RATIONAL TILLAGE

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INTRODUCTION

Recent economical developments have necessitated maximizing net returns of the Dutch arable farm, which has reactivated interest in rationalization and intensification. In this paper only implications with respect to soil tillage will be dealt with.

Rationalization aims at minimizing total production costs, of which roughly 15 % may be put down to the account of soil tillage. Because soil tillage is an integral part of the farming system, it may play an important rôle in achieving the above mentioned goal. Frequency, depth and intensity of soil tillage may be reduced to the extent that they meet the real demands of soil and crop, while what tillage is done may be performed in a more rational way, viz., wider implements, combined cultivations, etc.

Intensification aims at maximizing gross product per ha. This is achieved by incorporating more labour - consuming, financially interesting crops in the rotation, viz. potatoes and sugar beet. Also flower - bulbs and onions can be mentioned as well as double cropping of processing vegetables for the canning industry. On the one hand these crops are much more demanding with respect to soil structure than cereals, while on the other hand the chance of deleterious effects of harvesting operations on soil structure is much greater. It is clear that this implies adaptation of the tillage system, the more so as there is no doubt that problems with volunteer potatoes, mechanical weed control, soil-borne diseases etc. will only be aggravated (VAN OUWERKERK, 1973-2). In addition, in view of the fact that in these narrow rotations green manure can be applied only to a very limited extent, the odds are that organic matter content of the soil will decrease consistently, which may give rise to serious problems on unstable soils.

Sugar beet tops, cereal straw, and animal waste-products, which are nowadays abundantly available,may be of help. However, the incorporation of these products into the soil demands again an adaptation of the tillage system.

RATIONALIZATION OF TRANSPORT

Soil tillage in its broader sense can be defined as the collection of all those actions that result in a pressure of one kind or another on the soil. According to this definition tillage includes traffic over the field as well as soil handling when harvesting root crops. Therefore, rationalization of transport may also make an important contribution to the above mentioned goal. In this context measures may be mentioned that

a. reduce the deleterious effects on soil structure, i.e. better tyres, cage wheels, four-wheel drive, etc;

b. reduce the frequency of traffic, i.e. reduced tillage, combined cultivations, omission of harvesting sugar beet tops and cereal straw;

c. reduce the surface covered by wheelings, i.e. wider implements, streamlining the wheeling pattern with as utmost consequence the bed system;

d. shift traffic to periods when soil structure is less vulnerable, i.e. application of phosphate and potassium in autumn, application of nitrogen and initial seedbed preparation in lightly frozen soil, split - application of nitrogen, liquid fertilizers;

e. increase trafficability, i.e. improved drainage,lowering of the ground-water table, zero-tillage.

Recent developments in tractor and trailer design lead to the conviction that the axle width will be increased from the common 1.50 to 1.80 m or even 2.10 m. Accordingly, tyre widths will increase from the common 30 cm to anywhere between 40 and 70 cm. This trend has already renewed interest in wider row spacings for potatoes (VAN OUWERKERK, KOUWENHOVEN & KOOY, 1974), because with the common 75 cm distance between ridges the furrows in between are too narrow to fit wide tyres (figure 1). The interesting point is that increasing the row spacing means a decreasing depth of the layer of loose soil needed for building the ridges (table 1). Hence working depth in spring, when soil structure is usually very vulnérable, will have to be less. This means improved workability : the soil can be cultivated

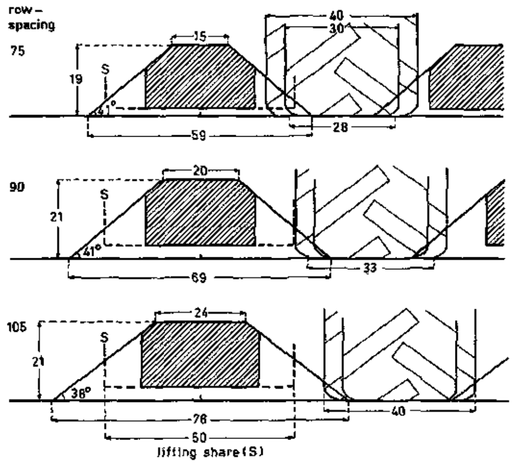

Fig. 1 - Increased row spacing enables wide tyres to pass between potato ridges without compacting the flanks (dimensions in cm).

TABLE 1. Required depth (cm) of loose soil in relation to cross - sectional area and row spacing of potato ridges

Row spacing (cm)	Cross-sectional area of the ridge (cm2)					
	500	600	700	800	900	1000
67	7,5	9,0	10,4	11,9	13,4	14,9
75	6,7	8,0	9,3	10,7	12,0	13,3
90	5,5	6,7	7,8	8,9	10,0	11,1
105	4,8	5,7	6,7	7,6	8,6	9,5

earlier with less chance to produce clods and smearing of the subsoil.

TILLAGE SYSTEMS

On the whole, tillage as such has a loosening effect on soil structure, while traffic has a compacting effect. According to the extent to which loosening and compacting effects are known to be present or are intended to be absent, four different tillage systems can be distinguished (table 2).

TABLE 2. Tillage systems.

Loosening effects	Compacting effects	Denomination
+	-	loose - soil husbandry
+	+	traditional tillage
-	-	rational tillage
-	+	zero - tillage

In the traditional system the soil is each year loosened deeply and intensively, However, because fertilizer application, seedbed preparation and sowing are accomplished in many separate passes, the soil is usually compacted to the extent that the loosening effect is completely nullified. It is thought that the level of bulk density which is maintained in this way is too high to represent an optimal physical environment for plant growth under all conditions.

The loose soil system tries to improve this situation by rationalization of traffic as outlined before. Moreover, much attention is given to the quality of ploughing, which has to be uniform, smooth and closed, with trash and straw properly turned under. In this way the number of cultivations needed for seedbed preparation and hence compaction is strongly reduced and may sometimes be left out altogether. For example,under favourable circumstances, winter wheat, barley and potatoes can be sown or planted directly in the furrow slice, that is, without previous seedbed preparation. When seedbed preparation is necessary, as it always is for sugar beet, it is preferably combined with sowing. Implement combinations are assembled in such a way that one pass is sufficient to create a seedbed of the required tilth. It must be kept in mind, however, that too sophisticated combinations may increase expenses considerably. It is further interesting to note that experiences with powered implements are not always favourable. When soil is fairly moist as it often is in spring, these implements may have a compacting and smearing effect on the layers underneath the seedbed. An obvious disadvantage of this system is the poor bearing capacity of the loose soil; hence excessive futting often occurs.

Zero-tillage is in Dutch denominated "vastegrondsteelt: ". The English equivalent is something like "firm-soil husbandry ". From this denomination it is already clear that the system is the complete opposite of the loose-soil husbandry.

In its full sense zero-tillage means that all tillage whatsoever is left out (BAKERMANS & DE WIT, 1970). However, for potatoes this is impractical as mechanical lifting is impossible without proper ridges. Therefore, by way of concession, potato ridges are made by full-width rotovating to a depth of 7 cm, which is combined with planting.

In this system compaction of the soil predominates. Apart from the inevitable soil disturbance when harvesting root crops, loosening effects are only very small: superficially this may be performed by frost action and, probably to a somewhat greater depth, by soil fauna activity which is undoubtedly greater than in ploughed soil. As a consequence soil structure soon becomes very homogeneous, dense and hard, which may be ideal for traffic, but can hardly be looked upon as a suitable environment for plant growth, In addition, it must be stressed that, although chemical weed control has made great progress, rhizomatous weeds are still a nuisance and in some cases may prevent continuation of the system already after a few years.

The similarity between loose - and firm - soil husbandry is that they both are not simply applicable in practice. However, for scientific research of soil tillage and plant cultivation they are of utmost importance as they represent the extremes in the whole range of tillage intensities. Therefore, they can no more be dispensed with than the extreme doses in fertilizing trials.

With respect to crop yields, experimental evidence reveals the striking fact that, at least in a wide rotation, crops are much more tolerant with respect to soil tillage than was initially supposed. As this even holds true to a great extent for zero - tillage one begins to wonder if frequency, depth and intensity of soil tillage could not be substantially reduced without serious, long - lasting damage to soil structure and catastrophic yield reductions. This question formed the starting point of the development of the rational tillage system, which may be regarded as the synthesis of all positive elements of the three tillage systems mentioned.

The <u>rational tillage system</u> aims at increasing the efficiency of soil tillage in technological and economical respect to enlarge the net return of the farm, averaged over the duration of the rotation (VAN OUWERKERK, 1973-1). While not denying that high yields are rightly looked upon as the basis for sound financial results, a rational farmer will be well aware of the fact that farming basically is not only a hobby or a way of life, but a way to make a living, and he will agree that the style of life he can afford has more to do with the height of the net return of his farm than with gross product per ha. Therefore, he will not aim at the maximum yield as this may increase expenses, and often involves too great risks with respect to soil structure, the establishment of the next crop, and last, but perhaps not least, pollution of the environment. For instance, obtaining maximum yields of sugar beet implies harvesting extra late, which may damage soil structure and endanger timeliness of ploughing and/or sowing of winter cereals; the maximum yield of cereals can only be attained by liberal application of chemicals, about which one begins to be uneasy.

The rational tillage system is in principle not as rigorous in design as the scheme in table 2 may suggest. What is really meant is that frequency, depth and intensity of soil loosening are brought into line with the specific demands of the individual crops in the rotation as they appear from soil tillage experiments and from practical experience. In practice this simply means that tillage is restricted to a rational or reasonable extent. This may mean reduction to nought (for cereals), but also ploughing to 28 cm depth (for sugar beet). It means also that alternatives for the reliable but slow plough, such as chisel plough or fixed-tined cultivator are actively tried. In this context the incorporation of cereal straw and/or green manure in combination with sowing of winter wheat is equally to the point.

Especially with this system it is essential to be on the alert with respect to soil structure and weeds so as not to endager gross yield and hence the net return. Therefore it is self - evident that one tries to safeguard the loosening effect as much as possible by taking the same measures as in the loose soil system.

EXPERIMENTS

Experiences with reduced tillage are already very old, if we only remember the numerous trials with different ploughing depths and are aware of the fact that the problem was usually framed in the converse way, namely : what can be gained by ploughing deeper ? Nowadays we put it more like : what may be lost by ploughing shallower ? This realization may also lead to a converse interpretation of the practical significance of trends appearing from the results of ploughing depth trials, viz, that reduction of tillage may be carried out without substantial yield reductions and with much less expenses. By way of example figure 2 shows some hitherto unpublished results pertaining to the former EHF "Zeeland", where on light, young clay soil two ploughing depths, viz., 10-15 and 25-30 cm, were compared with respect to crop response during 23 years (1946-1969).

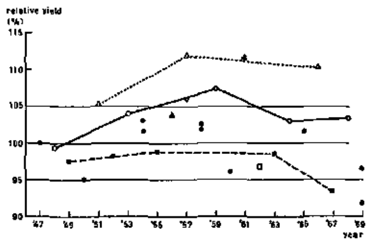

Fig. 2. EHF "Zeeland" (1946-1969) - Relative yield after deep ploughing (shallow ploughing = 100 %) (● cereals, ▪ potatoes, ○ sugar beet, ▲ flax, △ green peas, □ alfalfa, ▽ mawseed).

With cereals the differences in yield are restricted largely to plus or minus 5 % while they show no préference for either deep or shallow ploughing. Some large negative responses are due to difficulties with the seedbed preparation after deep ploughing (1950, 1969). Potatoes show a slight preference for shallow ploughing while sugar beet react clearly positively to deep ploughing, only in 1948 there was practically no difference, which was due to the after - effect of uniformly ploughing to a depth of 25 cm accompanied by subsoiling another 10 cm of the whole field in 1945. With structure - sensitive crops such as flax and green peas the positive effect of deep ploughing is even greater than with sugar beet.

With sugar beet there are clear differences in sensivity among different varieties. With long, deep rooting varieties differences are much larger than with short, shallow rooting ones (table 3). In both cases yield of tops was higher after deep ploughing, indicating a better availability of nitrogen. This had a slightly negative effect on sugar content. These results stress the fact that also plant breeding and fertilization research are indispensable for progress in the process of intensification and rationalization of the arable farm.

TABLE 3. EHF "Zeeland" (1953) - Relative yield (%) of different varieties of sugar beet after deep ploughing (shallow ploughing = 100 %).

Variety	Shape	Roots	Tops
Kuhn	long	106,1	107,6
Nemos	"	107,6	106,1
Pedigree	"	106,4	111,3
Hilleshög St.	short	101,4	109,7
Hilleshög P.	"	101,3	107,1

Soil physical research revealed a distinct plough sole (figure 3) which, especially on the shallowly ploughed plot may have hampered root growth of sensitive crops such as sugar beet, flax and green peas.

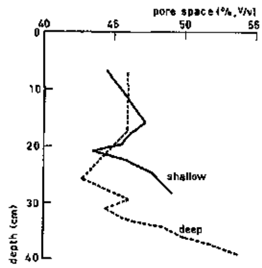

Fig. 3. EHF "Zeeland"(1965) - Low pore space indicates severe compaction at ploughing depth, on shallowly as well as on deeply ploughed plots

The effects of ploughing depth depend to a large extent on soil type and climatological conditions. Nevertheless, trends are often similar to those emerging from the data quoted above (VAN OUWERKERK, 1965). Therefore, it is my conviction that for most crops, at least in a wide rotation, ploughing deeper than 20 cm is not necessary; only for sugar beet and a few well-known sensitive crops ploughing to 30 cm may be justified.

These and many other data with respect to reduced tillage were kept in mind when we designed over first rational tillage system on the EHF "Westmaas" (near Rotterdam) and compared it with the traditional and the zero-tillage system. This was accomplished in a unique, jointly financed and operated project with workers of research institutions, the agricultural university and the advisory service. Open discussions were held frequently to determine what would be rational under the prevailing conditions of soil, climate and crop rotation. Appropriate research on physical and chemical soil fertility was carried out in close cooperation (VAN OUWERKERK & BOONE, 1970).

The experiment which, due to re-allotment operations could last only from 1968 to 1971, was run in a five - year rotation, viz., alfalfa or ryegrass - sugar beet - winter wheat - potatoes - barley or oats. It is apparent that, on the average, the traditional tillage system has only a slightly stronger loosening effect on soil structure than the rational tillage system (table 4). Non - tilled layers (zero - tillage) rapidly become dense and firm. This is further illustrated in table 5 from which it is clear that the compacting effect of sugar beet harvest on the soil layers below 12 cm persisted after superficially cultivating on the rational tillage plot. With sugar beet, differences in pore space in the 12-17 cm layer were in favour of rational tillage as here seedbed preparation was performed with a simple wooden float, whereas in the traditional tillage system a reciprocating harrow was used for this purpose. With potatoes, the high pore space in the 2-7 cm layer of the zero - tillage plot reflects the effect of rotovating (BAKERMANS, BOONE & VAN OUWERKERK, 1974). Crop response in this experiment was in line with the results of ploughing depth trials.

In 1971 a new experiment was started, in which rational tillage is compared with loose - soil husbandry and zero - tillage in a four - year rotation, viz., sugar beet - barley - potatoes - winter wheat. Again, as could be expected from the still relatively wide rotation, results with respect to soil structure and crop yield are promising for the rational tillage system.

TABLE 4. EHF "Westmaas" (1968-1971) - Pore space (%, v/v), averaged over 4 years and 5 crops.

Depth (cm)	Tillage system		
	Traditional	Zero	Rational
2 - 7	49,5	45,9	48,9
12 - 17	46,7	44,0	45,6
22 - 27	46,3	44,7	45,5

TABLE 5. EHF "Westmaas" (1968-1971) - Pore space (%, v/v) for three crops, averaged over 4 years.

Tillage system	Depth (cm)	Sugar beet	Winter wheat	Potatoes
Traditional	2- 7	49,7	49,1	55,8
	12-17	45,9	47,9	46,6
	22-27	46,2	46,9	46,8
Zero	2- 7	45,4	44,8	56,1
	12-17	44,1	44,1	44,3
	22-27	45,2	44,6	44,6
Rational	2- 7	51,6	47,0	55,8
	12-17	47,1	44,6	46,1
	22-27	46,8	44,9	46,3

RATIONAL TILLAGE IN NARROW CROP ROTATIONS

To what extent the above mentioned results will hold for extremely narrow rotations as sugar beet - potatoes - wheat - potatoes, sugar beet - potatoes and even continuous potatoes and continuous sugar beet, and what new problems will arise is unknown so far. Therefore, experiments on the subject have already been started or will start soon.

One of the problems which certainly has to be deal with is the potato root eelworm(Heterodera rostochiensis). Regulations are that when susceptible potato varieties are grown more than once in four years the soil has to be chemically disinfected. Results depend to a large extent to soil tillage before or during fumigation, especially on heavy soils. Injection with the share - injector to the depth of the tilled layer, shallow rotovating and sealing of the finely crumbled topsoil with a powered smooth roller (all in one pass) promises to give best results (ANDRINGA,1973). However it is not sure that the finely crumbled soil(which has a very high waterholding capacity) will always allow the necessary backploughing after three weeks. Moreover, on unstable silt soils it is likely that adverse weather conditions shortly after disinfection will cause severe slaking. Finally, one has to realise that disinfection not only means killing of potato root eelworms but also of a large percentage of the other soil fauna and soil flora, which is clearly not welcomed by environmentalists.

The most important problem of arable farms with narrow rotations is posed by volunteer potatoes, which constitute a nasty weed in the next crop. It cannot be destroyed by chemicals and only partly by mechanical means, so it poses a first - order phytosanitary problem. Research of the Research Station of Arable Farming has shown that adaptation of soil tillage after potato harvest, i.e. using the fixed - tined cultivator instead of the plough gives best results (LUMKES, 1974). In this way potatoes which were shattered at harvest remain in the topsoil where chances of freezing are best. Unfortunately, winter in Holland does not always mean frost, so adapted tillage cannot give a watertight solution. Therefore, the Dutch Ministry of Agriculture has now offered a prize for the best alternative solution.

APPLICATION OF RATIONAL TILLAGE IN PRACTICE

Rational tillage practices are not restricted to clay soils (DAVIES, EAGLE & FINNEY, 1972). On the contrary, sandy soils give in principle many more possibilities, because here, in contrast with clay soils, the weathering process is not needed to obtain a good tilth. For example, ploughing may be carried out in spring, in combination with seedbed preparation and sowing or planting. However, on sand soil sensitive to drought it will be rational to plough in autumn and to minimize soil disturbance in spring to avoid undue loss of water.

On blowing soils, intensification of arable farming was made possible by introducing rational tillage methods together with a surface cover of winter rye (LUMKES & TE VELDE, 1973). After potato harvest the soil is tilled deeply with the fixed - tined cultivator, while at the same time rye is broadcast, In spring the rye is killed by means of chemicals, after which sugar beet are sown in the mulch with an adapted precision drill. For potatoes, after the preceding sugar beet harvest, two passes with a mounted rotary harrow are sufficient. In this case the rye is thinned in spring by means of the spring - tined cultivator and chemically killed of when potatoes are emerging. This also controls couch grass as this is already fully developed at that time. As this system with its fairly strongly reduced tillage gives satisfactory results, it gave rise to the introduction of the zero - tillage system in the rotation. How long this can be maintained unpunished is under investigation.

The foregoing illustrates that rational elements may be introduced in every link of the whole chain of subsequent measures, together comprising a tillage system. This may be realised if one is only willing to think about rationality before doing things. I hope that farmers, recognizing the fact that it is highly necessary to increase net returns considerably, may cultivated and cherish even the tiniest spark of ingenuity in this respect.

PERSPECTIVES

Considering the scarce land resources, it is obvious that enlarging the acreage of the Dutch arable farm will remain extremely difficult. Therefore, prospects are that the process of intensification will proceed at an ever increasing pace, which requires rationalization of tillage practices. Progress in tractor - and implement design opens excellent possibilities to accomplish this task, while the growing understanding and cooperation between research workers of different disciplines justify high expectations.

However, as outlined above, rational tillage means on the average, reduction of frequency, depth and intem sity of tillage treatments. As tillage has also an important effect on weeds, this development involves an increased use of chemicals. Already now agriculture is accused of a too abundant use of herbicides and, in fact, we must agree that chemical weed control is practised unquestioningly. As the growing concern of environmentalists and disciples of the so called alternative agriculture is gradually shared by the public opinion, it would not surprise me if this would result in the near future in calling a halt to further rationalization of soil tillage. Therefore, it is worthwhile to ask oneself honestly if it is justified to stress the advantages of herbicides and to neglect the possibilities of mechanical weed control. In fact, one must agree that mechanical weed control has been brushed under the carpet without proper research. In Holland, attempts are now being made to fill this gap in our knowledge and experience. In my opinion joint efforts in this research will result in a compromise satisfyin both environmentalists and agriculture.

In conclusion, I am convinced that it is appropriate to inspire and encourage farmers to use the recent findings of tillage research to the largest possible extent in composing their own rational tillage system, fully adapted to their own conditions of soil, climate, crop rotation and degree of mechanization. In Holland, farmers will be stimulated before long by the publication of the soil tillage recommendations for the main crops sugar beet and potatoes drawn up by our Working Group on practical applications of tillage research in arable farming.

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RESUME

Travail rationnel du sol

Des considérations économiques ont obligé de rationaliser et d'intensifier les exploitations de grande culture Hollandaises, ce qui comporte une simplification de la rotation et une adaptation du travail du sol Celui-ci peut être réalisé par un système de travail rationnel, basé sur les exigences réelles des plantes quant à la structure du sol ainsi que l 'exigence que le rendement net de l'exploitation pendant la durée de la rotation soit au maximum. Dans ce système la fréquence, la profondeur et l'intensité du travail sont réduits à un degré rationnel, c'est-à-dire, la structure du sol et les mauvaises herbes sont seuls pris en considération de telle façon qu'un compromis raionnable soit obtenu entre des récoltes élevées et des dépenses basses.
seuls pris en considération de telle façon qu'une compromis raisonnable soit obtenu entre des récoltes élevée et des dépenses basses.

Bien qu'on croit que le rôle des moyens chimiques contre les mauvaises herbes devrait diminuer en faveur des moyens mécaniques, les perspectives pour l'application du système de travail rationnel dans la pratique sont pleines d'avenir.

SUMMARY

Economical considerations induce rationalization and intensification of the Dutch arable farm, which involves narrowing of the crop rotation and subsequent adaptation of tillage practices. This may be achieved by a system of rational tillage, based upon the real demands of the crop with respect to soil structure and the demand that the net return of the farm over the duration of the rotation be highest. In this system the frequency, depth and intensity of tillage are reduced to a rational extent, i.e., soil structure and

weeds are only looked after to such an extent that a reasonable compromis between high yields and low costs is obtained.

Although it is believed that the rôle of chemical weed control will have to be decreased in favour of mechanical weed control, prospects for a wider application of the system of rational tillage in practice are promising.