensity which is the major cause of runoff-and erosion.

Natural vegetation is of course linked to weather conditions. Thriving vegetation protects the soil well and provides residual elements which offer an efficient strawlike mulch. In dry tropical regions however these conditions do not occur ; here even the harvest residues are used, either as cattle fodder, building material or fuel.

3.3. - The land-clearing age

A soil recently cleared for cultivation is, generally, more fertile than a soil which has known past cultivation. Cultural technics must take these very different situations into account.

First the situation where areas occupied by natural vegetation or by very sporadic shifting cultivation are to be reclaimed for agricultural use.

Secondly the situation calling for an improvement in land long under cultivation, where population growth has led to a reduction or, indeed, complete suppression of fallow periods.

In the first case the natural qualities of the environment must be protected and in the second there is often no alternative but to resort to working the soil to create a structure artificially.

4. - CONCLUSION

Tillage in tropical zones is then a complex problem which cannot be dealt with everywhere in the same way. Thus we see researchers obtaining varying results in different situations.

Each crop and each area has its corresponding type of land preparation. Let us then beware of making hasty generalizations.

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EFFECT OF PLOWED UNDER ORGANIC MATTER ON SOIL MOISTURE AND YIELD OF MAIZE GROWN AS MONOCULTURE

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SUMMARY

The effect of plowed under organic matter was investigated on a carbonate chernozem type of soil at the Maize Research Institute in Zemun Polje. The study was made on a plot where maize was grown in monoculture over several years.

Maize stalks and stable manure was plowed under into the soil as organic matter.

Variants:

Maize stalks:

a) cut and removed from the field
b) 50% plowed under, 50% removed
c) 100% plowed under

Stable manure:

a) without stable manure
b) o.5% of the volume of plowed soil
c) 1.5% of the volume of plowed soil

Maize stalks were plowed under every year in the fall during primary tillage. Stable manure was incorporated into the soil every third year also during primary tillage.

A deficit of water in the soil during the period of ontogenesis has a significant effect on the morphological and biological features of maize. An attempt is made by using culture practices to reduce the water deficit in the soil. Therefore, we have investigated on a chernozem type of soil K o s a n o v i ć (1960) the effect of maize plant residues and stable manure on soil moisture and maize yield.

Material and method

The investigation was conducted in 1977/1978 at the Maize Research Institute in Zemun Polje on a trial set up in 1971/1972. The treatments are given in the footnote of tables 1, 2, and 3.

Soil moisture was determined by the classical method of drying the sample at 105°C. Soil moisture was measured two times a week at a depth of 10-60 cm. It was expressed in % of field water capacity (FWC).

Hybrid ZP SC 3 was used for this investigation.

Results

Plant residues did not significantly affect soil moisture in the treatments where these were removed from the field or plowed under (50%, 100%).

It can be seen from Tab.1. that in none of the phases of ontogonesis did plant residues significantly and reliably affect soil moisture. The treatment with 50% of plowed under plant residues compared with the treatment where these were removed from the field (1977/1979) showed a higher soil moisture by .79%, and the treatment 100% plowed under residues by 1.84%.

Tab.1. - Effect of plant residues on soil moisture in % of FWC during different phases of ontogenesis and maize yield

Phase of development	Plant residues					
	removed from the field		50% removed 50% plowed under		100% plowed under	
	1977	1978	1977	1978	1977	1978
Emergence-3 leaf	74.54	75.86	75.10	75.92	77.09	77.51
3 leaf-9 leaf	62.45	77.48	63.07	78.63	63.83	79.26
9 leaf-tasseling	50.23	54.29	50.72	56.88	52.04	57.10
Tasseling-maturity	45.37	46.90	45.83	47.26	45.90	49.08
Average	58.14	63.63	58.68	64.67	59.70	65.73
Yield mc/ha of grain	82.23	92.83	84.21	94.81	83.27	94.46

CV (%) 5.03

F value not reliable for 5% and 1%

Stable manure affected soil moisture significantly (Tab.2.). Treatments .50% and 1.50% stable manure of the volume of plowed soil in comparison to treatment without stable manure showed during the ontogenesis of maize a higher soil moisture.

The treatment .50% stable manure of the volume of plowed soil in comparison to the treatment without stable manure had in the average (1976/1978) a higher soil moisture content by 2.43%, and the treatment 1.50% stable manure by 7.1%.

A positive effect of stable manure on soil moisture was also manifested in maize yield. The treatment .50% stable manure in comparison with the treatment without stable manure gave a higher yield by 6.43% (average for 1977/1978); treatment 1.50% by 9.04%. The value of F shows thate the difference is significant and reliable.

Tab 2.-Effect of stable manure on soil moisture in % of FWC during different phases of organogenesis and maize yideld

Phase of development	Stable manure					
	Without stable manure		50% of soil volume		1.50% of soil volume	
	1977	1978	1977	1978	1977	1978
Emergence-3 leaf	73.75	74.18	74.45	76.59	78.55	78.52
3 leaf -9 leaf	61.37	76.52	62.84	88.86	65.09	80.97
9 leaf-tasseling	49.10	54.10	50.59	55.71	53.28	58.46
Tasseling-maturity	44.74	45.36	45.44	47.28	47.28	50.58
Average	57.24	62.54	58.32	64.36	61.05	67.13
Yield mc/ha of grain	80.10	85.46	84.33	96.58	85.28	100.07

CV (%) 5.03

F realiable for 5% and 1%, 3.09 and 4.82 mc/ha,respectively.

Plant residues in combination(interaction) with stable manure did not significantly affect soil moisture (Tab.3.). The difference in soil moisture between the two treatments is slight, while the value for F shows that differences are neither significant nor reliable.

Tab.3.-Effect of plant residues and stable manure on soil moisture in % of FWC and maize yield

Stable manure		Plant residues			Average
		Removed	50% removed 50% plowed under	100% plowed under	
Without stable manure	Grain mc/ha FWC %	81.51 60.38	82.55 60.78	85.27 61.38	82.78 60.85
.50% of soil volume	Grain mc/ha FWC %	90.25 61.11	91.51 61.50	89.57 62.02	90.45 61.54
1.50% of soil volume	Grain mc/ha FWC %	91.82 62.48	94.15 62.88	91.76 63.40	92.58 62.92
Average	Grain mc/ha FWC %	87.86 61.32	89.40 61.72	88.87 62.27	88.60 61.77

F value i$ not reliable for 5% and 1%.

The interaction of stable manure and plant residues did not significantly affect maize yield (Tab.3). The value of F shows that the difference in yield is not reliable and justified.

Conclusion

Plant residues did not significantly affect soil moisture and maize yields.

Stable manure affected significantly soil moisture and maize yield.

The interaction of plant residues and stable manure did not significantly affect soil moisture and maize yield.