OPTIMIZING HARVESTING OPERATIONS ON A LARGE-SCALE GRAIN FARM

PROEFSCHRIFT

ter verkrijging van de graad van doctor
in de landbouwwetenschappen
op gezag van de Rector Magnificus, Dr. Ir. F. Hellinga,
hoogleraar in de cultuurtechniek,
te verdedigen tegen de bedenkingen van een commissie
uit de Senaat van de Landbouwhogeschool te Wageningen
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door

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STELLINGEN

I

Het verdient aanbeveling om de in dit proefschrift toegepaste methode van onderzoek voor de graanoogst te gebruiken voor de optimalisatie van de oogst en de verwerking van andere gewassen.

II

Bij de optimalisatie van een oogstsysteem is het noodzakelijk de verliezen aan produkt die bij de alternatieve systemen optreden in de kostenberekeningen te betrekken.

III

Het verdient aanbeveling om loonwerktarieven voor maaidorsen te differentiëren op basis van het korrelvochtgehalte en het rijpheidsstadium van het gewas.

IV

De optimale situatie van vliegvelden ten behoeve van werkzaamheden in de land- en bosbouw kan worden bepaald naar analogie van de in dit proefschrift toegepaste methode voor situering van graanverwerkingsinstallaties.

GROENEWOLT, W. J., 1968. Landbouwk. Tijdschrift, 80: 357-361.

V

De door o.a. BELDEROK gegeven beschrijving van het meest gunstige rijpheidsstadium van tarwe voor maaidorsen is gezien zijn beperktheid onbruikbaar voor de optimalisatie van de organisatie van de tarweoogst.

BELDEROK, B., 1965. Zeitschr. für Acker- und Pflanzenbau, 4: p. 299.

VI

De frequentieverdeling van het korrelvochtgehalte tijdens de oogstperiode vormt een te beperkt uitgangspunt voor de simulatie van de graanoogst ter bepaling van de optimale dors- en droogcapaciteit.

DONALDSON, G. F., 1968. Am. Journ. of Agr. Econ., 50: 24-40.

Proefschrift J. H. VAN KAMPEN
Wageningen, 30 mei 1969

VII

Voor de beslissing inzake aankoop van een landbouwwerktuig zijn de resultaten van vergelijkende capaciteitsmetingen van geringe betekenis te achten in vergelijking met andere informatie zoals die betreffende bedrijfszekerheid en service.

VIII

De toenemende mechanisatie van de werkzaamheden in de landbouw heeft tot gevolg dat bij de organisatie daarvan in bijzondere mate rekening moet worden gehouden met de weersomstandigheden. Dit maakt meer inzicht noodzakelijk in de relatie tussen plant, c.q. grond en machinale bewerking bij verschillende weersomstandigheden.

IX

Het verdient aanbeveling om bij het tot stand brengen van een proefschrift gebruik te maken van netwerkplanning.

X

Het valt te betreuren dat in Nederland voor het veranderen van een geslachtsnaam, welke als onwelvoeglijk of bespottelijk is aan te merken en waarvan in het maatschappelijk verkeer hinder wordt ondervonden, de financiële eisen belemmerend kunnen werken.

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CONTENTS

1 INTRODUCTION

In the last two decades techniques of agricultural production have changed considerably, in general resulting in a substitution of labour by machinery. Another trend in recent years is the decline in margins; i.e. the cost of the inputs has tended to rise relative to the price of the products. The net effect of these changes is that farming and farm management in developed countries change from a craft and a way of life towards a business requiring the discipline of business management to ensure a profit. This places a heavy burden on the farmers decision making function regarding the selection of farm equipment (MORRIS and GROENEWALD, 1968).

The sum of labour and machinery constitutes approximately 50% of the production costs on a modern arable farm in the centre of the Netherlands (ANON, 1968*a*). Therefore, with a given cropping program, an efficient selection and utilization of these means of production can contribute substantially to maximization of the profit. Although considerable research has already been done on systems design and equipment selection in crop production, mostly by cost minimizing, in many cases a clear cut model for these decisions is still lacking.

The objective of this thesis is:

1 Development of an operational model for grain harvesting
2 Application of the model to determine an optimal grain harvesting system i.e. number of combines, transport equipment and number, size and location of plants for drying and temporary storage. This is done by minimizing the sum of the costs of labour, equipment and product loss due to any of the selected systems (total harvest costs).

The optimal system depends on the climate and other conditions prevailing in a certain region. In this case the model is applied to a farm located in the centre of the Netherlands (52° 30′ N, 5° 37′ E).

The climate in the Netherlands is a maritime one with cool summers and mild winters. The weather during harvest is in general rather unfavourable for grain harvesting operations (precipitation 93 mm/month, temperature 16.8° C, relative humidity 86%). The moisture content of the threshed grain is in general such that part or all of it has to be dried artificially before it can

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be stored safely. Thus the weather affects the drying capacity, the available working hours for combining and the combine performance; it also affects the field losses. As a consequence the rate at which the harvest proceeds and the total harvest costs vary from year to year. With a known probable pattern of the weather during the harvest the criterion becomes the minimization of the average annual total harvest costs for a given cropping program over a large number of years. Assuming that the pattern of the weather will not change or that the change of weather can be predicted, the results may be used for the future.

The field losses and the harvest costs (labour and equipment) are affected by the scheduled duration of the harvest period in an opposite way. The longer the duration of the scheduled harvest period the higher the field losses but the lower the harvest costs because less equipment and less personnel are required. The relationships between the various factors involved in grain harvesting operations are shown in figure 1.

The field loss consists of dry matter loss, shatter loss and loss caused by the header of the combine (cutterbar and reel). Both field loss and decline in quality increase with time delay in harvesting after maturity.

The weather affects the crop moisture conditions, as indicated by kernel moisture content, and therefore the number of available combine hours, i.e. the hours that crop conditions allow combining during the scheduled duration of the harvest period.

The available combine hours together with the kernel moisture content during those hours determine the combine, drying and ventilated storage capacities required. The hourly combine capacity, the capacity of the combines while working on the field, is also affected by the level of separating loss from the rear of the combine; the higher the level permitted the higher the combine capacity. Further the combine capacity is positively correlated with the grain straw ratio which is determined by the height of cutting. The ventilated storage capacity is the space required for temporary storage of the moist grain to be dried, which is brought in at irregular intervals depending on the kernel moisture content. As shown in the diagram these three components are interrelated. For example a low drying capacity will necessitate a larger combine capacity and/or ventilated storage capacity. Conversely a large drying capacity will result in a smaller combine capacity and/or ventilated storage capacity.

The hourly combine capacity determines the conveying capacity required in the drying plant and affects the transport capacity required. The transport capacity and the number of drying plants are negatively correlated; the smaller the number of plants the higher the transport capacity required.
The relationships between the kernel moisture content of colza, barley, oats and wheat and the weather have been investigated during the harvest seasons 1963—1967. Then the kernel moisture content of the crops in the

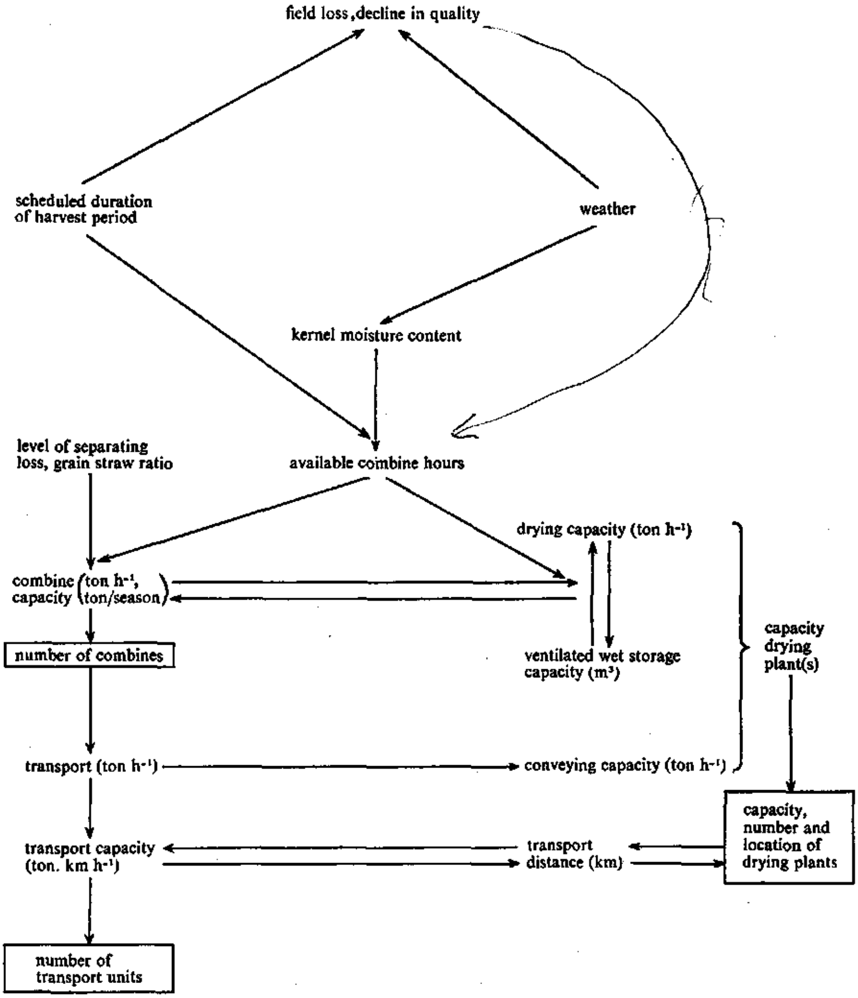

Fig. 1. Process diagram of the grain harvest.

period 1931—1967 were computed. Simultaneously measurements were made of the combine performance under influence of the crop moisture content, the level of separating loss and the grain straw ratio (height of cutting).

Also the harvesting organization has been studied; a system was developed to provide minimum costs of the separate components viz. combining, transport, drying and storage with a view to the minimum costs of the harvesting system as a whole. Selecting a harvesting system with minimum costs is only warranted when considering the place of the system in the work organization of a particular farm as a whole; i.e. the work to be carried out before and after the harvest with the machinery and personnel required. Also the conditions prevailing on that farm must be taken into account. In this case, the system has been used to minimize the total harvest costs of a 20,000 ha grain farm under actual weather conditions occurring during the harvest periods of the years 1931—1967.

The farm is a part of the reclamation activities of the Yssel Lake polders Development Project. As a result the location of the farm within the Yssel Lake area is being moved at regular intervals causing complications related to the transport distance and the location of the drying plants; these problems are discussed in this study.

The thesis has been developed as follows:

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Phase A	Description of the farm	2
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2 CHARACTERISTICS OF THE FARM

2.1 INTRODUCTION

The large-scale farm is a part of a land reclamation enterprise which is managed by the „Rijksdienst voor de IJsselmeerpolders" (Yssel Lake polders Development Authority), a board responsible for the integral development of the polders in the Yssel Lake.

According to the Zuyderzee Reclamation Act of 14 June 1918, the Yssel Lake Project includes the drainage of five polders totalling 220,000 ha. The location of the polders is shown in figure 2. The first, the Wieringermeer, was drained in 1930, followed by the North-Eastern Polder in 1942, Eastern Flevoland in 1957 and Southern Flevoland in 1968. According to the present planning the Markerwaard polder is to be drained in 1980. In 1968 the project was roughly halfway to completion.

In each of the polders the responsibility of the Authority is for a limited period only; it begins as soon as the polder is drained and it ends as soon as the polder, or a part of it, has been made suitable for the land use planned and developed to a certain level. Before the Development Authority starts its work another Government Service, the „Dienst der Zuiderzeewerken" (Zuyderzee Project Authority), constructs dykes, pumping stations, canals and roads. It also digs the canals.

Als a general rule the development work involved in each polder has the following sequence of operations:
building of dykes and pumping stations
draining of the polder
building of roads and construction of the field drainage system
preparation of the land for agriculture, i.e. the transformation of the mud into good agricultural soil by means of appropriate land development measures
provisions necessary to make the land suitable for the purposes for which it is planned
building of houses, shops and farmbuildings
creation of employment by attracting agricultural and other business
attraction of population and providers of basic services
organization of public services.
For a detailed description of the various development works see ANON (1959).

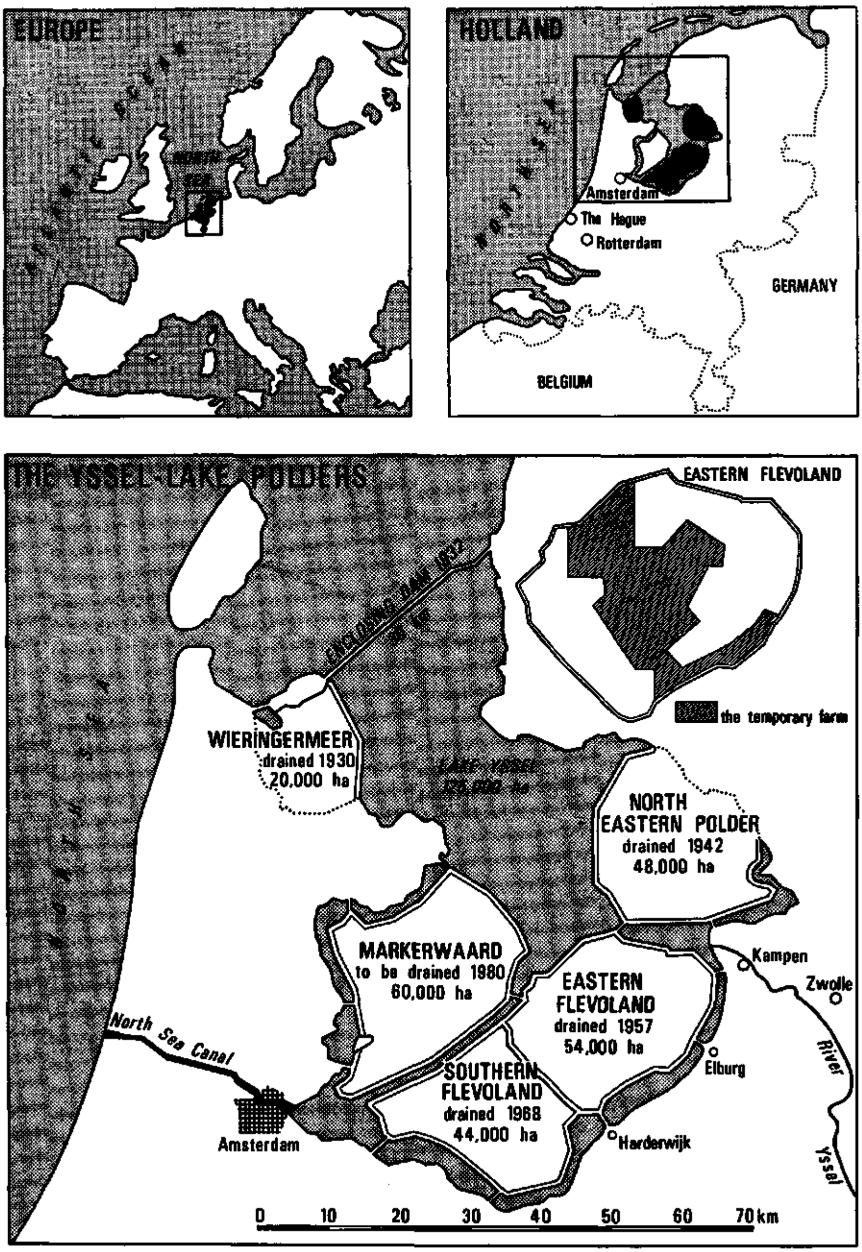


Fig. 2. Yssel Lake project and location of the farm

2.2 RECLAMATION OPERATIONS

The Authority enterprise referred to is responsible for preparing the land for cultivation and for making it suitable for the purpose planned. The work involved can be summed up as follows:

preparation for cultivation:

sowing reeds: reed seeds are sown from the air immediately after the polder has been drained; reeds help to keep weed growth down and to lower the soil moisture content. The reed vegetation is maintained until the area is reclaimed

killing reeds: destruction of the reeds by mechanical or chemical means on the annual area to be reclaimed

field drainage: the construction of a temporary field drainage system (open ditches), which is later replaced by a permanent subsurface drainage system

levelling: most of the reclaimed land is fairly flat, but spoil banks from the ditches and canals have to be levelled

profile improvement: deep ploughing, profile mixing and breaking up of hard layers

temporary farming: the land cannot be allocated to private farmers as it is at this stage of development owing to the low bearing capacity of the soil and other inconveniences. Through these difficulties the choice of crops is limited and special machinery has to be used. The low bearing capacity is due to the high moisture content of the soil. The water, bound to the soil particles has to be removed from the soil through the growing of plants. Consequently temporary farming by the Authority is usually neccessary for at least five years before the virgin soil is transformed into a good agricultural soil. A good agricultural soil is here supposed to be a soil that can be worked with normal farming equipment and that is fit for the crops commonly grown in the area: grains, potatoes, sugarbeets, vegetables and fruits

further preparation

forestation, planting of trees and shrubs along roads and in farm yards, the laying out of shrubbery in areas planned for buildings and playing fields. The shrubbery and playing fields laid out are cared for up to the time of their being handed over to the communities which will be responsible for them in the new settlements

The acreage to be reclaimed each year is determined by the date set for the draining of the next polder to be developed (in this case the Markerwaard polder). At present the average area to be reclaimed each year in Eastern and Southern Flevoland amounts to some 3,800 ha. This area fixes the annual program of other work, such as field drainage, profile improvement, forestation and temporary farming. Table 1 gives a summary of the program for 1967.

TABLE 1. Operations schedule for the Government enterprise in 1967.

Reclamation			*Temporary farm*	
killing reeds	3,910 ha		colza	3,655 ha
deep ploughing	500 „		barley [1]	3,460 „
profile mixing	500 „		oats	1,078 „
levelling spoil banks	250 km		wheat [1]	5,400 „
ditching	750 „			
subsurface drainage	2,100 „			13,593 „
			alfalfa	1,950 „
			flax, misc.	3,383 „
				18,926 ha
Forestry				
planting	woods	350 ha		
	farm yards	140 „		
	roadside trees	10 km		
maintenance	woods	2,800 ha		

[1] Only spring barley and winter wheat are grown, in the text they will be referred to as barley and wheat.

This work, which is very varied in nature, time and location, is largely carried out by farm personnel (about 780 men) using a considerable amount of machinery. Where possible and where rates are competitive, jobs are let completely or in part to contractors e.g. subsurface drainage, soil improvement and spraying. Part of the land is rented for flax production; alfalfa and straw are sold in the field. Figure 3 shows the type of operations carried out by farm personeel in 1967. It demonstrates the relatively large number of personnel required for the agricultural operation, and the relationship between the agricultural and the reclamation work. The agricultural work has two distinct peaks: sowing and harvesting. Between sowing and harvesting, from April until July, personnel and equipment are engaged in reclamation work. Then the weather is also most favourable for this highly mechanized work. The Maintenance Department takes care of repair and maintenance of the machinery. The Central Store Department is responsible for drying and storage of the harvested products and the delivery of materials like fertilizers, seeds and drainpipes.

Table 2 lists the machinery used. It shows that nearly 40% of the capital

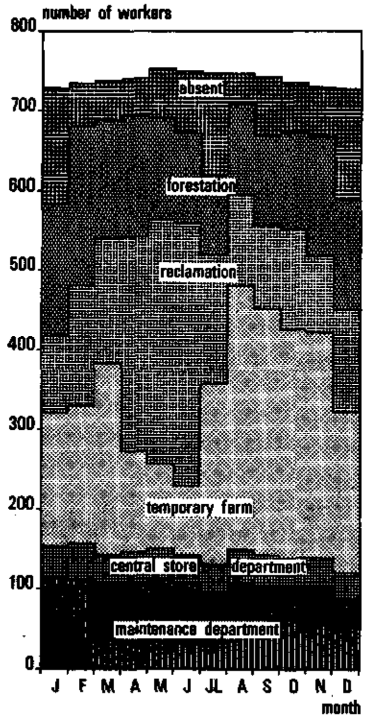


Fig. 3. Labour diagram of the work carried out in 1967.

is invested in harvesting equipment (drying plants included). About 30% is invested in crawler and wheeled tractors, 25% of which are employed in harvesting work.

TABLE 2. Equipment in 1967.

Type	Number	Hours/ year/ machine	Investment [1] × f [2] 1,000,000	Investment [1] in %
Crawler tractors	150	900	8.0	26.7
Wheeled tractors	140	800—1000	2.5	8.3
Swath mowers	50	70	1.0	3.3
Combines	80	200	2.8	9.3
Grain wagons	280		1.7	5.7
Drying plants	3		6.0	20.0
Reclamation tools			3.0	10.0
Miscellaneous			5.0	16.7
Total			30.0	100.0

[1] 1967 replacement value
[2] f = Dutch guilders

The extent of the temporary farming operation is determined by the five year soil development period already mentioned. Therefore 5 × 3,800 ha = 19,000 ha will be farmed if the area reclaimed each year is equal to that handed over to farmers and communities. Characteristic features of this farming operation are the limited cropping program and the gradual change in location.

2.3 THE TEMPORARY FARM

2.3.1 *Cropping program*

The following factors establish the choice of crops grown on the temporary farm:

a. the low bearing capacity of the soil and the tillage problem, that make root crops impractical to harvest
b. crop rotation requirements and the fact that reeds are the first „crop"
c. the requirement that the virgin soil is transformed in good farm land
d. within the described limits the economic consideration to achieve the highest possible net return.

As a result of these considerations the following crops have been selected: colza, barley, oats, wheat, alfalfa and flax. The colza and grains are sown, cultivated and harvested by own personnel, except the straw that is sold in the windrow. Flax, alfalfa and miscellaneous crops are contracted out either by renting the land or by selling the crop. The crop rotation and operating scheme can be demonstrated as follows:

annual area to be reclaimed (constant): A
area under cultivation : $F = 5A$
annual area to be allocated to others : $U = A$

The following crops feature in the rotation scheme:

Crop	*Acreage*
reeds (reclamation)	A
colza	x_c
barley	x_b
oats	x_o
wheat	x_w
alfalfa	x_a
flax and miscellaneous	x_f
different crops (after allocation to others)	U

where $x_c + x_b + x_w + x_o + x_a + x_f + A + U = 7\,A = F + 2\,A$ (2.1)

The acreages sown with the different crops are then broadly speaking determined by the following conditions:

Colza is well suited as the first crop after reeds so:

$$x_c = A \tag{2.2}$$

The crops to be harvested by farm personnel ripen in the following order: colza, barley, wheat and oats. Based on the scheduled duration of the harvest of each crop (see 3.3) the farm management decided for the following ratios:

$$x_b = x_c \tag{2.3}$$

$$x_w + x_o = 1.8\,x_c \tag{2.4}$$

The acreage to be sown with the crops harvested by own personnel then follows from 2.2, 2.3 and 2.4:

$$x_c + x_b + x_w + x_o = 3.8\,A \tag{2.5}$$

The acreage available for alfalfa, flax and miscellaneous then follows from 2.1 and 2.5:

$$x_a + x_f = F - 3.8\,A = 1.2\,A \tag{2.6}$$

In view of the contracts with purchasers the acreage for alfalfa is constant at:

$$x_a = 0.5\,A \tag{2.7}$$

The acreage available for flax and miscellaneous can then be deduced from 2.6 and 2.7:

$$x_f = 1.2\,A - 0.5\,A = 0.7\,A \tag{2.8}$$

For selecting a crop rotation due account must be taken of certain basic agronomic requirements. One of the most important on these newly reclaimed soils is caused by the high incidence of *Ophiobolus graminis* Sacc., the origin of the take-all disease. Therefore a close rotation of barley and wheat in the first years often results in heavy losses in these crops, especially in wheat (BOSMA, 1962). After some years there is a decline of *Ophiobolus* (GERLACH, 1968). Then, as in other parts of the Netherlands, *Cercosporella Herpotrichoides*, causing eyespot of wheat, has to be observed more than *Ophiobolus* in rotations dominated by cereals. Oats is regarded a favourable rotation crop with other cereals, the only drawback is that it is the least profitable crop. Therefore the acreage under oats is kept at the minimum necessary for a good crop rotation.

On the basis of these requirements, the cropping schedule shown in figure 4 has been developed. For various reasons this schedule is not followed strictly. For instance the acreage of flax has been reduced in recent years owing to the inability of flax to control the development of reeds and the

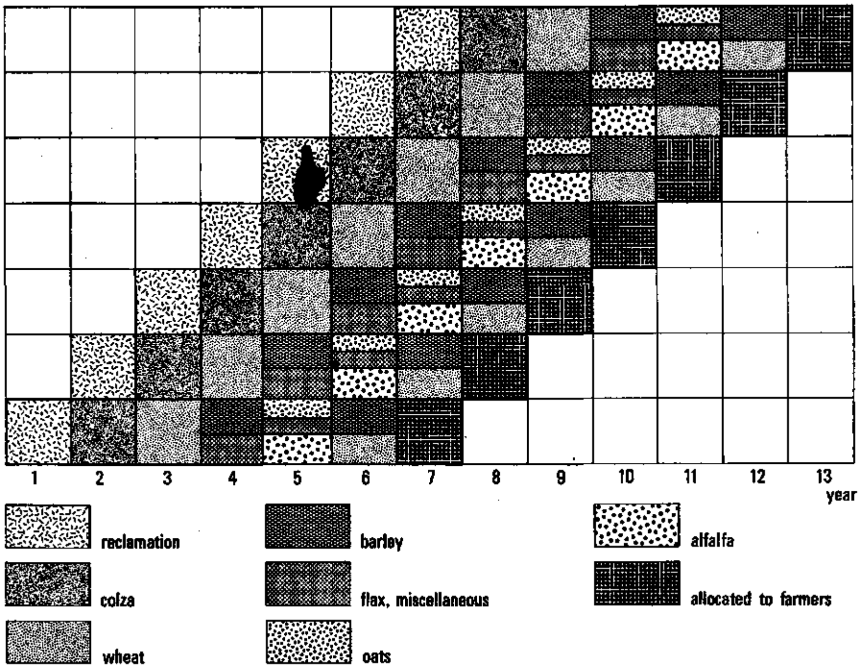


Fig. 4. Crop rotation scheme of the temporary farm.

reduction in flax quality when reeds are present; this resulted in a larger acreage of oats. Further, at present a small acreage of alfalfa is sown as the first crop after reclamation because of the better results compared with sowing under barley; the result of this is that colza is now sown on an equal acreage after barley. Also the duration of the temporary farming is sometimes longer or shorter than five years.

In general the crop rotation scheme has sufficient flexibility for these deviations not to affect the overall plan. Over recent years the farm area has been some 19,000 ha, about 14,000 ha of which have been used for cereals and colza harvested by farm personnel.

2.3.2 *Trends of prices and costs on the farm during the period 1960—1969*

The farm's management has introduced the profit element as a measure for the efficiency of the work on the farm. The objective is therefore to achieve the highest possible net return within the technical limitations described above. In recent years this policy had to deal with two important external factors affecting the net return: the sharp rise of the labour costs and the relatively small rise of the prices received for the products. Both trends

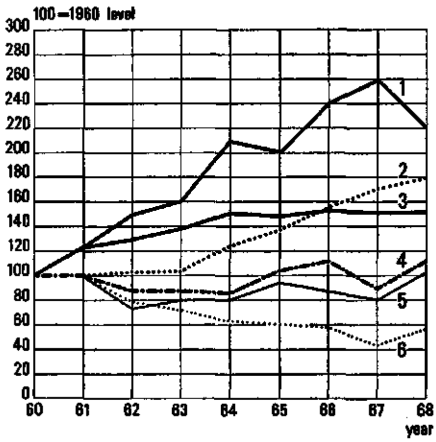


Fig. 5. Some trends of prices, costs and man hours on the farm.
1. net return (100 = f 80/ton)
2. cost of labour (100 = f 7,000/year)
3. price of wheat (100 = f 23/100 kg)
4. cost of harvesting (100 = f 54/ton)
5. cost of combining (100 = f 20/ton)
6. man hours for growing of cereals and colza (100 = 16 man hours/ton)

demonstrated in figure 5 show the wide divergence since 1964. It was therefore decided to avoid a possible decline in margin by speeding up the substitution of labour by machinery.

Some of the results of this policy are shown in figure 5. The line representing the cost of harvesting (approximately 25% of the total cost of production) shows that the increase of labour cost did not cause a rise in the cost of harvesting. This is also valid for the cost of combine harvesting which was kept at the same level by the use of larger combines and by the improvement of the organization. The overall result of this policy was that the required labour decreased with approximately 40% while the net return increased with approximately 100%. It should be mentioned that the rise of the net return was not only caused by the substitution of labour by machinery but also partly by an average increase in yield of 300 kg/ha during the period 1960—1969.

The lines representing the net return, the cost of harvesting and the cost of combining serve only to demonstrate the trends of these yardsticks. They cannot be used for comparison with the results of other farms or with costs mentioned in this thesis because the calculation methods used are not the same.

2.4 HARVESTING

The crop is threshed either from swath (colza) or directly (grains) by combines. The colza has to be swathed in order to prevent seed losses caused by pods springing open. Swathing has also been tried out for grain crops (VAN KAMPEN, 1959). However, the results were not such as to warrant making it standard practice, chiefly because under our weather conditions grain crops in swaths dry very slowly after wetting, often resulting in sprouting.

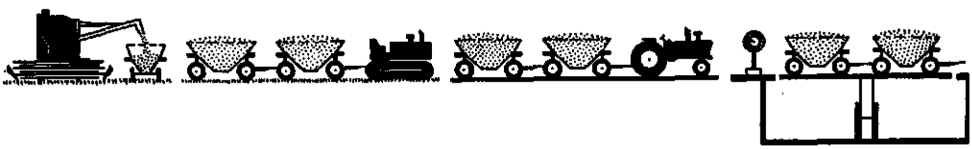
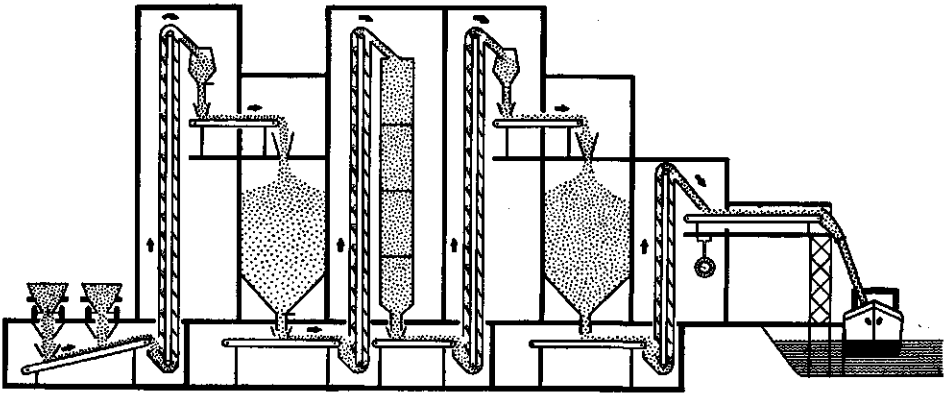


Fig. 6. Sequence of grain harvesting operations.

The threshed grain is discharged from the combine grain tanks into grain wagons. The loaded wagons, coupled in pairs, are hauled on to the metalled road by crawler tractors. From there wheeled tractors transport the wagons to the three transshipment (drying) plants located in different places. These plants dry the grain to a moisture content which is sufficiently low to permit safe shipment to storage installations elsewhere in the country. Colza, barley and oats are shipped to rented storage facilities where they are further dried. They are then gradually put on the market. Most of the wheat is sent directly to the flour mills. A small part is stored in the transshipment plants as a profitable means of utilizing the space after the harvest is finished.

The harvest as a whole is a chain of operations, the duration and extent of which have to be planned so that each phase fits in with the next in such a way that the work can proceed without delay. The operations can be summarized as follows (figure 6): combining - transfer into grain wagons - transport on the field - transport on the road - weighing - unloading - preliminary cleaning - temporary ventilated wet storage - drying - cleaning - temporary dry storage - shipment - final storage.

A complication arising during the harvest period of two months is the very irregular progress made due to the effect of the weather. Combining can in fact not be carried out before the moisture content of the standing crop has dropped below a certain level, as the combines cannot handle a crop with a moisture content above that level. Below this level in question the actual moisture content will determine whether drying is needed before shipment and storage. A rough classification for wheat can be made based on the kernel moisture content (see also 7 and 9):



a. moisture content > 28%: crop too wet for combining

b. moisture content 17—28%: drying necessary after threshing and before storage; the following two intermediate situations can occur:

b_1. moisture content 19—28%: temporary ventilated storage possible, drying necessary before shipment

b_2. moisture content 17—19%: shipping possible but drying neccessary before final storage

c. moisture content < 17%: shipping and storage possible without drying.

In the case of colza, barley and oats similar situations occur but at diffeıent moisture contents.

A further complication is due to the regular movement of the farm through the polders. This means that the average distance to the transshipment plants gradually increases, so that after a certain period of time these have to be moved or the transport capacity has to be increased.

The equipment and personnel required in 1967 for harvesting work and the capital investment per hectare are summarized in table 3. Of the fifteen workers needed per 1,000 ha or 4,000 tons of grain, twelve are involved in combining and transport and three in drying and shipment.

2.5 SUMMARY

The large-scale farming and land reclamation enterprise is part of the Yssel Lake polders Development Authority. The land in the polders cannot be

TABLE 3. Equipment and personnel for harvesting 14,000 ha of grains and colza (55,000 m. tons) and the capital investment per hectare in 1967. Swathing excluded.

Type	Number	Description	Personnel [1]	Investment/ hectare [2]
Combines	80	3.6—5.4 m	85	f 200
Grain wagons	80	8 m^3		„ 120
Grain wagons	200	4.5 „		
Crawler tractors	15	70 hp	16	
Wheeled tractors	20	100 „	21	„ 30 [3]
Wheeled tractors	40	50 „	43	
Drying plants	3	drying cap.:		
		60 tons h^{-1} [4]	29	„ 430
		conveying cap.:		
		280 tons h^{-1}		
		ship loading:		
		140 tons h^{-1}	10	
		storage:		
		13,000 m^3		
Total			204	f 780 [5]

[1] 6% reserve included
[2] 1967 replacement value
[3] 20% charged to the harvest (see 10)
[4] capacities for drying, conveying and ship loading are based on requirements for wheat (in m. tons)
[5] Dutch guilders

allocated to individual farmers immediately after reclamation owing to the low bearing capacity of the soil. Hence a period of at least five years of farming by the Authority is necessary to transform the mud into good farm land. At present this enterprise has 19,000 ha under cultivation. Because of different limiting factors the following crops are grown: colza, barley, oats, wheat, alfalfa and flax. The first four of these crops are managed with farm personnel and equipment; alfalfa and flax are managed by others. The cropping program and crop rotation are shown in figure 4. Trends of prices (wheat) and costs (labour) demonstrated together with the trends of some yardsticks used for measuring the efficiency of the operations (1960—1969, figure 5) show the results of managements strategy.

The harvesting of the grain is done with combines, transport equipment and transshipment plants (table 3). The chain of operations (figure 6) and the progress of the harvesting depend to a great extent on the kernel moisture content. The different situations that can arise are described.

3 MATURITY DATES AND FIELD LOSSES OF THE VARIOUS CROPS

3.1 INTRODUCTION

In agriculture certain data relating to field work are needed: for the planning of the work, to determine the machinery required and for the construction of models useful in farm and machinery management. These data, for example the probable starting time, the available period, and the available time (see 7.3) vary for different operations. They depend on a complex of factors of which the weather is the most important.

In the Netherlands POSTMA and VAN ELDEREN (1963) and POSTMA (1966) provided a catalogue of work requirement data. These data are used for estimates of the required labour; the influence of the weather is allowed for by adding an estimated percentage . The percentage varies between 10 and 45 dependent on the type of work to be done; for example the percentage for the grain harvest is 40%. KREHER *et al* (1963) and LERMER (1961, 1963) in Germany studied the variation in the available hours due to the variation in weather. As rainfall was found to be a dominating factor, it proved to be possible to establish the annual variation with the aid of precipitation data for a number of years. For planning purposes they based their calculations on a probability of 80%. Above authors obtained the data from records kept on a large number of farms and from surveys.

HESSELBACH (1964) draws attention to the following shortcomings of these methods:

the data are greatly influenced by the knowledge of the farmer

the intensity of machine utilization, the work schedule and the management of the farm have a considerable influence

the available hours depend greatly on the method (machine) used and they are rarely clearly defined.

As a consequence their results are of a limited value. These problems can be approached in a more fundamental way by first determining the relations between weather, crop and machine. Then an impression of the variation can be gained with the aid of the relevant weather data over a number of years. STAPLETON *et al* (1965) state this problem clearly for a harvest schedule design as they bring in the costs and returns: „an effective harvest schedule design must optimize net return from harvest; for this design knowledge of the crop and crop machine functions with time and weather are required before machine selection can be considered".

Examples of studies using this approach are the following. VOIGT (1955) studied the moisture content of cereal crops under influence of the saturation deficit of the air at 2 p.m., the rainfall and the dew. With the relationships found and with the aid of meteorological data it was then possible to estimate the kernel moisture content during a harvest period of 50 days. The results are given as the numbers of hours when the kernel moisture content is below 20% for the different regions in Germany in the period 1946—1954. The results are often used to calculate the combine capacity required on farms in the various regions. LINK (1964) presents the development of a mathematical model for predicting the effects on a system of farm field machinery of possible adverse weather and crop conditions. He applies the model to a farm in Iowa (U.S.A.) where a single crop (maize) is grown. The basic concepts are drawn from PERT (program evaluation and review technique). The seasonal sequences of jobs required of the machinery system are the organizational framework on which the model is based. The uncertainty, at the beginning of a crop season, of future weather and crop conditions leads to the use of probabilities in the model. Probabilities of occurrence of various weather and crop conditions are combined in the model with the specifications of the machinery system. The results of the calculations give an indication of the probability of completion of the various jobs as a function of time. STAPLETON *et al* (1965) studied the harvesting schedule for the cotton harvest with special respect to defoliation experiments. They developed a harvesting schedule which provides combinations of crop quality and yield producing the greatest return. As a basis for this schedule they studied four years of cotton production and cotton machine functions in relation to time and weather. After assigning numerical values to the crop related functions a model has been developed for providing Figures of Merit (representing the loss in yield and quality as the harvest is delayed) for numerical comparison of the results of cotton harvest scheduling. This method quantifies the subjective system used by the farmer and assigns numerical values to the relationships he uses in a „hunch" estimate. They conclude that the use of numerical values gives management a tool for improving net return. VON BARGEN (1965) reports on systems analysis in hay harvesting. He uses the „open haying day" criteria developed in Missouri for planning hay harvesting operations. With the aid of probability data on the number and lengths of periods of consecutive open haying days the operating capabilities of alternative hay harvesting systems are computed. DONALDSON (1968) analyzed a farm management decision on the optimum capacity system for harvesting various acreages of cereal grains. He attempted a simulation approach using Monte Carlo techniques to assess the variables. Criteria used to determine the kernel moisture content were rain-free days and the average distribution of moisture content levels during these days. With the aid of the rain-free days during a 40 year period the patterns of kernel moisture content were represented in the form of cumulative time at successive moisture levels. The variables used were:

drying capacity, size of combines and acreage to be harvested. He then calculated the total of fixed and variable costs for drying and combining.

In this chapter we estimate maturity dates, scheduled harvesting period and field losses of colza, barley, oats and wheat. In chapters 4 and 6 we then proceed to estimate the available hours for the harvesting.

3.2 MATURITY DATES OF THE CROPS

3.2.1 *Definition of maturity*

In general two types of maturity can be distinguished: morphological maturity and technological maturity. Both are related to a certain stage of development of the kernel. A number of authors have described the development of kernels of cereals: HARLAN (1923): barley; FREY, RUAN and WIGGANS (1958) and MOULE (1960): oats; BRENCHLEY and HALL (1908), GESLIN (1944), GESLIN and JONARD (1948); PAQUET (1964): wheat. No data are available on the development of the colza kernel. The development of the wheat, barley and oat kernels show the same general pattern with some minor differences. GESLIN (1944), GESLIN and JONARD (1948), MOULE (1960) and PAQUET (1964) demonstrated that the development of the wheat and oat kernels after heading is related to a factor K.

$$K = t^{\circ} \sqrt{R} \tag{3.1}$$

where:

t° = average daily temperature in °C, R = total daily radiation in cal.
The development of the kernel then can be described with:

$$P = \sum_{n_1}^{n_2} K$$

where:

n_1 = date of heading, n_2 = date of maturity.

Figure 7 according to GESLIN and JONARD (1948) shows the development of the wheat kernel in relation to the sum of the daily factor K. Using the development of the kernel as illustrated in figure 7 two types of maturity can be seen — morphological and technological maturity.

Morphological maturity

Morphological maturity is the stage at which the increase in dry matter has come to an end. For wheat this stage is reached when the moisture content is about 49 % [1]. After this stage the moisture content drops gradually

[1] For commercial purposes the moisture content of the kernel is recorded on a wet basis, for research on a dry basis. The connection between the two is as follows: 20 % wet basis $= 100 \times (\frac{20}{100-20}) = 25\,\%$ dry basis.
When not indicated the moisture content is expressed on wet basis.

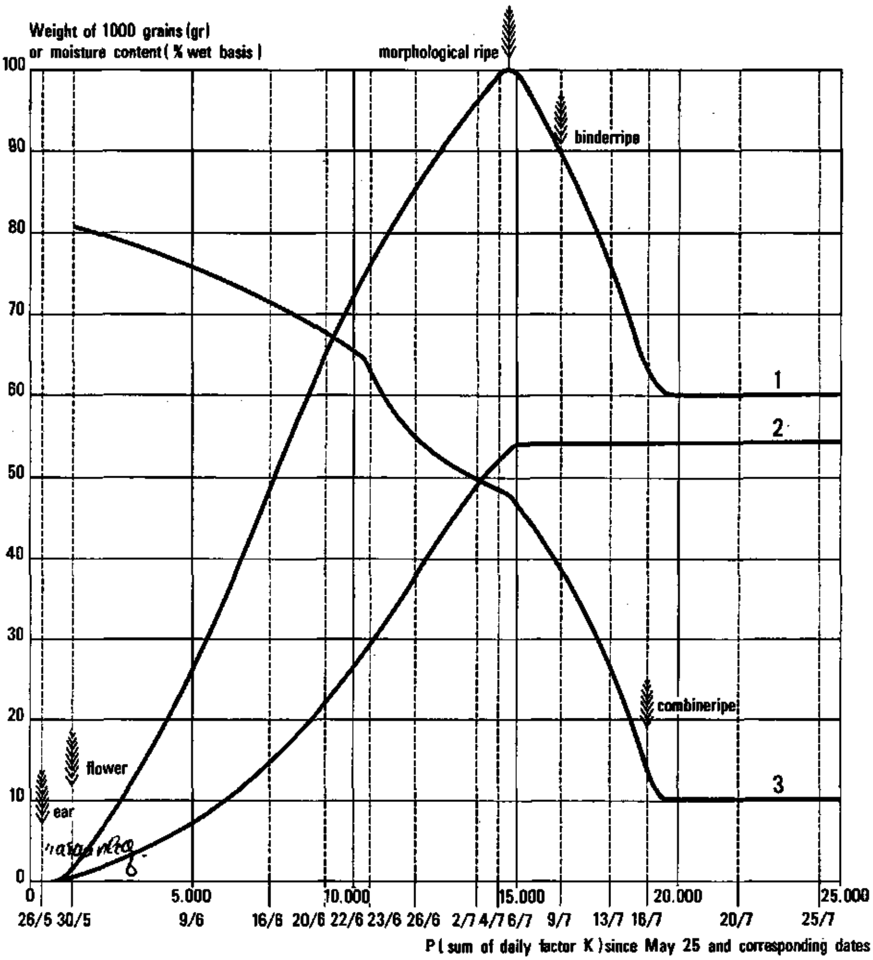


Fig. 7. Development of the wheat kernel (GESLIN and JONARD, 1948).
1. weight of 1000 grains-wet
2. weight of 1000 grains-dry
3. moisture content

while the amount of dry matter remains constant. The lowest moisture content ultimately reached depends on the climate; 7% in an arid climate and 15% in a maritime climate.

Technological maturity

Technological maturity is reached when the crop can be harvested while the reduction in dry matter yield and quality remain within the standards set during cutting, threshing, drying and storage.

From this definition follows that technological maturity depends on the purpose for which the crop is grown and on the harvesting system used. In general two types of technological maturity are observed: binder ripe and combine ripe. For wheat these stages are described by BELDEROK (1965) using the FEEKES scale that distinguishes consecutively: milk-ripeness, mealy-ripeness, full-ripeness and dead-ripeness. For wheat the stage of full-ripeness is the most favourable stage for harvesting with the binder; the kernel is hard (difficult to dent with the thumb nail) and the straw is entirely dead. The dead-ripe stage is the most favourable stage for harvesting with the combine; the kernel is very hard (can be broken with the finger nail), the moisture content is between 12 and 15% and the straw desintegrates readily during combining.

This description of binder and combine ripeness cannot be used for the purpose of this study as it does not meet the definition of technological maturity. Also, owing to weather during the harvest in the Netherlands, moisture content and hardness of the kernel cannot be used as the only measures of ripeness, as both show considerable variations as a result of precipitation and dew. Therefore the colour of the straw is usually the most important yardstick for assessing the degree of ripeness. The stages can be described as follows. Wheat is binder ripe when the stalk and the leaves are yellow and the nodes are still green, the moisture content then declines steadily as ripening continues. Wheat is combine ripe when the nodes of the stalks have turned brown, the moisture content of the kernels is then more or less in balance with the prevailing weather conditions. On the basis of this distinction the average time between binder and combine ripeness is about seven days. This assessment is fairly subjective: if, however, the assessment is made by one person the maximum possible error amounts to two days according to BELDEROK (1965).

However, the application of these standards to barley and oats is more difficult, as the straw frequently ripens at a slower rate than the kernel. Thus the kernel can be combine ripe when the straw is not; in that case the assessment must be based on colour and hardness of the kernel. In the case of colza the binder ripe stage is indicated by a brown colour of the kernels; the stalk and leaves are still green. In this stage the colza is swathed because of the considerable losses which can occur through pods springing open if the crop is left standing. About ten days have to elapse before the swathed crop can be threshed.

In the following, maturity is taken to be the stage of combine ripeness as described for these various crops.

3.2.2 *Maturity dates*

The maturity date of a crop is determined by a large number of factors. The most important factors are weather, type of soil, variety, time of sowing and rate of nitrogen applied. If we take the type of soil (clay 35% < 2 μ) and nitrogen application as constant, the time of sowing and the weather remain as the two main factors affecting the maturity date. The influence of these factors on the maturity date has been investigated using data from trial fields which have been laid out in the Yssel Lake polders since 1942.

a. Influence of the date of sowing on the date of ripening

Sowing should be done during a specific period; the scheduled time span is determined by minimizing the total costs i.e. the sum of the cost of sowing and the value of the decline in yield caused by sowing too early or too late. If colza and wheat are sown too early the crop will be too far advanced before winter, causing a considerable risk of frost damage; for wheat also the chance of damage by root diseases is enhanced. Sowing too late usually leads to lower yields. Colza can be sown in the second half of August without decline in yield; sowing in the first half of September leads to an average decline in yield of 1% for each day colza is sown later than September 1[1]. For wheat, the date of sowing in the period October 1 — November 30 hardly affects the yield, sowing in December leads to an average decline in yield of 0.2% for each day wheat is sown later than November 30. The decline depends on the variety; the larger the cold requirement the higher the decline in yield (DE JONG, 1961).

In the case of spring crops sowing is started as soon as the condition of the soil permits preparatory tillage operations which is usually in March. Delay in sowing leads to lower yields: for barley delay in sowing in the period March 15 — April 20 results in an average reduction in yield of 0.25% for each day barley is sown later than March 15; for oats the average reduction is 0.7% per day for the same period (DE JONG, 1966).

With the equipment and personnel available the crops are sown as follows:
Colza: August 15 to September 1, frequently extending to September 15
Wheat: October 1 to November 15, occasionally to December 1
Barly and oats: March 1 to April 1, frequently extending to April 15 as precipitation delays preparatory tillage operations.

The influence of the date of sowing on the maturity date has been evaluated from the results of the above mentioned trial fields. The results are shown in figure 8 in which the lines connecting the points have not been fitted statistically. In the case of colza the sowing date has little effect; a delay of sowing of 30 days results in ripening about 3 days later. For wheat, sown 45 days later, ripening is delayed 7 days, while barley and oats ripen 12 days later if the date of sowing is 45 days later.

[1] Personal communication DE JONG.

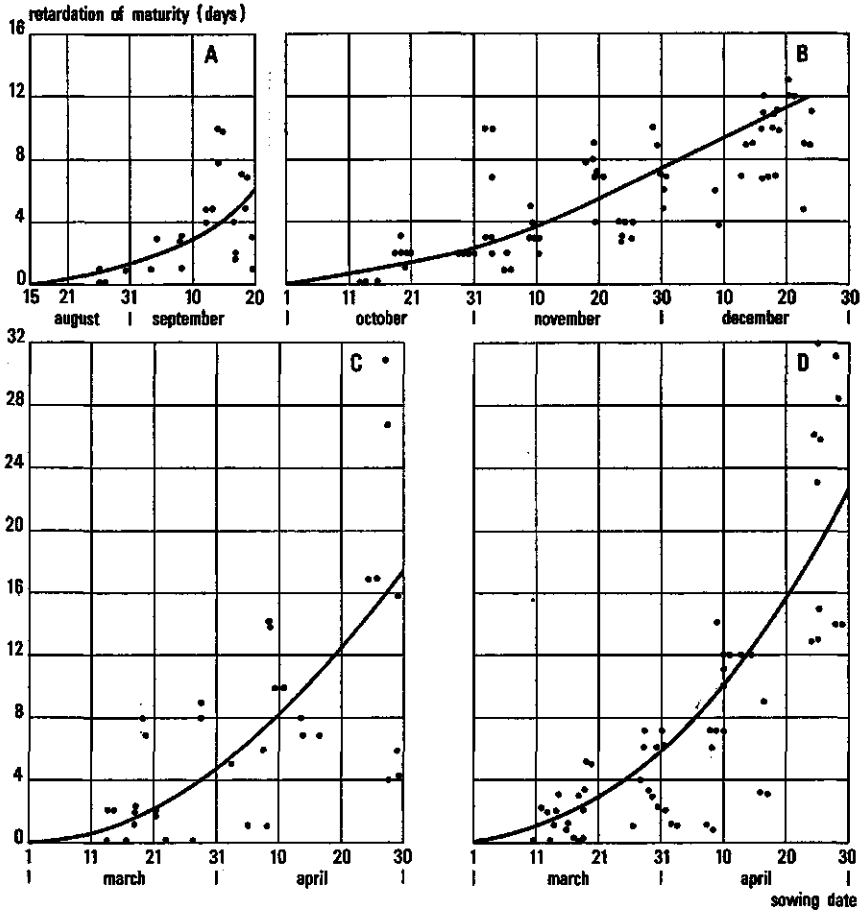


Fig. 8. Maturity date as affected by the date of sowing. Retardation in days compared with the earliest date of sowing i.e. for: colza: August 15 (A), wheat: October 1 (B), oats: March 1 (C), barley: March 1 (D).

b. Effect of the weather on the maturity date

Various empirical methods and formulae have been proposed as a means to correlate the growth rate and the development of plants with some of the major agrometeorological elements. NUTTONSON (1953) and KRAMER (1954) both review the literature on the various methods.

One of the methods is the remainder index system. According to this system a given stage in the development of any plant is reached when that plant has received a certain amount of heat regardless of the time required. The heat requirement of the plant is usually expressed in degree-days; a degree-day being the daily mean temperature above a certain base temperature. For example if a base temperature of 5 °C is used the summation for one day having a mean temperature of 20 °C would be 15 degree-days. Similarly the summation for three days, each having an average daily temperature of 20 °C would be 15 times 3 or 45 degree-days.

Some authors have suggested improvements on the remainder index system as more factors are involved in the development of the plant. SCHNEIDER (1952) takes into account the tendency of the amount of required degree-days for a certain period of growth to become proportionally smaller when the starting date of the period is later than the average. KRAMER (1954) demonstrates that the results obtained for wheat are improved when the radiation is also taken into account.

However, the remainder index system has so far attained the widest acclaim and use, owing both to its simplicity and to the rather satisfactory results it yields (NUTTONSON, 1953). He obtained good results in calculating the maturity dates of winter wheat in Czechoslovakia with the remainder index system. He selects 5 °C as the base temperature and concludes that in predicting the date of maturity of winter wheat March 1 is a satisfactory starting point.

Whether the maturity dates of the crops concerned can be estimated with the remainder index system has been checked with the maturity dates of the trial fields over the period 1946—1966 and the degree-days. The varieties were those most commonly grown in those years and the sowing periods were as stated. Differences in variety were found to be slight and have accordingly been ignored. March 1 has been taken as starting date for colza and wheat; April 1 for barley and oats and 5 °C has been selected as the base temperature. The summation of degree-days calculated in this way are given in table 4. Plotting the data on probability graph paper established that the summations were normally distributed.

TABLE 4. Average sums of degree-days on the maturity dates of colza and grains (base temperature 5 °C, starting date for wheat and colza March 1, for barley and oats April 1).

Crop	Average of degree-days	σ [1]
Colza	935 °C	± 50
Barley	1070 °C	± 53
Oats	1198 °C	± 77
Wheat	1210 °C	± 59

[1] σ = standard deviation.

The standard deviations shown in table 4 suggest that the summations of degree-days calculated in this way can be used to estimate the maturity dates in years for which no field trial data are available.

The maturity dates of the trial fields made it also possible to estimate the periods available between the maturity dates of the successive crops. The average and the standard deviation of these data are summarized in table 5.

TABLE 5. Maturity dates and available periods for harvesting the successive crops.

Crop	Maturity date Average	Maturity date σ[1] (days)	Crop	Available period Average	Available period σ[1] (days)
Colza	22—7	± 8	Colza-barley	15	± 5
Barley	7—8	± 7	Barley-wheat	10	± 7
Oats	17—8	± 10	Colza-wheat	25	± 5
Wheat	17—8	± 10			

[1] σ = standard deviation.

The high standard deviations shown in table 5 suggest that the weather greatly affects the available periods as well as the maturity dates. Both data follow a normal distribution; the confidence limits of the maturity dates and the available periods at 70% probability are shown in figure 9. It should be pointed out that these data are based on the sowing periods already stated. On the farm wheat and colza will usually be sown on schedule. However, the sowing of spring crops may be retarded considerably on account of precipitation during the sowing time. For example in 1966 the

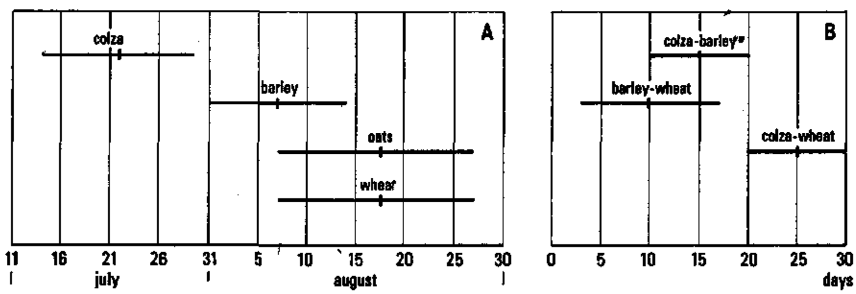


Fig. 9. Maturity dates (A) and the length of the periods between the maturity dates (B) as affected by the weather in seven of ten years.

spring sowing on the farm was delayed until the end of April owing to precipitation; consequently barley and wheat matured practically simultaneously. However, in trial fields in the same year the barley matured fourteen days before wheat, because, unlike what happened on the farm barley was sown in the middle of March. Consequently the periods shown in table 5 for colza-barley tend to be longer and for barley-wheat tend to be shorter in practice.

3.3 SCHEDULED DURATION OF THE HARVESTING PERIOD

The start of the harvest is the date on which the colza is mature. It should be noted that the work preceding this — reclamation — does not affect the beginning of the harvest, as reclamation work is not tied to any particular period. After harvesting, different operations must be carried out. They have to be finished before December 7 because after this date soil conditions in general do not allow large-scale tillage operations any more. The main sequential operations after the harvest are shown in figure 10.

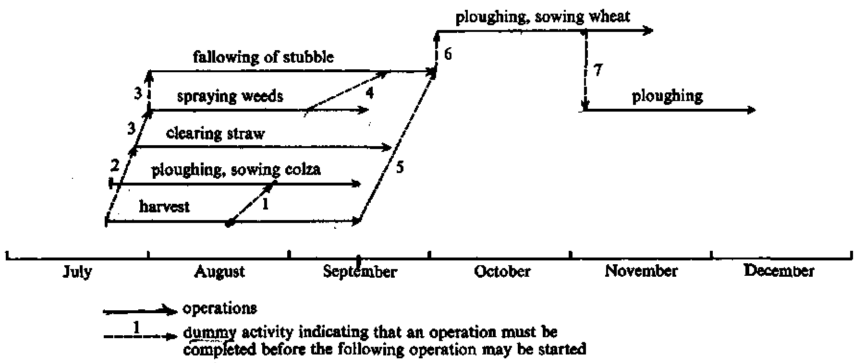


Fig. 10. Diagram of sequential operations after start of the harvest.

On the reclaimed area the preparatory tillage operations for sowing colza start at the end of July, sowing starts on August 15 and lasts until September 15. The tillage operations for colza to be sown after flax or barley can start after the land has been cleared by the middle of August (1).

Immediately after the first fields are harvested the straw is baled by contractors from the windrows and hauled to the road (2). When green matter is present in the straw, baling has to be retarded until the green matter has dried sufficiently to permit baling.

After clearing the straw a start can be made with the following operations (3): spraying of weeds and fallowing of the stubble fields. Spraying is done on fields contaminated with weeds; the effect of spraying decreases at a later date. It is in general zero after September 15. Fields not sprayed by that time may yield less in the next year. Fallowing is carried out for two reasons: preparation of the land for ploughing and killing of weeds. On fields with few weeds fallowing starts after clearing the straw (3). On fields sprayed the fallowing cannot start earlier than three weeks after spraying (4), an earlier start would diminish the effect of spraying. Fallowing continues until the beginning of October, fields not fallowed by that time are dropped from the fallowing program. For these fields this often results in higher costs and lower quality of the subsequent ploughing operations.

The ploughing and subsequent sowing of wheat is scheduled for the period October 1 — November 15. Actually these operations can only start on a sufficient scale after personnel and tractors used for harvesting (5), sowing colza (5) and fallowing (6) become available. This is usually 7—14 days after the end of these operations due to holidays of the operators.

The ploughing operations for the spring crops start at the beginning of November when personnel and equipment used for sowing wheat become available (7). Also during the fall other operations like subsurface drainage, ditch cleaning and tree planting must be carried out. Consequently personnel and tractors are fully employed during fall.

On account of aforementioned the end of the harvest is scheduled at the middle of September or at least October 1. Within this period the minimization of the total harvest costs must be carried out. It has to be admitted that the scheduled end of the harvest is rather arbitrary as it depends on the present organization of the harvesting and tillage operations that is not necessarily the optimal organization. If for example the end of the harvest period was scheduled for October 15, this would cause a smaller harvesting capacity and a bigger tillage capacity being needed. However, the optimization of the joint harvesting and tillage operations is outside the scope of this study. Therefore the scheduled end of the harvest is fixed on October 1. The existing uncertainty is taken into account by assessing different penalties because of untimely operations (see 11.2.1).

The harvest is divided into three phases — colza, barley, wheat and oats. An attempt is made to keep the acreages of colza and barley at such a minimum level that harvesting of these crops is not completed before the following ones — barley and wheat respectively — are ripe. This is done to prevent equipment standing idle while it waits for the next crop to ripen. At the moment a ratio of 1 : 1 : 1.8 for colza, barley and wheat plus oats is usual. This is not a firm rule, because economic considerations and crop rotation requirements also play a part in planning the cropping program. In this study we shall try to verify whether the ratio is a correct one to permit the harvesting work to continue without interruption (see 11.3.*d*).

3.4 FIELD LOSSES AND DECLINE IN QUALITY OF GRAIN IN THE MATURE CROP

The main factors affecting the harvesting capacity required are the field losses and the deterioration of grain quality in the mature crop, together constituting the „harvest risk". Quantitative data on these factors as the harvest progresses are generally lacking because they have been studied very little. Consequently this „harvest risk" is a subjective concept. The assessment of this risk by farmers is closely tied up with, inter alia, the relative value of the crop, the experience in the previous year or else in recently disastrous year and above all the attitude of the farmer (VERVELDE, 1962). In this paragraph the „harvest risk" will be discussed for the grains. No data are known for colza.

a. Field losses

The sources of field losses are: dry matter losses, shatter losses and combine header losses (cutterbar and reel). Dry matter losses are caused by leaching and oxidation. Shatter losses are caused by wind, birds and wildlife. The header losses of the combine are caused by cutterbar and reel. Header losses are influenced by the kernel moisture content as shown by JOHNSON (1959) for wheat and GOSS *et al* (1958) for barley; the lower the moisture content the higher the header losses.

The field losses have been investigated by JOHNSON (1959) in Ohio, U.S.A. for wheat, by DE JONG and ZELHORST (1967, 1968) in the Netherlands (Yssel Lake polders) for barley, oats and wheat, and by FEIFFER (1962) in Germany for wheat. FAJERSSON and KRANTZ (1965) studied in Sweden the losses caused by shattering in winter and spring wheat (1952—1965). In addition the yields from trial fields with various varieties in the Yssel Lake polders that were harvested at varying times (1—13 days after combine ripeness) provide some information on the losses involved.

Figure 11 (A, B) summarizes for wheat results of JOHNSON (1959), DE JONG and ZELHORST (1967, 1968). JOHNSON'S results were obtained over a five year period with Seneca soft wheat; those of DE JONG and ZELHORST during two years with Flevina and Sylvia, both soft wheat varieties with a high resistance to shatter losses (ANON, 1966). The results in figure 11 should be interpreted as a range of values since the variability between the years studied is great. Both results indicate that the field loss increases exponentially as the harvest date progresses, the main cause being the shatter loss.

The wheat losses on the farm were estimated during some years (VENEMA, 1961—1967). They vary between 0.25 and 0.50% per day taking a 25-day harvest period as an average and correspond faily well with the losses shown in figure 11. FEIFFER (1962) concludes that over a certain, not defined period, the shatter loss of some wheat varieties varies from 50 to 600 kg per ha. He stresses the importance of breeding varieties with a high resistance to shatter loss. FAJERSSON and KRANTZ (1965) show that the losses of wheat due to shattering vary considerably from one variety to another, and because of weather effects, from one year to another. For varieties with a high resistance to shattering the average losses were approximately 10 kg per day during a 35-day period.

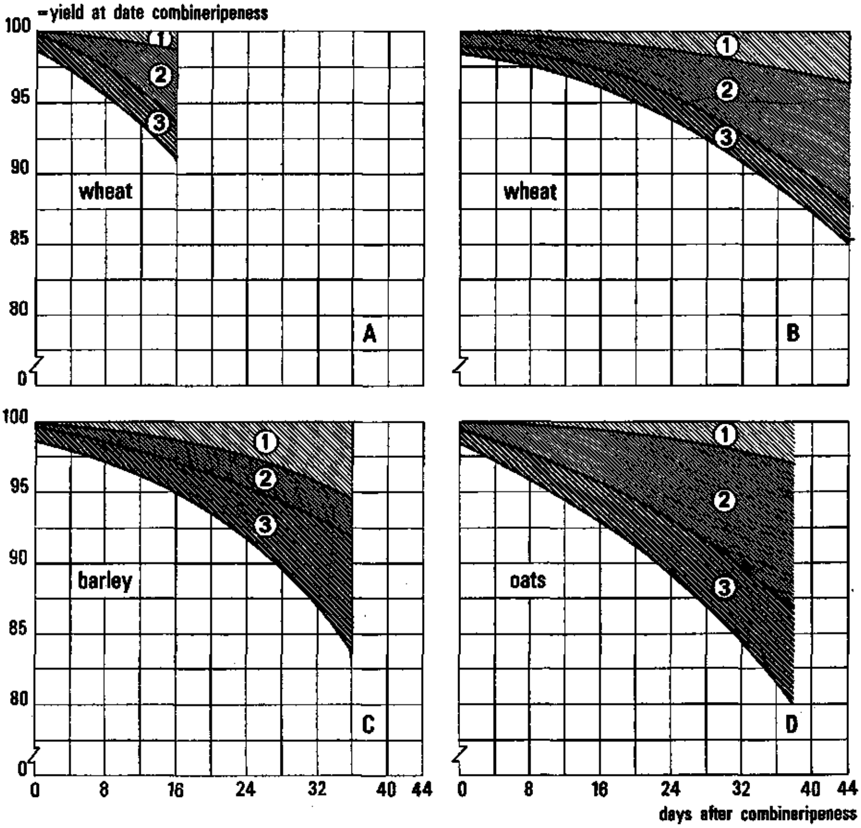


Fig. 11. Sources of field losses of wheat, barley and oats as the harvest date progresses.

A. according to JOHNSON (1959)
B, C, D. according to DE JONG and ZELHORST (1967, 1968)

1. dry matter loss
2. shatter loss
3. combine header loss

Figure 11 (C, D) summarizes the results of DE JONG and ZELHORST (1968) for barley and oats. The results were obtained during one year with Delisa barley and Astor oats. For both crops the field losses are higher than for wheat. They increase exponentially as the harvest date progresses. In barley the increase in field loss is mainly caused by the combine header, i.e. the cutting of hanging ears; in oats both shatter and combine header cause the increase in field loss. In earlier field trials the dry matter and shatter losses were measured in barley (variety Minerva) and oats (variety Marne). For barley the results correspond with the losses shown here; the losses in oats were higher resulting in a field loss of 1% per day.

The results of DE JONG and ZELHORST (1967, 1968) are summarized in table 6. They are represented as average daily losses assuming average yields.

TABLE 6. Daily field loss in various crops after combine ripeness (DE JONG and ZELHORST, 1967, 1968).

	Unit	Wheat	Barley	Oats
Average yield	kg/ha	4,900	4,000	5,000
Period	days	44	36	38
Field loss	% of yield	0.3	0.4	0.5
„ „	kg/ha	15	16	25
Shatter loss	% of field loss	56	16	50
Combine header	„ „ „ „	16	50	34
Dry matter loss	„ „ „ „	28	34	16

b. Decline in quality of the grain

The characterization of grain quality and the financial consequences of a reduction in grain quality depend on the utilization of the grain. The crops on the farm are at present utilized as follows. Barley and oats are mainly sold for feedstuffs, wheat is sold for food and colza for the extraction of oil. For this utilization the description of the European standard quality and the price discounts (ANON, 1968) provide a basis by which the grain is marketed. For the purpose of this study the main characteristics of grain quality to be applied are test weight [1] and % sprouting. According to the present market structure the following is the relationship of these characteristics and price discounts for 100 kg of wheat (ANON, 1968). Test weight: 74—76 kg hl^{-1} no discount, 73 — f 0.18 discount, 72 — f 0.36, 71 — f 0.54; sprouting: 4% — f 0.27 discount, 6% — f 0.63, 8% — f 0.98, above 8% wheat cannot be used for food and it has to be sold for feedstuffs at a discount of f 10 — f 15. The discount for colza is mainly based on oil content.

For the purpose of this study the decline in quality of wheat, barley and oats is considered during the period the mature crop stands in the field. No data are known for colza.

b. 1 Wheat

JOHNSON (1959) reported in his earlier mentioned study on the quality of wheat during a twenty day period following the date of maturity. He observes a slight decline in kernel quality: 6% reduction in test weight, 4% reduction in germination and a small reduction in milling quality. Quality for baking seemed unchanged. He concludes: „in general, the time grain stands in the field does not significantly alter the quality as long as grain is handled well during and after harvest". Observations on the farm

[1] Test weight is a weight per unit volume; here expressed as kg hl^{-1}.

during two years (1967, 1968) showed an average reduction in test weight of 4 % during a period of 20 days. Sprouting can cause considerable damage to the quality. In the Netherlands BELDEROK (1965) investigated the tendency for wheat to sprout in the ear. He proves that in any particular wheat variety the tendency to sprout depends on the temperature sum (days x excess of temperature beyond the level of 12.5 °C) during the stage of mealy-ripeness. These results make it possible to warn farmers when the tendency to sprout, due to warm weather in the mealy-ripe stage, is increased with certain varieties. The farmer then can make proper arrangements to keep sprouting damage within reasonable limits. Up to the present the sprouting damage in wheat has been slight on our farm. Since the introduction of combines in 1948 serious damage in wheat happened only in one year (1960). In that year almost the entire wheat crop had to be sold for feed. The main cause of this damage was that, owing to yellow rust calamities in the preceding years, only varieties susceptible to sprouting were available. The adverse effects could not have been prevented even with a considerably higher harvesting capacity because sprouting developed right at the beginning of the wheat harvest. DE JONG and ZELHORST (1967, 1968) in their above mentioned studies and in the trial fields of 1968 [1], using varieties with a high resistance to sprouting, did not observe incidence of sprouting before the beginning of October. At present the warning system together with the availability of varieties with a high resistance to sprouting are useful tools for the farmer to prevent severe damage in wheat from sprouting.

b. 2 Barley and oats

Observations on the farm during two years did not show a reduction in test weight during a period of 16 days. DE JONG and ZELHORST (1968) in their above mentioned study and in the trial fields of 1968 [1] did not observe incidence of sprouting.

From the above it can be concluded that the losses caused by reduction in grain quality are probably negligible in comparison with the field losses. Only if the harvest is prolonged sprouting may cause considerable losses, especially in wheat. Therefore, the losses by decline in quality of the grain will be ignored. The high losses caused by sprouting will be taken into account by the introduction of a time limit for harvesting and then counting grain not harvested at that date as a complete loss (11.2.1.*d*).

3.5 SUMMARY

The maturity dates, available periods and field losses of colza, barley, oats and wheat are estimated. The order of maturing of the crops grown is colza,

[1] Personal communication DE JONG.

barley, wheat and oats. The maturity date (combine ripeness) of the crops grown on the farm is chiefly determined by the date of sowing and by the weather during the growing season. The influence of the date of sowing has been investigated using trial field data. The results are shown in figure 8. The influence of the weather has been investigated with the results of field trials and with the aid of the remainder index system. The results are shown in tables 4 and 5.

Two factors determine the available period for harvesting, i.e. the work that has to be done next and the field losses of the mature crops. The harvest is followed immediately by tillage operations that have to be finished before December 7 (figure 10). With the tillage capacity presently available efforts are made to finish the harvest by the middle of September or at least October 1. Based on the average maturity dates the average periods available for combining colza and barley are seventeen and ten days respectively. In practice the period for colza is likely to be longer and that for barley shorter as sowing of barley is sometimes retarded. The standard deviations of the data indicate that considerable deviations from the averages can occur between various years.

In the mature crop both field losses and deterioration of grain quality occur. The field losses, caused by dry matter losses, shatter losses and combine losses are shown for wheat, barley and oats in figure 11. The average daily field header are summarized in table 6. No data are known for colza. The losses caused by the deterioration of the grain quality are probably negligible in comparison with the field losses.

4 KERNEL MOISTURE CONTENT AS AFFECTED BY THE WEATHER

4.1 INTRODUCTION

The crop moisture content considerably affects the capacities required of the sequential grain harvesting operations: threshing, transport, drying and wet storage. The moisture content of the kernel is of great importance for the relationship between the combine capacity and the drying capacity; the moisture content of the straw has an appreciable influence on the number of available hours for combining.

The crop moisture content varies under influence of the weather on both a daily and a seasonal basis. Knowledge of the crop moisture contents during the harvest period over a number of years will accordingly help towards optimal capacity selection of the sequential harvesting operations. This chapter describes the results of a study to determine the quantitative relationship between the kernel moisture content of colza, barley, oats, wheat and various meteorological factors.

A limited amount of research has been done on the kernel moisture content under the influence of the weather compared with the considerable attention which has been devoted to the kernel moisture content during artificial drying and storage. BERG and OTTOSSON (1949) studied the kernel moisture content of barley, oats and wheat as affected by the weather. They conclude that the moisture content of the oat kernel increases and declines more rapidly as a consequence of weather influences than that of the wheat kernel, the reaction of the barley kernel is somewhere in between. VOIGT (1955) studied the quantitative effect of the saturation deficit at 2 p.m., the duration of rainfall and dew on the kernel moisture content of certain, not specified, grains. GELS (1959) carried out a similar study, however, without mentioning the meteorological factors used. By means of an inquiry on farms DE WILJES (1965) established a relationship between the hours with a kernel moisture content below 20% and the rainfall. BRÜCK (1967) described the daily moisture content of wheat utilizing similar meteorological factors as VOIGT. The relationships found by VOIGT (1955) and BRÜCK (1967) are based on grain samples taken directly from the ears; the kernel moisture contents found in this way are lower than the actual moisture contents after combining as the kernel moisture content increases during threshing (5.3).

4.2 WEATHER DURING HARVEST TIME

The climate in the Netherlands is a maritime one with cool, wet summers and mild winters. During the summer months the weather is chiefly governed by westerly winds blowing inland from the sea. The average monthly data for the central part of the Netherlands are for August, the main harvest month, as follows (De Bilt, 1931—1960): temperature 16.8 °C, precipitation 93 mm, relative humidity 86%.

The average data for other parts of the country are slightly different. In general during summer along the coast the number of hours of sunshine is greater and the precipitation a little less than more inland. For the purpose of this study it is important that during the summer the weather at Wageningen and De Bilt (from both places meteorological data for the period 1931—1964 were obtained) is practically the same as that of the region under consideration, though the rainfall is different in some years (PRINS and REESINCK; 1948, VAN KAMPEN and ZUIDEMA, 1966).

The annual variation of the summer weather in the Netherlands has been described by VAN DER HAM (1957) and TEN KATE (1966). Some meteorological data of the period studied are shown in table 7.

TABLE 7. Precipitation and „summer" days in the summers (June-August) of the period 1911—1966 (TEN KATE, 1966).

Period	Rainfall (mm) [1]	Summer days [2]
1911—1920	216	16.3
1921—1930	202	15.3
1931—1940	194	21.5
1941—1950	207	22.4
1951—1960	242	12.2
1961—1966	253	8.5

[1] Average.

[2] Average, „summer day" is a day with maximum temperature > 25° C.

The data show that the summers of the period 1951—1960 were exceptionally wet with few summer days, the summers of the period 1961—1966 were even worse. As so far little is known about the causes of these variations, no forecasts can be made regarding the type of summers to be expected in the immediate future. For the purpose of the present study it has been assumed that the summer weather in the period 1931—1967 is indicative of what may be expected in coming summers.

4.3 MEASUREMENTS OF KERNEL AND STRAW MOISTURE CONTENTS AND METEOROLOGICAL DATA

From 1964 to 1967 various observations were carried out during the harvest. Samples were taken hourly from 6 a.m. to 7 p.m. [1] to determine:

[1] All times in Central European Time.

the kernel moisture content before threshing (1964)
the kernel moisture content after threshing (1964—1967), sampling was also continued during some nights
the straw moisture content after threshing (1965).

The grain samples were taken from the tanks of a group of three to six combines. The straw samples were taken from the swaths. The kernel moisture contents of barley, oats and wheat were established by means of drying in a desiccator for 1.5 hours at 130 °C, those of colza by drying for one hour at 130 °C.

The meteorological observations were carried out with the following instruments:

rain gauge, later replaced by a pluviograph
Bellani pyranometer (from Physikalisches-Meteorologisches Observatorium Davos)
relative humidity recorder
anemometer
thermometer.

Except for the anemometer, which was set up 25 km away from the trial area at Lelystad, the instruments were located in such a way that the combines were less than three kilometers distant. The instruments were positioned (figure 12) in an open space in the wheat crop [1].

The Bellani pyranometer, set up 1.8 m above the ground, measures the circumglobal radiation, i.e. the short wave radiation from sun, sky and earth. This radiation is measured in cal cm^{-2} globe surface day^{-1}. The principle of the instrument consists of the conversion of radiation into heat, which results in the distillation of alcohol from an irradiated spherical receiver into a cylinder. This pyranometer, which is being used increasingly in meteorological and ecological research, is less accurate than the Moll-Gorczynski pyranometer. The Moll-Gorczynski pyranometer with a potentiometer indicates the total global radiation on a horizontal plane in cal cm^{-2} min^{-1}. Both instruments, described in greater detail by STEUBING (1965) have been in use for many years at two places in the Netherlands: the Moll-Gorczynski pyranometer at Wageningen since 1931 and at De Bilt since 1957, the Bellani pyranometer at De Bilt since 1957. The two types have been compared by MONTEITH and SZEICZ (1960) in Britain and by DE BOER (1960) in the Netherlands.

MONTEITH and SZEICZ (1960) conclude that the Bellani pyranometer is suitable for use in agricultural and ecological research for eight months

[1] Positions as advised by WOUDENBERG of the Royal Netherlands Meteorological Institute, De Bilt.

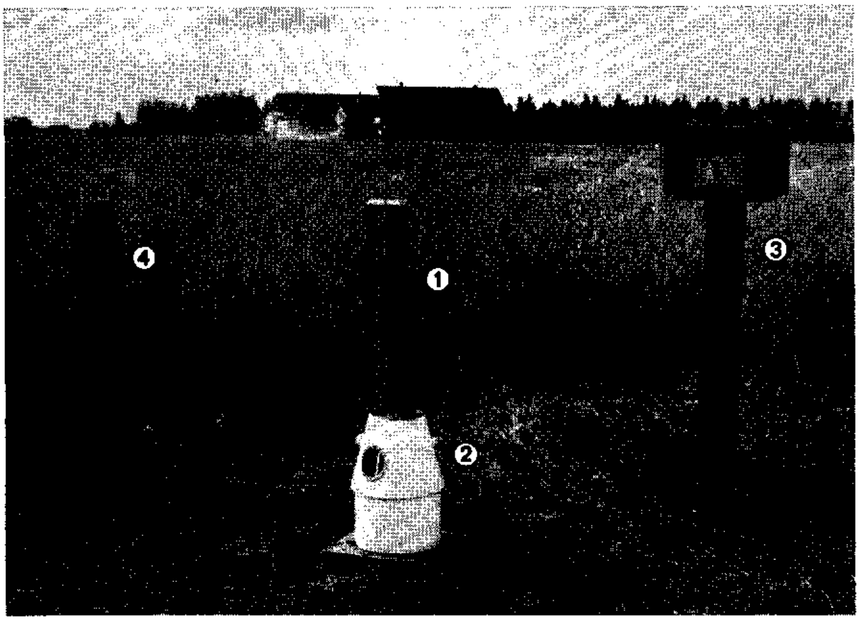


Fig. 12. Position of instruments.
1. Bellani pyranometer
2. pluviograph
3. relative humidity meter (self recording)
4. thermometer

of the year in climates similar to that of the British Isles. DE BOER (1960) finds during the summer months a distinct linear connection between the daily circumglobal radiation totals as measured with the Bellani pyranometer and the global radiation totals as measured with the Moll-Gorczynski pyranometer. He provides a regression equation for each month (see 5.1.*a*) which can be used to compute the global radiation if the circumglobal radiation is known (from 8 a.m. to 8 a.m.). This equation can also be used to convert the global radiation measured since 1931 at Wageningen into circumglobal radiation. In view of this possibility and the simplicity of operation of the Bellani pyranometer it has been used for the measurement of the daily circumglobal radiation.

4.4 DRYING OF THE GRAIN

4.4.1 *Introduction*

The research done so far on the drying of grains can be split into studies of the equilibrium conditions and work on the more complicated dynamic processes involved in artificial drying. The equilibrium moisture contents of grains are usually expressed in isobars having a sigmoid form (BABBITT, 1949; BECKER and SALLANS, 1956; KREYGER, 1964).

The artificial drying of solids has been described by LENIGER (1957) and VAN DER HELD (1957). Artificial drying is the evaporation of water from the solid and the removal of the water vapour by a current of the drying agent, in this case air. The heat necessary for evaporation is also brought in by the air. The drying process, consisting of mass-transfer, is a diffusion process; it only takes place when there is a difference in vapour pressure between the air and the surface to be dried. In drying a distinction is made between the constant-rate period and the falling-rate period. During the constant-rate period the material being dried behaves as a wet body, the evaporation being equal to that from a free water surface. The rate of drying, which is dependent on wet-bulb depression, air velocity and temperature, can be calculated with quite a considerable degree of accuracy. During the falling-rate period the diffusion of water or vapour to the surface of the material cannot keep up with the rate of evaporation; consequently the rate of drying declines. The point at which the constant-rate period changes in the falling-rate period can vary for a given material since it depends largely on the drying conditions. Since the artificial drying of grains occurs as a rule in the falling-rate period, the calculation of the drying rate is rendered quite difficult and bulk grain drying is accordingly an essentially empirical operation.

In the field the grain will dry under the influence of the weather. Numerous methods have been developed for calculating the evaporation from the earth's surface. LEVINE (1959) and UHLICH (1954) provide comparative surveys of a number of methods. Many of these are based on empirical correlations with climatological data such as the mean temperature and the length of the day (THORNTHWAITE, 1948) or the saturation deficit (HAUDE, 1955). PENMAN (1948) has approached the evaporation from a free water surface by taking into account the energy available and the rate of diffusion of vapour as affected by wind velocity and relative humidity. For the calculation of the evaporation from a plant cover an empirically determined reduction factor is introduced.

The evaporation calculations are generally made to cover fairly long periods (months); for periods of some days the results can be quite inaccurate.

The factors determining the drying rate of the kernel are:

a. the speed with which the vapour formed is removed from the air layer adjoining the evaporating surface

b. the rate of diffusion of water or vapour to the evaporating surface of the grain kernel *c.* the quantity of energy available at the evaporating surface per unit of time

Each of these factors can have a restrictive influence on the drying rate of the grain kernel.

a. The speed of removal of the vapour formed

Two layers are distinguished in the removal of water vapour: the laminar boundary layer and the turbulent layer. The transport of water vapour through the laminar layer takes place by molecular diffusion, while in the turbulent layer it occurs by means of irregularly eddying air currents. Water vapour transport in the turbulent layer will probably not have a restrictive effect, since the wind speed over the treeless area practically never falls below 2 m sec^{-1} and the amount of water evaporated from the ripe crop will not exceed about 0.1 — 0.2 mm day^{-1}. The transport in the laminar layer depends largely on the thickness of the layer, which depends in turn on the wind speed. However, no data are available on the velocity of the air movement around the grains in the ear.

The observations provided no indication that wind speed affects the drying rate, thereby confirming VOIGT'S (1955) conclusion that the drying rate is not affected by the wind velocity.

b. The rate of diffusion within the kernel

As already stated, the rate of diffusion of water and vapour in the kernel is determinative for the drying rate during the falling-rate period. The drying rate is then governed almost entirely by the temperature, since the temperature determines the internal diffusion rate. BECKER and SALLANS (1956) show that in the case of artificial drying of wheat the falling-rate period occurs at moisture contents of 15—27%. They also demonstrate that the drying rate declines when the moisture is irregularly distributed inside the kernel.

The drying rate resulting from natural drying is about 10—20% of the drying rate usual during artificial drying. As a consequence the point at which the constant-rate period changes into the falling-rate period during natural drying will be at a lower moisture content than during artificial drying.

c. The available energy

Many of the relationships between physics of atmosphere and the physiology of crops are dominated by the effects of radiation (MONTEITH, 1965). In respect of the drying of grain the most important feature of the radiation climate is the intensity, or the amount of energy received by unit surface in unit time; it is usually quoted in cal cm^{-2} min^{-1}.

Radiation as an important part of the energy balance of atmosphere and earth is described by SCHOLTE UBING (1959) and MONTEITH (1965). At the outer limit of the earth's atmosphere the mean intensity of solar radiation on a surface that is perpendicular to the solar beam is 2.0 cal cm^{-2} min^{-1}, a value known as the solar constant. As the solar beam traverses the atmosphere, radiation is absorbed by gases and is scattered by gas molecules and by dust. These losses decrease the maximum intensity of radiation at sea level to approximately 1.3 cal cm^{-2} min^{-1} at noon when the sun is 50° above the horizon.

When sunlight is intercepted by clouds, radiation is scattered in all directions. On average 34% of the radiation incident on clouds is transmitted to the surface below. Thus the actual insolation in the Netherlands between May and August is 300—400 cal cm^{-2} day^{-1} (DE VRIES, 1955).

Solar and short-wave radiation absorbed by atmospheric gases and by clouds is reemitted as long-wave radiation at wave lengths between 3 and 100 μ. Over Europe the monthly longwave income in summer does not exceed 800 cal cm^{-2} day^{-1}.

Radiation losses occur by reflection, transmission and emission. The reflection coefficient depends on the earth's surface. In ripe grainfields the reflection coefficient for solar elevation 40—60° amounts to approximately 0.26 (SCHOLTE UBING, 1959; MONTEITH, 1965). Transmission of solar radiation in a field crop is the part of the radiation that filters between the leaves and reaches the soil in the form of sunflecks. SZEICZ *et al* (1964) measured the transmission in barley and kale at different heights. They report that in nearly ripe barley the transmission varies from 12% at soil surface to 90% at nearly the top of the barley plant.

The crop absorbs and emits long-wave radiation like a black body. When the sky is cloudless, the income of long-wave radiation is usually about 70% of the emitted long-wave radiation; when the sky is overcast with low clouds, the upward and downward fluxes of long-wave radiation are almost equal.

The net amount of radiation absorbed by a crop is the difference between radiation gained from the sun and the atmosphere, and that lost by reflection, transmission and emission. To satisfy the conservation of energy, the intensity of net radiation must be exactly equal to the rate at which the vegetation dissipates heat by convection and evaporation and stores heat.

When transmission is negligible the empirical equation for the dependence of net radiation on short-wave radiation under clear skies can be written (MONTEITH and SZEICZ, 1962):

$$\begin{aligned} R &= (1 - \alpha)\, S - (L_d - L_u) \\ &= \left(\frac{1 - \alpha}{1 + \beta}\right) S + L_o \qquad (S > O) \qquad (4.1) \end{aligned}$$

The unit of radiation is cal cm^{-2} per minute, hour or day; further:

R = net radiation for all wave-lengths
α = reflection coefficient for short-wave radiation
β = heating coefficient defined as the increase in net long-wave loss (L_d—L_u) per unit increase of R
S = incoming short-wave radiation from sun and sky
L_d = downward long-wave radiation from the atmosphere
L_u = upward long-wave radiation from the surface
L_o = net incoming long-wave radiation, when $S = 0$ then $R = L_o$.

Values of β range in Britain from 0.41 for bare soil to 0.15 for vegetation completely covering the ground and never short of water (MONTEITH and SZEICZ, 1962). For ripe crops the value of β will range between these values because of higher surface temperatures in comparison with freely transpiring crops. Further β probably depends on wind and on crop structure; for example the normal spacing of a cereal allows free air movement below the crop canopy and in given weather the effective surface temperature (and hence β) may be less than for a densely growing crop.

The mean reflection coefficient (α) for grain fields is approximately 0.26. On the diurnal variation of reflection coefficients is reported by MONTEITH and SZEICZ, (1961); reflection is least at mid-day and increases almost linearly with decreasing solar elevation. After rain and dew the reflection is enhanced. Surface heating (β) and reflection (α) are equally important discriminants in the radiation balance of natural surfaces, combining to give a range of $\pm$ 18% in net radiation at given short-wave income (MONTEITH and SZEICZ, 1962).

The incoming short-wave radiation from sun and sky (S) can be represented by a curve which is symmetrical to mid-day (DE VRIES, 1955; MONTEITH and SZEICZ, 1961). For example in August the hourly radiation rises from 4 a.m. until the maximum of 40—50 cal cm^{-2} h^{-1} is reached at mid-day, then it gradually drops to zero at 7 p.m.

Net radiation (R) shows on clear days a similar pattern as the incoming short-wave radiation in August, it is positive between one hour after sunrise and one hour before sunset. On a daily basis the ratio R/S varies for cloudless days from 0.37 over a bare soil to 0.46 for a tall crop (MONTEITH and SZEICZ, 1962). In cloudy weather these ratios will be higher because long-wave loss decreases more rapidly than solar radiation income. MONTEITH (1965) concludes that the ratio R/S changes very little during summer: the average ratio was approximately 0.55 over a freely transpiring vegetation in a temperate climate. On an hourly basis the ratio R/S is always smaller in the afternoon than in the morning because of higher afternoon surface temperatures. This effect is most pronounced over a bare soil.

No data on the radiation balance for mature cereals are available; it is likely that the above mentioned will also be valid for mature cereals though at other quantitative values.

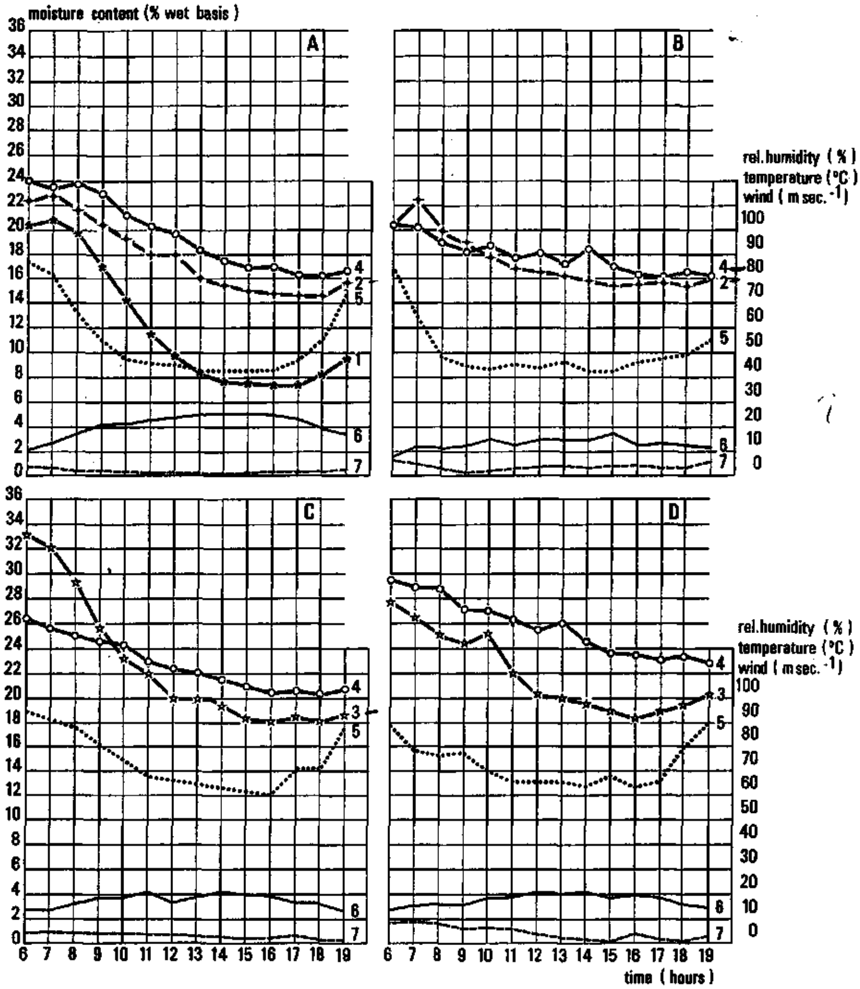


Fig. 13. Kernel moisture content of colza, barley, oats and wheat on some cloudless days.

A. 13-8-1966, circ. glob. rad.: 274 cal day^{-1}
B. 16-8-1966, „ „ „ 250 „ „
C. 30-8-1966, „ „ „ 154 „ „
D. 1-9-1966, „ „ „ 204 „ „

1. colza
2. barley
3. oats
4. wheat
5. rel. humidity
6. air temperature
7. wind velocity

4.4.2 *Discussion of the results*

The results of the measurements in wheat in 1964 and 1965 have been discussed by VAN KAMPEN and ZUIDEMA (1966) and BERGER and VAN KAMPEN (1965). They found on clear days that the kernel moisture content declines nearly rectilinearly from about 7 a.m. to 5 p.m. The gradient of the line depends on the initial moisture content, and is steeper with higher moisture contents.

In 1966 simultaneous measurements were made for a number of days in colza, barley, oats and wheat in order to check the behaviour under comparable weather conditions. Some results obtained on clear days are given in figure 13, showing the kernel moisture content, the air temperature, the relative humidity and the wind velocity. Colza and oats dry at a faster rate than barley and wheat, with barley drying at a slightly faster rate than wheat. The drying occurs in the period between 6—7 a.m. and 5—6 p.m. The circumglobal radiation is given as a daily total; reliable hourly values cannot be obtained with the Bellani pyranometer on account of the slowness of the instrument (DE BOER, 1960).

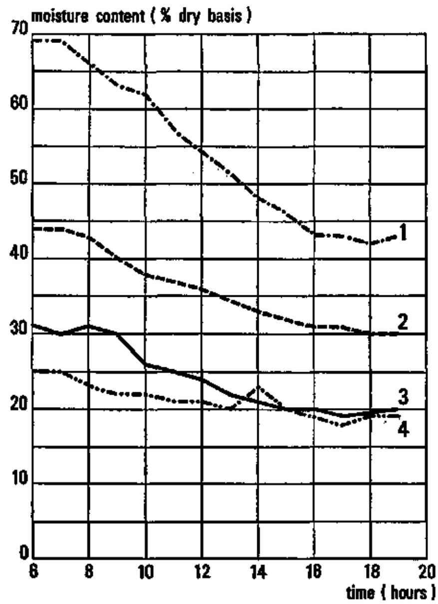


Fig. 14. Kernel moisture content (dry basis) of wheat on some cloudless days.

1. 14-8-1964 circ. glob. rad. :250 cal day -1
2. 15-8-1964 „ „ „ 250 „ „
3. 13-8-1966 „ „ „ 274 „ „
4. 16-8-1966 „ „ „ 250 „ „

Figure 14 presents the drying of the wheat kernels on a number of clear days with approximately the same amount of daily radiation. This shows that the lower the initial moisture content of the kernel the greater is the energy needed to evaporate a certain amount of water. There is no indication that the diurnal variation of the radiation affects the drying rate, even in the case of wet wheat (moisture content dry basis 70%) which has to be considered as a wet body as far as evaporation is concerned. This presumably arises from the non-uniform distribution of the moisture in the kernel as a result of the wetting by dew or precipitation prior to drying and from the higher afternoon kernel temperatures.

Comparison of the daily observations at different initial moisture contents reveals that the drying process follows an exponential course. Assuming that the daily radiation and the initial kernel moisture content are the two factors mainly determining the rate of drying, the exponential decrease of the moisture content has been plotted against the cumulative circumglobal radiation with the aid of data obtained on dry days.

Let the final moisture content be y, the initial moisture content x_1 and the radiation x_2 then:

$$y = f(x_1, x_2) \tag{4.2}$$

On the basis of the results found and what is known of the drying process, the equation can be represented by the exponential function

$$y = x_1 e^{-bx_2} \tag{4.3}$$

where b is a constant indicating the curvature of the line.

In 4.3 y can assume all values $\geqslant 0$. For the case in which the final moisture content cannot drop below a certain level (value a); 4.3 can be written as follows:

$$(y - a) = (x_1 - a) e^{-bx_2} \tag{4.4}$$

on the assumption that x_1 and x_2 are normally distributed.

The function fits in best with the data if the sum of the square of the deviations:

$$\sum [(y - a) - ((x_1 - a) e^{-bx_2})]^2$$

is as small as possible.

When the calculation is carried out in this way it becomes clear that for the crops studied it is preferable to have a = 0, i.e. that the kernel moisture content should in principle be able to fall to zero. The constant b is also fixed for the kernels. This is the basis on which the exponential functions shown in figure 15 have been calculated. The t criterion has been used to indicate the 95% reliability range.

colza: $$y = x_1 e^{-0.00303x_2} \tag{4.5}$$
$$y = \hat{y} \pm 5.13$$

barley: $$y = x_1 e^{-0.00115x_2} \tag{4.6}$$
$$y = \hat{y} \pm 3.83$$

$$\text{oats:} \quad y = x_1\, e^{-0.00203 x_2} \qquad (4.7)$$
$$y = \hat{y} \pm 6.23$$

$$\text{wheat:} \quad y = x_1\, e^{-0.0011 x_2} \qquad (4.8)$$
$$y = \hat{y} \pm 2.55$$

The deviation of the results around the curve is particularly marked in the case of oats and colza; in the case of wheat it is much less. Some of the tendencies known from the artificial drying process agree with the above equations. Oats dry more quickly than wheat, barley dries at about the same rate as wheat. Colza dries a little quicker than oats; though the difference is less than reported by KREYGER (1964).

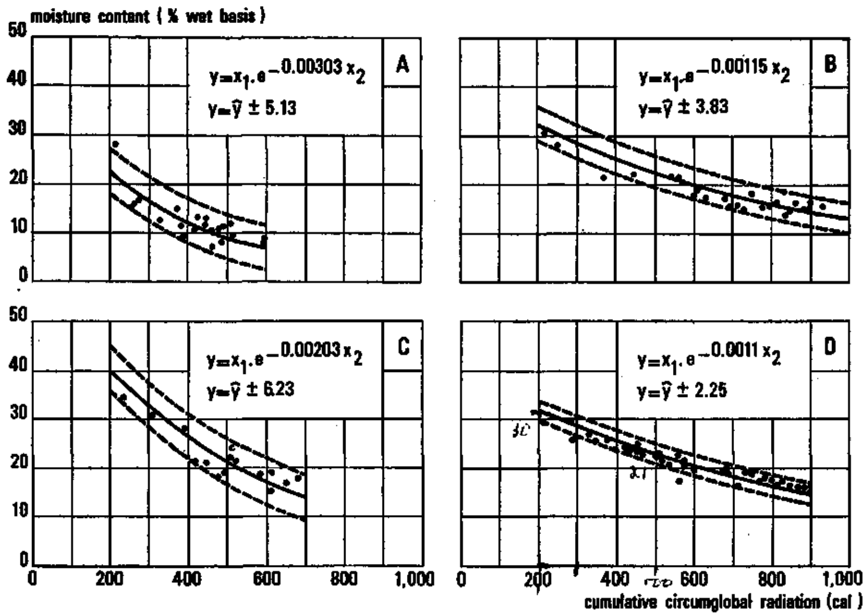


Fig. 15. Relationship between cumulative daily circumglobal radiation and drying of the kernels of:

A. colza B. barley C. oats D. wheat

The daily drying rate can be read off from figure 15 if the initial moisture content and daily circumglobal radiation are known. For instance if the initial moisture content of wheat is 30% and the radiation measured is 300 cal, then the moisture content at the end of the day will be 21%.

4.5 INCREASE OF THE KERNEL MOISTURE CONTENT UNDER INFLUENCE OF THE WEATHER

4.5.1 *Introduction*

The kernel moisture content can be increased in two ways: through contact with water and through absorption of water vapour. BRADBURY *et al* (1960) summarize the research carried out on the wetting of the wheat kernel, this reveals that the kernel moisture content will rise in both cases through diffusion under the influence of a concentration gradient. In nature it is chiefly water in the form of precipitation and dew which causes the rise in moisture content, since absorption of water vapour is a slow process (DILLMAN, 1930). Factors affecting the rate of entrance of water into the kernel are: the concentration gradient, the temperature of the water, the time of immersion, the size of the kernel and internal fissuring. JONES (1949) distinguishes three stages of absorption by a wheat kernel during immersion viz. a rapid initial pick-up of 4—5 percent water, immediately followed by a fairly short period (2—12 min) during which the rate of pick-up is falling and a long period of much slower but relatively steadily maintained absorption. In this last period the relation between pick-up and time of immersion is nearly linear. The rapid pick-up during the first stage is the result of water entering the wheat kernel chiefly through the germ, with mellowing of the endosperm occurring first near the germ. In the following stages the water spreads gradually towards the beard. The water is absorbed in smaller amounts and more slowly through the surface of the kernel as a whole. According to SIMMONDS *et al* (1953) the rate of moisture uptake by the wheat kernel during immersion at 10 °C can be described by the equation:

$$\log (81.5 - W) = - 0.02335\, T + 1.7745 \qquad (4.9)$$

where W = moisture content dry basis and T is time of soaking in hours.

4.5.2 *Rise in moisture content under influence of dew*

When the temperature of the earth's surface and of the lower air layers falls at night owing to loss of heat by radiation, water vapour from the atmosphere can condense as dew on the surface. Dew can only occur under certain atmospheric conditions. HOFMANN (1955) calculated for Central Europe a maximum dew of 0.07 mm per hour. MONTEITH (1957) observed a maximum condensation of approximately 0.035 mm per hour overnight in Britain under extremely favourable conditions for dewfall. VOIGT (1955) observed that dew occurred in a grain crop in thirteen out of twenty-two nights during harvest time in Germany, the average rise in kernel moisture content during thirteen nights being 1.3%. VAN KAMPEN and ZUIDEMA (1966) showed that in the trial field the moisture content of the wheat kernel during the night rose on the average with 2% ($\sigma \pm 0.9$) which corresponds with approximately 0.01 mm of dew.

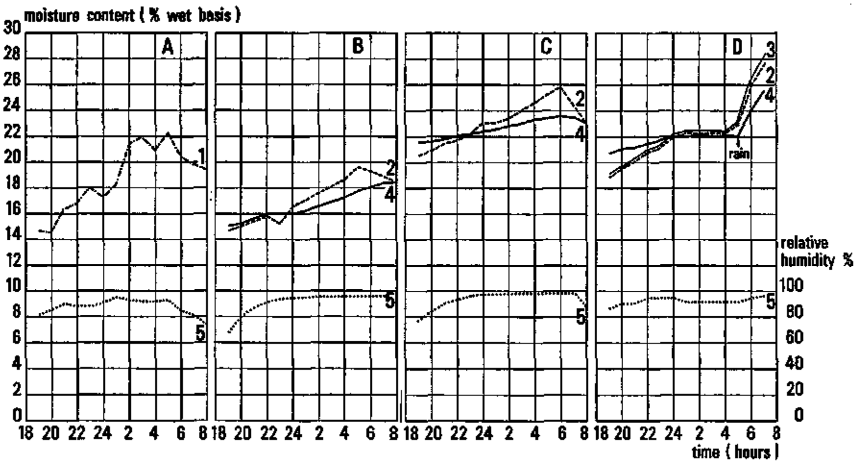


Fig. 16. Kernel moisture content of colza, barley, oats and wheat during some nights (1966).

A. 5/6 -8-1966
B. 18/19-8-1966
C. 24/25-8-1966
D. 30/31-8-1966

1. colza
2. barley
3. oats
4. wheat
5. rel. humidity

The grain moisture content was measured during a number of nights in 1966. The results (figure 16) show that the moisture content rises from around 7 p.m. to 6—7 a.m., i.e. from about one hour before sunset to about half an hour after sunrise. The moisture uptake of barley (figure 16B, C) is appreciably greater than that of wheat, but drying starts about two hours later in wheat than in barley. This presumably results from the fact that the wheat ear is of a less open type. The moisture uptake of oats (figure 16D) is also higher than that of wheat; in this case the natural rise by dew was interrupted by precipitation at 4 a.m. The rise in the moisture content of colza (figure 16A) is considerably more pronounced than that observed in grains.

Since dew occurs on most nights during the harvest season — although admittedly in varying quantities — an approximate value for the influence of the dew on the kernel moisture content of a particular crop can be obtained by using the length of the nights and the initial moisture contents as the main factors affecting the rate of uptake of water.

With the rises in moisture during rainless nights it is possible — as in the case of radiation — to plot the nightly increase in moisture content against

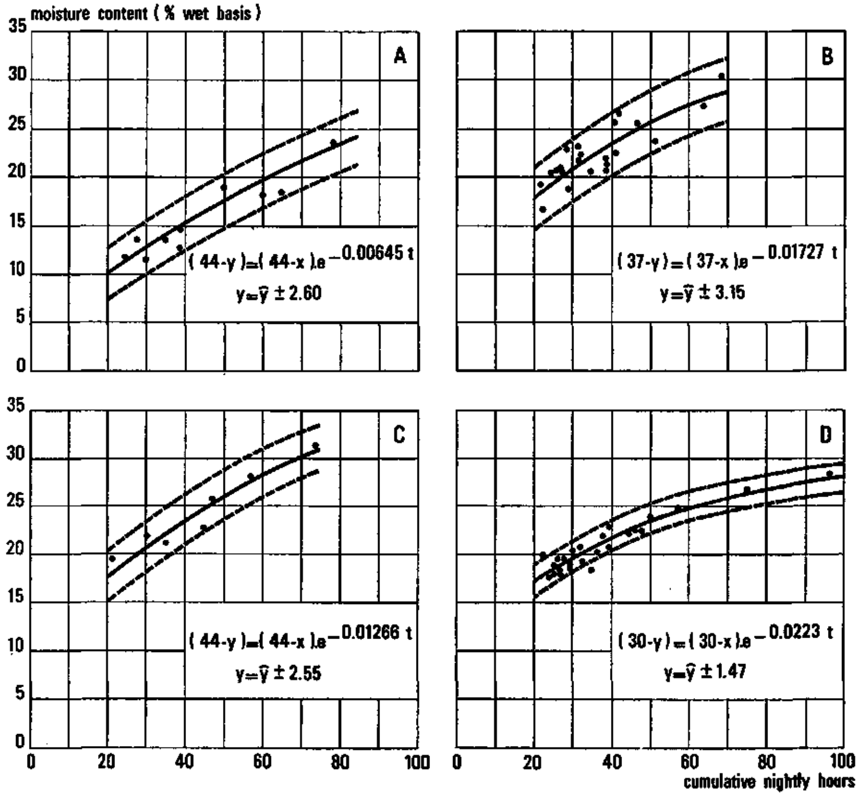


Fig. 17. Relationship between the cumulative nightly hours and increase in moisture content of the kernels of:

A. colza B. barley C. oats D. wheat

the cumulative night hours. The night hours being the hours between one hour before sunset and half an hour after sunrise.

This relationship can be expressed by:

$$(a - y) = (a - x)\,e^{-bt} \tag{4.10}$$

where:

a = maximum of the moisture content
y = the final moisture content
x = the initial moisture content
t = the number of nightly hours
b = constant, depending on the type of seed

The quantities a and b are then estimated in the same way as for the radiation. The results are given below; see also figure 17.

colza: $(44 - y) = (44 - x)\, e^{-0.00645t}$ (4.11)
$y = \hat{y} \pm 2.60$

barley: $(37 - y) = (37 - x)\, e^{-0.01727t}$ (4.12)
$y = \hat{y} \pm 3.15$

oats: $(44 - y) = (44 - x)\, e^{-0.01266t}$ (4.13)
$y = \hat{y} \pm 2.55$

wheat: $(30 - y) = (30 - x)\, e^{-0.0223t}$ (4.14)
$y = \hat{y} \pm 1.47$

The moisture contents of colza and oats increase more than those of barly and wheat, the rise is least in the case of wheat. The maxima also decrease in the same order.

4.5.3 *Moisture content as affected by precipitation*

The interception of precipitation by a particular crop highly depends on the amount and duration of the precipitation and on the wind velocity (CLARK, 1940). His measurements with oats and wheat indicate that the interception is positively correlated with the amount and duration of the precipitation and negatively correlated with the wind velocity.

A part of the precipitation will be absorbed by the kernels, as a consequence of which the kernel moisture content will rise. The extent to which the kernels of the crops intercept precipitation is not known.

Throughout one harvest season samples were taken every half hour from the beginning of precipitation up to two hours after it stopped. In two other harvest seasons the samples were taken hourly. The moisture contents at the beginning and at the end of the precipitation were estimated with the aid of the moisture contents of these samples. An exponential relationship has been established between the rise in the moisture content and the product of the precipitation duration in minutes (t) and the square root of the mean intensity in mm per minute (i).

This exponential relationship is as follows:

$$(a - y) = (a - x)\, e^{-bt\sqrt{i}} \qquad (4.15)$$

Since t is expressed in minutes and i in mm per minute, 4.15 can be written as follows:

$$(a - y) = (a - x)\, e^{-b\sqrt{mt}} \qquad (4.16)$$

where:

a = maximum moisture content

y = moisture content one hour after the end of the precipitation [1]
x = moisture content at the start of the precipitation
b = constant, depending on the crop
m = precipitation in mm
t = duration of precipitation in minutes.

The unknown parameters a and b are estimated in the same way as for the radiation. The relationships found, shown in graph form in figure 18, are as follows:

colza: $$(44 - y) = (44 - x)\, e^{-0.01559 \sqrt{mt}} \qquad (4.17)$$
$$y = \hat{y} \pm 3.60$$

barley: $$(34 - y) = (34 - x)\, e^{-0.03005 \sqrt{mt}} \qquad (4.18)$$
$$y = \hat{y} \pm 6.40$$

oats: $$(51 - y) = (51 - x)\, e^{-0.01652 \sqrt{mt}} \qquad (4.19)$$
$$y = \hat{y} \pm 6.95$$

wheat: $$(60 - y) = (60 - x)\, e^{-0.00605 \sqrt{mt}} \qquad (4.20)$$
$$y = \hat{y} \pm 2.29$$

In the case of wheat the relationship found in this way is reasonable. With the other crops the degree of uncertainty is rather high, probably because the number of data is rather small compared with wheat. Another cause may be that these crops react more quickly to wetting and drying than wheat.

Compared with the influence of dew, the calculated limits to which the kernel moisture contents can rise through precipitation are by and large in agreement except for wheat. The calculated limit of 60% for wheat seems rather high in comparison with the limit of 30% in 4.14 and the limit of 45% arrived at by SIMMONDS *et al* (1953) with formula 4.9.

4.6 SUMMARY

The climate in the Netherlands is a maritime one, with cool, wet summers and mild winters. Consequently the kernel moisture content of the grains varies during the harvest period on both a daily and an annual basis.

[1] The kernel moisture content increases during a certain period (for wheat during approximately one hour) after the end of the precipitation. This is due to water attached to the kernel. The length of this period varies and depends on the rate of evaporation and the amount of water attached to the kernel. Less water is attached to colza, barley and oats than to wheat, thus this period is for those crops in general shorter than for wheat. For the computations the period is fixed at one hour for all crops.

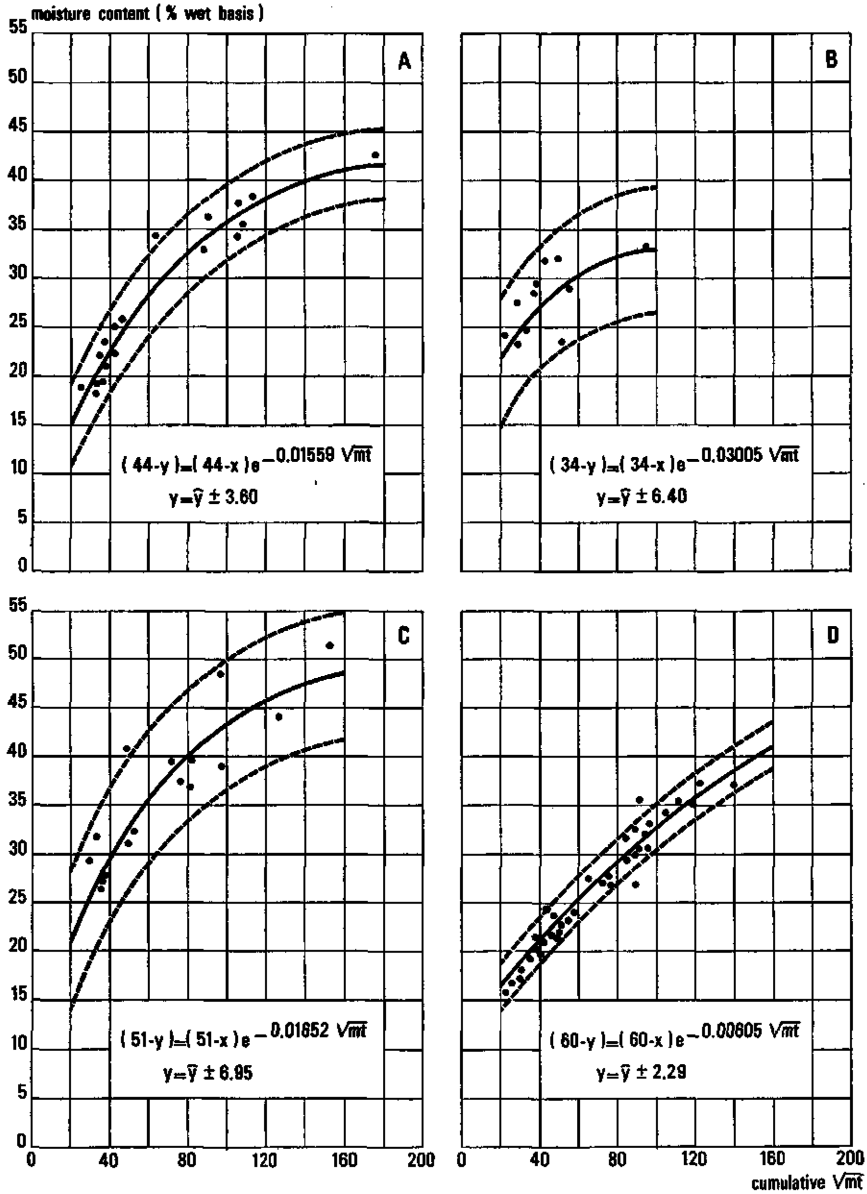


Fig. 18. Relationship between increase of the kernel moisture content of:
A. colza B. barley C. oats D. wheat and cumulative $\sqrt{mt}$ (m = rain in mm, t = duration of rainfall in min).

Knowledge of the kernel moisture content during the harvest period over a number of years can be made useful for optimal capacity selection of the sequential harvesting operations. From 1964—1967 various meteorological observations were carried out during the harvest. Grain samples were taken hourly from the graintanks of a group of combines. The crops studied were colza, barley, oats and wheat.

Drying of the kernel takes place between 7 a.m. and 5 p.m.; the daily drying is determined by the energy input in the form of solar radiation and the initial moisture content. As a general rule, the higher the initial moisture content of the seed, the lower the energy input required to evaporate a certain amount of moisture (figures 13 and 14). There are differences between the seeds involved: colza and oats dry at a faster rate than barley and wheat. For all seeds exponential relationships have been established between the drying rate and the cumulative daily circumglobal radiation (figure 15).

The moisture content of the kernel rises under the influence of dew and precipitation. The rise in the case of dew usually begins around sunset after the moisture content remained practically constant in the two previous hours. The moisture content generally ceases to rise at one hour after sunrise. The increase in moisture content depends on the initial moisture content and the quantity of dew. The increase is proportionally higher at a lower initial moisture content. Dew occurs practically every night during the harvest period; the quantity of dew during the night can vary, however, since it is influenced by atmosferic conditions. A number of nocturnal observations showed that the rise in moisture content during the night has a nearly linear character (figure 16). Exponential relationships have been found between the rise in moisture content overnight and the cumulative nightly hours (figure 17). They show that under the influence of dew the moisture contents of colza and oats increase more than those of barley and wheat.

The rise in kernel moisture content resulting from precipitation has been found to depend on the initial moisture content, the amount and duration of the precipitation. Exponential relationships have been established between the increase in moisture content and the square root of the product of the amount and the duration of the precipitation (figure 18).

5 STRAW MOISTURE CONTENT

5.1 INTRODUCTION

The daily pattern of variation in the straw moisture content has to be considered as another factor determining the number of available hours as well as the combine capacity. The higher the straw moisture content the lower will be the combine capacity as a general rule. If the straw moisture content rises above a certain level the crop can no longer be combined (see 7.3). The moisture content of the straw also affects the kernel moisture content since during threshing some moisture often is transferred from the straw to the kernel. As a consequence, kernel moisture content in such cases is higher after threshing than before.

As with the kernel, the daily variations in moisture content of the straw are primarily governed by the weather. Other factors that affect the moisture content of the straw are the degree of ripeness, the cutting height and the amount of weeds. The height of cutting significantly affects the straw moisture content, as is apparent from table 8 (VAN DER KANT, 1962).

TABLE 8. Distribution of moisture and dry matter in wheat straw, variety Felix, kernel moisture content 18% (VAN DER KANT, 1962).

Height above ground level (cm)	Dry matter (% of total)	Moisture content (%)
100—110	7.4	14.0
90—100	7.9	14.4
80—90	8.1	14.8
70—80	8.5	16.8
60—70	9.0	20.0
50—60	10.0	24.0
40—50	11.2	28.1
30—40	12.3	32.3
20—30	13.2	36.8
10—20	12.4	44.3
Total	100.0	Average 28.0

The marked effect of the stubble height on both the quantity of straw to be handled by the combine and its moisture content is evident. If large quantities of green weeds and undersown crops are mixed with the straw, the moisture content of the straw will be much higher than it would be otherwise. The straw of barley and oats frequently ripens later than the kernel; hence when the crop is combined with only the kernel ripe the moisture content of the straw is bound to be high. The influence of the weather on the daily changes in straw moisture content will then be less important. It will therefore be apparent that the moisture content of crops to be combined can be considerably modified by the stubble height and any green vegetation which enters the combine. Some idea of the daily pattern of the moisture content of the straw is nevertheless important, since the combine capacity is closely linked with it.

5.2 RELATIONSHIP BETWEEN THE STRAW MOISTURE CONTENT AND THE KERNEL MOISTURE CONTENT

No publications are available on the influence of the weather on the straw moisture content. In 1964 the moisture content of wheat straw was measured during some days in conjunction with the study of the kernel moisture content as discussed in 4. Samples were taken from the swaths left by a combine cutting at a height of 20 cm; the crops concerned were all combine ripe and free from weeds. The straw and grain moisture contents of wheat over a period without rain are shown in figure 19. These data, which are similar to the other observations, reveal that during a night without rainfall the straw moisture content rose from 15 to 27%. It then fell rapidly between 6 a.m. and 8 a. m., after which it followed the same pattern as the kernel moisture content. This nocturnal rise in the moisture content of the straw is primarily the result of dew. The hygroscopic properties of the straw probably play a subordinate role in this process since the establishment of an equilibrium occurs gradually. This has been demonstrated by placing samples of straw in contact with air of varying temperature and relative humidity for periods of five and ten hours in the laboratory (table 9).

TABLE 9. Straw moisture content of wheat straw as affected by relative humidity and temperature.

Rel. humidity (%)	Temp. (° C)	Straw moisture content (%)		
		at start	after 5 hours	after 10 hours
89	8.9	9.1	12.6	14.2
82	7.1	9.1	12.8	14.9
96	10.6	17.1	18.2	19.4
87	17.0	17.1	17.0	18.7

The same pattern as during the night is followed during and after rainfall; the straw moisture content can then rise to 60%. If the energy input is small after wetting, the straw moisture content will fall less quickly to the level of the kernel than is indicated by figure 19; the time taken for this level to be reached may be as long as four to five hours.

The fact that the moisture contents of straw and kernel follow practically identical patterns during a large part of the day indicates that a relationship can probably be found between the kernel and the straw moisture contents.

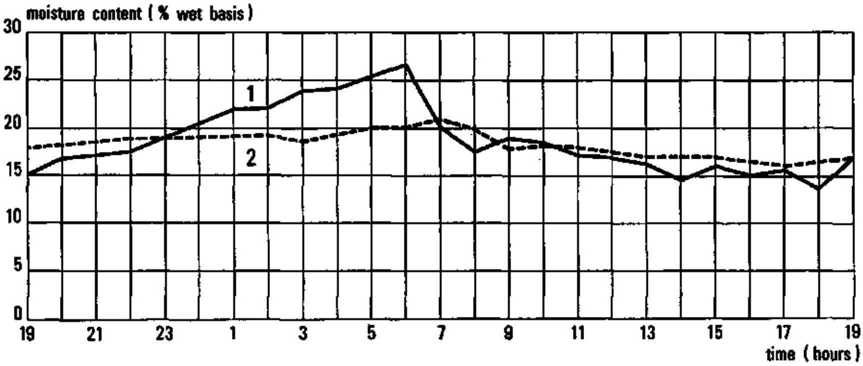


Fig. 19. Straw moisture content and kernel moisture content of wheat during the night and during the following cloudless day (1-9-1964).

1. straw moisture content
2. kernel moisture content

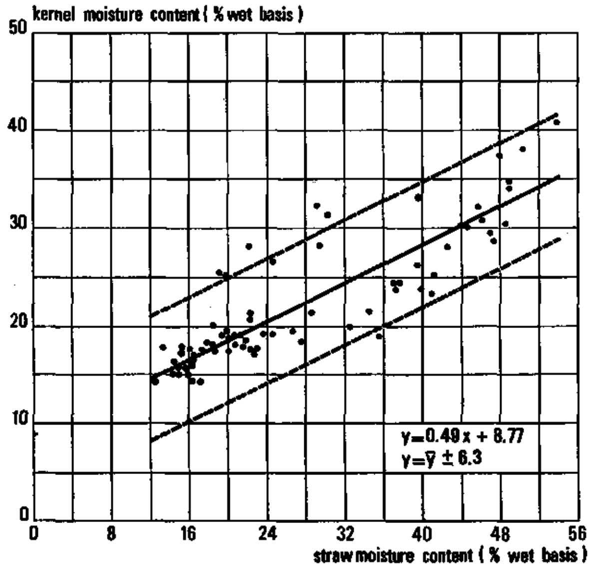


Fig. 20. Relationship between kernel and straw moisture content of wheat.

This relationship is shown for wheat in figure 20 where the average grain moisture content of three-hourly periods (from 7 a.m. to 7 p.m.) is plotted against the corresponding straw moisture content measured in the same manner.

The relationship is of the form

$$y = ax + b$$

where:

y = grain moisture content
x = straw moisture content
and a and b are constants with estimated values of 0.49 and 8.77 respectively. So the relationship can be expressed as:

$$y = 0.49x + 8.77 \tag{5.1}$$

The 95% confidence interval of the observations has been calculated according to $y = \hat{y} \pm 6.3$. The considerable scatter evident is due to the difficulty in obtaining representative straw samples and the fact that the straw moisture content is high initially after dew or rain.

No observations were carried out for colza. Those made for barley and oats provided no indication of any relationship because the straw was not yet ripe. With these crops the degree of ripeness of the straw is in many cases the chief factor determining the straw moisture content.

5.3 INCREASE OF THE KERNEL MOISTURE CONTENT DURING COMBINING

The kernel comes into close contact with the straw during the threshing process. In many cases moisture is transferred from straw to kernel, the actual quantity transferred depending on the initial moisture contents of the two. VON HÜLST (1957) notes an increase in kernel moisture of 2% in wheat. The greatest increase occurs in wheat with 12% moisture. When the moisture level of the kernel is higher, less moisture is absorbed, despite the fact that the moisture level of straw is also higher. FEIFFER (1958) notes a rise in kernel moisture content of 0.5 to 1.0% in wheat with a straw moisture content of approximately 15%.

In 1964 work was also done as part of the present study to determine the extent to which the kernel moisture content rose as a result of the threshing process. This revealed (ZUIDEMA, 1965*a*) that the rise in the moisture content of the wheat kernel was greater when the straw moisture content was higher; for example the rise was 0.1 and 0.8% at straw moisture contents of 20 and 40% respectively. The increase in kernel moisture content of colza was higher: 1.0% and 3.0% at straw moisture contents of 20 and 50%.

A previous study (VAN DER KANT, 1958) showed that the rise in kernel moisture content of barley following threshing can be considerable if the straw is not ripe. In this case a straw moisture content of 50% resulted in an increase of 3% in the kernel moisture content.

No data have been reported for oats. However, here also considerable increases in kernel moisture content will have to be taken into consideration at times since the straw matures slower than the kernel.

5.4 SUMMARY

The straw moisture content influences the combine capacity, it also affects the kernel moisture content during threshing. Therefore some idea of the straw moisture content as influenced by the weather is important. However, the straw moisture content is highly irregular owing to other factors involved: the degree of ripeness, the cutting height and the amount of weeds present.

For wheat it is shown that the moisture content of straw and kernel follow nearly identical patterns during a large part of the day (figure 19). The relationship between the moisture content of straw and kernel is shown for wheat (figure 20). For barley and oats no relationship could be found. With these crops the ripeness of the straw is the chief factor determining the straw moisture content.

During the threshing process moisture is transferred from straw to kernel, the actual quantity depending on the initial moisture content of kernel and straw and on the degree of ripeness of the straw. The increase in kernel moisture content varies between 0.1% and 3.0%.

6 DETERMINATION OF THE NUMBER OF AVAILABLE COMBINE HOURS FOR THE PERIOD 1931—1967

6.1 CALCULATION METHOD

In chapter 4 the influence of circumglobal radiation, dew and rainfall on the kernel moisture content of colza, barley, oats and wheat was investigated. The relationships are now used to compute the kernel moisture contents and the available combine hours during the harvest seasons of the period 1931—1967.

The daily global radiation has been measured at Wageningen [1] since 1931. The rainfall (quantity, starting time and duration) has been recorded at De Bilt [2] over the same period. These data have been used to calculate the kernel moisture content for the period 1931—1964 assuming that rainfall and radiation were exactly the same for Wageningen and De Bilt. Own meteorological observations have been used for the period 1964—1967.

The procedure for the computations is as follows.

a. Radiation

— 1 am - 9 am.

The radiation during hours (8 a.m. — 7 p.m.) with rainfall has been subtracted from the daily global radiation. In addition, the daily radiation has been divided into radiation before and after rainfall. This deduction and division has been estimated using the diurnal variation of the global radiation (DE VRIES, 1955). Next the global radiation has been converted into circumglobal radiation by means of the regression lines established by DE BOER (1960). The regression equations used are:

July: $y = 1.787x - 4.8$
August: $y = 1.688x - 5.7$
September: $y = 1.465x + 8.0$

where y = global radiation and x = circumglobal radiation.

b. Dew

The amount of dew has been calculated on the basis of the number of nightly hours. The length of the nights has been set at 13 hours (7 p.m.— 8 a.m.) from July 20 to September 15, and at 17 hours (5 p.m. — 10 a.m.) from September 15 to October 1. The influence of the dew has not been calculated during nightly hours with rainfall.

[1] Department of Physics and Meteorology, Agricultural University, Wageningen, the Netherlands.

[2] Royal Netherlands Meteorological Institute, De Bilt, the Netherlands.

c. Rain

The influence of rain has been calculated with the duration and amount of precipitation.

d. Starting date, initial moisture content and time limit

As starting date for each crop the average maturity date as given in 3.2.2 has been taken. As the actual moisture content at the maturity date is not known it has been assumed to be 13% for colza and 19, 18 and 20% for barley, oats and wheat respectively. These moisture levels are the probable levels of combine ripe crops without interference of rain or dew. However, the actual moisture content might have been higher or lower due to the weather in the preceding days. As rainfall is of primary influence it has been tried to reduce this influence by starting the calculations only on that day or a later day if the preceding 24 hours had been without rainfall. The calculations were carried out until the time limits mentioned in 11.2.1.*d*.

e. Processing of the data

The kernel moisture contents of the crops during the harvest periods have been calculated with the aid of a computer using the above mentioned meteorological data and the formulae in 4. The kernel moisture content after each of the three meteorological factors has been plotted by the computer on a time axis as a bar graph. In this way the kernel moisture content at any desired time can be approximated by rectilinear interpolation. For the processing of the data the kernel moisture contents have been split into three moisture ranges:

grain: < 19%; 19—23%; 23—28%
colza: < 10%; 10—14%; 14—18%

This classification is closely in line with the situations referred to in 2.4 as likely to occur during the harvesting of grains on account of the kernel moisture content. It also takes into account the fact that during artificial drying not more than 4% of the moisture is removed during each pass through the dryer, as a rule.

f. Available combine hours

In view of the form in which the results are presented the definition of available hours in 7.3 is of importance. Available combine hours are taken as the hours without rainfall in which the kernel moisture content of grain is below 28% (colza 18%). As a result of the conditions of employment of the combine operators the available hours are only recorded from Monday to Friday between 9 a.m. and 7 p.m. and on Saturday between 9 a.m. and 4 p.m. The number of available combine hours within a particular moisture range can then be approximated from the calculated kernel moisture contents.

g. Test of the computations

With the above method for computing kernel moisture contents a number of inaccuracies are introduced through which the calculated moisture contents may differ from the actual ones. To estimate the resulting differences between calculated and measured kernel moisture contents some tests were carried out in 1967.

g. 1 Comparison of the calculated and measured kernel moisture contents

The actual moisture contents were measured in samples taken from the combines hourly. The calculated moisture contents were determined in the manner described previously. They are based on meteorological observations made on the spot. As the kernel moisture content at the starting date was taken the measured kernel moisture content. The results, represented as available combine hours in the particular moisture range are shown in table 10.

TABLE 10. Measured (a) and calculated (b) available combine hours in three moisture ranges (1967).

Crop	Period	Moisture ranges Colza < 10% Grain < 19%		10—14% 19—23%		14—18% 23—28%		Total	
		a	b	a	b	a	b	a	b
Colza	17/7—25/7	58	56	14	10	5	6	77	72
Barley	28/7—14/8	29	13	16	22	26	33	71	68
Wheat	16/8— 3/9	56	58	36	29	11	13	103	100
Oats	24/8—29/8	40	43	7	4	0	0	47	47
Total		183	170	73	65	42	52	298	287

This table shows that the computed available hours correspond quite well with the measured available hours. However, some divergencies exist between the hours shown in the various moisture ranges. Particularly in the lowest moisture range of barley there is quite a difference between the number of measured and calculated hours. A possible cause could be that the barley was in the dead-ripe stage with dry straw during combining in 1967 resulting in less moisture transfer from straw to kernel during threshing.

g. 2 Influence of the kernel moisture content at the starting date

As already stated, the kernel moisture content of a crop at the starting date is unknown. In order to check the influence of the initial moisture content, the kernel moisture content for the period 1959—1964 has been computed for wheat on the basis of initial moisture contents of 15, 20, 25 and 30%. These calculations showed that the kernel moisture contents differed by less than 1% after three to four days. BRÜCK (1967) reached a similar conclusion for wheat. With the already taken precaution of a rainless period of 24 hours preceding the starting date it may accordingly be justified to assume that the moisture content at the starting date has very little effect on the further moisture variation pattern. The moisture contents have accordingly been set at 13% for colza and 19, 18 and 20% for barley, oats and wheat respectively.

6.2 CALCULATED AVAILABLE COMBINE HOURS FOR THE PERIOD 1931—1967

Appendix I gives the available hours by moisture range per year; a summary of the data is given in table 11. For colza and barley the available hours are stated within the time span between the average date of maturity and the average maturity date of the following crop. For oats a period of two decades has been taken, while for wheat arbitrarily two alternative periods haven been taken: two (II) and three (III) decades.

From the large standard deviations shown in this table it is evident that the total number of available hours per year for a particular crop can vary appreciably. As is apparent from the detailed data provided in Appendix I, this pronounced variation is largely due to the variable harvest weather during the period 1950—1967. The annual variation in the number of available hours in the years up to 1950 is much less.

TABLE 11. Number of available combine hours in three moisture ranges for colza, barley, oats and wheat. Average of 36 years (1931—1967).

Crop	Period	Moisture range			Total	σ
		Colza < 10%	10—14%	14—28%		
		Grain < 19%	19—23%	23—28%		
Colza	22/7— 7/8	56	20	13	89	± 21
Barley	7/8—17/8	16	14	14	44	± 22
Oats	17/8— 6/9	75	17	20	112	± 33
Wheat II	17/8— 6/9	56	34	27	117	± 24
Wheat III	17/8—16/9	78	54	44	176	± 41
Total (oats and wheat II excluded)		150	88	71	309	± 55

The average total number of available hours from July 22 to September 16 is 309. During roughly half of this time colza and grain in the lowest moisture range can be combined: i.e. artificial drying is not strictly necessary. The colza and grain in the remaining 159 hours can only be combined if sufficient drying capacity is available. This shows that the annual harvesting capacity of one combine is nearly doubled if the required drying capacity is available.

It should be pointed out that the data in tabel 11 are valid for crops that are not lodged and without sprouting. Especially if sprouting occurs the kernel moisture contents will tend to be higher than those computed here, resulting in a relative increase of the available hours in the higher moisture ranges. No data are available on the influence of sprouting on the kernel moisture content as affected by the weather.

6.3 SUMMARY

The kernel moisture contents of the crops have been calculated for the harvest periods of the years 1931—1967. The results are presented as available combine hours in three moisture ranges within certain time spans. For the calculations the daily measurements of global radiation and the rainfall measurements at two meteorological stations, Wageningen and De Bilt, have been used. The amount of dew has been calculated on the basis of the number of night hours.

Two tests on the reliability of the calculations have been carried out in 1967. The results show that the measured available combine hours correspond quite well with the available combine hours computed with local meteorological observations (table 10). Further it was found that the influence of the initial kernel moisture content on the results is negligible.

The results of the calculations per year are shown in Appendix I and summarized in table 11. The large annual variation in available combine hours is due to the variable weather during the harvesting season. The average number of available hours from July 22 until September 16 is 309. Approximately 50% is in the moisture range where no immediate artificial drying is necessary.

7 COMBINE PERFORMANCE

7.1 INTRODUCTION

The performance of agricultural machinery is measured by the rate at which the operations are accomplished and by the quality of the work. The rate of machine performance, the machine capacity, is expressed in terms of quantity per unit of time. With most machinery the capacity is expressed in ha per hour; harvesting-machine capacity is quoted per hour as the weight of harvested material or as the weight of material handled, the throughput. The throughput of the combine therefore comprises the total weight of grain, chaff, straw and weeds that enter the header. In this chapter the combine capacity is expressed in weight of harvested grain (kg or ton [1]). This should be accompanied by the moisture content of the grain and straw and the grain straw ratio. Different time or work elements can be distinguished when a combine is harvesting:

Effective time: the time the combine is performing cutting and threshing operations; the combine capacity during this time element is the „effective capacity"

Net working time: the time the combine is working on the field; the combine capacity during this time element is the „net capacity". In 7.3 a detailed specification of the net working time is given

Available time: the time that soil moisture conditions and crop moisture conditions allow combining less the time when rain is falling

Time efficiency: the ratio of the net working time to the available time expressed as a percentage

Field efficiency: the ratio of the effective time to the net working time expressed as a percentage

Factors affecting these ratios are: the work organization, the size and shape of the fields, the combine characteristics, the work method and the conditions of crop and soil; they will be discussed on the following pages.

7.2 THE WORK ORGANIZATION AND THE SIZE AND SHAPE OF THE FIELDS

On the farm a number of 80 self-propelled combines are used for harvesting; technical specifications are presented in table 14. A team consisting of the heads of the grain sales and drying departments meets daily to decide the daily output. This decision affects the fields where the combines are to operate, the transport of the grain to the drying plants, the shipping from the drying plants and the maximum amount to be combined if the grain has

[1] metric ton (1000 kg).

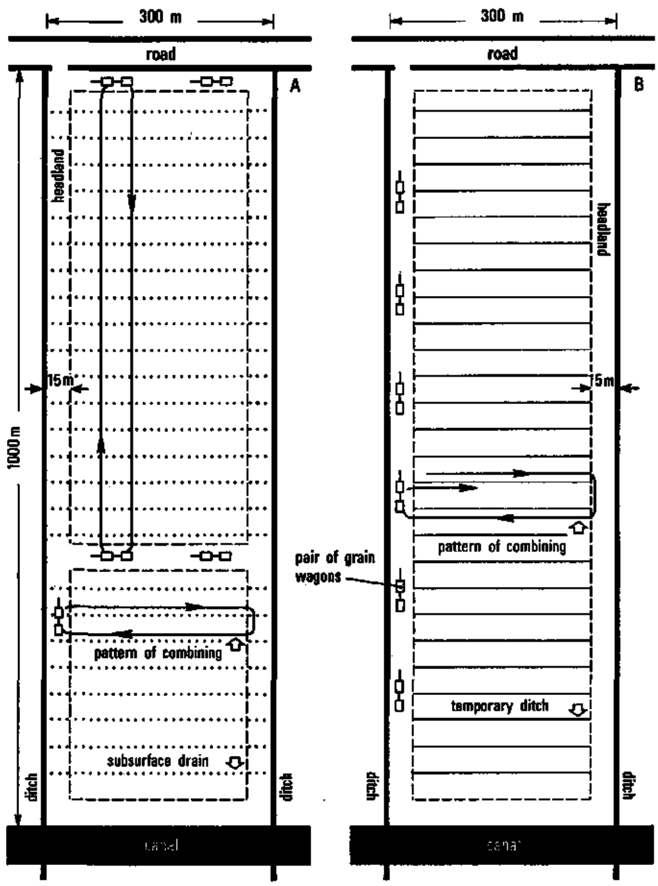


Fig. 21. Field pattern of combines on fields of 30 ha with subsurface drainage system (A) and temporary ditches (B).

to be dried. Important factors affecting this decision are: the moisture content of the grain, the weather forecast, the priorities for fields with weeds or with lodged crops, the market situation for certain crops and the available drying and storage capacity. As a result the field managers, each in charge of an area of approximately 1,500 ha, receive daily instructions on the quantity of the grain to be harvested and on the drying plant to which it has to be delivered.

The combines operate in groups of six on one field. The fields are 300 m wide and 1,000 m long (figure 21), they are situated in parallel strips on either side of a metalled farm road. Behind the fields is a main drainage canal; ditches run from the road to the canal down the length of the field. Two different drainage systems are found on the fields. One is a system of small open ditches with spacing at distances of 8 to 48 m across the field; these ditches are generally used for a few years after killing the reeds. The other is a subsurface drainage system that replaces the open ditches after the soil has dried sufficiently. Consequently there are two patterns of field operations which are shown in figure 21. In both cases headlands 12—15 m wide are first cut all round the field. The six combines work simultaneously on one sub-area. They unload into two grainwagons with a total volume of 16 m³, standing on one of the headlands. The size of the sub-area depends on the pattern of combining, the yield per ha and on the capacity of the wagons. For example, with a system of open ditches, a yield per ha of 4,900 kg (wheat) and two grainwagons with a total volume of 16 m³ the size of the sub-area is approximately 2.5 ha, with a width of 90 m and a length of 280 m.

7.3 ANALYSIS OF TIME ELEMENTS ASSOCIATED WITH COMBINE HARVESTING

The time elements spent in combine harvesting operations and the definitions used are shown in table 12. The definitions are mainly based on the recommandations of an O.E.C.D. report (ANON, 1965).

TABLE 12. Time elements in combine harvesting.

Available time			*a.* Machine preparations before and after the harvest
	Net working time (net capacity)		*b.* Repairs during harvesting
			c. Operator off duty
			d. Daily servicing of the machine
		Effective time (effective capacity)	*e.* Machine is cutting and threshing at an optimum forward speed
			f. Turning
			g. Discharging [1]
			h. Control and inspection by the operator (chain and belt tightening, other adjustments) [1]
			j. Travel (on the field and from one field to another)
			k. Waiting (because of shortage of grainwagons)
			l. Waiting (due to shortage of drying or storage capacity)

[1] Including rest allowance.

Not all of the time elements are commonly charged against combine operations and combine capacities are often termed differently. HUNT (1965) defines the effective capacity as the capacity during the time elements b, e, f, g and h; the field efficiency is the ratio of the elements: $\frac{e}{b + e + f + g + h}$.

DRICOT and PAUWELS (1960) define the „rendement global du chantier" as the ratio of the time elements: $\frac{e + h}{f + g + j}$. POSTMA and VAN ELDEREN (1963) and MOENS (1959) use the internationally adopted framework for a presentation of work requirement data as proposed in the O.E.C.D. report. They define „task-time", expressed in manhours, as the gross time for a certain amount of work; they charge the elements c, e, f, g, h, j and k against the combine operations. A report (ANON, 1967) on comparative tests with combines charges the elements e, f, g, and h against combine operations; the combine capacity during these time elements is referred to as „gross capacity". All writers charge the elements b through k in whole or in part to the combine operations. The element a, for preparations before and after the harvest, is usually ignored.

For the purpose of this study and for computations of machine capacities in general, the time elements b through k have to be known in connection with the available time, only then the time efficiency can be determined.

The available time

As seen from the definition, the available hours are limited by soil and crop moisture conditions. The numerical values of these limiting conditions will now be considered. Soil conditions can stop combine operations if the moisture content becomes so high that the rolling resistance of the soil increases to a point where the combine can no longer move forward. This, however, occurs so seldom on this farm that this influence on the available time need not be considered.

The condition of the crop can also stop combine operations when the moisture content rises above a certain level. VOIGT (1955), FEIFFER (1962) and GELS (1959) advise that a combine should only operate in cereals if the grain moisture content is below 20%. Their opinion is based on the diminishing combine capacity and on the consequence of artificial drying of the grain when threshed with a higher moisture content. Actually from our experience the straw moisture content is the limiting factor for combine operation. When the straw moisture content reaches a certain level the threshing cylinder gets stuck and the separating and cleaning mechanisms stop functioning.

ZUIDEMA (1965) investigated throughout one season the influence of the straw and grain moisture content on the rate and quality of combine harvesting of a wheat crop with few weeds. He reported a diminishing effective combine capacity as the straw and grain moisture content increased, kernel losses remaining the same. He concluded that the combine can operate with a reduced capacity up to a straw moisture content of approximately 40%. Combine harvesting above this level is hardly possible as the clogging of the threshing and separating mechanisms causes a sharp increase of the losses and of the number of breakdowns. The level of 40% is only valid when the straw is ripe and a small amount of green matter (weeds, undersown crops) is present. When the straw is not ripe and/or green matter is present the level will be lower; it will be higher when the straw is dead ripe and no green matter is present.

On account of the linear relationship between the grain and straw moisture content (figure 20) this upper limit can also be expressed as corresponding to a grain moisture content of 28% [1]. This linear relationship does not hold during the hours after sunrise and before sunset, when the straw moisture content is higher than that predicted from the linear relationship in figure 20. Therefore the beginning and the end of the available time cannot be determined by the grain moisture content during these hours. Daily observations concerning these times were carried out by some combine operators in August, 1966, for wheat after nights without rainfall. Combine harvesting was judged possible when no clogging of the threshing cylinder occurred during combine harvesting. These observations showed that the beginning varied between 8 a.m. and 10 a.m., while the end varied between 6.30 p.m. and 8 p.m. Consequently the beginning and end of the available time in July and August have been fixed for this study at 9 a.m. and 7 p.m. respectively. In September the available time will be shorter which is caused by the lengthening of the nights. Therefore from September 15 on, the beginning and end of the available time have been fixed at 10 a.m. and 5 p.m. respectively.

In determining the available hours, the quality of the threshed grain has also to be considered. The quality of threshed grain as affected by combine harvesting is usually reported in terms of damaged kernels, test weight, germination and germinative energy. The effect of kernel moisture content on the quality of combine harvested grain has been investigated by:
MITCHELL *et al* (1955, 1955*a*) who investigated the quality of barley and wheat as affected by moisture content, cylinder speed and concave clearance; THIELEBEIN and FISCHNICH (1957) who investigated the quality of rye as affected by moisture content, cylinder speed and different cylinder bars; JOHNSON (1959) who investigated the quality of wheat as affected by moisture content and different cylinder and concave types; our own investigations concerned the amount of split kernels in wheat as affected by moisture content (ZUIDEMA, 1965*a*).

The effect of mechanical treatment can be summarized as follows. The effect of cylinder speed is for germination and germinative energy to fall with an increase in cylinder speed from 1,000 r.p.m. to 1,500 r.p.m. while the visual damage tends to increase. Up to about 25% moisture content the effect is small; above this level, however, the effect of increasing cylinder

[1] The transshipment plant (conveying equipment and dryer) can also limit harvesting. It was observed that the drying plant cannot handle wheat with a higher moisture content than 30% on account of clogging (Personal communication, BIES).

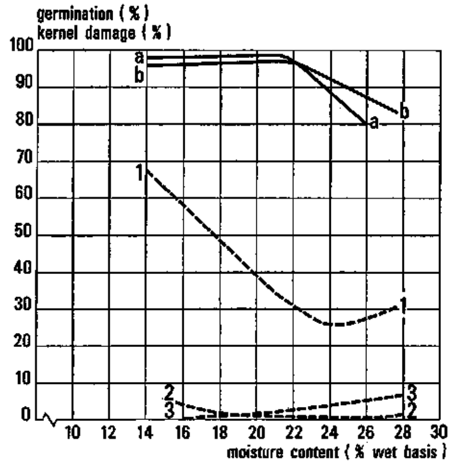


Fig. 22. Effect of kernel moisture content on the quality of combine harvested wheat.

germination

a. JOHNSON (1959)
b. MITCHELL (1955)

kernel damage

1. visual damage (% grains) MITCHELL (1955)
2. kernels split (% weight) ZUIDEMA (1965*a*)
3. kernels split (% weight) JOHNSON (1959)

speed becomes more marked. The effect of the concave setting is not so marked as that of cylinder speed, although the germination tends to decrease the closer the concave is set.

Some of the results for wheat obtained with optimum combine setting are presented in figure 22. The results are similar except for the increase in kernel damage with a higher moisture content as reported by JOHNSON. The reason for this difference is not clear as JOHNSON did not succeed in minimizing the kernel damage with different cylinder and concave types while THIELEBEIN and FISCHNICH report that a decrease in kernel damage of rye can be obtained with rubber cylinder bars. From these data it appears that below 16% moisture content a marked increase in the number of visibly damaged kernels occurs although this takes place without any outstanding reduction in germination. Above 22% moisture content a pronounced decline of germination begins.

The evidence suggests that, from the standpoint of the resulting grain quality, the optimum moisture content range in which to harvest wheat is between 16 and 22%. This result is also valid for barley (MITCHELL *et al*, 1955*a*), no data are known for oats and colza.

The quality requirements for the threshed wheat as discussed in 3.4 show that the reduction in grain quality caused by threshing at moisture contents up to 28% need not be a limiting factor for combine harvesting. Thus the available time for harvesting wheat can be defined as that part of the time between 9 a.m. and 7 p.m. when the grain moisture content is below 28% less the time when rain is falling. Based on some observations in 1968 concerned with combine harvesting at different straw moisture contents in barley, oats and colza it is assumed that a similar definition of the available time will hold for these crops, with the exception that for colza the maximum moisture level is 18%.

Net working time and effective time

By definition, the net working time is the available time less time losses due to daily servicing, repairs, the operator's off duty time and waiting time.

The daily servicing includes lubrication, refueling and cleaning of the separating mechanisms; this requires about two man hours a day. As work starts at 7 a.m., daily servicing will be finished by 9 a.m.; thus the time for daily servicing is outside the available time and need not be considered as a time loss.

Time losses due to repairs are affected by the reliability of the particular make and model of combine, the condition of the crop and the availability of a repair crew. The factors were investigated for three consecutive seasons with a group of 30 combines under conditions prevailing at the farm; DE JONG (1965) reported that the average time loss due to repairs amounted to 4% of the available time.

Time losses caused by operator's off duty time are governed by the conditions of employment. During the harvesting season working hours are from 7 a.m. to 7.30 p.m. from Monday to Friday, including two hours overtime. Work on Saturday is overtime, but the harvest continues from 7 a.m. to 4 p.m. if the weather is favourable. No work is done on Sunday. Three breaks of 20 minutes each are included each day from Monday to Friday and two on Saturdays. Consequently, from 9 a.m. Monday to 4 p.m. Saturday the combine does not operate for 11% of the available time assuming that these time losses are proportional to the available time.

The sum of these factors causes a total time loss of $4 + 11 = 15\%$. Thus the time efficiency is 85%. Here the waiting time (*k* table 12) is ignored.

The following time elements are associated with the net working time (table 12):

e. Effective time
f. Turning time
g. Discharging time
h. Time for control and inspection by the operator
j. Travel time
k. Waiting time

The relative importance of these time elements is affected by the following factors:

a. Forward speed of the combine

The relative value of the effective time decreases as this increases.

b. Size and shape of the fields

These factors affect the turning time and the travel time. FLEMING (1960), FIL (1963), RIGHOLT (1962) and VAN ELDEREN (1966) have investigated their effect. They concluded that they can be ignored in rectangular fields larger than 10 ha.

c. Pattern of combining

This factor affects the turning time and the travel time on the field; it concerns the division of the field into sub-areas, the headland pattern, the routing and the different ways of cutting at corners. The effect of this factor is extensively discussed by FLEMING (1960) and HUNT (1965).

d. Position of the grain wagons

The greater the load capacity of the wagons the farther apart they should stand on the headland, consequently the turning time will increase.

e. Soil and crop conditions (yield, lodging)

These factors affect the effective time and the turning time. The relative value of these factors increases with high yields and a rough surface.

f. Organization

This factor affects the waiting time and the travel time. It mainly depends on the number of combines working together on each sub-area and the order in which the fields are worked.

A description of the factors under *b*, *c*, *d* and *f* is given under 7.2. As they are on the average fairly constant on the farm it is assumed that their relative values do not vary much. The time elements were measured over periods of 10 days in 1966 and 1967 in wheat and barley, standing crops,

TABLE 13. The average time elements of the net working time of a combine.

Time elements	% of net working time		minutes
e. Effective time		65.1	2.3 min/100 m
f. Turning time			
on headland without grain wagon	3.1	10.7	0.6 min each
on headland with grain wagon	7.6		1.4 „ „
g. Discharging		7.4	1.4 „ „
h. Servicing by operator		6.0	32.4 min per day [1]
j. Travel time		7.8	42.1 „ „ „
k. Waiting time			
unloading	1.4	3.0	7.6 „ „ „
for grain wagon	1.6		8.6 „ „ „
Net working time		100.0	

[1] 9 a.m. — 7 p.m.

with yields between 5,000 and 6,000 kg per ha, grain moisture content approximately 20%, 5.4–m combines, drainage system with open ditches or with subsurface drainage. The results are shown in table 13.

Field efficiency of the combine is 65.1%. The turning time, at 10.7%, is rather high. This is due to the average distance of 90 m between the pairs of grain wagons (total volume 16 m^3) and to the fact that sometimes the grain wagons are not stationed in the right place or are not fully loaded after harvesting of the sub-area. In this case a combine sometimes has to travel back from another sub-area to finish filling the wagons.

The waiting time amounts to 3%; nearly half of this is due to the concentration of six combines in one sub-area of approximately 2.5 ha. Though two combines can unload simultaneously into a pair of grain wagons, it sometimes happens that a third combine has to wait.

The travel time includes travelling to and from the work (on the field) moving on to the next sub-area and moving from field to field. Both travel time and turning time will decline between 30 and 40% of the present value in the near future when the width of the fields is increased from the present 300 m to 500 m; this will raise the field efficiency to 70%.

Time losses due to incidental factors such as sudden absence of the operator (illness), travelling to distant fields and adjusting the combine for a next crop have not been measured. The time losses due to these factors have been arbitrarily fixed at approximately 5%. Thus under these circumstances the field efficiency of the combine is approximately 60%.

7.4 EFFECTIVE COMBINE CAPACITY

7.4.1 *Effective combine capacity and separating loss*

The effective capacity is expressed in kg grain per hour. The term separating loss as used here denotes the kernel losses from straw walkers and shoe at the rear of the combine. The optimum travel speed and the optimum setting of the combine are primarily determined by the separating losses from the rear of the machine. Therefore the separating losses are the dominant criteria of combine performance. Sometimes other factors can be the dominant criteria: roughness of the field, a low yielding crop or a lodged crop; these factors will not be considered here.

The mechanism of the combine performs five operations: cutting, feeding, threshing, separating and cleaning. The flow of material into the combine is as follows. Grain and straw are fed into the cylinder where threshing takes place. Up to 90% of the threshed grain penetrates the concave and concave extension; the remainder is discharged on to the straw walkers with the straw. At higher feed rates more kernels are dumped onto the straw rack along with a greater amount of straw. The losses over the straw walkers

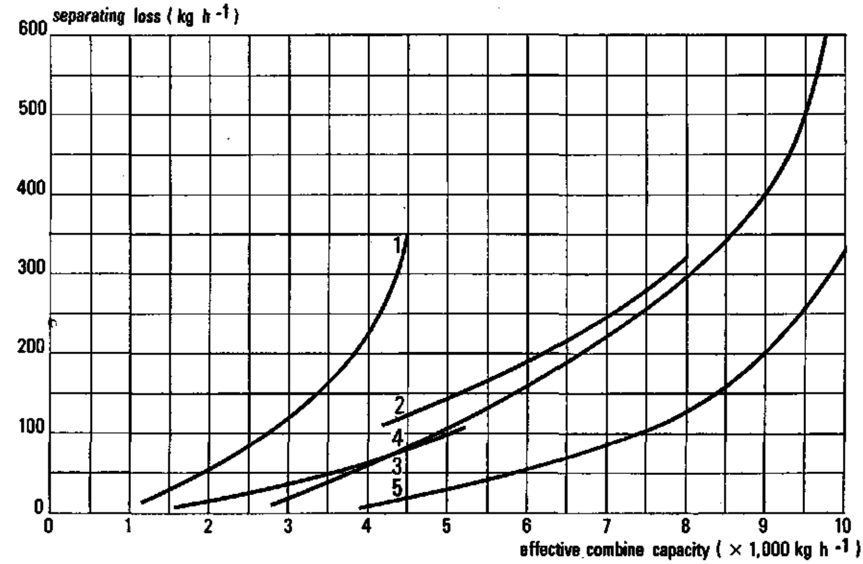


Fig. 23. Separating loss curves of a combine in various countries under different conditions (wheat). Modified data of MARK (1963), losses and capacities at 20% wet basis.

	grain straw ratio	straw and kernel moist. cont. (% wet basis)	
1. Italy	0.85 : 1	7.5	9.2
2. England	1.14 : 1	13.0	15.5
3. France	1.21 : 1	9.7	11.5
4. Germany	1.05 : 1	16.0	16.5
5. U.S.A. (Idaho)	1.42 : 1	8.0	9.2

increase rapidly at a higher feed rate as the bed of straw over the grid prevents the kernels from falling through. Losses also increase with a lower grain straw ratio (at a given feed rate) and with a higher moisture content, as shown by JOHNSON (1959), VAN DER KANT (1962), ZUIDEMA (1965) and WIGCHERING (1966). MARK *et al* (1963) report that shoe losses rise if the load to the sieve becomes excessive; this happens with dry, mature straw (moisture content less than 10%), which desintegrates readily. In this region, with relatively high moisture contents and a low grain straw ratio, the kernel losses over the straw walkers form the major part of the separating losses; with grains the shoe losses can generally be avoided.

The characteristic pattern of the separating loss curves is similar for combines operating in different regions of the world but differs in quantitative values, as MARK *et al* (1963) show. The results, reproduced in figure 23 demonstrate that the losses increase rapidly with increasing feed rates.

Combine size is generally expressed by the width of the cutter bar. It is obvious from the foregoing that this indication is not altogether adequate as the effective combine capacity is limited primarily by the threshing and separating mechanisms. A technical specification of two types of combines on the farm is therefore given in table 14. They were used in the various investigations regarding the effective combine capacity. In the text they are indicated by the width of the cutter bar: 3.6-m and 5.4-m respectively.

TABLE 14. Specifications of the combines on the farm.

	Unit		
Cutter bar	m	3.6	5.4
Engine power (DIN)	hp	80	105
Cylinder			
diameter	cm	60	60
width	„	100	128
Straw walkers			
length	„	314	360
width	„	100	129
Sieve area	m^2	2.06	2.89
Tank volume	m^3	2.0	2.8

The characteristic loss patterns of the 3.6-m combines were investigated during one season uuder conditions prevailing in the region (VAN DER KANT, 1965), The loss curves are shown in figure 24. Also shown are three lines representing losses of 25, 50 and 100 kg per ha respectively. The data were obtained in wheat, the straw and grain moisture contents being approximately 20%. The various feed rates were obtained by using different travel speeds with optimum setting of the combine for each speed; the variation in grain straw ratios was obtained by cutting at different heights. The curves in figure 24 show that the losses increase with an increase in feed rate. The increase, however, is much less with higher grain straw ratios. The main reasons for this are the smaller amount of straw in relation to the amount of grain and a lower straw moisture content because of the unequal distribution of the moisture in the straw (table 8). The effect of the level of losses on the effective combine capacity can also be shown. For example, the effective combine capacity will amount to 6,000 kg with a stubble of 18 cm and losses at 25 kg; this capacity can be increased to approximately 6,700 kg with losses at 50 kg and to approximately 7,500 kg with losses at 100 kg.

It should be noted that the possibility of leaving a higher stubble applies in practice only to wheat as this crop usually does not lodge. Barley and oats usually have to be cut at a height of approximately 20 cm on account of lodging.

The effective combine capacity is thus greatly affected by the grain straw ratio (the stubble height) and the level of losses permitted. The instructions

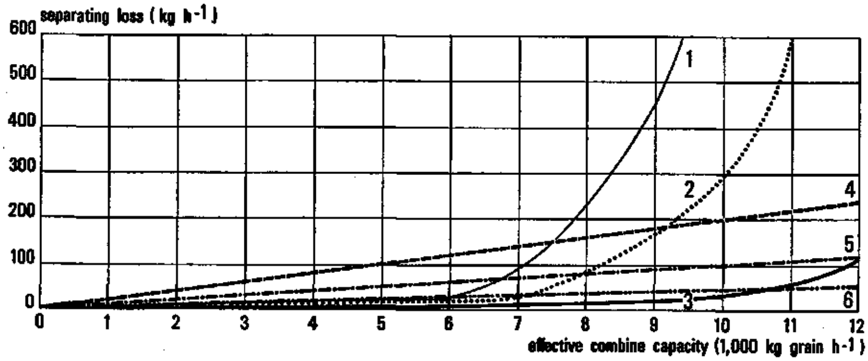


Fig. 24. Separating loss in wheat as affected by effective combine capacity and grain straw ratio. Data of 3.6-m combines, losses and capacities at 20% wet basis, (VAN DER KANT, 1965).

1. stubble height ± 18 cm (grain straw ratio: 1.07 : 1)
2. „ „ ± 33 cm „ „ „ : 1.40 : 1)
3. „ „ ± 45 cm „ „ „ : 2.00 : 1)
4. permitted losses per hour based on a loss of 100 kg per ha
5. „ „ „ „ „ „ „ „ „ 50 kg per ha
6. „ „ „ „ „ „ „ „ „ 25 kg per ha

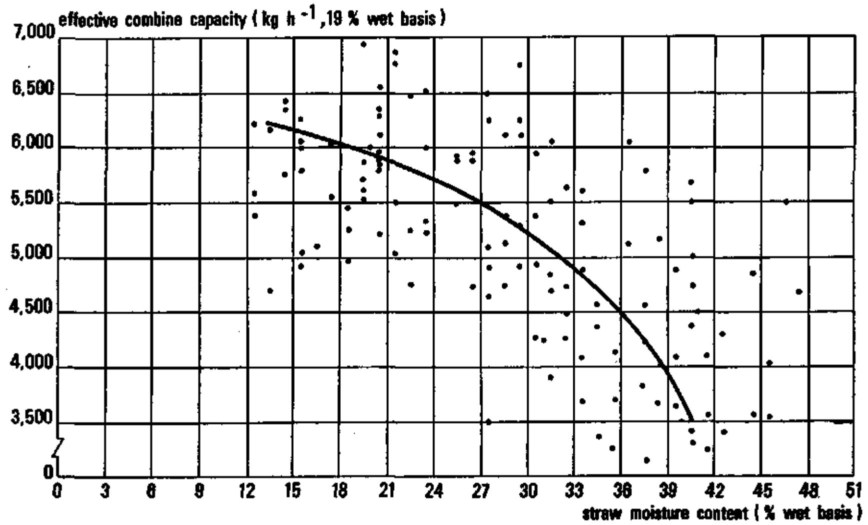


Fig. 25. Effective combine capacity (3.6-m combine) as affected by straw moisture content (wheat) (ZUIDEMA, 1965).

in force on the farm are such that stubble height and permitted losses are at the minimum levels which can be attained reasonably in practice: 20 cm and 0.5% of the yield. These instructions raise the farm's gross income as this stubble height permits to sell the straw from swath and this level of losses keeps the losses at a minimum. With a higher stubble the straw cannot be sold and the remaining straw and stubble must be destroyed by burning or by chopping. However, these instructions lower the combine capacity thereby raising the costs of combining. Whether the instructions are justified i.e. whether the extra costs for combining are offset by the extra income will be discussed in 11.3.*b*.

Comparative tests in wheat with 5.4-m combines showed similar losses with effective hourly capacities of 2,500 to 3,500 kg higher than with 3.6-m combines (VAN DER KANT, 1962).

7.4.2 *Effective combine capacity under influence of crop moisture conditions*

The moisture content of the crop, including weeds, greatly affects the combine capacity. ZUIDEMA (1965) reported on the influence of the straw and grain moisture content on the effective combine capacity. Measurements were made during one season with a group of six 3.6-m combines operating in barley, oats and wheat. As the straw of barley and oats was not ripe the straw moisture content hardly varied during the investigation, so the influence of this factor on the combine capacity could not be established. The data for wheat were obtained between 8 a.m. and 6 p.m. in a ripe crop; yields were 4,900 kg grain and 5,000 kg straw per ha, stubble height approximately 20 cm and kernel losses not exceeding 25 kg per ha. The results given in figure 25 show that the points are widely scattered which is largely due to the difficulty in obtaining reliable straw samples from the swath. A line has been drawn through the scattered points, assuming an exponential relationship between the straw moisture content and the effective capacity in this moisture range. From this line can be estimated that on the average the effective capacity decreases by approximately 100 kg for each unit percent rise in straw moisture content.

It is however necessary to relate the effective capacity to the kernel moisture content as this figure is more easily available. The linear relationship between straw and kernel moisture contents shown in figure 20 can be used for this purpose. From this figure we may conclude that the effective capacity decreases by approximately 200 kg for each percent increase in kernel moisture content.

No data are available for colza, barley and oats; it is assumed that the decrease, expressed as a percentage of the effective capacity in the lowest moisture range, for these crops will be similar. The same also holds for the 5.4-m combines.

7.4.3 *Effective combine capacity under average crop conditions*

Crop conditions, such as grain straw ratio, yield, straw maturity, presence of weeds and lodging show a wide variation and, consequently, the effective combine capacity also varies. Capacity ratings should therefore be valid for the average crop conditions in the field. The effective capacities of 3.6-m and 5.4-m combines were measured during two seasons. The average crop and moisture conditions were as follows: grain moisture content 19% (colza 10%), few weeds (mostly reeds), little lodging, mature straw, separating losses not exceeding 0.5% of the yield, stubble height 20 cm. The results are presented in table 15 together with the average grain yields. Also the effective capacities at different grain moisture contents are shown and, for wheat also with a stubble of 45 cm. These figures have been computed from the data given under 7.4.1 and 7.4.2. The results shown can be used to compute the net capacities (60% of effective capacity).

TABLE 15. Effective capacities (kg h^{-1}) of 3.6-m and 5.4-m combines for three grain moisture ranges and two stubble heights (wheat only).

Crop		Colza	Barley	Oats	Wheat		
Stubble height (cm)		40 (swath)	20	20	20	45	
Grain yield (kg/ha)		2,700 [1]	4,000 [1]	5,000 [1]	4,900 [1]		
Moisture range (%)							
Colza	Grain						
< 10	< 19	3,000	5,900	5,800	6,000	8,800	3.6-m combine
10—14	19—23	2,800	5,500	5,400	5,600	8,200	
14—18	23—28	2,400	4,700	4,600	4,800	7,000	
< 10	< 19	4,200	8,300	8,200	8,400	12,500	5.4-m combine
10—14	19—23	3,900	7,700	7,600	7,800	11,600	
14—18	23—28	3,400	6,600	6,600	6,700	10,000	

[1] Yields at moisture contents 10% and 19% for colza and grain respectively.

7.5 SUMMARY

Combine performance is measured by the travel speed and efficiency with which the operations are accomplished. The rate of combine performance, the combine capacity, is expressed in kg or ton grain per hour. The terms used are as follows:

Available time: that part of the time between 9 a.m. and 7 p.m. that the grain moisture content is less than 28% (colza 18%) and no rain is falling. Below this moisture content the effect of combining on the grain quality can probably be neglected at the level of quality required at present.

Net working time: the available time between Monday 9 a.m. and Saturday 4 p.m. less time for repairs and operator's off duty time. The net working time averages 85% of the available time (time efficiency). Capacity during this time is the net capacity.

Effective time: the time during which the machine is cutting and threshing at an optimum forward speed under average crop conditions. The effective time is 60% of the net working time (field efficiency). Capacity during this time is the effective combine capacity.

Separating loss, the loss from shoes and walkers, is the principal criterion of effective combine capacity. It increases with higher feed rates. Graphically this relation may be expressed by a loss curve. The quantitative values of the loss curves of wheat are primarily affected by the grain straw ratio (figure 24) and the straw moisture content (figure 25). The effective combine capacity increases with an increase in grain straw ratio and with a higher level of separating losses (figure 24). For each percent rise in straw moisture content the effective combine capacity decreases by approximately 100 kg (figure 25), or 200 kg for each percent rise in kernel moisture content (figure 20). It is assumed that this effect is also valid for colza, barley and oats. The effective capacities of 3.6-m and 5.4-m combines have been calculated with these data and with the data on effective capacities under average crop conditions and prevailing instructions (table 15).

8 TRANSPORT AND CONVEYING OF THE GRAIN

8.1 INTRODUCTION

The transport of the threshed material from the field to the drying plant is a part of the harvesting process consisting of threshing — transport — unloading — conveying — drying and temporary storage. The total net capacity of the combines is the main factor determining the required capacity of each of the subsequent links in the chain. The hauling distance is an additional factor to be taken into account when determining the transport capacity required. Since the net combine capacity is expressed in kg or ton per hour while the distance is stated in km, the transport capacity is usually expressed in ton.km h^{-1}. In addition the transport capacity is also expressed as the number of transport units needed, for which the capacity (m^3 or tons) and the speed (km h^{-1}) should be known. The latter method of expression, number of transport units, will be used.

On the field the combine transfers the threshed product into a container for transport. For the subsequent transport from the field to the drying plant, road or water transport may be used, the choice being determined primarily by the cost. This, in turn, depends mainly on the fact whether access to the field and the drying plant is easier by road or by water and on the distances to be covered. Since all fields of this farm are on metalled roads and only a few on navigable canals, it is assumed, partly from the cost calculations for paddy transport [1], that road transport is to be preferred owing to the lower cost.

For the calculation of the required transport capacity in combination with various harvesting machines transportformulae have been developed and discussed by TISCHLER (1959, 1960), REICHENHEIM (1960) and others. Using one of these formulae SZESNY (1963) calculated the transport equipment needed for a large farm. BOONMAN (1966) used the formula of TISCHLER to describe the transport organization on a family farm in the Netherlands during the harvesting of grains and potatoes. VAN DUIN and LINTHORST (1962) developed and applied a similar formula to investigate the influence of the distance over which excavated earth has to be moved on the choice of the means of transport. VAN ELDEREN (1966*a*) and HARTLOPER (1967) programmed a number of models of harvest transport systems in order to find the optimum wagon type for a family farm. ZIMMERMAN (1967) described large wagons used on some wheat farms in the U.S.A.

[1] A cost calculation for alternative transport by road or canal was carried out for paddy transport in the Wageningen Polder in Surinam. All fields had direct access to both roads and navigable canals. At a distance of about 15 km the cost of the two methods proved to be the same (ANON, 1967*a*).

So far as noticed from the recent literature, the optimization of the transport on a large-scale farm as influenced by harvest organization and size of transport equipment has received little attention. In this chapter the results are given of the investigations into this problem under the circumstances prevailing on the farm.

8.2 SELECTION OF THE TRANSPORT EQUIPMENT

8.2.1 *Possibilities and limitations*

For transport three systems were considered which are used presently in agriculture for field to plant transportation of products:

I. Wagons hauled by wheeled tractors from the field to the plant; this system is applied for relatively short distances (maximum 10—15 km)

II. Trucks or self propelled wagons from the field to the plant; this is applied for medium and long distances (more than 10—15 km), a prerequisite is that the trucks must be able to travel in the field

III. A combination of above two methods, i.e. grain wagons for transport in the field and trucks for transport on the road; this is applied for long distances (more than 20 km) when soil conditions do not permit trucks travelling in the field

Within technical and other limitations, the selection of the system is determined by the cost. The limitations are:

a. Soil trafficability

b. Access to the fields

c. Hauling distance

d. Type of material hauled

e. Government regulations on the use of agricultural vehicles on the roads

f. Alternative use of transport equipment at other times of the year

a. Soil trafficability

There are no metalled tracks on the fields. Soil trafficability depends to a great extent on the bearing capacity of the clay soil ($35\% < 2\mu$). The bearing capacity as used here is to denote the maximum contact pressure of vehicle tires, above which limit the vehicle is apt to sink. The bearing capacity of the clay soils under weather conditions during harvest time depends mainly on the time since draining. Immediately after draining the polder it is very low (50 gr cm^{-2}), then it increases gradually through evaporation and construction of a field drainage system. After approximately 5 years the bearing capacity varies between 500 and 800 gr cm^{-2} (VAN KAMPEN, 1964). Therefore the contact pressure of the transport equipment must be such that the minimum limit is not exceeded. This limit should be observed strictly since owing to the short time the soil has had to ripen the bearing capacity is lower in the deeper layers. In view of this limitation, transport of grain by trucks in the field is eliminated. This means that transport in the field has to be carried out with grain wagons.

b. Access to the fields

The fields (figure 21) are all on metalled roads; an earth dam 10 m wide connects the fields with the roads. The metalled road is 3.5 m wide; with a permissible load of 10,000 kg per axle it is adequate for heavy trucks. The verges on either side of the metal are about 5 m wide.

c. Hauling distance

If distances are short, the cost of transport by wagons direct from combine to drying plant is less than when the grain is transferred into trucks, since it is not possible to take full advantage of the larger capacity and speed of the trucks. The difference in cost becomes less as distances increase; after the break-even point the cost with transfer into trucks becomes less than of

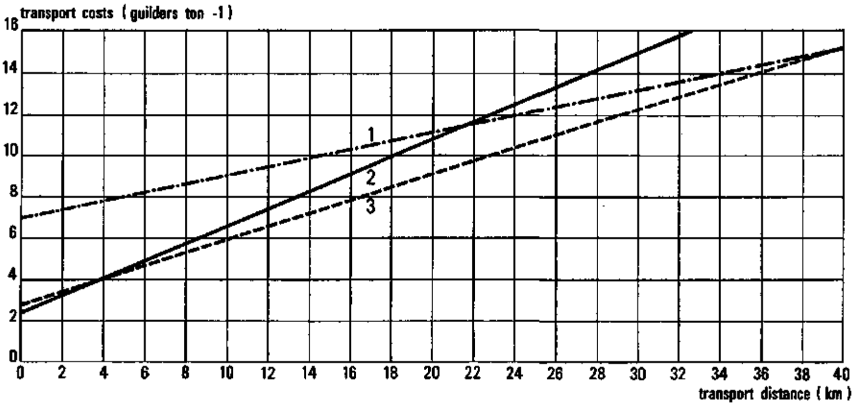


Fig. 26. Costs of grain transport (in guilders per ton wheat) as affected by distance and transport system. Computed with formulae 8.6, 8.9 and 8.10.

1. wagons, tractors (as in 2) and trucks (trailers, vol 25 m^3); loading at transfer centres; average distance from field to transfer centre 5 km; speed 40 km h^{-1}; cost per harvest season, driver included, f 8,000
2. wagons, medium tractors (tractors 50 pk; wagons vol 4.5 m^3); speed 20 km h^{-1}; cost of tractor, operator included, and wagon per harvest season f 4,200 and f 500 respectively
3. optimal wagons and tractors (tractors 100 pk; wagons vol 8m^3); speed 25 kmh^{-1} cost of tractor, operator included, and wagon per harvest season f 5,000 and f 1,100 respectively.

direct transport with wagons. A comparative cost calculation for both systems (figure 26, 1 and 3) shows that the break-even point is reached at a distance of about 40 km. Since distances larger than 40 km do not occur on the farm, a transport system with transfer into trucks has been eliminated.

d. Type of material hauled

Grain is a granular material that can be transported in bulk. A factor of importance for unloading is that the minimum tipping angle for unloading grain with a moisture content of 28% is about 45°. At lower moisture content the angle required is smaller.

e. Government regulations on the use of agricultural vehicles on the roads

Because of the special circumstances relating to this farm a number of exemptions from the national traffic regulations have been granted. However, in due time the same safety measures may be introduced, so the national regulations should be taken into account when designing a transport system. The most important regulations applied in the Netherlands in 1967 are:

Maximum speed: 16 km h^{-1}, provided both tractor and trailer are fitted with brakes. The braking capacity has to be at least 1 m sec^{-2} which amounts to a stopping distance of 9.85 m. The speed limit will presumably be raised to 25 km h^{-1} in the future: if the braking capacity is then kept at 1 m sec^{-2} this will amount to a stopping distance of 24 m
Maximum width: 3 m
Maximum length: 18 m
Maximum number of wagons that may be towed by a tractor: 2
Maximum wheel load: 2,400 kg

A tractor may therefore tow two four wheeled wagons of 9,600 kg each and the stopping distance should be a maximum of 9.85 m at a speed of 16 km h^{-1}.

f. Alternative use of transport equipment at other times of the year

Other possible uses on the farm for the equipment selected should also be considered. In the first place other materials to be transported are limited to the spring time transport of 6,000 tons of fertilizers, which is only 9% of the annual grain tonnage. Secondly, the selection may be influenced by other work to be done. This relates primarily to the tractors, that are used for other farm operations.

Crawler tractors are, owing to their small ground pressure, required for the reclamation of the soils and for fall tillage operations during the years that the soil bearing capacity does not allow tillage operations with wheeled tractors. The resulting peak which determines the number of crawler tractors required is shown in figure 27. Specifications of the crawler tractors at present available on the farm are reported in table 16.

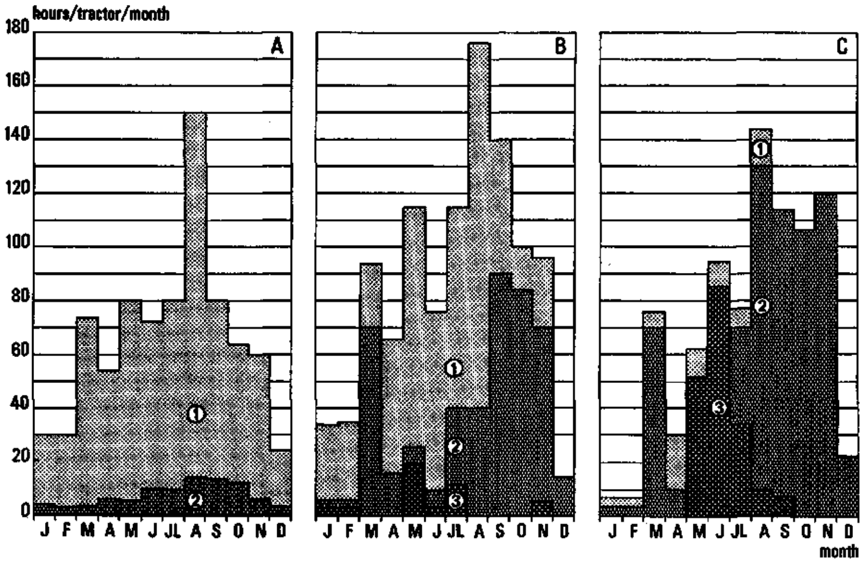


Fig. 27. Work diagram of tractors on the farm in average tractor working hours per month (1967).

A. wheeled tractor „medium"
B. wheeled tractor „large"
C. crawler tractor

1. miscellaneous (mostly transport)
2. tillage operations (farm)
3. tillage operations (reclamation)

Wheeled tractors are required for transport, application of fertilizer, spraying, mowing and other operations requiring relatively high speeds. Until a few years ago only medium size tractors (50 hp) were available in the Netherlands. These tractors could not compete in the cost and quality of tillage operations with the crawler tractors; therefore, they were not used for large-scale tillage operations. The large wheeled tractors (100 hp) that have become available have proved to be competitive with crawler tractors in tillage operations on soils with a sufficient high bearing capacity (> 500 gr cm^{-2}; BERKERS and VAN DER KANT, 1965). These large wheeled tractors have substituted some of the crawler tractors for part of the tillage operations. This can be seen from the workdiagrams of the medium and the large tractors on the farm as shown in figure 27.

Technical details and some data on drawbar pull of the tractors (BERKERS and VAN DER KANT, 1965) are reported in table 16.

From the discussion of the factors *a* to *f* follows that it is desirable to use special-purpose wagons for hauling the grain from the field to the plant. In designing this special-purpose wagon the above described limitations should be observed.

TABLE 16. Specifications of the tractors present on the farm in 1968.

	Unit	Crawler tractors	Wheeled tractors Medium	Large
Power (power take-off)	hp	60	50	100
Weight	kg	6,400	2,300	4,100
Tracks				
length (on ground)	cm	184	—	—
width	„	61	—	—
Tyres (rear)			14—30	15.5—38
Ground pressure	$g\ cm^{-2}$	280	—	—
Drawbar pull [1]	kg	5,000	1,700	2,600
and speed	$km\ h^{-1}$	2.2	3.3	2.9
Drawbar pull [2]	kg	3,000	700	1,500
and speed	$km\ h^{-1}$	2.2	3.3	2.9

[1] First gear, dry soil.
[2] First gear, soil condition stated as „poor" during harvesting.

At present even larger tractors (140 hp) are available. They are however too heavy for these soils.

Trucks (5 ton) are only required to a limited extent on the farm for transporting light equipment, seed and fertilizers.

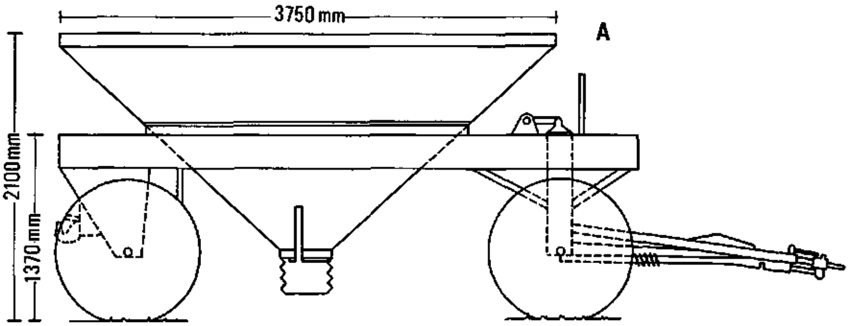
8.2.2 *The optimal size and design of the grain wagon*

The optimal design of a grain wagon is determined by the cost of transport; the design is optimal when the costs of transport are minimum. The many factors involved in designing an optimal wagon for transport of harvested products on a family farm have been programmed by VAN ELDEREN (1966*a*). With this program the transport costs can be calculated for different values of the factors involved.

In developing an optimal grain wagon for the farm, calculations of transport costs have been omitted. It was arbitrarily assumed that the minimum costs of transport are obtained with the largest load capacity possible within the above mentioned limitations. The limiting factors are: bearing capacity of the soil, tractive power of the tractors and traffic regulations on the use of agricultural vehicles.

Two types of wagons have been designed with a load capacity of 8 m^3 (figure 28, table 17) and 10 m^3 respectively. Both wagons have a hopper-type container, the angles of inclination of the hopper sides vary between 45° and 60°. When the flap valve in the bottom of the hopper is opened the wagon can be emptied in one minute.

A number of tests have been carried out comparing these wagons with the 4.5 m^3 ones already in use on the farm. Stopping distances were measured on the road with pairs of wagons towed by a 100-hp wheeled tractor. Draft



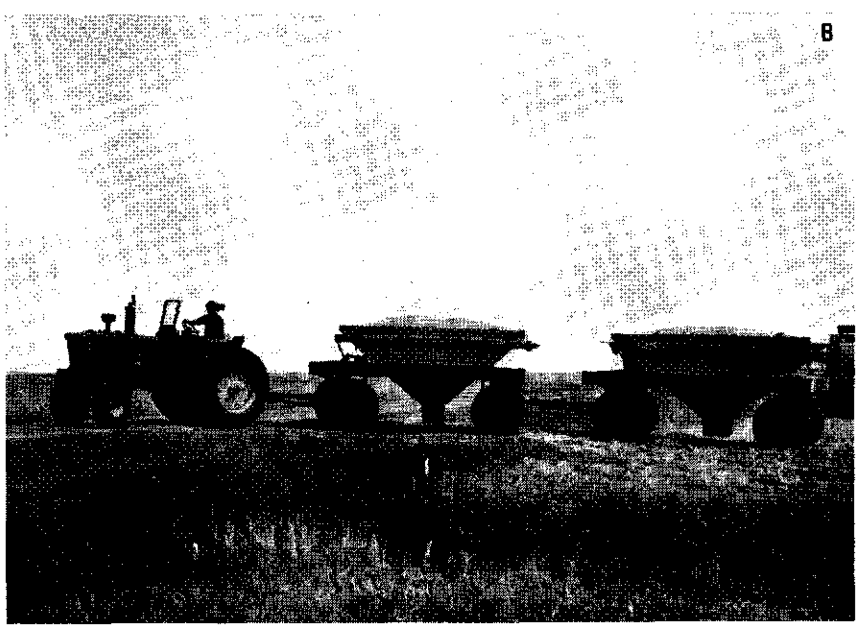


Fig. 28. Grain wagon with a volume of 8 m³.
A. vertical section
B. transport unit; two wagons and a large tractor

and sinkage were measured in the field under different soil conditions with pairs of loaded grain wagons drawn by a crawler tractor. Table 17 gives the technical data and test results for the wagons of 10 m^3, 8 m^3 and 4.5 m^3 capacity. It is evident that the 10 m^3 wagon cannot be used on the field on account of sinkage (20 cm) and high tractive power required. The wagon is too heavy with the standard tyres presently available, though the present construction of the wagon would not allow the use of oversize tyres. The tractive power required in the field is greater for the 8 m^3 wagons than for the 4.5 m^3 ones but remains below the 3,000 kg which can be exerted at maximum by the specified crawler tractor (table 16) under poor conditions. If the soil conditions are extremely difficult, which they may be during the first few years after the polder has been drained, the wagons can be hauled on to the road one by one.

TABLE 17. Technical specifications and data on tractive power, sinkage and stopping distance of grain wagons of 10 m^3, 8 m^3 and 4.5 m^3 capacity.

Specifications and test results	Unit			
Volume	m^3	10	8	4.5
Weight, empty	kg	2,800	2,500	1,050
Total weight				
fully loaded (wheat)	„	10,300	8,500	4,550
Tyre size		16—20	16—20	9—16
Overrunning brake		yes	yes	no
Brake-drum	mm	400 × 100	400 × 100	—
Overall length	„	6,760	6,030	5,570
Overall width	„	2,500	2,500	2,000
Wheel base	„	3,560	3,250	2,370
Tractive power required				
(two loaded wagons) [1]	kg	3,500	2,100	1,500
Sinkage				
(two loaded wagons) [1]	cm	20	11	9
Stopping distance at a speed of [2]:				
16 km h^{-1}	m	9	4	13
20 km h^{-1}	„	12	11	26
25 km h^{-1}	„	20	13	35
Wheeled tractor [3]:		large	large	medium

[1] Average of tests on a number of fields with moderate soil conditions, speeds varying between 3 and 5 km h^{-1}.

[2] Braking tests on a wet clean asphalt road surface.

[3] See table 16.

The stopping distances are shorter for the 8 m^3 wagon than for the 4.5 m^3 wagon. The 8 m^3 wagon meets easily the legal requirements set at speeds of 16 km h^{-1}. It meets also the presumed future requirements: a stopping distance of 24 m at a speed of 25 km h^{-1}.

8.3 THE LOADING AND UNLOADING OF THE GRAIN WAGON

8.3.1 *Loading*

The positioning systems used for the grain wagons are shown in figure 21. To shorten the loading time of the wagons, concentration of the combines is desirable. The degree of concentration is however limited by the increasing time losses of the combines: the waiting time at the unloading point and the travel time. Table 13 shows that, for a group of six combines, the waiting time and the travel time are 1.4% and 7.8% of the net working time. Trials with a group of nine combines showed an increase of both time elements with 300%. Therefore it seems that a concentration of six combines loading into one pair of wagons is the maximum.

The grain wagons are loaded and transported in the fields in pairs. This method has drawbacks for the combines as the time needed for travelling on the headlands would be less if the wagons were handled separately. In that case they would have to be hooked together on the road for transport to the drying plant. However, the coupling of these wagons with their wide tyres is such a difficult job that it is preferable to have coupled wagons standing on the headlands.

A crawler tractor is used for transport from the field to the road, it is in use for only 50% of the time. Recent studies showed that in the future the entire transport on both the field and the road can perhaps be done with large four-wheel-drive wheeled tractors, which can exert a tractive force of some 3,000 kg on the field. In that case the costs for transport in the field will be reduced.

Before a wheeled tractor hauls the wagons to a drying plant the foreman puts a threshing ticket in the pouch on one of the wagons. On the ticket are recorded: number of the field, numbers of the wagons and the crop variety.

8.3.2 *Unloading*

The wagons are unloaded over the pits in the reception area. The conveying capacity of the drying plant is of considerable importance for the organization of the transport. The following possibilities can be defined:

a. Conveying capacity smaller than the total net capacity of the combines

In this case a large number of grain wagons will be required in part to act as temporary storage of the threshed grain if the combining is to continue unhindered. These wagons are then brought to the reception points outside the combining hours. They consequently form a mobile wagon reserve which can be used for the grain transport outside the combining hours. This situation prevailed on the farm up to a few years ago. For each ton of net combine capacity, there was 0.7 ton conveying capacity and 6 tons (wheat) of wagon capacity assuming a transport distance of 7 km. The organization has been studied by WIJKEL and VAN KAMPEN (1964). Some results are presented in table 18, they are comparable with the data on the present organization in tables 19 and 21.

The waiting time for the wagons is high, showing inefficient use of this equipment. Especially the waiting time in the reception area is long; it also varies widely (0—400 min). Consequently foremen do not know when to expect empty wagons back in the field. To be on the safe side foremen collect more wagons than allotted, resulting in an additional wagon shortage and thus combines standing idle elsewhere on the farm.

The high loading time is caused by combines operating in small groups of 1—4 combines; the loading time was decreased in 1963 by concentrating the combines in groups of six. Tractor waiting time in the reception area is due to the order from the foremen not to return to the field without empty wagons.

Summarizing it can be concluded that efficient use of the transport equipment is impossible unless the conveying capacity is equal to the total net combine capacity. It was accordingly decided to increase the conveying capacity of the plants to this capacity. This resulted, as can be computed from figure 32 in a decrease of wagon capacity required from 6 to about 3 tons per ton net combine capacity.

TABLE 18. Standard times and other data related to grain wagons and wheeled tractors for wheat transport in 1962, (WIJKEL and VAN KAMPEN, 1964).

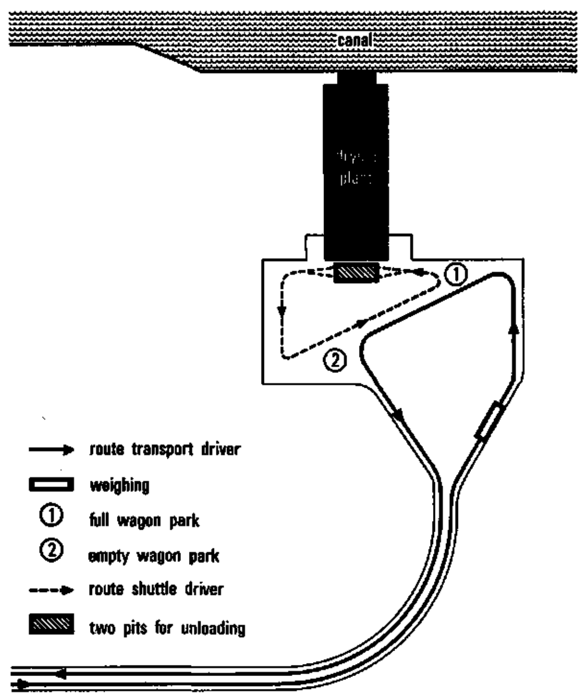
	Unit	Two wagons	Tractors (medium)
In field			
effective load capacity [1]	kg	6,700	
loading	min	63	
waiting (empty and full)	,,	60	
transport (empty and full)	,,	14	
On road			
(un)hitching	,,	3	3
waiting (empty and full)	,,	40	14
transport	km h^{-1}	20	20
In reception area			
weighing and transport to full-wagon park	min	4	4
waiting (empty and full)	,,	160	17
(un)hitching, moving to empty wagon park	,,		6
unloading	,,	9	
transport	,,	3	

[1] As loaded in the field; effective load capacity is approximately 96% of load capacity (fully loaded).

b. Conveying capacity equal to the total net capacity of the combines

The conveying capacity, the layout and the equipment of the reception area must be such as to minimize tractor and wagon waiting times. Some waiting is unavoidable, as different numbers of pairs of wagons can be

Fig. 29. Weighing and unloading in the reception area of the drying plant.



brought in simultaneously. In order to limit the waiting time of the tractors a shuttle service is used, having a separate driver on duty in the reception area. The layout of the reception area of the drying plant from figure 33 is shown in figure 29. This drying plant, designed for 24 combines (5.4-m), has a conveying capacity of 120 tons h^{-1}.

The reception area is organized as follows. The transport driver brings the two wagons on to the weighbridge, gets off the tractor, takes the threshing ticket from the pouch on one of the wagons and inserts it into the weight printer, which prints the weight of the grain on the ticket. He puts the ticket back in the pouch. Then mounts the tractor and parks the two wagons in the full-wagon park (1), unhitches the tractor, moves to the empty-wagon park (2) and hitches to the empty wagons. The shuttle driver using a tractor with an automatic hitch tows the two loaded wagons from the park (1) to one of the two reception pits, unhitches the tractor, dismounts, takes the threshing ticket from the pouch and opens the flap valves of the wagons, whereupon the grain flows into the pit. The driver hitches the tractor to the preceding wagons which have been emptied at the next pit and brings them to the empty-wagon park (2), he then hauls two other loaded wagons from the park and takes them to the pit.

The two reception pits have a capacity of 6 tons each; about 3—4 tons of this capacity is utilized with this method of unloading from hopper-type wagons. In fact no more space is required than that needed for the quantity of grain required to keep the conveyor operating at capacity for the time when no wagons are over one pit (2 min). As the conveying capacity of each pit is one ton min^{-1}, the minimum amounts to: $2 \times 1 = 2$ tons. However, since it is necessary to unload two wagons simultaneously, the pits must be nine meters long. Therefore their capacity could not be made less than 6 tons.

8.4 THE NUMBER OF TRANSPORT UNITS REQUIRED

The number of transport units needed for the transport of harvested material is equal to the ratio of the duration of the entire transport cycle of one unit to the loading time of this unit (at a constant rate of flow of threshed material). The duration of the transport cycle includes the time for unloading, loading, (un)hitching, transport and delays. On this basis TISCHLER (1959) established a formula for the calculation of the number of wagons required to work with one harvesting machine.

TISCHLER's formula is:

$$A = \frac{t_{lo} + t_{ul} + t_t + t_{hw}}{n\,(t_f + t_{ut})} \qquad (8.1)$$

where:

A = number of transport units
t_{lo} = loading time of the transport unit
t_{ul} = time for unloading of the transport unit
t_t = time for transport
t_{hw} = time for waiting, hitching and unhitching
$n = \dfrac{\text{volume wagon (s)}}{\text{volume grain tank}}$
t_f = time for filling the grain tank
t_{ut} = time for unloading the grain tank into the transport unit.

For the organization on the farm formula 8.1 can be written as follows:

$$t_{hw} = t_h + W \qquad (8.2)$$

where:

t_h = time for hitching and unhitching
W = the time that the transport unit, empty or full, is waiting.

The time for which the grain wagon has to remain stationary during the essential „loading, unloading and (un)hitching" operations is stated as follows:

$$t_{lo} + t_{ul} + t_h = L \tag{8.3}$$

and further:

$$n\,(t_f + t_{ut}) = \frac{T}{C} \tag{8.4}$$

where:
T = effective load capacity of one transport unit in tons.
C = net combine capacity in tons h^{-1}

Further

$$t_t = \frac{2D}{V} \tag{8.5}$$

where:
D = distance in km
V = speed in km h^{-1}

After substitution of 8.2—8.5 in 8.1 the following equation is obtained:

$$A = \frac{C}{T} \cdot \left(\frac{2D}{V} + W + L\right) \tag{8.6}$$

where:
A = number of transport units
C = net capacity of the combine(s) in tons h^{-1}
T = effective load capacity of transport units in tons
D = distance in km
V = speed in km h^{-1}
W = waiting time in hours
L = time for loading (t_{lo}), unloading (t_{ul}) and for (un)hitching (t_h) in hours.

Both the number of wagons and the number of wheeled tractors can be calculated using 8.6. The waiting time is clearly indicated as the yardstick for evaluating efficiency of the transport organization at the same time. It should be noted in this connection that the transport organization has to be evaluated as a component of the harvest organization as a whole, involving the combines and the grain reception arrangements as well. As the ratios of the annual operating costs (operator included) of a 5.4-m combine, a 100 hp wheeled tractor and an 8 m^3 grain wagon can be approximately expressed as 13 : 5 : 1 (table 26), it will be evident that minimization of the waiting times should be sought in that order.

For the calculation of the number of transport units needed the parameters of 8.6 have to be known. A number of time measurements have been carried out during the harvesting of wheat and with the loading and unloading organization as described under 8.3.*b*. They are summarized in table 19 (omitting waiting times) and can be used with the data on utilization and net capacities (grain moisture content $< 19\%$) given for the 5.4-m combine in tables 13 and 15. For other crops these data will be different on account of the net combine capacities in these crops (table 15) and the test weights (in kg hl^{-1}: wheat, 75; barley, 66; oats, 52; colza, 60). This results in different numbers of transport units being required for each crop: for oats 23% more and for colza 40% less than for wheat and barley. Owing to the large area sown with barley and wheat in comparison with oats, the results in wheat are used for computing the transport capacity required. Thereby the higher transport capacity required for oats is ignored.

TABLE 19. Standard times and other data related to 8 m^3 grain wagons and 100 hp wheeled tractors for transport of wheat harvested by a group of six 5.4-m combines.

	Unit	Two wagons	Tractors
In field			
effective load capacity	kg	11,600	
loading	min	23	
transport (empty and full)	,,	10	
On road			
(un)hitching	,,	1.5	1.5
transport	km h^{-1}	25	25
In reception area			
weighing and transport to full-wagon park	min	2.3	2.3
unhitching, moving to empty-wagon park, hitching	,,		2.0
unloading	,,	11.0	
transport	,,	3.0	

The data in table 19 can be used to calculate the unavoidable waiting times of grain wagons and wheeled tractors, these times being the result of both the difference in cycle times for the wagons and tractors and the fact that integer quantities of equipment must be used. The number of wheeled tractors A_t needed for hauling the grain from the field can be worked out by dividing the tractor cycle time 0_t by the loading time t_{lo} for a pair of wagons:

$$A_t = \frac{0_t}{t_{lo}} \tag{8.7}$$

As soon as the cycle time becomes an integer number of the loading time t_{lo} an integer number of wheeled tractors is required, then they are fully employed. From the data in table 19 and formula 8.7 it can be deduced that one, two, three and four tractors are needed at distances of 3.5, 8.3,

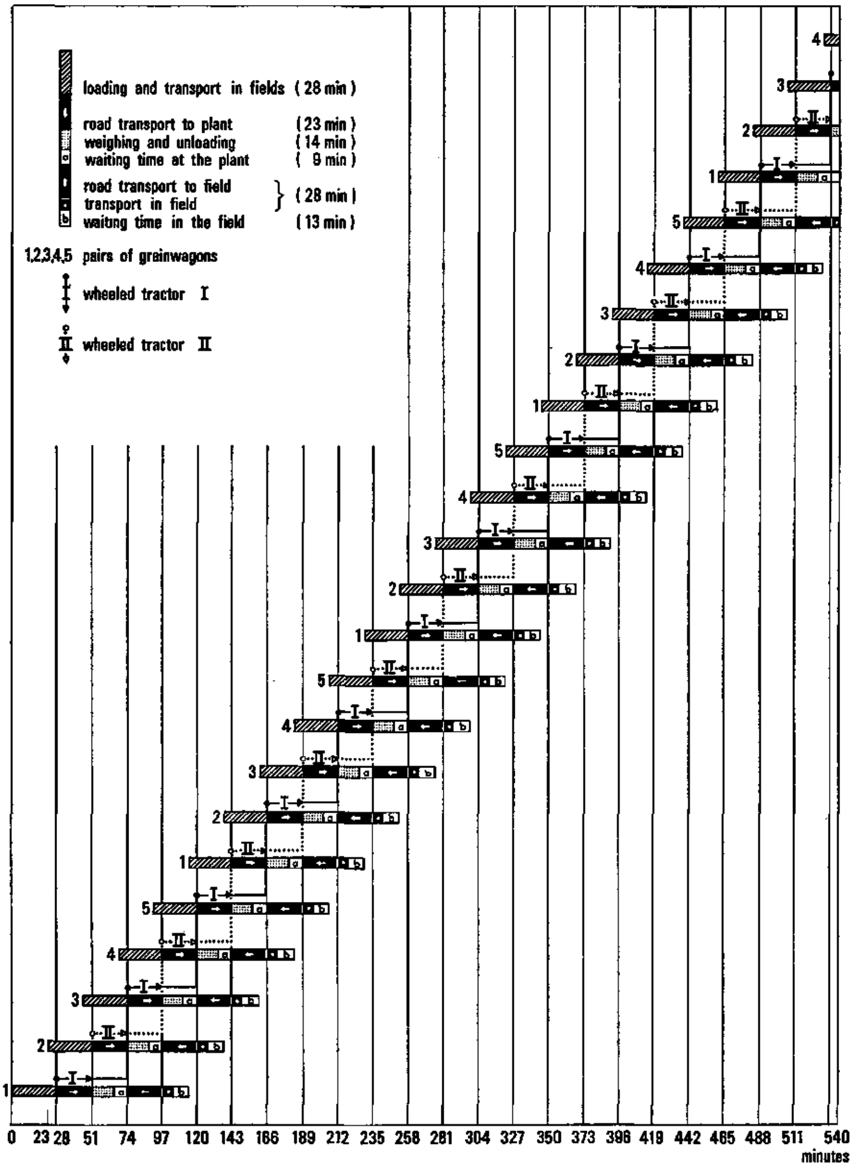


Fig. 30. Theoretical transport scheme for the transport of the grain threshed by six 5.4-m combines (total net cap. 30 tons h^{-1}, wheat) and cycle times for two wheeled tractors and 5 × 2 grain wagons. Transport distance 8.3 km.

13.1 and 17.9 km respectively. At other distances the tractors would not be fully employed and consequently waiting times would result.

The above also applies mutatis mutandis for the number of grain wagons A_w calculated by dividing the cycle time 0_w by the loading time t_{lo}:

$$A_w = \frac{0_w}{t_{lo}} \tag{8.8}$$

From formula 8.8 and the data of table 19 it can be deduced that three, four, five and six pairs of wagons are needed at distances of 4.4, 9.2, 14.0 and 18.8 km respectively.

Owing to the difference in cycle times of tractors and wagons, waiting times are unavoidable for one of them. Since the annual operating costs of wheeled tractors and grain wagons are in a ratio of 5 : 1, minimization of tractor waiting time should be one of the major concerns when allocating and calculating the transport equipment required.

The waiting times of tractors and wagons are calculated on this basis with the model transport organization given in figure 30. This has been worked out around a ninehour working day and a transport distance of 8.3 km. At this distance exactly two tractors are needed, since the ratio of cycle time to loading time comes to two. At time 0 the loading of the first pair of wagons is started, after 23 minutes the wagons are full and are then brought up to the road in 5 minutes by the crawler tractor. Wheeled tractor 1 then brings this pair of wagons to the reception point where they are weighed and parked, the total time for this being 23 minutes. The tractor then travels back to the field.

In the reception area (figure 29) a pair of wagons is unloaded and moved into the empty-wagon park in 14 minutes by the wheeled tractor working there. After waiting 9 minutes these empty wagons are taken back to the field by wheeled tractor 2 which has arrived at the area in the meantime; once back on the field the crawler tractor takes them up to the loading point, where they will have to wait 13 minutes since loading of wagon pair 5 has been started 10 minutes earlier. This scheme calls for five pairs of grain wagons in addition to the two wheeled tractors. Using this equipment twenty-one loads can be moved over 8.3 km between the loading point and the reception area in each nine-hour working day. The cycle times of the wheeled tractors and grain wagons are 46 and 115 minutes respectively, with a waiting time of 22 minutes for the grain wagons only.

However, the model transport scheme will not be realized in practice. For example the wagons are exchanged in the reception area with those from other combine groups. This will result in shorter waiting times after unloading, as is shown by table 21 where the average waiting time after unloading is 6 minutes. The same table shows that the average waiting time before unloading is 8 minutes due to the occasional arrival of two or more pairs of wagons simultaneously. As a consequence the total average waiting time of a pair of wagons in the reception area is increased to $8 + 6 = 14$ minutes. This is five minutes more than it should be according to the model. In addition, waiting time is also unavoidable on the roadside where the exchange between road transport and field transport is effected. The waiting time available before loading is 8 minutes (22—14), which is not sufficient for the variation in loading times [1].

In practice it will be wise to increase the margin of safety by allocating an extra pair of wagons to each combine group which increases the calculated waiting time per wagon cycle by 23 minutes to $22 + 23 = 45$ minutes. This also applies for transport distances of 3.5, 13.1 and 17.9 km, for which one, three and four wheeled tractors and five, seven and eight pairs of grain wagons will then be needed respectively.

It may be assumed that the actual transport distances are regularly distributed between the above distances where the tractor cycle time is a full multiple of the loading time. The number of transport units needed for such intermediate distances, e.g. 6 km, is equal to the number required for the next longest distances for which a full number of tractors is needed, in this case 8.3 km. The equipment arrangements are accordingly based on distances grouped as shown in table 20.

TABLE 20. The numbers of wheeled tractors and grain wagons required at different transport distances for the transport of the wheat delivered by six 5.4-m combines. The total net combine capacity is 30 tons h^{-1}.

Distance	Wheeled tractors	Grain wagons
< 3.5 km	1	5×2
3.5— 8.3 „	2	6×2
8.3—13.1 „	3	7×2
13.1—17.9 „	4	8×2

The equipment arrangements as shown in table 20 result in an increase in average waiting times on the entire farm. Figure 31 gives the cycle times of wheeled tractors and grain wagons; they show that with an even distribution of the distances the average waiting times of wheeled tractor and grain wagons per cycle will be 12 minutes and $45 + 12 = 57$ minutes respectively.

The calculated waiting times have been verified by measuring the actual waiting times at a distance of 5 km. The results are summarized in table 21.

[1] Net working time includes some time losses as daily averages (table 13, *h* and *j*) that are not necessarily spread uniformly over the net working time. Therefore the total net capacity of a group of 6 combines may occasionally be 14% higher.

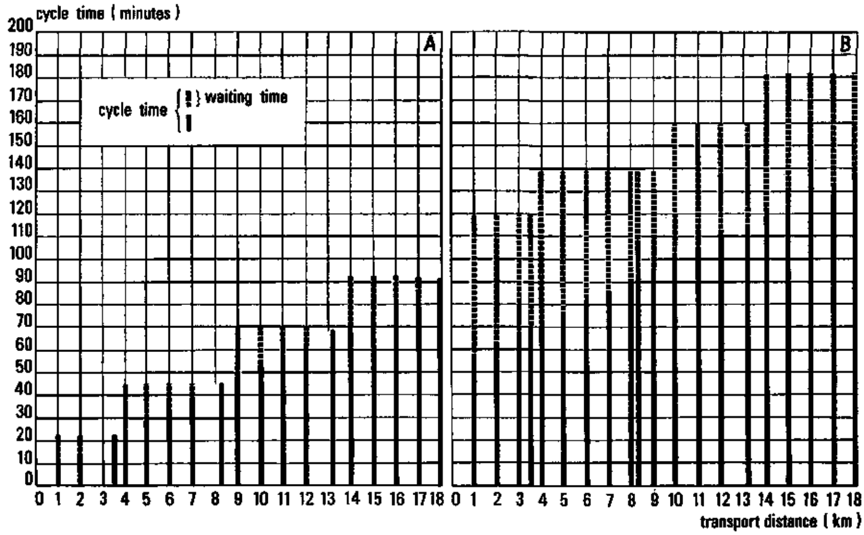


Fig. 31. Cycle times and waiting times of wheeled tractors and grain wagons at different transport distances.
A. wheeled tractors
B. grain wagons

TABLE 21. Average measured and calculated waiting times of tractors and wagons for a distance of 5 km (min).

Place	Grain wagons		Wheeled tractor	
On roadside and field			9	
empty	31			
full	12			
In reception area				
before unloading into pit	8		8	
after unloading into pit	6			
Measured total waiting time	57	$\sigma : \pm 29$	17	$\sigma : \pm 9$
Calculated total waiting time	58		16	

It can be seen from table 21 that the calculated and measured waiting times are in close agreement. However, the standard deviations of the waiting times, which show a normal distribution, are rather large. This is caused primarily by the fact that the wagons are sometimes loaded in a different order. This occurs when the wheeled tractors bring empty wagons on to the headland and there are no full wagons ready on the roadside.

The time spent by the wheeled tractors in the field is included in the waiting times measured, as the transport of empty wagons could have been done by the crawler tractor. Despite the large standard deviations the average waiting times will be used for the calculation of the number of transport units needed.

Two other factors must still be taken into account: capacity lost due to repairs of the transport equipment and the variation in the average daily transport distances.

Capacity loss due to repairs has been estimated from farm records; they show that during the harvesting season 4% of the wheeled tractors and 2% of the wagons is not available due to repairs.

The influence of the variation in daily transport distances is estimated as follows. The theoretical transport distance is the distance using a sequence of harvesting the various fields that is most favourable for the transport organization. It has been compared with the actual daily average transport distances measured in 1967 for barley, oats and wheat. The results are reported in table 22.

TABLE 22. The theoretical transport distance in comparison with the daily average transport distances as observed in 1967 (km).

Crop	Theoretical transport distance	Actual daily transport distance	
		Average	σ
Barley	8.7	8.5	$\pm$ 2.3
Oats/wheat	9.4	9.7	$\pm$ 2.0

The data show that the theoretical distance corresponds fairly well with the average of the actual daily distance. The daily variations in the actual transport distances, showing a normal distribution, are large as is indicated by the standard deviations. These variations are largely caused by the priority which is given to the harvesting of certain fields, for example fields for seed production or with risky crops. This procedure and the resulting increase in the transport distance have been accepted as unavoidable. Assuming that the transport capacity has to be adequate in 95% of the situations arising, the transport distance that determines the transport capacity for wheat (the actual transport distance) is $1.65 \times 2.0 = 3.3$ km greater than the theoretical distance. This is valid for a theoretical transport distance of 9.4 km; it is assumed that the distance to be added (3.3 km) is the same for other theoretical transport distances. The error introduced in this way is small and will be neglected.

Allowing for these two factors and inserting the measured times of tables 19 and 21 in formula 8.6, it can be used for the calculation of the required number of tractors and grain wagons.

The number of wheeled tractors A_t is obtained from:

$$A_t = \frac{104}{100}\ \frac{C}{11.6}\left\{\frac{2\,(D + 3.3)}{25} + \frac{6 + 12}{60}\right\} = \frac{C\,(2D + 14)}{275} \qquad (8.9)$$

The number of grain wagons A_w is obtained from:

$$A_w = \frac{102}{100} \times 2 \times \frac{C}{11.6}\left\{\frac{2\,(D + 3.3)}{25} + \frac{23 + 10 + 14 + 57}{60}\right\} =$$
$$= \frac{C\,(6D + 150)}{426} \qquad (8.10)$$

where:
C = total net combine capacity in tons h^{-1} (wheat)
D = theoretical transport distance in km; i.e. the distance determined using a harvesting sequence of the fields most favourable for the transport organization.

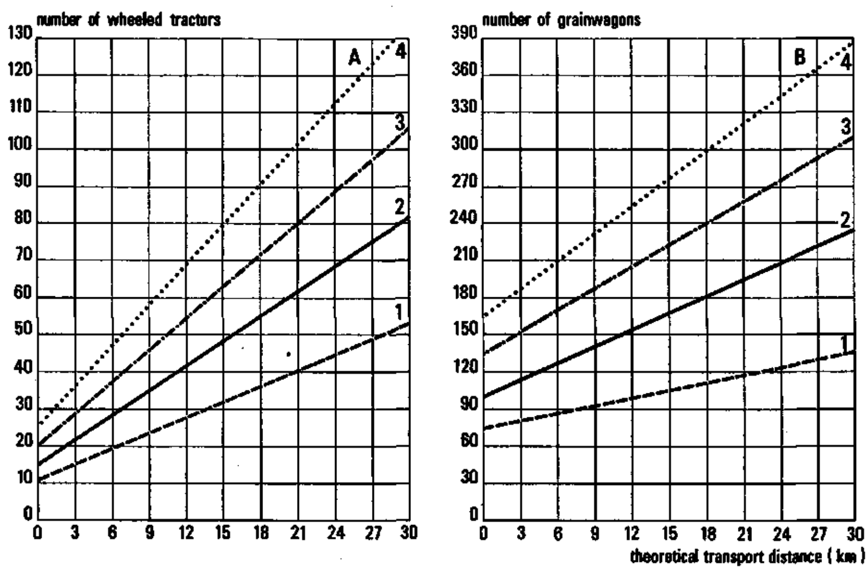


Fig. 32. Numbers of wheeled tractors (A) and grain wagons (B) required as affected by transport distance and total net combine capacity for wheat.
1. 200 tons h^{-1}
2. 300 „
3. 400 „
4. 500 „

Figure 32 is based on formulae 8.9 and 8.10. It can be used to find the numbers of wheeled tractors and grain wagons required for different transport distances and total net combine capacities.

8.5 SUMMARY

The organization of the grain transport is closely bound up with the load capacity of the equipment, the number of combines working in a group and the conveying capacity of the drying plants as they affect the times required for loading and unloading.

In view of the prevailing limitations and conditions the choice of the transport equipment is restricted to grain wagons pulled by crawler tractors and wheeled tractors in the field and on the road respectively. Within the limits set by soil trafficability, available tractors and traffic regulations governing agricultural vehicles on the road a grain wagon with a volume of 8 m^3 discharging at the bottom has been developed (figure 28 and table 17) for use in pairs. The units are loaded on the headlands by the six combines of each group and they are brought to the road by crawler tractors. Large (100 hp) wheeled tractors bring the wagons in a shuttle service to the drying plants. Unloading has been organized in such a way that the waiting times of the tractors are minimum (figure 29).

The conveying capacity of the drying plant is of considerable importance for the organization of the transport. The conveying capacity could be either lower or equal to the total net combine capacity. The effect on the transport organization has been investigated. It is concluded that an efficient transport organization is only possible when the conveying capacity is at least equal to the total net combine capacity.

For the calculation of the required numbers of wheeled tractors and wagons a formula adapted from TISCHLER (8.6) is used. In this formula the waiting time of the equipment is indicated separately; it is the yardstick for evaluating the organization. Delays are, however, unavoidable owing to the difference in wagon and tractor cycle times and the indivisibility of the equipment. With the aid of a theoretical transport scheme (figure 30) based on the standard times of table 19 (for wheat and barley) the unavoidable delays have been calculated. They have been verified by observation of the actual waiting times (table 21). With the measured parameters and taking into account two factors: losses due to repairs and the difference between theoretical and actual transport distance (table 22), formula 8.6 can be written as formulae 8.9 and 8.10 for wheeled tractors and grain wagons respectively. In figure 32 are shown the required numbers of wheeled tractors and grain wagons for different theoretical transport distances and total net combine capacities.

9 DRYING AND STORAGE OF THE GRAIN

9.1 INTRODUCTION

Most of the combined grain must be dried before it can be safely stored. The whole of postharvest treatment is organized in relation to the prevailing marketing policy and the facilities available for drying and storage. The following points must be kept in mind:

a. The amount of grain harvested is:

Colza	9,500	tons
Barley	14,000	„
Oats	4,500	„
Wheat	27,000	„
Total	55,000	„

The utilization of the crops is as follows: colza is sold for the extraction of oil, barley and oats are mostly used as feedstuffs and wheat is solely for human consumption. Some of the grain is saved for seed to be used on the farm. The average amounts kept back for this purpose in recent years have been:

Colza	13	tons
Barley	130	„
Oats	100	„
Wheat	270	„

The quality requirements for colza, barley and oats therefore are not very exacting.

b. Marketing policy requires that colza, barley and oats have to be delivered over the period August to May in order to minimize disturbance of the market (DE GROENE, 1964); this means that the crops must be stored until marketed. Wheat, which is disposed of entirely at the fixed prices of the bread grain market, is shipped direct to the flourmills at a moisture content that prevents deterioration during shipment. The wheat harvested last is, however, stored for a time in the silos of the drying plants in order to qualify for the storage premium.

9.2 SYSTEMS FOR DRYING AND STORING OF GRAIN

KREYGER (1964) describes the ways in which grain can be dried and stored in central facilities. He distinguishes the following extremes:

transshipment centre, in which 10—20% of the grain handled is stored; here the emphasis is on equipment for handling, filling and unloading; considerable drying capacity is required

storage centre, in which 50—80% of the grain handled is stored; emphasis here is on storage facilities and to a lesser extent on equipment for handling. Compared with the transshipment centre the drying capacity needed is small since the period available for drying is appreciably greater

As already mentioned, to comply with the marketing policy, storage facilities for colza, barley and oats are essential. Therefore, a storage capacity of some 28,000 tons must be available. The choice of drying and storage systems is then reduced to the following two alternatives:

a. farm storage centre capable of taking 55,000 tons of grain and storing 28,000 tons.

b. farm transshipment centre with a rented storage for 28,000 tons of colza, barley and oats elsewhere.

The choice is chiefly based on the costs, including the unavoidable cost of periodically moving these centres (10.2). When combines with grain tanks came into use the decision was taken to construct three transshipment centres and to rent storage facilities elsewhere. The procedure followed under this system is described first; then briefly a possible method using central storage facilities.

a. Grain handling with transshipment centres

A prerequisite with this system is that rented storage facilities must be available within a reasonable distance. This requirement is met by the proximity of the ports of Amsterdam and Rotterdam, 60 and 120 km away respectively, where storage space can be rented. An advantage is that this storage is at the waterside and has drying equipment. Since the canals in the polders are navigable for ships of up to 600 tons, the wheat and the other grains are transported by water to the flour mills and the storage respectively.

TABLE 23. Moisture contents considered safe for shipment compared with data on storage without and with ventilation according to KREYGER (1964).

Crop	Maximum moisture content [1] for shipment	Estimated maximum time of storage in days, temp 20° C moist. cont. [1]	days	Estimated maximum time of ventilated storage (30 m^3m^{-3} grain per hour) moist. cont. [1]	days
Colza	10—12	12	35	—	—
Barley	18—19	19	17	24	10
Oats	17—19	19	14	24	9
Wheat	19—20	19	10	24	3

[1] % wet basis.

The grain has to be loaded into the ships with a moisture content that is low enough to ensure that no deterioration can occur during transit, which may on occasions last several days, including waiting days. The maximum safe moisture content also depends on the temperature of the grain and of the air. Experience to date indicates that with transport by ship the ranges of moisture content shown in table 23 give a minimum risk of deterioration. Also given in table 23 are some data on safe storage of the crops by KREYGER (1964).

The capacity of the transshipment centres — which can work round the clock — therefore has to be such that grain brought in at irregular intervals with varying moisture contents, can be reduced to a suitable moisture content for shipment without holding up harvesting. During harvest there is generally more than enough shipping available, so that this is not a source of delay.

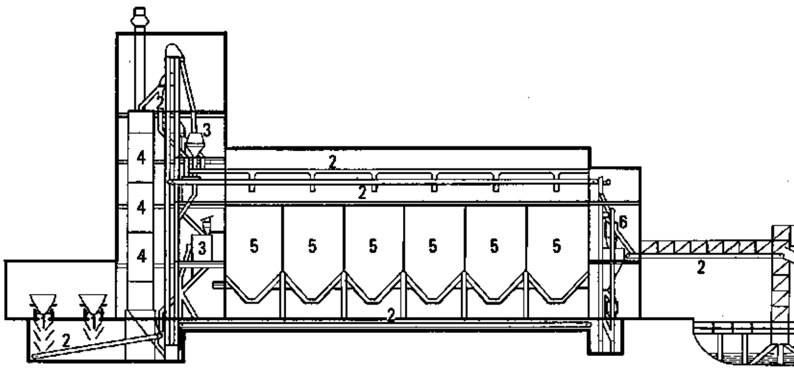
The sequence of operations in a transshipment centre is as follows (figure 6): unloading - preliminary cleaning - temporary ventilated storage of wet grain - drying - cleaning - temporary storage of dry grain - shipment. The preliminary cleaning is done with a separator that separates the heavy coarse parts from the grain. Then the wet grain is brought into ventilated cells from which it passes into the dryer. If necessary it is then dried, the moisture content being reduced as a rule by about 4% each time it passes through the dryer. After drying, the grain is cleaned and then stored for a brief period before shipment. If the moisture content of the grain brought in from the field is below the maximum set for shipment it is sometimes loaded directly into the waiting ship only passing through the separator.

TABLE 24. Some data related to the transshipment centre shown in figure 33.

	Type	Capacity	Comments
Dryer [1]	cascade dryer	20 [2] tons h^{-1}	4% reduction in moisture content from 22—18% for wheat
Reception	belt conveyors	120 [2] ,,	the three handling systems are completely separate
Dispatching	,, ,,	60 [2] ,,	
To and from dryer	chain conveyor	30 [2] ,,	
Storage	12 gravity-discharging cells	330 m^3 each cell	all cells are ventilated; 30 m^3 m^{-3} grain h^{-1}
Staffing	two per shift, hence 3 × 2 =		6
	one tractor driver for reception	(one shift)	1
	one supervisor	(one shift)	1
	one controller for shiploading	(three shifts)	3
		Total	11

[1] Available hours: 22 h day^{-1}.

[2] Capacities based on requirements for wheat.



A

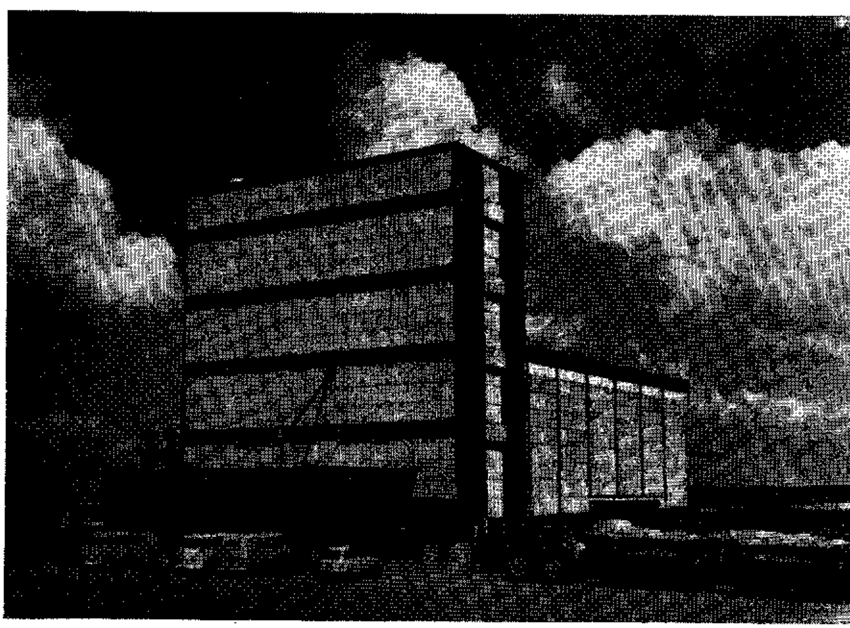


Fig. 33. Transshipment plant.

A. vertical section B. photograph

1. pits for unloading
2. conveyors
3. cleaning installations
4. drying installation
5. storage space for wet and dry grain
6. weighing machine

The storage space for wet and dry grain has two purposes: to maintain a stock of wet grain for drying and a stock of dry grain for shipment. The size of this store depends primarily on the rate of delivery, on the moisture content of the grain and also the means by which it is removed from the centre. Figure 33 shows a photograph and a vertical section of a transshipment centre of this type established in 1966. The components are described in table 24.

b. Grain handling by storage centres

The harvested grain can also be dried and stored on the farm. With this system the drying capacity required is undoubtedly smaller than when utilizing transshipment centres, since the ventilated storage can be large. Consequently the wet grain brought in can be kept in good condition until after the harvest and the dryer can be used for a greater number of hours. On the other hand the costs involved in moving to other places will be higher than for the transshipment system.

The possible forms of storage centres are legion; however, as soon as the requirement is introduced that they should be easy to move, the choice is limited to „bins", in which the grain can both be kept ventilated and dried (for centres smaller than 10,000 tons). A diagram of a storage centre based on bins is given in figure 34. These bins are filled and emptied by means of movable augers or belts. Drying is effected in situ in one or more silos by blowing heated air under the perforated floors. The maximum thickness of the grain layer on these floors depends on the grain moisture content. Experience with this system on a small scale over recent years has been satisfactory (COOLMAN *et al*, 1966). The cost of removing storage centres erected on this pattern is presumably lower than of other types.

9.3 RELATIONSHIP BETWEEN NUMBER AND FREQUENCY OF MOVING OF THE DRYING PLANTS AND THE TRANSPORT DISTANCE

The diagram of the Eastern and Southern Flevoland polders shown in figure 35A indicates the actual position of the polders, the farm, the land under reclamation and the three drying plants in 1967; this has been used as a basis for calculation. The basic data assumed are the following (figure 35B):

the area reclaimed each year forms a rectangle of 4,000 ha, 20 km long and 2 km wide

the area turned over to farmers each year is of the same size and shape, so the farm moves 2 km every year

the farm is consequently rectangular with an area of 20,000 ha and sides of 20 and 10 km

the area sown with a certain crop is not located in one or two blocks but scattered throughout the entire area of the farm

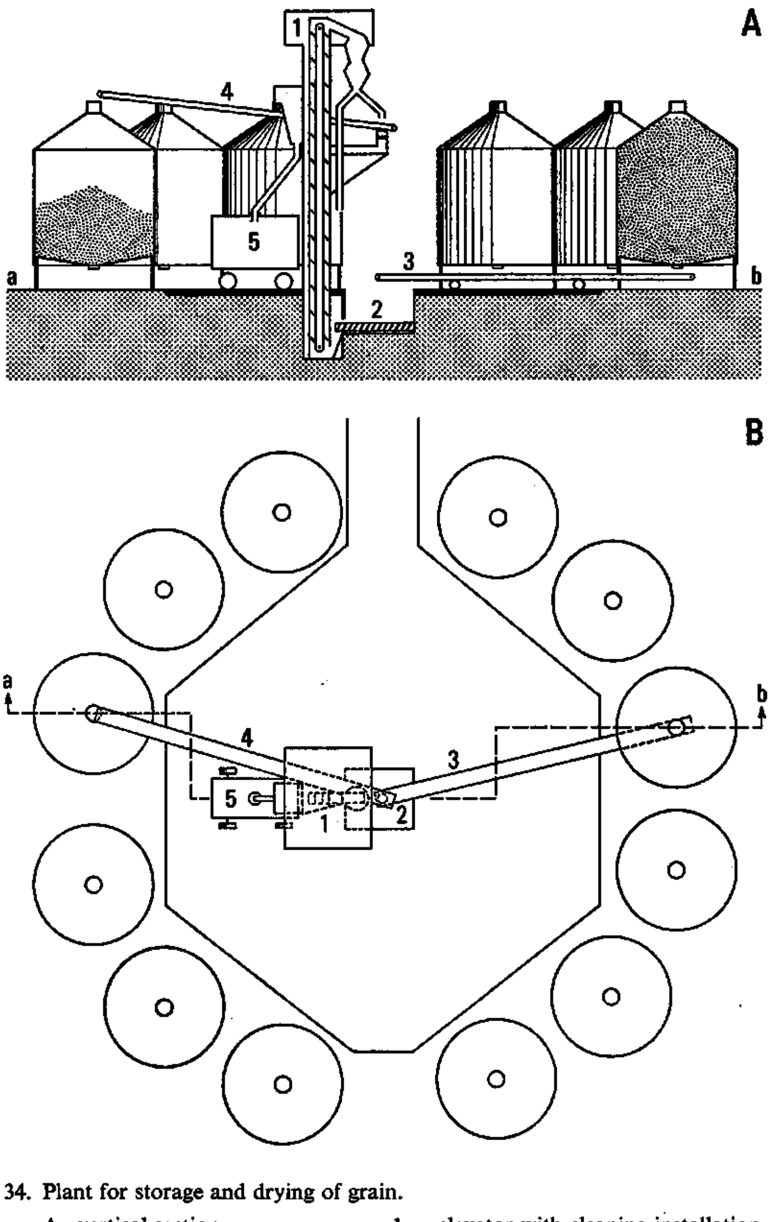


Fig. 34. Plant for storage and drying of grain.

A. vertical section
B. horizontal section

1. elevator with cleaning installation
2. pit with auger conveyor
3, 4. conveyors (belt or auger)
5. chaff wagon

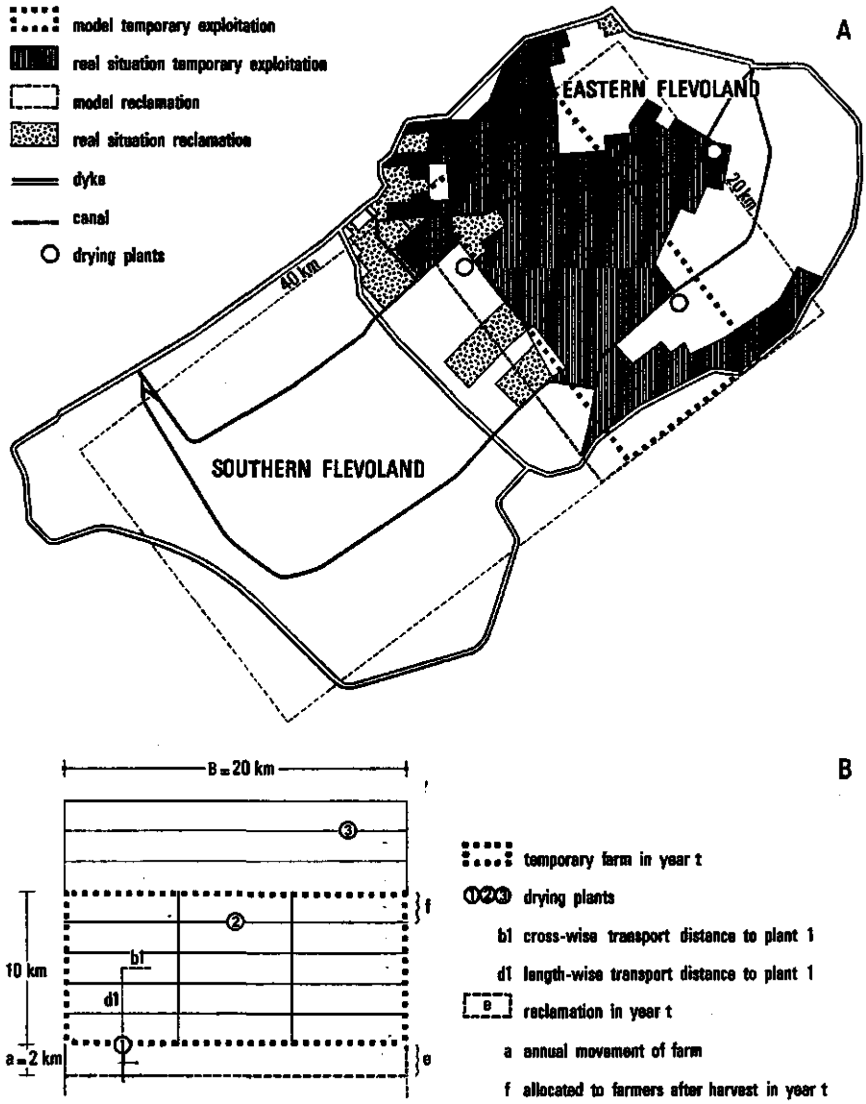


Fig. 35. Model of temporary farm.

A. model and actual farm *1967*

B. *model of temporary farm* (20,000 ha) with three drying plants in year t, removing frequency of a plant once in ten years

the transport involved is only lengthwise or crosswise
the position of the drying plants is not restricted by roads or canals.

Figure 35B shows the model with three drying plants in a situation which can occur if each plant is removed once every ten years. Plant no 1 has here been moved to the farthest boundary of the farm for the harvest of the year concerned. If each plant handles the grain harvested in the block in which it lies the mean transport distance $\overline{D}$ is made up from the mean cross-wise distance $\bar{b}$ and the mean lengthwise distance $\bar{d}$ to x plants, where x is the number of plants:

$$\overline{D} = \frac{\sum_{1}^{x} (b_{1 \ldots x})}{x} + \frac{\sum_{1}^{x} (d_{1 \ldots x})}{x}$$

$$\overline{D} = \bar{b} + \bar{d} \tag{9.1}$$

The crosswise distance b is the same for each block at the symmetrical position assumed for the plant:

$$b = \frac{B}{4x}$$

hence $$\bar{b} = \frac{B}{4x} \tag{9.2}$$

$\bar{b}$ is accordingly constant each year if the number of plants remains the same.

For the mean lengthwise distance:

$$\bar{d} = \frac{\sum_{1}^{x} (d_{1 \ldots x})}{x} \tag{9.3}$$

The distance d to the plant concerned (figure 35B) varies each year because of the annual movement of the farm (a = 2 km) and the frequency of moving the plant.

For instance in figure 35B plant no 1 has been moved right up to the farthest limit of the farm in year t; the transport distance to this plant in subsequent years is shown in table 25.

TABLE 25. The lengthwise transport distance d to a plant in the years after it has been moved, a = annual movement of farm in km, t = year of removal.

Year	t	+1	+2	+3	+4	+5	+6	+7	... f min.
Transport distance d	2.5a	1.7a	1.3a	1.3a	1.7a	2.5a	3.5a	4.5a	... 1 max

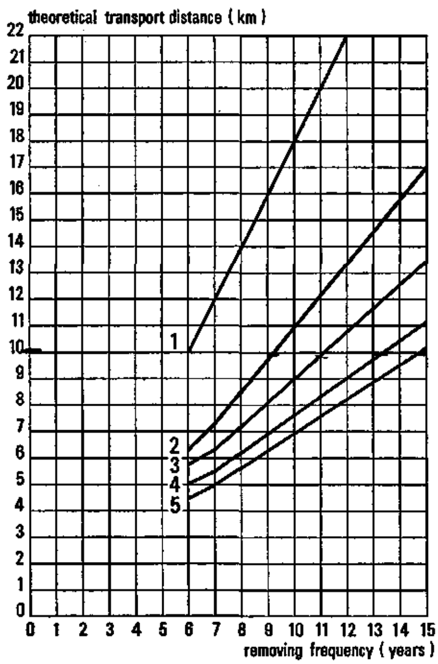


Fig. 36. Influence of number of plants (x) and removing frequency (f) of the plants (number of years after which the plant is moved) on the theoretical transport distance.

1. x = 1
2. x = 2
3. x = 3
4. x = 5
5. x = 10

The plant remains inside or on the boundary of the farm for six years, after which the transport distance increases each year by „a" until d_{max} has been reached. Accordingly d_{max} is determined by the frequency of removing. Similar series can be prepared for all the plants, with movements distributed as regularly as possible. For each year the mean lengthwise distance $\bar{d}$ to the plants can be determined with 9.3. Calculation of these series indicates that the mean transport distance varies from year to year and reaches its maximum in several years. Using these maxima we then find:

$$\bar{d}_{max} = \frac{\sum_{1}^{x} (d_1 \ldots _x) \max}{x} \tag{9.4}$$

9.1 may therefore be written as follows:

$$\bar{D} = \frac{B}{4x} + \frac{\sum_{1}^{x} (d_1 \ldots _x) \max}{x} \tag{9.5}$$

$\bar{D}$ is similar to the theoretical transport distance D in formulae 8.9 and 8.10.

The graph shown in figure 36 has been constructed with formula 9.5. This graph reveals that the mean theoretical transport distances become greater with decreasing removal frequencies; the increase becomes proportionately less as x becomes greater. It can further be seen that at a certain frequency of removal the influence of x decreases as x becomes greater. Finally, the graph can also be used to find how a certain transport distance can be obtained: for example a theoretical distance of 10 km can be obtained using two, three or five plants with removing frequencies of once per nine, eleven and thirteen years, respectively.

The question arises whether the conclusions drawn from the model have any practical value since the model incorporates stringent restrictions. The deviations from the model are:

a. the plants cannot be placed everywhere, since they have to be on a canal, while the actual pattern of reclamation and of allocation to farmers and consequently also the shape of the farm is far less regular than that assumed

b. it has been assumed that each plant only receives the products from its own block: in reality, however, products will also be brought in from adjoining blocks since the transport distance is reduced by so doing

c. the regular distribution assumed for a given crop over the entire area will not occur in practice, since the distribution of the crops is closely related to the position of the area reclaimed each year

In view of these major deviations from the model, the results have been checked with the results obtained for the actual organization with three plants (VAN KAMPEN, 1965). It was found that the theoretical transport distance agrees with figure 36; it will increase by about 1 km per year. At a removal frequency of once every ten years the theoretical transport distance would be about 9 km. This indicates that, despite the many restrictions introduced, the results of the model calculations are valid for the actual situation.

9.4 SUMMARY

Approximately 55,000 tons of colza, barley, oats and wheat are harvested annually. Colza is sold for the extraction of oil; barley and oats mostly as feedstuffs and wheat for human consumption. Marketing policy requires that colza, barley and oats must be stored from August to May. Wheat is shipped directly to the flour mills.

The present system is described; three transshipment plants dry the grain, if necessary, to the moisture content required for shipment. One of the transshipment plants is described (figure 33, table 24). Another possibility for grain handling by storage is briefly discussed (figure 34). This system was chosen because the cost of removal is presumably lower than for other systems.

The relation between number and frequency of removing of the drying plants and the theoretical transport distance is computed from the model in figure 35. Results are shown in figure 36.

10 COSTS OF THE HARVEST COMPONENTS AND REDUCTION OF THE VARIABLE FACTORS

10.1 INTRODUCTION

The operating costs of the components have to be known before minimization of the total harvest costs can be carried out. The costs, computed according to HORRING (1948) [1], are based on farm records. If only inadequate data are available, costs are based on the most accurate estimates possible. The latter was the case, for instance with the costs of the large wheeled tractors and the removal of the drying plants.

The annual operating costs of specific harvesting equipment such as combines, grain wagons and drying plants, can be charged completely to the harvest. This cannot be done for the tractors or for the personnel as these are employed on the farm the year round. In such cases the annual costs have been prorated and charged to the harvest, with the harvest requiring 200 working hours for the tractors and two months for the personnel. However, the area to be worked by a machine or by a worker per harvest affects the operating costs as the number of hours varies with the area. The variable costs of a machine and the cost of a worker charged against the harvest are lower or higher when the harvest lasts less or more than 200 hours respectively. The error introduced in this way is small and is consequently ignored.

All costs are based on 1967 price levels; overhead (26%) is not included because this is considered to be a constant which is independent of the size of the harvesting operation.

10.2 PERSONNEL AND EQUIPMENT

a. Personnel

The total annual cost of a worker (working 2,400 hours) is f 12,000. The fraction of this to be charged to the harvest has been estimated as follows. Every effort is made to distribute the work as uniformly as possible throughout the year; this is rather well attained except in the months of December,

[1] Assuming no variation in yearly capacities, the average annual operating costs of equipment are computed with:

$$K_n = \frac{A - R + \Sigma I_n + \Sigma C_n}{n} \text{ and } \Sigma I_n = i\,\frac{A + \dfrac{A-R}{n} + R}{2}\,n$$

where K_n = average annual operating costs, A = purchase value, R = residual value, ΣI_n = total cost of interest in n years, ΣC_n = total variable costs (fuel, repairs) in n years, n = number of years used, i = rate of interest.

January and February, when the weather together with the lack of sufficient work leaves only a small amount of productive work. The total annual labour costs are divided equally over nine months, the monthly cost per man being: $\frac{\text{f } 12{,}000}{9}$ = f 1,330. The cost of wages for a worker during the two-month harvest period is accordingly 2 × f 1,330 = f 2,660. To this has to be added the cost of overtime (f 340) and of a 6% personnel reserve for illness, leave, etc. These bring the annual cost per worker employed in harvesting to f 3,200. The cost of labour thus computed will be termed „medium labour costs". This sum will tend to be higher if during part of the remaining seven months insufficient productive work is available for full employment of the labour force. It will, however, tend to be lower if sufficient work is available during the months December, January and February. Therefore in the cost minimization program the following alternative possibilities for labour costs will be considered:

a. 1 High labour costs

Outside the harvest season the amount of productive work available is only sufficient for the labour force required to operate a number of e.g. 50 combines and the associated transport. Thus when working with more combines the total annual cost of each extra worker has to be charged in total to the harvest. This amounts to f 13,060 for each worker.

TABLE 26. Average operating costs per harvest period of combines, tractors and grain wagons.

	Unit	Combine (5.4-m)	Crawler tractor (70 hp)	Wheeled tractor (100 hp)	Grain wagon (8 m³)
1. Purchase price	f	34,000	50,000	35,000	6,300
2. Residual value	„	8,000	5,000	4,000	500
3. Life	years	6	13	10	10
4. Life	hours	1,200	12,000	10,000	2,000
5. Hours used/year	„	200	900	1,000	200
6. Interest/year	f	1,380	1,710	1,260	201
7. Repairs/year	„	3,380	3,090	2,410	177
8. Maintenance, housing/year	„	400	450	500	100
9. Fuel/year	„	400	1,170	1,750	
10. Costs/year	„	9,890	9,760	9,920	1,064
11. Costs/harvest period	„	9,890	2,170	1,984	1,064
12. 11 plus surcharge [1]	„		2,387		
13. 12 plus operator	„	13,090	5,590	5,180	1,064

[1] 10% allowance for time lost due to repairs for crawler tractors

a. 2 Low labour costs

Irrespective of the number of workers required for harvesting it is assumed that ample employment on the farm is available outside the harvest season. In this case only the man hours directly connected with harvesting operations are to be charged against the harvest. The cost per worker during the harvest then amounts to: $\frac{200 \times 13{,}060}{2{,}400} = f\,1{,}080.$ 12.000 + 6% + 340

b. Equipment

The breakdown of the annual operating costs is given in table 26, the total average costs per harvest season including the operator's costs are shown in line 13. Later (11) the value of the separating loss of the combine (table 31) is added to the cost of combining.

c. Transshipment centres

The average annual operating costs (K) of the transshipment centres as described in 9.2 consist of: average depreciation (A), average cost of interest (R), average cost of maintenance (T), average cost of energy (E) and average cost of labour (B) minus the average gain obtained by storing wheat after the harvest (N).

$$K = A + R + T + E + B - N \qquad (10.1)$$

This formula is used to compute the annual operating costs as affected by the variables: number of centres (x), frequency of removing (f), drying capacity (d) and storage capacity (w).

c. 1 Depreciation (A)

Let the cost of building one centre of a certain capacity be S_1 and the costs of building x centres jointly representing the same capacity be S_x. It is assumed that for a certain capacity the building costs rise proportionately with the number of units. The building costs of x units will then be:

$$S_x = S_1 \pm C_s\,(x - 1) \qquad (10.2)$$

where C_s is a constant.

In this special case study the depreciation is closely linked with the frequency of removing the centres; it is estimated that:

(1) 50% of the sum invested is re-utilizable at the first move

(2) 25% of the sum originally invested is re-utilizable at the second and third moves.

The annual depreciation is made up as follows.

Usable once: $$\frac{S_1 + C_s\,(x - 1)}{1 \times 2f} \qquad (10.3)$$

where f is the number of years after which the centre is moved.

Usable twice: $\dfrac{S_1 + C_s(x - 1)}{2 \times 4f}$ (10.4)

Usable three times: $\dfrac{S_1 + C_s(x - 1)}{3 \times 4f}$ (10.5)

The residual value at end is assumed to be zero. The mean annual depreciation is found by adding 10.3, 10.4 and 10.5:

$$A = 8.5 \left\{\frac{S_1 + C_s(x - 1)}{12f}\right\} \tag{10.6}$$

c. 2 Interest (R)

The rate of interest is 6%; the average annual interest charges will, slightly simplified, amount to:

$$R = 0.03 \{S_1 + C_s(x - 1)\} \tag{10.7}$$

c. 3 Maintenance (T)

Maintenance is at 1% of the initial cost of building:

$$T = 0.01 \{S_1 + C_s(x - 1)\} \tag{10.8}$$

c. 4 Energy (E)

Smaller centres consume relatively more energy than large ones, a linear relationship is assumed between the number of plants and the energy consumption. The energy costs per ton product then may be estimated by:

$$E = E_1 + C_e(x - 1) \tag{10.9}$$

where E_1 represents the energy costs per ton product for one plant and C_e is a constant.

c. 5 Labour (B)

Relatively more labour is required with smaller plants than with large ones. Assuming a linear relationship again, the cost of labour works out at:

$$B = B_1 + C_b(x - 1) \tag{10.10}$$

where B_1 represents the labour costs of one plant and C_b is a constant.

c. 6 Storage of wheat (N)

The gain from the storage of wheat works out at:

$$N = (P - R_w)\,\frac{75\ W}{100} \tag{10.11}$$

where P is the average price increase per ton, R_w is the interest charge on stored wheat, w is the storage space (m^3) and 75 is the test weight of wheat.

c. 7 Annual operating costs

By inserting formulae 10.6, 10.7 and 10.8 in 10.1 we obtain:

$$K = \left(0.04 + \frac{8.5}{12f}\right) S_x + E + B - N \qquad (10.12)$$

S_x, E, B and N are determined as follows:

c. 7.1 Building costs (S_x)

These costs are based on given capacities for both drying and storage. As these two can vary independently, the building costs can be written:

$$S_x = C + e_d \cdot d + e_w \cdot w + C_s (x - 1) \qquad (10.13)$$

where:

C = the constant part of the building cost, which is practically independent of d and w
e_d = the building costs for one ton h^{-1} drying capacity
d = the drying capacity in tons h^{-1}
e_w = the building costs for one m^3 of storage
w = the total storage capacity in m^3.

The parameters of 10.13 are calculated using the estimated building costs of one and of ten plants, both representing a total drying capacity of 60 tons h^{-1} and a storage of 12,000 m^3. The costs are shown in table 27.

TABLE 27. Total building costs of one and of ten transshipment centres (drying capacity 60 tons h^{-1} and storage of 12,000 m^3).

Component	One centre Number	One centre Cost (× f 1,000) [1]	Ten centres Number	Ten centres Cost (× f 1,000)
Pits	4	800	10	1,000
Dryers	3	300	10	500
Conveyor system		160		200
Storage, ventilated, gravity discharging	12,000 m^3	2,700	12,000 m^3	3,000
Extra cost for movability		500		800
Weighbridge	1	35	10	350
Access road (metalling)		75		500
Earth work, fendering		300		1,500
		4,860		7,850
Supervision, (10% of design)		486		785
Total		5,346		8,635

[1] Dutch guilders

The relationship between e_d and e_w and the number of plants x, can be clearly seen in this case:

at x = 1: e_d = f 5,500 and e_w = f 248 (including 10% supervision)
at x = 10: e_d = f 9,166 and e_w = f 275 (including 10% supervision)

Assuming that e_d and e_w increase linearly with x; e_d and e_w will therefore increase by f 407 and f 3 respectively for each unit increase in x.

So $e_d = 5{,}500 + 407\,(x - 1)$
and $e_w = 248 + 3\,(x - 1)$

From these data C_s and C can be determined. The building costs of one plant, excluding the cost of dryers and storage and the proportional part of the supervision costs, amount to f 5,340,000 — (2,700,000 + 300,000) × 1.10 = f 2,040,000.

For ten plants the cost on a similar basis amounts to f 4,780,000.

So $C_s = \dfrac{4{,}780{,}000 - 2{,}040{,}000}{9} =$ f 305,000
and C = f 2,040,000.

Inserting the values for e_d, e_w, C_s and C in 10.13 gives

$$S_x = 2{,}040{,}000 + d\,\{(5{,}500 + 407\,(x - 1)\} + \\ + w\,\{248 + 3\,(x - 1)\} + 305{,}000\,(x - 1) \qquad (10.14)$$

c. 7.2 Costs of energy (E)

The energy consumption is calculated using real data from centres of different sizes under conditions and working methods currently in use on the farm. For one centre the cost of energy consumption amounts to f 0.90 per ton grain when 85% of the grain is dried (f 0.45 for electricity and f 0.45 for fuel). This gives an annual energy cost of approximately f 50,000 for the handling and drying of 55,000 tons of grain. For each additional extra centre the annual cost of energy rises with f 3,000. Consequently 10.9 becomes:

$$E = 50{,}000 + 3{,}000\,(x - 1) \qquad (10.15)$$

In practice the cost of energy (especially of fuel) varies with the amount of grain to be dried; however, this influence will be ignored.

c. 7.3 Costs of labour (B)

The labour costs are calculated as follows. For one centre are required 11 workers. For a small plant 6 workers (2 per shift) are sufficient, thus for 10 plants: 10 × 6 = 60 men.

As a consequence 10.10 becomes:

$$B = 35{,}200 + (x - 1)\,17{,}400 \qquad (10.16)$$

c. 7.4 Gain from stored wheat (N)

Wheat is stored for about seven months resulting in an average price increase of f 25 per ton. With the rate of interest at 6% and a price of f 370 per ton, the interest charge will be f 13. Formula 10.11 then becomes:

$$N = 9\,w \tag{10.17}$$

After inserting formulae 10.14—10.17 in 10.12 the following equation is obtained:

$$K = \left(0.04 + \frac{8.5}{12f}\right) \{1{,}735{,}000 + 5{,}093\,d + 245\,w + \\ + x(305{,}000 + 407\,d + 3\,w)\} + 64{,}800 + 20{,}400\,x - 9\,w \tag{10.18}$$

This formula can be used to compute the annual operating costs of the transshipment centres for different values of d (drying capacity), w (storage capacity), f (frequency of removing) and x (number of centres).

d. Storage centres

Instead of transshipment centres, storage centres as discussed in 9.2. might be used. If it is intended to use storage on the farm, the building costs together with the associated interest, depreciation, maintenance and removing costs will be higher. On the other hand, the cost of (ship) transport to storage facilities and the cost of hired storage space no longer enter the calculation. Table 28 shows the costs for one and ten storage centres.

TABLE 28. Building costs of one and of ten storage centres with a drying capacity of 40 tons h^{-1} and storage of 66,000 m^3.

Component	One centre Number	One centre Cost (× f 1,000)	Ten centres Number	Ten centres Cost (× f 1,000)
Pits	4	800	10	1,000
Dryers	2	200		250
Conveyor system		100		100
Storage ventilated, gravity discharging	9,000 m^3 at f 200 m^{-3}	1,800	9,000 m^3	2,550
Storage (10% ventilated)	57,000 m^3 at f 115 m^{-3}	6,600	57,000 m^3	8,300
Extra cost for movability		1,445		825
Weighbridge	1	36	10	360
Access road		75		500
Earth work, fendering		300		600
		11,356		14,485
Supervision cost (10% of design)		1,135		1,448
Total		12,491		15,933

In the case of one centre one high silo is assumed, while for ten centres the system of low silos (9.2.*b*) is used. Compared with the transshipment centre of table 27 the drying capacity is lower and the ventilated storage capacity is higher thereby lowering the operating costs of the storage centre. It is assumed that this storage centre can handle the grain brought in at the same rate as the transshipment centre of table 27.

Formula 10.12 can be adapted for the calculation of the annual operating costs. In this case the storage capacity is constant. For the present the ventilated storage and drying capacity are considered as constants. Further C_b (10.10) may be omitted because drying in situ as assumed for the ten-centre case requires only one worker for each centre. Also a deduction must be added because of the savings made for ship transport and storage (f 400,000). The gain from storage applies only to the storage of wheat.

S_1 = f 12,491,600
C_s = f 384,500
B_1 = f 35,200
E_1 = f 100,000
C_e = f 500

Formula 10.12 then becomes:

$$K = \left(\frac{8.5}{12f} + 0.04\right) \times (12{,}106{,}500 + 384{,}500\,x) + + 5{,}500\,x - 580{,}350 \qquad (10.19)$$

10.3 REDUCTION OF THE VARIABLE FACTORS

The number of variables to be introduced in the minimization program can be reduced in the following way:

a. Storage or transshipment centres

The annual operating costs for storage and transshipment centres as affected by the removing frequency and the number of centres have been calculated with formulae 10.18 and 10.19. They are based on the comparable capacities reported in tables 27 and 28. The operating costs are compared in figure 37. This graph shows that the cost using transshipment is lower when $f < 14$ for $x = 10$; $f < 16$ for $x = 3$ and $f < 17$ for $x = 1$; if f is larger than one of these, the cost works out lower for storage centres.

To limit the various possibilities the cost minimization will be carried out on the basis of transshipment centres. If it appears in a later stage of the study that the removing frequency is larger than mentioned above or that the drying capacity or storage space of these centres is considerably more

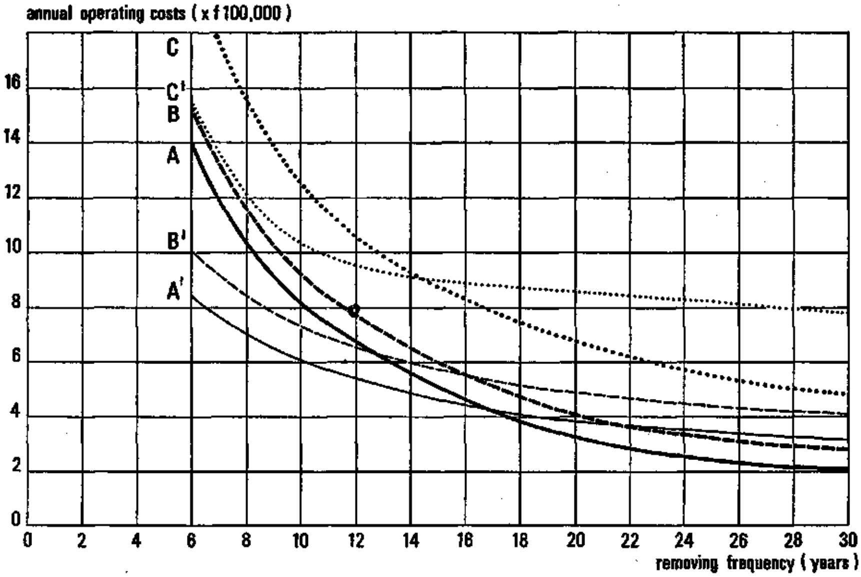


Fig. 37. Annual operating costs of transshipment plants and storage plants (x = 1, 3 and 10), as affected by the removing frequency.

x	storage	transshipment
1	A	A'
3	B	B'
10	C	C'

than 60 tons h^{-1} and 12,000 m^3, storage centres should be chosen instead of transshipment centres.

b. Transport costs and the cost of relocating the plants

The average transport distance can be calculated from the relationship between the number of plants, the removing frequency of the plants and the transport distance given in figure 36. For instance the theoretical transport distance will be 10 km with 10 plants and a removing frequency of once every 15 years. However, this distance can also be obtained with 3 plants removed over periods of 11 years.

By inserting the calculated removing frequency (f) and the number of plants (x) in formula 10.18 the minimum operating costs of the transshipment centres can be found for the various theoretical transport distances (5—28 km). Figure 38 shows the result of these calculations. The operating costs are at their minimum with the transport distances under consideration if the number of plants is two or three. The costs move upward as soon as more or fewer plants are used. In view of the almost identical costs involved, the choice between two or three plants can be based entirely on

the deviations from the model used as found in practice. In further calculations a number of three plants will be assumed. The total of the costs for transport to the plant and the operating costs of the centres can now be estimated for each value of the theoretical transport distance with the aid of:
the numbers of tractors and wagons from figure 32;
the equipment and labour costs from table 26
the operating costs of three plants as given in figure 38

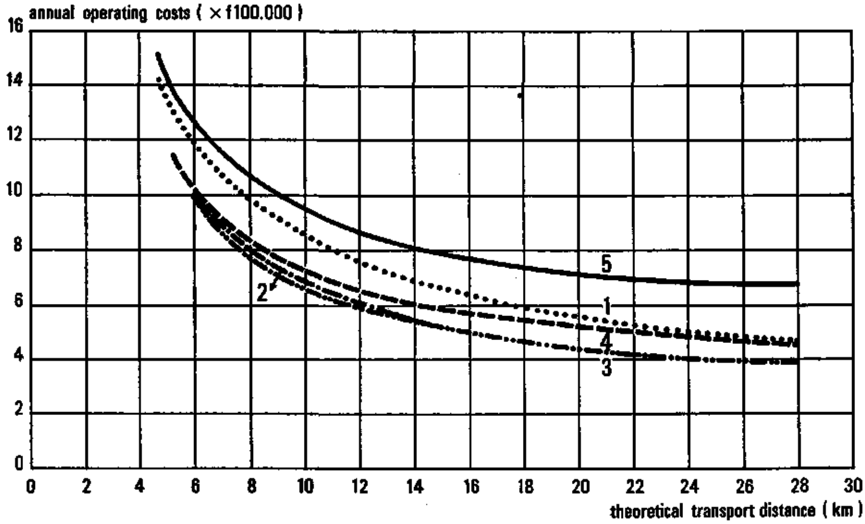


Fig. 38. Relationship between annual operating costs of the transshipment plants (x = 1, 2, 3, 5, 10) and theoretical transport distances to these plants.

1. x = 1
2. x = 2
3. x = 3
4. x = 5
5. x = 10

Figure 39 shows the totals of transport costs and operating costs of the centres computed for various transport distances with three centres in operation. As the desired total combine capacity is not yet known, the theoretical total net combine capacities of 200, 300, 400 and 500 tons h^{-1} have been used in this graph. The point at which the minimum is reached depends on the hourly production and varies from 11 km at an hourly production of 500 tons to 19 km at 200 tons. Since the slope of the lines near the minimum value at hourly productions < 500 tons is quite small, it is reasonable to conclude that at the hourly levels of production considered the minimum total costs will be achieved at a theoretical transport distance of 11 km.

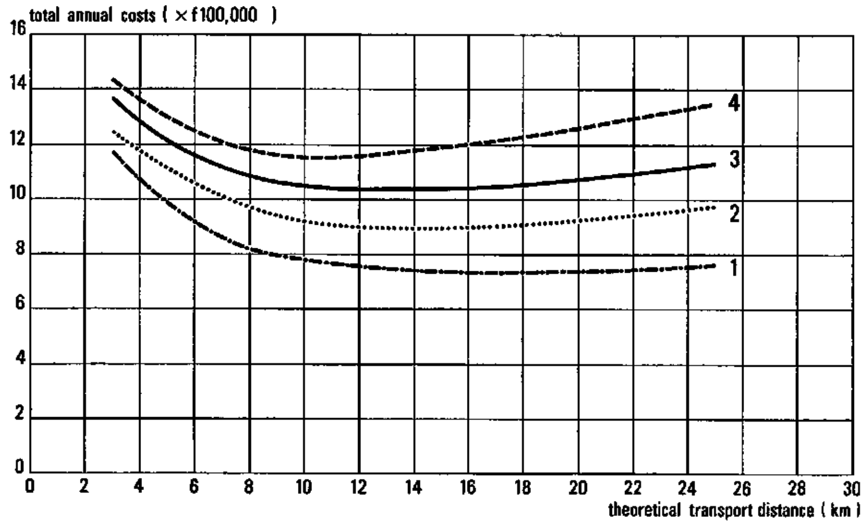


Fig. 39. Relationship between the total annual costs (for transport and for operating three transshipment plants) and the theoretical transport distance. For total net combine capacities of 200 (1), 300 (2), 400 (3) and 500 (4) tons h $^{-1}$.

The error thus introduced is quite small; correction will only be required if it would be found in a later stage of the study that extremely high or low production rates are desirable. This theoretical transport distance of 11 km (actual transport distance 14.3 km, 8.4) can be achieved with three plants by removing each plant once every fifteen years.

For the calculations only the total drying and storage capacity of the plants then have to be considered as variable. The operating costs of these plants have been calculated with 10.18. They are given in table 29 for total drying capacities of 20 to 120 tons h^{-1} and total storage capacities of 4,000 to 20,000 m^3.

TABLE 29. Annual operating costs (× f 1,000) for three transshipment centres, relocated once every 15 years, at various drying and storage capacities.

Storage capacity (m^3)	Drying capacity (tons h^{-1}) 20	40	60	80	100	120
4,000	420	430	440	450	460	470
8,000	470	480	490	500	510	520
12,000	520	530	540	550	560	570
16,000	570	580	590	600	610	620
20,000	620	630	640	650	660	670

a. The annual costs for threshing and transport

It has been shown that the minimum total costs of transport, removal and the operation of the transshipment centres are obtained at a theoretical transport distance of 11 km. For this transport distance table 30 gives the costs of threshing and transport, per combine and per ton h^{-1} capacity, in harvesting wheat at two stubble heights. These costs are computed with: the net combine capacity (60% of effective capacity shown in table 15), the numbers of wheeled tractors and grainwagons (formulae 8.9 and 8.10), the number of crawler tractors (one per six combines) and the costs of equipment and labour (table 26).

TABLE 30. Annual operating costs for threshing and transport (theoretical distance 11 km) for cutting wheat at a low or at a high stubble.

	5.4-m combine	
	per combine	per ton h^{-1}
Low stubble	f 20,000	f 4,000
High stubble	„ 23,000	„ 3,100

b. The value of field losses and separating losses

The prices used and the calculated values of field losses and separating losses are reported in table 31.

The separating losses are taken according to the instructions at 0.5% of the yield. To obtain the harvest costs, the value of the separating losses must be added to the cost of combining.

The field losses of barley, oats and wheat are estimated from the data reported in 3.4.*a*. For wheat two levels of losses are assumed, both will be used in the minimization of the total harvest costs. For colza no data are known; in this case a daily field loss of 7 kg is assumed to occur.

TABLE 31. Price of products and values of separating losses and field losses.

Crop	Price	Separating losses		Field losses per day	
	(f/100 kg)	kg/ha	f/ha	kg/ha	f/ha
Colza	70	13	9.10	7	4.90
Barley	32	20	6.40	15	4.80
Oats	29	25	7.25	50	14.50
Wheat	37	25	9.25	13	4.81
				or 25	9.25

c. Costs involved with cutting at a high stubble

If a high wheat stubble is left the following costs per ha must also be included:

loss of income from sale of straw:	f 70
removal of straw residue:	„ 40
Total	f 110

In the cost minimization program results will also be computed for the case that the extra costs involved with a high stubble are lower.

10.5 SUMMARY

The harvest components consist of: labour, combines, grain wagons, crawler tractors, wheeled tractors and drying plants. The average annual costs of the harvest components are computed with the aid of farm records and estimates where no data are available. For tractors and for personnel that are employed on the farm the year around a part of the annual cost has been prorated and charged to the harvest. The harvest requiring 200 working hours for the tractors and two months for the personnel per annum.

The cost per man during the harvest is f 3,200. Two alternative costs per man viz. „high" and „low", depending on the labour requirements the year around are computed. For combines, tractors and grain wagons the costs per harvest period are shown in table 26.

A formula (10.18) has been developed for calculating the annual operating costs of transshipment centres for various values of drying capacity, storage capacity, number of centres and removing frequency. The annual operating costs of storage centres for different values of number of centres and relocation frequency can be computed with formula 10.19. Based on both formulae the annual operating costs of transshipment centres and storage centres are compared (figure 37). It demonstrates that the operating costs of transshipment centres are lower than those of storage centres provided that the plants are relocated in less than 15 years and storage at the transshipment centres is not larger than 12,000 m^3.

The minimum operating costs of the transshipment centres to achieve a desired transport distance between 6 and 28 km are obtained with two or three centres (figure 38).

The total of the costs of grain transport and the operating costs of three transshipment centres are at minimum for a theoretical transport distance of 11 km and for a total net combine capacity between 200 and 500 tons h^{-1}. The plants then have to be removed once every 15 years (figure 39).

Based on this removing frequency and on three centres the annual operating costs of transshipment centres are shown in table 29 at various drying and storage capacities.

The annual costs for threshing and transport are reported per combine in table 30. Further the value of separating losses, field losses and the costs involved with high cutting are computed at present price levels (table 31, 10.4.*c*).

11 MINIMIZATION OF THE TOTAL HARVEST COSTS

11.1 INTRODUCTION

The objective of this study is to minimize the total harvest costs over a number of years allowing for the influence of the weather. For this purpose the relationships from figure 1 have been quantified in 3—9 and the components of the total harvest costs have been computed in 10. The independent variables to be taken into account are:

Number of combines
Technique of operating the combines (high or low stubble)
Drying capacity of the transshipment centres
Storage capacity of the transshipment centres

Other variables as the cropping system and the maturity dates will be introduced as constants. Then for every combination of the four variable factors the progress of the harvesting operations and the field losses have to be computed. As the progress of the harvest depends to a great deal on the weather, the field losses will accordingly vary from year to year.

The sum of the computed harvest costs and the value of the field losses, referred to as the total harvest costs, is a valuable information to compare various harvesting systems. Both analytical and simulation techniques can be applied to estimate the average field losses. Analytical methods for describing the weather have been applied by WEISS (1964), who describes sequences of wet and dry days by a Markov chain probability model and by WAITE (1966) who has calculated the wet-dry day probabilities for Iowa. Similar methods have been employed in systems engineering in agriculture for the cotton harvest by STAPLETON *et al* (1965) and by LINK (1964) for machinery selection.

Simulation methods have been applied by ZUSMAN and AMIAD (1965) for farm planning under conditions of weather uncertainty, by HALTER and DEAN (1965) for large-scale ranch decision making in the face of uncertainties in weather and market prices for beef and by DONALDSON (1968) for assessing harvest machinery capacity in cereals under influence of the weather.

HESSELBACH (1966), LOMBAERS (1967) and ROCKWELL (1967) discussed the pros and cons for analytical and simulation methods. ROCKWELL states „Simulation is a term used by system analysts both with reverence and distrust. Some view it as a panacea, the exlixir of the operations researcher, the only way to deal with large, complex systems. Others view simulation as a poor excuse for inadequate modelling and a very expensive way to learn what one can already logically deduce from system characteristics". These authors conclude that simulation methods are useful when the analytical approach is impossible or would involve too many complications.

This is normally the case with dynamic systems with stochastic non-linear relationships. It may be considered as a major advantage of simulation models that their use provides better user acceptance than analytical models as he can see the reality of the simulation and thus he usually will have more faith in the conclusions from the simulation output. Another advantage is that interpretation of simulation methods does not usually demand a mathematical background on his part. The differences between the two methods are clearly pointed out by KOLLER (1966) in his definition of simulation: „By simulation we understand the calculation of individual alternative possible cases of a decision model. Unlike the analytical process, there is no formal algorithm here which leads inevitably to an optimal solution. In a series of calculation experiments the appropriate dependent variable is determined each time for a given set of coefficients of independent variables. Instead of the direct search for the „best" solution as in analytical processes the question asked is: What happens, when . . . .?".

For an analytical approach an estimate of the average annual total harvest costs as a function of four independent variables should be made with a stochastic model of the weather. The average annual costs can then be computed with the aid of the probability distribution of the number of available hours. In this case a solution has been sought by simulation for ease of application instead of an analytical approach.

11.2 SIMULATION OF THE HARVEST ORGANIZATION

11.2.1 *Basic data and limitations*

a. Cropping program

In using the mean numbers of available hours in each range of kernel moisture content (Appendix I) and the combine capacities for the three moisture ranges (table 15), the number of hectares for each crop that can be threshed by a 5.4-m combine specified in table 14 has been calculated. The results together with the available periods assumed (table 5) are shown in table 32.

TABLE 32. Average available harvest period per crop and the average area that can be threshed by a 5.4-m combine in this period.

Crop	Available period	Area (ha)
Colza	22/7— 7/8	67
Barley	7/8—17/8	36
Oats	17/8— 6/9	38
Wheat (I) [1]	17/8— 6/9	40
Wheat (II) [1]	17/8—16/9	72

[1] I, II; estimated available period two and three decades respectively.

The available periods for oats and wheat (I, II) have been arbitrarily fixed in this table. Its effect will have to be judged from the results of the simulation. The data reported in table 32 have been used to calculate three cropping programs for 14,000 ha as shown in table 33.

TABLE 33. Three cropping programs (ha).

Crop	I [1]	II [2]	III [3]
Colza	5,200	4,400	4,300
Barley	2,800	2,400	2,600
Oats	2,900	2,500	1,500
Wheat	3,100	4,700	5,600
Total	14,000	14,000	14,000

[1] wheat harvest in two decades
[2] wheat harvest in three decades
[3] program for simulation

Program III is similar to program II except for the area of oats, which has been reduced to 1,500 ha with a corresponding increase of the wheat area. This is because wheat is a more profitable crop than oats; the 1,500 ha of oats is the minimum area now considered essential for proper crop rotation.

b. Combines

With a few exceptions, the combine operates during all available hours. The exceptions are:

b. 1 When harvesting of a crop is completed before the following crop is ripe, there is an interval in which no combining is done

b. 2 When the harvest of a particular crop is finished during a day, no combining is done for the remaining hours of that day because the combines have to be cleaned before harvesting of the next crop can be started

b. 3 If either the drying or storage capacity is fully occupied and no extra grain can be received

Combining of oats and wheat is started simultaneously with half of the number of combines in each crop. After the harvesting of oats is completed all the combines work in the wheat crop.

c. Drying, storage and shipment

c. 1 The plant can, with three shifts, work for 22 hours per day or for $6 \times 22 = 132$ hours a week

c. 2 The moist grain can be kept in good condition for an unlimited period by ventilation during storage

c. 3 A maximum of 90% of the storage space can be used *c.* 4 If the storage is full, sufficient combines are kept operating to bring in grain at the same rate at which is it dried and shipped

c. 5 Grain with a moisture content in the range of 23—28% passes through the dryer twice, grain with a moisture content in the range of 19—23% is dried in one operation. The same applies for colza in other moisture ranges

c. 6 It is assumed that dry grain can be shipped out continuously, i.e. that an unlimited number of ships is available. In practice this is true. However, some dry grain storage is indispensable for efficient operation of the transshipment centre and to enable the ships to be loaded quickly. As ships of approximately 670 m^3 are used, this storage is fixed at two shiploads or 1,340 m^3 per centre, making 4,000 m^3 for three centres

d. Field losses

d. 1 In a year the maturity dates of a particular crop vary in different fields. This is due to the variation in the date of sowing. Therefore, it is assumed that no field losses occur in the week after the average maturity date of the crop

d. 2 One week after the crop is ripe the following daily losses are assumed to occur: colza 7 kg; barley 15 kg; oats 50 kg; wheat 13 or 25 kg (table 31).

d. 3 A time limit has been set for completing harvesting of each crop; after this date the crop is assumed not to be harvested. The introduction of this date in the computer program results in printing out the portion of the crop not harvested. However, in practice the crops remaining in the field on the time limits set will be harvested and are not lost. The introduction of the time limit, though, makes it possible to take into account the following factors which will tend to increase the costs:

d. 3.1 After a certain period the field losses will tend to become larger than those predicted because the daily field losses increase exponentially

d. 3.2 The reduction in grain quality

d. 3.3 The land must be available by a certain date for the work scheduled to be carried out next

d. 3.4 Equipment and personnel are needed for other work

These factors will cause an increase of harvest costs or of other costs which cannot be quantified. Therefore two alternative possibilities have been considered: the unharvested quantity at the time limit is lost for 50% or 100%.

The following time limits have been fixed:

Colza: August 20; after colza several operations are needed to prepare the fields for sowing of wheat

Barley: September 7; colza has sometimes to be sown on a limited acreage after barley; this sowing must be completed before September 15

Oats: two weeks after combining has started; this limit has been fixed because of the susceptibility to lodging and shattering

Wheat: October 1; personnel and equipment must be available for fall operations

11.2.2 *The computer program*

The program is written in ALGOL; the simulation model of combining, drying and storing is as follows. The grain in moisture range 1 ($< 19\%$) is shipped immediately and need not be considered in the model. For the description of the daily flow of the grain in the moisture ranges 2 (19—23%) and 3 (23—28%) (to be dried once and twice respectively) a special ALGOL procedure has been developed.

The following notations are used in the description:

C_i = daily supply of grain in moisture range i, $i = 1, 2, 3$

t = point of time during the ten hours (at maximum) that grain is brought in from the field

$v_i(t)$ = amount of stored grain in moisture range i on time t

$v(t)$ = total amount of stored grain on time t, $v(t) = v_2(t) + v_3(t)$

t_0 = point of time when no grain of moisture range 3 is present any more in the storage space, therefore $v_3(t) = 0$ for $t > t_0$

t_1, t_3 = points of time when the storage space should become fully occupied, thereafter only a part (μ) of the combines can go on working ($0 \leqslant \mu \leqslant 1$)

t_2 = point of time that the amount of grain in moisture range 3 stored at t_1 has been transferred by drying into moisture range 2

d = drying capacity

m = volume of storage space (90% of actual storage space)

The six important situations that can arise in the storage space are shown in figure 40. In the situations 1, 2 and 3 the course of line v(t) changes on time t_0. This means that before t_0 the drying capacity was more than sufficient to dry the supply of grain in moisture range 3 ($0.1\ C_3$), the remaining part of the drying capacity ($d - 0.1\ C_3$) can then be used to dry the amount of grain in moisture range 3 present at the beginning of the day ($t = 0$).

Time t_0 is computed with the formula

$$t_0 = \frac{v_3(0)}{d - 0.1\ C_3} \tag{11.1}$$

After $t = t_0$, $v_3(t)$ remains zero until $t = 10$ (end of the day). After time t_0 the remaining drying capacity ($d - 0.1\ C_3$) is used to dry the amount of grain in moisture range 2 at t_0: $v_2(t_0)$. The moisture content of this grain has only to be reduced with 2% and therefore the drying rate is twice as fast as the drying rate of moisture range 3. The rate of removal of this grain into moisture range 1 is then 2 (d — 0.1 C_3).

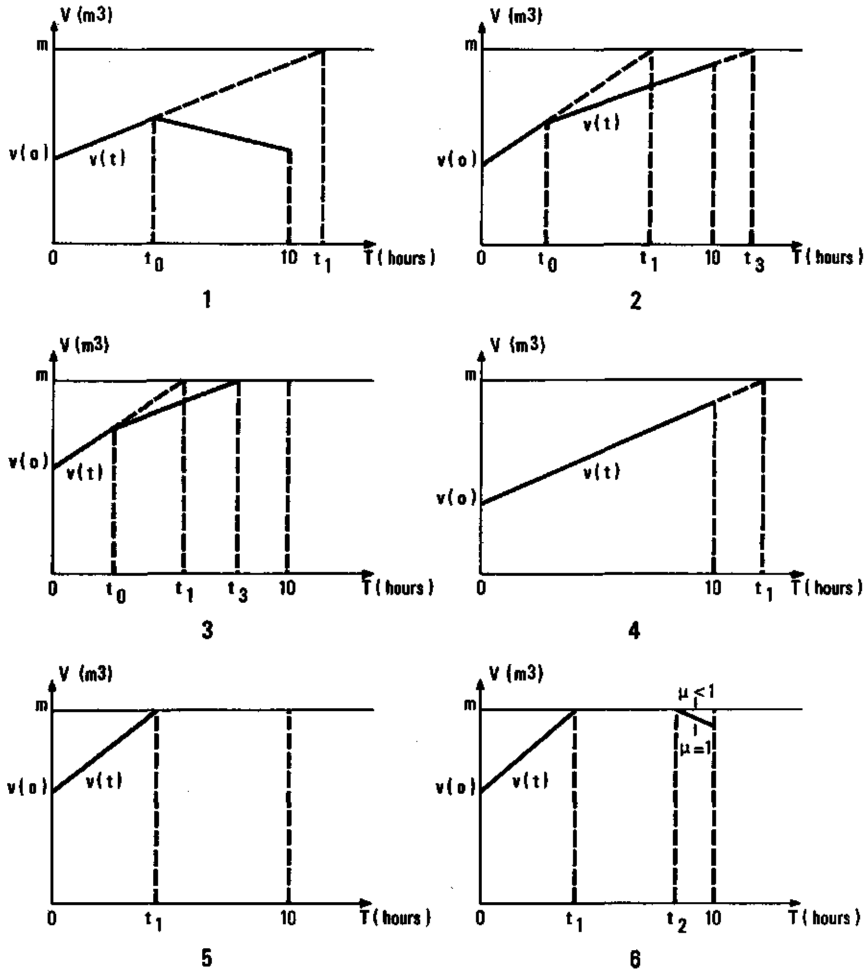


Fig. 40. The six situations that can arise in the storage space.
T = time during one day
O = 9 a.m.
10 = 7 p.m.
V = storage space

The supply of grain in moisture range 2 consists of the amount dried from range 3 in range 2: 0.1 C_3, and the supply from the field in range 2:

$0.1\ C_2$. The course of $v(t) = v_2(t)$ is then linear with slope $0.1\ C_2 + 0.1\ C_3 - 2\ (d - 0.1\ C_3)$.

If the slope is positive then v(t) increases (situations 2 and 3); if the slope is negative then v(t) decreases (situation 1). In situation 1 the storage space will not be filled with grain during the day. In situation 3 the storage space will be filled at time t_3; the time t_3 is computed with the formula:

$$t_3 = t_0 + \frac{m - v_2\,(t_0)}{0.1\,C_2 + 0.1\,C_3 - 2\,(d - 0.1\,C_3)} \tag{11.2}$$

From time t_3 only a part (μ) of the combines can go on working; μ is chosen in such a way that the storage space remains exactly occupied. Then the slope of v(t) must be zero for a grain supply $\mu\ (0.1\ C_3 + 0.1\ C_2)$. This slope is: $0.1\ \mu\ C_2 + 0.1\ \mu\ C_3 - 2\ (d - 0.1\ \mu\ C_3)$ and it follows that:

$$\mu = \frac{2d}{0.1\,C_2 + 0.3\,C_3} \tag{11.3}$$

In situation 4, v(t) increases linear but the storage space does not get filled during the day. The slope of $v(t) = 0.1\ C_2 + 0.1\ C_3$ when the drying capacity is not sufficient to dry the supply in range 3 ($0.1\ C_3$) into moisture range 2; then $d < 0.1\ C_3$. The slope of $v(t) = 0.1\ C_2 + 0.1\ C_3$ also for $d > 0.1\ C_3$, $v_3\ (0) > 0$ and $t_0 > 10$.

It can also happen that the slope of $v(t) = 0.1\ C_2 + 0.1\ C_3 - 2\ (d - 0.1\ C_3)$ viz. when $v_3(0) = 0$. This situation is the same as situation 3 for $t_0 = 0$. In the situations 5 and 6 the storage space is filled during the day on time t_1. Time t_1 is computed with the formula:

$$t_1 = \frac{m - v\,(0)}{0.1\,C_2 + 0.1\,C_3} \tag{11.4}$$

In these situations the combines are stopped until time t_2 when the amount of grain in moisture range 3 at time t_1, $v_3(t_1)$, is dried into moisture range 2.

Time t_2 is computed with the formula:

$$t_2 = t_1 + \frac{v_3\,(t_1)}{d} \tag{11.5}$$

If $t_2 \geqslant 10$ then the combines do not start working any more during that day (situation 5). If $t_2 < 10$ then situation 6 arises. During the remaining time $10 - t_2$ a part μ of the combines starts working when:

$$0.1\ \mu\ C_2 + 0.1\ \mu\ C_3 - 2\ (d - 0.1\ \mu\ C_3) = 0.$$

All the combines ($\mu = 1$) start working when:

$$0.1\ C_2 + 0.1\ C_3 - 2\ (d - 0.1\ C_3) \leqslant 0.$$

The decision strategy for the six situations is shown in a block scheme (figure 41). For the six situations, the stored quantities at the end of the day, $v_2(10)$ and $v_3(10)$, can be computed. As during the night drying is done during 12 hours, $v_2(0)$ and $v_3(0)$ for the following day can be computed.

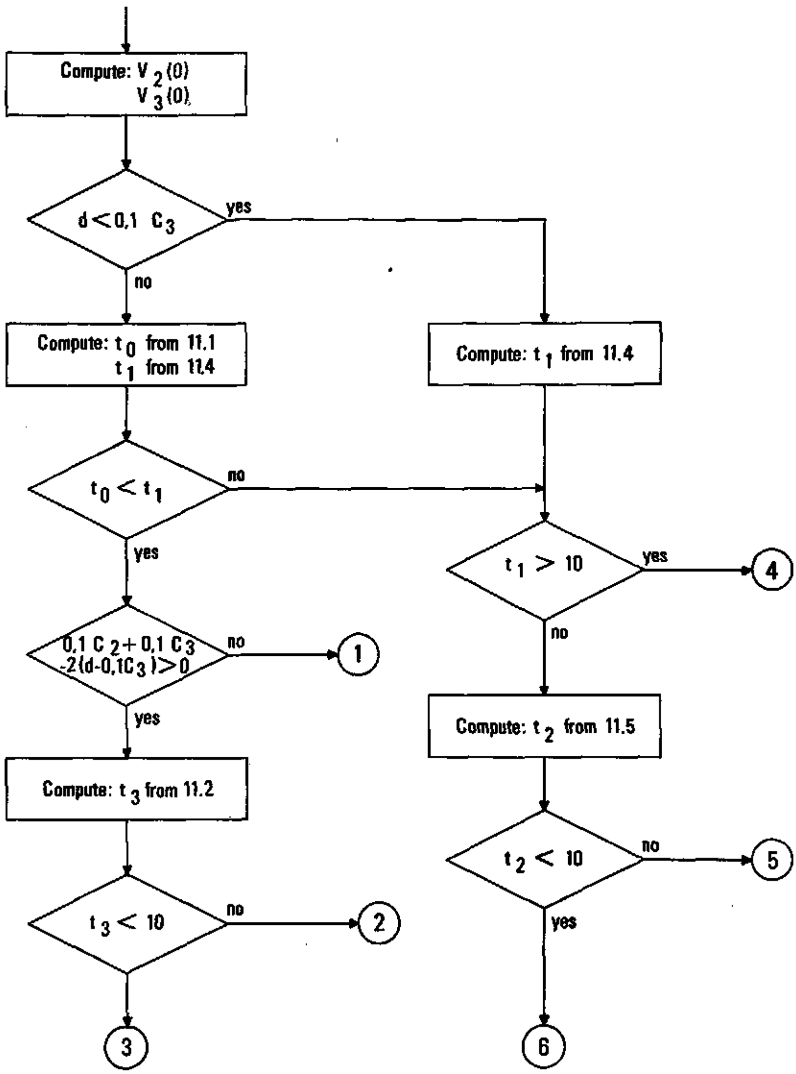


Fig. 41. Block scheme showing how is decided for one of the six situations.

When $v_3(10) > 12d$ then:
$v_3(0) = v_3 - 12d$ and $v_2(0) = v_2(10) + 12d$.

When $v_3(10) < 12d$ then
$v_3(0) = 0$, and $v_2(0) = v_2(10) + 3\ v_3(10) - 24d$, if $v_2(0) < 0$ then $v_2(0) = 0$.

The following limits have been set on the variables:
combines (5.4-m): 30—110 (number)
drying capacity: 20—120 (tons h^{-1})
ventilated storage capacity: 4,000–20,000 (m^3)
combine operation: high or low stubble

The output provides the following data for each year:
Dates of completion of combining (each crop)
Unused drying capacity for each crop
Unused combine capacity, i.e. the number of hours the combines have not been able to work due to shortages of drying and/or moist grain storage capacity
Field losses for each crop (for wheat at both 13 kg and 25 kg per day)
Quantities remaining in the field on the time limits set
Total value of field losses (the unharvested quantities for 50 and 100% lost)

The same data are given as annual averages over the period 1931—1967. Also given are the total harvest costs as annual averages for three levels of labour costs and for clearing the straw.

11.3 DISCUSSION OF THE RESULTS

With a few exceptions the results are discussed on the basis of average data of the period 1931—1967. To simplify the text the assumptions shown in table 34 for three levels of field losses and labour costs are used.

TABLE 34. Assumptions on the levels of field losses and labour costs.

	Level	Low	Medium	High
Field losses	wheat loss/day	13 kg	13 kg	25 kg
	loss after time limit	50%	100%	100%
Labour cost/worker/harvest		f 1,100	f 3,200	f 3,200 and f 13,060 [1]

[1] see 10.2.*a*.1.

In judging the results it must be noted that some approximations and simplifications have been introduced in the computer program. For that reason the minima of the cost curves should not be considered as absolute. The minima will in general be described as a certain range (number of combines or drying capacity for example). The limits of the ranges have been set as the points where the cost curves rise more than f 25,000 above the minimum.

a. Storage capacity for grain to be dried

Deliveries of grain for drying are irregular and quantities vary. The larger the storage capacity the easier it will be to cope with peaks in delivery and the more the combines can be fully employed during the available hours. The storage capacity required is closely linked to the number of combines on the one hand and to the drying capacity on the other. The larger the number of combines the larger will be the rate of delivery of grain and consequently the larger the required storage capacity. However, with a large drying capacity the storage capacity required will be smaller, for the grain can then be dried and be shipped out at a faster rate.

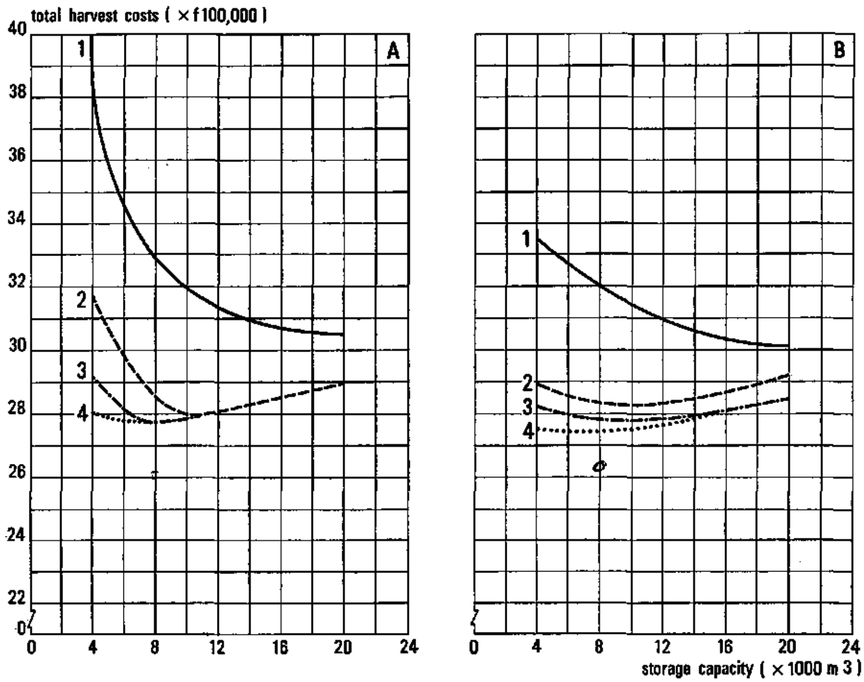


Fig. 42. Average annual total harvest costs for 70 (A) and 90 (B) combines and various drying- and storage capacities. Medium level of field losses and labour costs.

1. drying cap. 40 tons h^{-1}
2. „ „ 60 „ „
3. „ „ 80 „ „
4. „ „ 100 „ „

Figure 42 illustrates the trend of the average total harvest costs for 70 and 90 combines as affected by drying and storage capacity. This shows that when the drying capacity is increased the storage required decreases. The location of the minima in the least cost curves (drying capacities 80—100 tons h^{-1}) is of the greatest interest. For these curves the minima are located at storage capacities ranging from 5,000—10,000 m^3 with 70 combines and from 3,000—12,000 m^3 with 90 combines. With other numbers

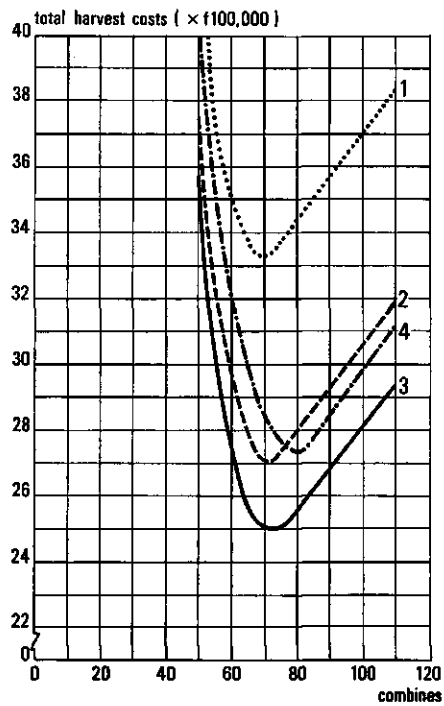


Fig. 43. Average annual total harvest costs as affected by the number of combines and the cutting height in wheat.
Drying cap. 80 tons h^{-1}, storage cap. 12,000 m^3. Medium level of field losses and labour costs.

1. high stubble; extra costs: f 110 per ha and f 3,000 per combine
2. high stubble; extra costs: f 3,000 per combine
3. high stubble; no extra costs
4. low stubble

of combines the minima of the least cost curves occur in the same range, although tending to shift towards 4,000 and 10,000 m^3 respectively as the number of combines declines or increases. Because of this, further cost comparisons may safely be based on a storage capacity of 8,000 m^3 irrespective of the combining and drying capacities.

Adding the 4,000 m^3 of storage required for dry grain (11.2.1.*c*) brings the total storage capacity to 12,000 m^3. This total does not exceed the limit of 12,000 m^3 which has been determined (10.3.*a*) as the limit above which storage plants would be preferable to transshipment plants. Therefore the limits imposed are not exceeded and the cost calculations can be based on transshipment plants.

b. Stubble height

The effect of cutting wheat with a high stubble is an increase of the cost of harvesting because of the cost of clearing the straw and the additional transport capacity required. These costs are offset to some extent by lower wheat losses since the wheat harvest will be completed sooner. Figure 43 presents the annual total harvest costs when cutting with low and high stubble, assuming different costs for the extra work involved.

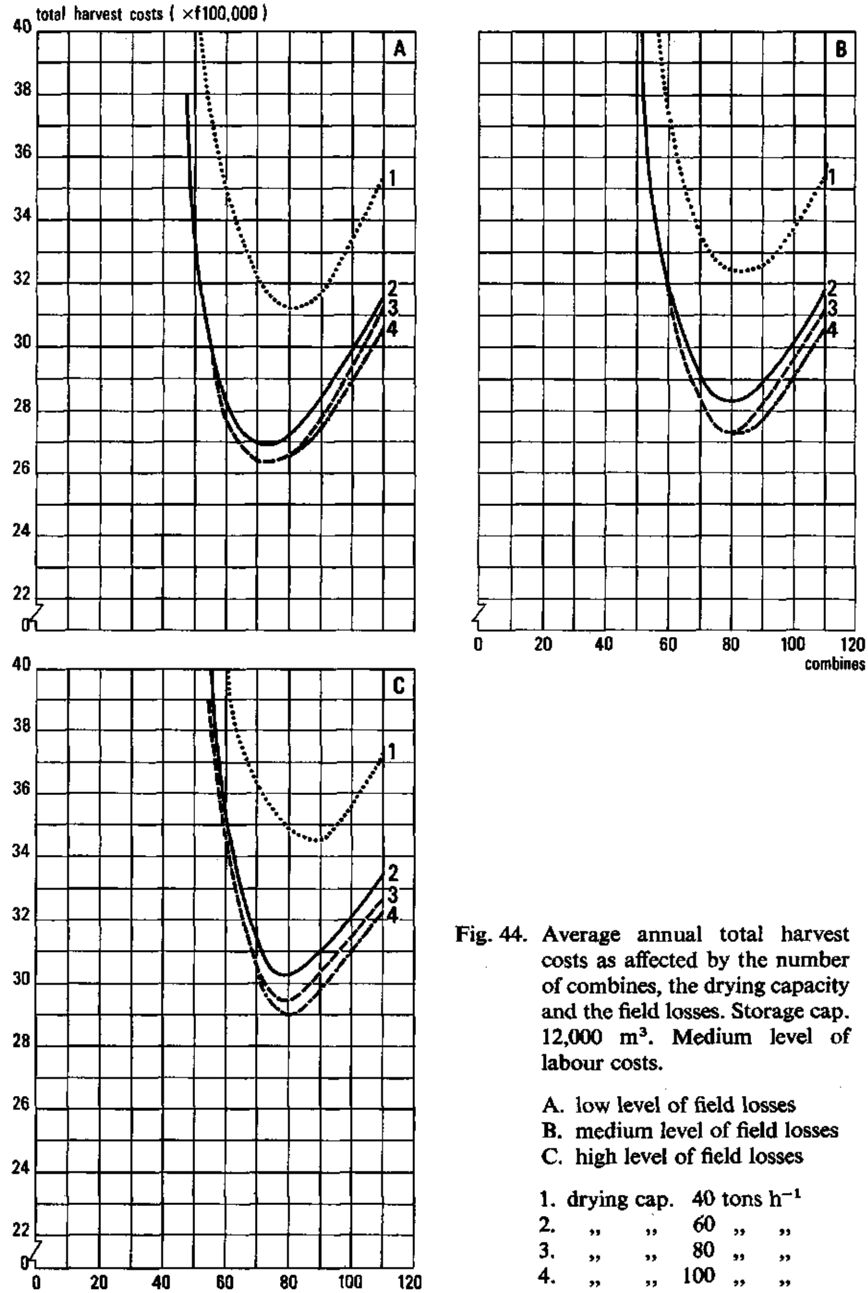


Fig. 44. Average annual total harvest costs as affected by the number of combines, the drying capacity and the field losses. Storage cap. 12,000 m³. Medium level of labour costs.

A. low level of field losses
B. medium level of field losses
C. high level of field losses

1. drying cap. 40 tons h^{-1}
2. ,, ,, 60 ,, ,,
3. ,, ,, 80 ,, ,,
4. ,, ,, 100 ,, ,,

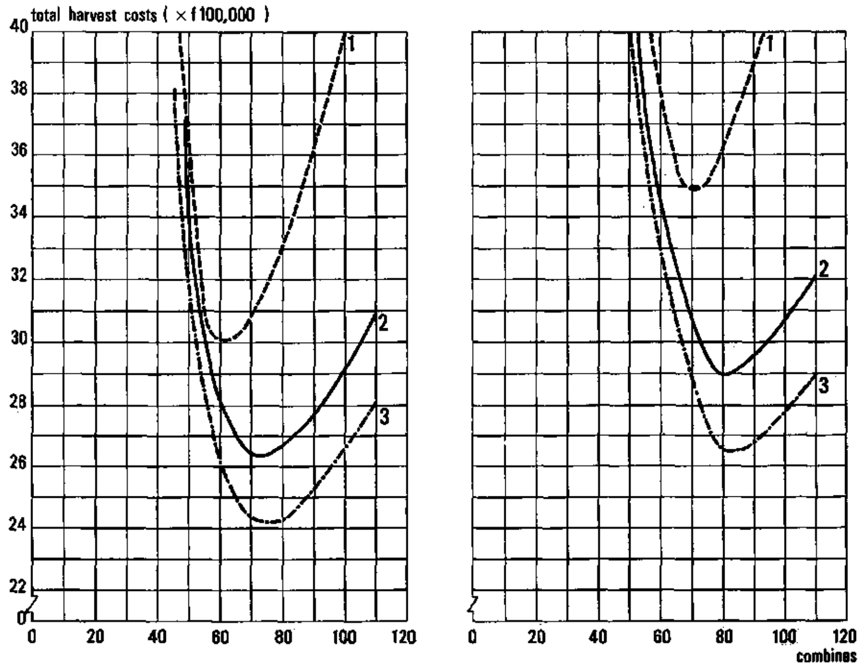


Fig. 45. Average annual total harvest costs as affected by variable labour costs and field losses. Storage cap. 12,000 m³, drying cap. 80 tons h⁻¹.

A. low level of field losses
B. high level of field losses

1. high level of labour costs
2. medium level of labour costs
3. low level of labour costs

The minimum of the high stubble curve, assuming no extra costs are involved, is about f 200,000 lower than the minimum of the low stubble curve. These minima are obtained with 70 and 80 combines respectively. Only allowing for the costs of additional transport, the minimum of the high stubble curve is obtained at about the same level as that of the low stubble curve. When the cost of clearing straw is also included, the minimum of the high stubble curve is about f 600,000 higher than that of the low stubble curve. At present all extra costs for a high stubble are involved. Thus there is no advantage in cost in combining wheat with a high stubble.

In certain exceptional years, however, it may be advantageous to do so. This was the case for instance in 1950 when the weather was extremely wet during harvest time. With a fleet of 70 combines the quantities remaining to be harvested on October 1 in 1950 would have been 12,000 tons for „low" and 4,600 tons for „high" cutting. If these quantities are regarded as a 100% loss, this amounts to a loss of f 2,738,000 less for „high" than for „low" cutting. The higher harvest costs involved in „high" cutting are f 826,000, so in that year „high" cutting would have yielded an advantage of f 2,738,000 — f 826,000 = f 1,912,000. However, switching over to „high" cutting when the harvest proceeds slowly is fairly impossible as the straw is sold on contract before the harvest has started.

c. The average total harvest costs

Figure 44 shows the effect of the number of combines and the drying capacity at the three levels of field losses on the cost curves for transshipment centres with 12,000 m^3 storage capacity. The curves with 120 tons h^{-1} drying capacity are not shown because they are equal to or higher than the curves with 100 tons h^{-1} drying capacity. From these curves it can be concluded that the minimum costs are obtained with drying capacities between 80 and 100 tons h^{-1}. With drying capacities lower than 80 tons h^{-1} the total costs rise substantially. The minima of the curves range from 75 combines with „low" losses to 83 combines with „high" losses. Figure 45 illustrates the influence of the level of both labour costs and field losses on the minimum cost curves in figure 44. With „low" losses the minima of the cost curves range for „high" and „low" labour costs from 63 to 76 combines. With „high" losses these minima range from 73 to 85 combines.

The minimum cost ranges from figures 44 and 45 are summarized in table 35.

TABLE 35. The combine and drying capacities at the minima of the total harvest cost curves as affected by the level of field losses and of labour costs.

field losses [1]	labour costs [1]	5.4-m combines (number)	drying cap. (tons h^{-1})	min. total harvest costs (× f 1,000)
low	low	70—82	80	2,420
low	medium	69—79	80	2,630
low	high	60—67	80	3,000
medium	medium	76—84	80—100	2,730
high	low	79—89	100	2,650
high	medium	78—86	100	2,900
high	high	69—76	80—100	3,480

[1] see table 34.

These data show that the harvest capacities at the cost minima vary between 60—67 and 79—89 combines with 80 and 100 tons h^{-1} drying capacities respectively.

A breakdown of the costs for medium level of field losses and labour costs is shown in figure 46 and summarized in table 36. At minimum cost, with about 80 combines, the annual costs of equipment and labour account for 83.9% of the total. The combines, including operators and

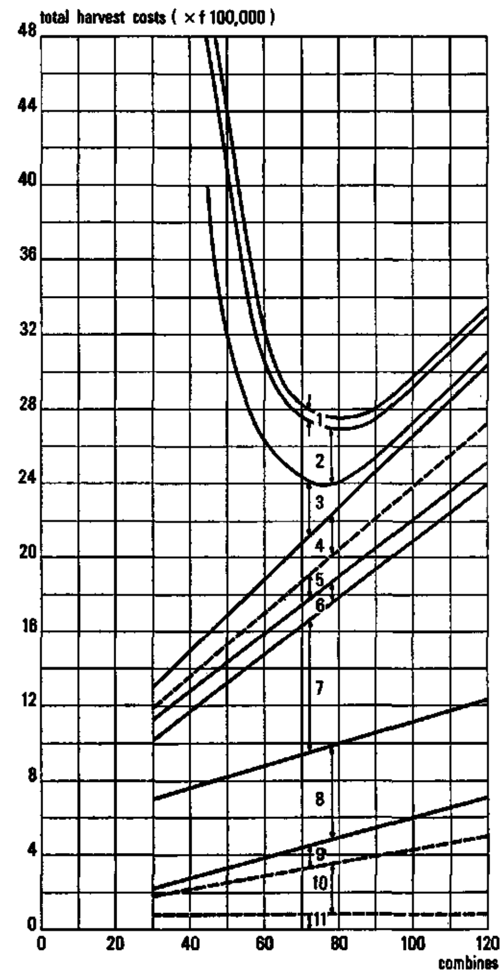


Fig. 46. Breakdown of the average annual total harvest costs as affected by the number of combines. Drying cap. 80 tons h^{-1}, storage cap. 12,000 m^3. Medium level of field losses and labour costs.

1. field losses in colza and barley
2. field losses in oats and wheat
3. loss due to crops not harvested at time limits
4. wagons
5. tractors
6. separating loss of combines
7. combines
8. transshipment plants
9. tractor drivers
10. combine operators
11. personnel of transshipment plants

separating losses account for a large share (43.6%) of the total cost. With 70 and 90 combines the annual costs of equipment and labour are 73.4% and 89.4% respectively with losses accounting for 26.6% and 10.6% of the total.

In table 36 the level of separating losses is fixed at 0.5% per ha. If the permitted level of losses had been fixed at 2% per ha then the value of the separating losses would rise with f 360,000. This rise in cost would be counteracted by the lower costs of combining as the effective combine capacity would increase with approximately 25% (figure 24) causing a decline in the number of combines required. For example 80 combines working at a 0.5% level have the same total capacity as 64 combines working at a 2%

level. The annual cost of combining then decreases with 16 × f 13,100 = f 209,600; this is not sufficient to balance the rise in value (f 360,000) of the separating losses. Therefore, in the minimum cost range combining with permitted separating losses at 0.5% per ha is preferable to combining with separating losses at 2%.

TABLE 36. Breakdown, in %, of the total harvest costs for different numbers of combines. With drying capacity 80 tons h^{-1}, storage 12,000 m^3 and medium level of field losses and labour costs.

Number of combines →	60		70		80		90	
Labour								
drying plants	2.0		2.1		2.2		2.0	
combines	5.9		7.9		9.4		10.5	
transport	4.5		6.0		7.5		8.1	
		12.4		16.0		19.1		20.6
Equipment								
drying plants	15.2		17.6		18.0		17.5	
combines	18.7		24.9		29.8		32.7	
separating losses	3.8		4.3		4.4		4.3	
tractors	3.1		3.8		5.1		5.4	
wagons	5.0		6.8		8.0		8.9	
		45.8		57.4		65.3		68.8
Field losses								
standing crop								
colza, barley	3.3		1.5		1.5		1.2	
wheat, oats	14.4		13.0		10.0		6.9	
after time limit	24.1		12.1		4.1		2.5	
		41.8		26.6		15.6		10.6
Total		100.0%		100.0%		100.0%		100.0%
100% = (× f 1,000)		f 3,190		f 2,820		f 2,730		f 2,810

If for the farm under discussion both field losses and labour costs are taken as „medium" the results of the simulation may be summarized as follows. During the period 1931—1967 the minimum total harvest costs are obtained with a fleet of 76—84 combines (5.4-m) and drying and storage capacities of 80—100 tons h^{-1} and 12,000 m^3 respectively. That is: each 5.4-m combine needs an available drying capacity of about one ton h^{-1}, a ventilated storage capacity of 100 m^3 and a dry storage capacity of 50 m^3. With the assumed cropping program one such harvesting unit can then handle 166—184 ha per harvest season. The transshipment centres should be removed once in fifteen years, resulting in a mean transport distance of 11 km. With this organization the total harvest costs are made up as follows:

Drying and temporary storage:	20.2%
Transport:	20.6%
Combines:	43.6%
Field losses:	15.6%

In reaching above conclusions the field losses have been taken at the „medium" level. When more research into the field losses, including the crops lost after the time limit, would show higher or lower losses these conclusions can be modified with the results shown in figures 44 and 45.

It is possible though that the field losses can be diminished in the future by the introduction of varieties with a high resistance against lodging or shattering. Another factor that may influence the harvesting capacity giving the minimum cost in the future years is the ratio of labour costs to product prices. In recent years the labour costs have increased considerably faster than the product prices (figure 5). If this trend persists in the years to come then the optimum number of combines will tend to decline unless the increase of harvest costs can be balanced by a reduction in other cost components. One possibility for a reduction in costs may be found in the cost of combining which accounts for about 40% of the harvest costs. In the period 1957—1967 the combine capacities have increased with approximately 35%, consequently the costs of combining could be kept at the same level as shown in figure 5. If this trend continues the resulting lower costs of combining may possibly counteract the increasing costs of labour.

Another possibility might be found in the use of contractors for the wheat harvest as they finish harvesting of wheat on the private farms in the area within 10 days after wheat has reached maturity (VAN KAMPEN, 1968).

The most important factor affecting the harvesting capacity in the years to come will continue to be the weather. For the purpose of this study it has been assumed that the weather will follow a similar pattern in the future. As already shown the harvest weather during the first half of the period 1931—1967 was more favourable for harvesting operations than during the second half of this period. To illustrate the difference in the effect of the weather during these two periods on the optimum harvesting system, the curves for these periods are presented in figure 47. These show clearly the great difference in results between the two periods; in 1930—1949 the minimum total harvest costs would have been obtained with 60—70 combines (230—200 ha per combine) and a drying capacity of 80 tons h^{-1}; in the period 1949—1967 on the contrary 80—90 combines (175—155 ha per combine) with a drying capacity of 100 tons h^{-1} would have been necessary to obtain the minimum costs. If this pattern of weather could be shown to be predictable, the total harvest costs could be diminished since the har-

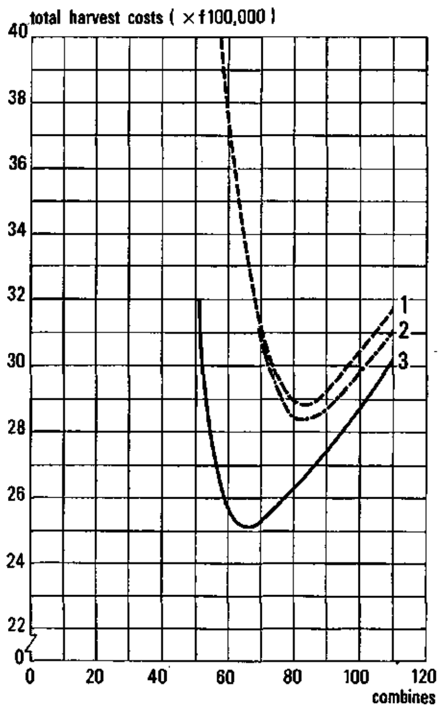


Fig. 47. Average total harvest costs as annual averages of 1931—1949 and 1949—1967. Storage cap. 12,000 m³. Medium level of field losses and labour costs.

1. 1949—1967, drying cap. 80 tons h^{-1}
2. 1949—1967, drying cap. 100 tons h^{-1}
3. 1931—1949, drying cap. 80 tons h^{-1}

vesting capacity could be adjusted to the predicted weather pattern. At present the available harvesting capacity of the contractors in the area may be used for this purpose.

d. The harvesting operations

Table 37 contains average data on the harvesting operations and the use of combines and dryers.

TABLE 37. Average and standard deviation of harvest periods of crops with different threshing and drying capacities and average idle capacities of combines and dryers during the harvesting period.

		Duration of harvest in number of days				Date of completing wheat harvest			Average of the not utilized available time	
combines (number)	drying cap. (tons h^{-1})	colza	barley	oats	wheat			in 95% of the years before	dryers[1]	combines[2]
60	80	19 ± 5	12 ± 6	11 ± 4	25 ± 5	18—9	± 9	2—10	59%	1.5
70	80	17 ± 5	10 ± 6	9 ± 4	22 ± 7	12—9	± 9	28— 9	68%	1.4
80	80	15 ± 5	9 ± 6	9 ± 3	19 ± 6	8—9	± 8	21— 9	67%	3.2
90	100	14 ± 4	9 ± 6	8 ± 3	17 ± 6	6—9	± 8	19— 9	73%	4.0
110	100	11 ± 3	7 ± 6	7 ± 4	15 ± 5	2—9	± 7	14— 9	73%	6.0

[1] % of available time
[2] hours per combine

This shows that with 70—80 combines the average duration of the harvest of colza and barley is roughly equal to the average time available between the ripening dates of colza and barley and of barly and wheat. If a larger number of combines is employed, there is some idle combine capacity since harvesting will be completed in a shorter time than that available between the ripening dates of the respective crops. For example with 90 combines only 14 of the available 18 days will be utilized for the colza harvest and 9 of the 10 days for the barley harvest. From the point of view of utilization of combine capacity a larger area would then have to be sown with colza at the expense of the area with oats and wheat. Therefore, taking 70—80 combines as the optimal number, the ratios of areas sown with colza, barley and wheat plus oats should be 1 : 0.6 : 1.6. This means that compared to the ratios used up till now (1 : 1 : 1.8) more colza and less barley will have to be sown.

Also shown are averages and the standard deviations of the final dates of the harvest; from these data can be estimated the dates on which the wheat harvest will be completed in 95% of the years. It should be noted, however, that the computed final dates are affected to some extent by the time limits assumed, especially when a small number (60) of combines is employed. In this case the actual final dates will be a few days later than the computed dates since harvesting will be continued after the time limit. It is apparent that with 70 combines the harvest will be completed on average on September 12, while in 95% of the years the harvest will be over before September 28. So with 70 combines the requirement that the harvest is on the average completed before September 15 is easily met.

For the combines the not utilized available time is negligable with drying capacities of 80 and 100 tons h^{-1}. The idle time of the dryers is high; in practice the idle time will be lower because the idle time will then be used to dry the grain to a lower moisture content than required for shipping.

Table 38 contains data on the average annual losses per crop. It stands to reason that the smaller the number of combines the bigger will be the losses. Generally, losses of wheat expressed in tons are about twice as much as the aggregate losses of the other crops. The table gives particulars of the years in which the harvesting of the various crops had not yet been finished by the time limits. Except for colza in 1941, time limits were exceeded only after 1949. With 60 combines the date limits for wheat are exceeded in six years, leaving a total unharvested quantity of about 54,000 tons. By increasing the fleet of combines to 70 the number of years with unharvested wheat is halved and the quantity not harvested is reduced to less than half, i.e. 24,000 tons. If the number of combines is further increased, time limits will hardly ever be exceeded.

In the program the average ripening dates of crops were taken as a basis for simulation. However, as shown in 3, the actual ripening dates may differ

TABLE 38. Average annual field losses per crop (including crops not harvested at time limits) and the crops not harvested on the time limits in specified years (both in tons) for different combining and drying capacities.

combines (number)	drying capacity (tons h^{-1})	field losses per crop			
		colza	barley	oats	wheat
60	80	217	400	540	2,429
70	80	98	273	191	1,280
80	80	76	181	151	783
90	100	46	121	122	480
110	100	25	70	93	317

combines (number)	drying cap. (tons h^{-1})	not harvested crops at time limits													
		colza			barley		oats			wheat					
		'41	'58	'60	'60	'63	'50	'56	'57	'50	'54	'56	'57	'60	'63
60	80	2,044	870	737	4,535	5,468	1,389	1,597	1,240	18,659	3,392	5,409	20,327	189	6,440
70	80	509			2,483	4,646				12,119			10,174		1,442
80	80				63	3,824				1,226			6,948		
90	100					3,002							2,564		
110	100					1,359									

considerably from these averages. So when in certain years the crops ripen before or after the average maturity dates used for simulation, the harvesting is completed before or after the computed terminating date. This will affect the annual results, especially in those years that the time limit is, or nearly is, reached. The average results will probably not be affected, assuming that the weather during the growing season is not related to the weather during harvesting. To verify this assumption, the actual ripening dates were determined (from experimental fields or calculated according to the remainder index system) for the years that the simulated terminating date with 70 combines was after September 15. This showed that the actual ripening dates were proportionately distributed around the average maturity dates. Therefore it may safely be concluded that the average results will hardly be affected by taking the average maturity dates of the crops as the starting point for harvesting of each crop.

11.4 COMPARISON OF COMPUTED AND ACTUAL PROGRESS OF THE HARVESTING OPERATIONS IN 1968

The harvest organization in 1968 has been simulated with the above mentioned computer program; the results have been compared with the results of the actual organization in 1968. For a useful comparison the computer program was adapted to the following actual conditions in 1968: starting date at July 17 instead of the average date (July 22); the real areas of the crops (total area 14,500 ha with a yield of 60,000 tons).

Simulation was carried out for the values of the variables mentioned in 11.2.3; the following values of the actual harvesting capacity were used for comparison:

number of 5.4-m combines: 65 (on the farm there were 80 combines of various capacities, the total capacity was equal to that of 65 5.4-m combines)

drying capacity: 60 tons h^{-1}

ventilated storage capacity: 7,000 m^3

dry storage capacity: 6,000 m^3

The weather in 1968 was extremely unfavourable for harvesting operations. The number of available hours, computed with weather data measured on the farm, was 230 i.e. 80 hours less than the average; this will occur once per twenty years. The actual and computed progress, based on 5-day periods, are shown in figure 48. Two lines represent the actual progress: with and without hired combine capacity. The first case was added as additional combine capacity was hired on September 4 because of the slow progress of the harvest. The line representing the progress with this additional capacity (3,500 tons) shows that the harvest was finished on September 27 except

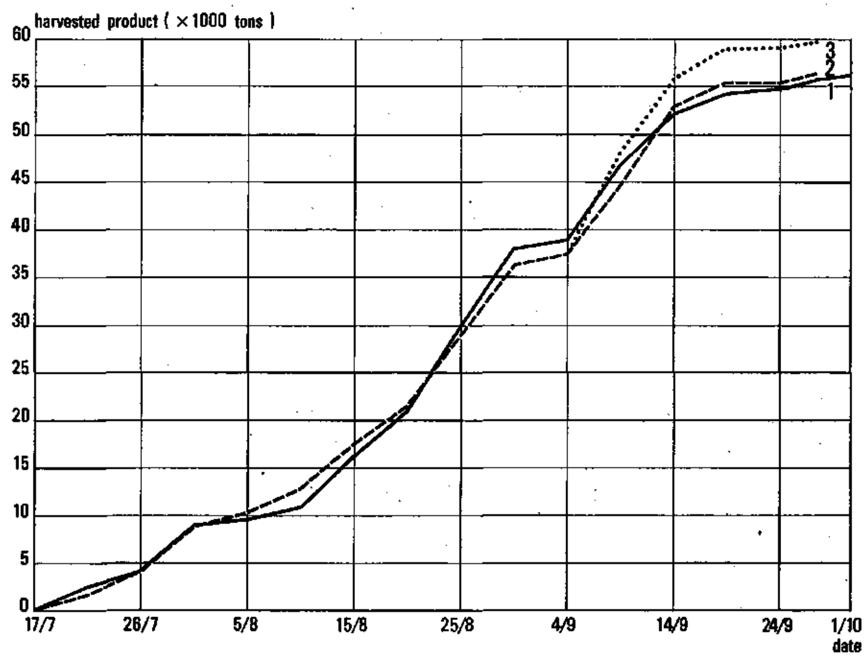


Fig. 48. Actual and computed progress of the harvesting operations in 1968.

1. computed progress
2. actual progress
3. actual progress with hired combine capacity

for 100 tons of wheat. From September 27 — October 7 the weather did not allow any combining to be done; after this date the 100 tons of wheat were deteriorated to such an extent that they were not harvested any more.

The line representing the progress without the additional combine capacity shows that 3,600 tons would not have been harvested on October 1; under the weather in 1968 they would be totally lost. The calculated progress does not deviate greatly from the actual progress; on October 1 the computed progress is only 1000 tons less than the actual progress. Analysis of the ca 1,5 maanden. actual and simulated progress on a day to day basis shows the following causes for some of the disparities.

Sometimes the actual daily progress was smaller or larger than the computed progress because of the irregular distribution of the precipitation on the farm's area.

Each Friday management has to decide whether the work will continue (in overtime) on the following Saturday. On a certain Friday it was decided not to harvest on Saturday because of the unfavourable weather forecast.

However, the weather was actually such that the harvest could have proceeded. Therefore the simulation showed that 1,300 tons were harvested on Saturday.

According to simulation no combining is done for the remaining hours of a day when the harvest of a particular crop is finished during that day (11.2.1.*b*). In this case simulation showed that the harvesting of barley was finished at 10 a.m. on a certain day with in total 9 available hours; the harvest did not proceed during the remaining hours. Actually management plans the operations in such a way that a large part of the combines finishes harvesting a certain crop at the end of the day so as to minimize the time lost for cleaning the combines. Therefore on this day the actual progress was 2,000 tons more than the simulated progress. This shows that this factor should be taken into account in the computer program.

Allowing for above main deviations, it may safely be concluded that the computer program is representative for the actual harvesting organization.

Above calculations were based on the real date of maturity (July 17); if the average date of maturity (July 22) was taken as the starting point then the crop not harvested on October 1 would have amounted to 9,600 tons.

Simulation with other values for the independent variables in 1968 showed that the total harvest costs would be at minimum with 80 5.4-m combines, drying capacity 80 tons h^{-1} and 8,000 m^3 ventilated storage capacity, the harvest will then be finished on September 9. Further it was shown that in this year a drying capacity of one ton h^{-1} for each combine gave the lowest costs.

11.5 SUMMARY

The total harvest costs under influence of the weather in the period 1931—1967 have been minimized by simulation. The independent variables introduced in the computer program, written in ALGOL, are:
Number of combines
Technique of operating the combines (low or high stubble)
Drying capacity of the transshipment centres
Storage capacity of the transshipment centres

The computer output gives the annual and average data for the following: the dates at which the harvesting of each crop is completed, the idle drying capacity and combine capacity for each crop, the field losses for each crop and the quantities remaining unharvested on the time limits. Average total harvest costs are given for varying costs of labour, unharvested quantities and clearing of the straw.

Some basic data and limitations are introduced in the simulation model. One of the most important limitations is the cropping program shown in table 33. This program is based on the average available harvesting periods and the average areas which can be threshed by a 5.4-m combine in these periods. The data for wheat are based on three decades. The following conclusions are drawn from the results.

The storage capacity required for grain to be dried is in the minimum cost range approximately 8,000 m^3 irrespective of the threshing and drying capacities (figure 42). Adding the 4,000 m^3 of storage capacity for dry grain gives a necessary storage capacity of the transshipment plants of 12,000 m^3. When wheat is cut with a high stubble then the value of field losses will be decreased by approximately f 200,000 a year (figure 43). If the extra costs for clearing the straw and for the additional transportation capacity are less than f 200,000 per year (f 36 per ha) the high stubble would be more profitable. At the present price levels, however, these extra costs are much higher, consequently the combines should cut at a low stubble.

The average annual total harvest costs as affected by three levels of field losses and labour costs are shown in figures 44 and 45. The harvesting capacities at the minima of the total cost curves are summarized in table 35; at the minimum costs they vary between 60—67 and 79—89 combines with drying capacities of 80 and 100 tons h^{-1} respectively.

Taking both crop losses and labour costs at medium level (table 34) the minimum harvest costs are obtained when for each 5.4-m combine are available a drying capacity of one ton h^{-1} and a storage capacity of 150 m^3. Each combine can then handle 166—184 ha per harvest season.

The components of the total harvest cost are shown in figure 46 and table 36. With this harvesting capacity the average harvesting periods of colza and barley are roughly equal to the periods available between the ripening dates of colza and barley and barley and wheat. The wheat harvest will then be completed on the average between the 8th and 12th of September. From the point of view of the utilization of the harvesting capacity the ratios of the acreages sown with colza, barley and wheat plus oats accordingly will be 1 : 0.6 : 1.6.

To show the effect of the period studied the average total harvest costs are computed for two periods, viz. 1931—1949 and 1949—1967 (figure 47). This clearly demonstrates that the results from the first period are vastly different from those of the second period.

In 1968 the actual progress of the harvest was compared with the simulated progress of the harvest. The result (figure 48) demonstrates that the operational model of the grain harvesting system can be applied to simulate the progress of the harvesting operations under actual weather conditions.

SUMMARY

1. The object of this study is the optimization of the grain harvesting operations by minimizing the total harvest costs under weather conditions prevailing in the centre of the Netherlands. The sequential grain harvesting operations consist of: combining-loading of grain wagons-transport-unloading-ventilated storage-drying-dry storage.

The capacities required of the sequential operations are mainly determined by the grain moisture content and therefore by the weather. This especially concerns the capacities of combining, drying and ventilated storage. As the weather is the key factor and varies from year to year, the criterion becomes the minimization of the average annual total harvest costs for a given cropping program over a large number of years. The total harvest costs comprise the field losses of the mature crop and the costs of personnel and harvesting equipment.

Also the harvesting organization has been studied; a system was developed to provide minimum costs of the separate components: combining, transport, drying and storage with a view to the minimum costs of the system as a whole. Selecting a system with minimum costs can only be carried out with a view to the organization of a particular farm and taking into account the conditions prevailing on that farm. Therefore, the results found have been used to minimize the total harvest costs for a 20,000 ha grain farm under the actual weather occurring during the harvest periods of the years 1931—1967.

2. The farm is a part of the reclamation enterprise of the Yssel Lake polders Development Authority which is responsible for the integral development of the polders in the Yssel Lake.

Owing to the high moisture content of the mud, the land is not ready for the planned land use immediately after reclamation. Hence a period of at least five years of farming by the Authority is required to transform the mud into a good soil. The crops grown on this temporary farm are: colza, barley, oats, wheat, alfalfa and flax. The first four of these crops (14,000 ha) are managed with farm personnel and equipment; alfalfa and flax are managed by others.

The harvesting of the grain is done with combines, transport equipment and transshipment plants. The transshipment plants dry the grain to a moisture content which is sufficiently low to permit safe shipment to storage installations elsewhere in the country. Based on the kernel moisture content the following classification for wheat can be made:

a. moisture content > 28%: crop too wet for combining

b. moisture content 17—28%: drying necessary after threshing and before storage; the following intermediate situations can occur:

b_1. moisture content 19—28%: temporary storage possible with ventilation, drying necessary before shipment

b_2. moisture content 17—19%: shipping possible but drying necessary before storage

c. moisture content < 17%: grain can be shipped and stored without drying.

In the case of colza, barley and oats similar situations occur but at different moisture contents.

3. The order of maturing of the crops grown is colza, barley and wheat; the oats mature practically simultaneously with the wheat. The maturity date (combine ripeness) of the crops is chiefly determined by the weather during the growing season. Using trial field data, both the average and standard deviation of the maturity dates have been determined. The average maturity dates of colza, barley, oats and wheat are July 22, August 7, August 17 and August 17 respectively. Consequently the average available periods for colza and barley are 17 and 10 days respectively. The available periods for oats and wheat are determined by the date before which the work to be done next must be finished and the available capacity. The work consisting mainly of tillage operations and the sowing of wheat has to be finished before December 7. Based on the available capacity for these fall operations efforts are made to finish harvesting by the middle of September or at least October 1.

Other factors affecting the available period and therefore the harvesting capacity required are the field losses and the deterioration of grain quality in the mature crop. Sources of field losses are: shatter losses, dry matter losses and combine losses (caused by cutterbar and reel). Investigations in the Lake Yssel polders show that the daily field losses increase exponentially; the following average daily field losses per ha occur during 36 days after combine ripeness: barley 16 kg, oats 25 kg, wheat 15 kg. No data are known for colza.

Little is known about the losses caused by reduction in grain quality; it is shown that on this farm they can probably be neglected in comparison with the field losses.

4. During three seasons (1964—1967), the kernel moisture contents of colza, barley, oats and wheat, as affected by the weather have been investigated. Grain samples were taken hourly from the graintanks of a group of combines. The following meteorological factors have been measured: rainfall, relative humidity, temperature, wind velocity and circumglobal radiation.

Empirical exponential relationships have been established between: drying of the kernel and the circumglobal radiation

rise in kernel moisture content and the square root of the product of amount and duration of the precipitation
rise in kernel moisture content (by dew) and the length of the night

In 1967 the kernel moisture contents have been calculated with the aid of meteorological data and the relationships found. Comparison with the measured kernel moisture contents showed that they corresponded fairly well. With meteorological data from De Bilt and Wageningen in the years 1931—1967 the kernel moisture contents have been computed for the harvest periods of those years. Then the available combine hours were computed. The average total number of available combine hours from July 22 to September 16 is 309 ($\sigma \pm 55$). During roughly half of this time colza and grain in the lowest moisture range (for wheat < 19%) can be combined; artificial drying is then not strictly necessary. In the other half of the time the moisture content is such that drying is necessary.

5. The available time for combining wheat is defined as that part of the time between 9 a.m. and 7 p.m. when the kernel moisture content is below 28% less time when rain is falling. It is assumed that a similar definition holds for barley, oats and colza, with the exception that for colza the maximum moisture content is 18%.

The effective time is the time during which the combine is cutting and threshing; combine capacity during this time, the effective capacity is expressed in kg h^{-1}. Time measurements showed that, due to different time losses, the effective time is approximately 60% of the net working time and 50% of the available time between Monday 9 a.m. and Saturday 4. p.m.

The effective combine capacity is affected by the straw moisture content, the permitted level of separating losses and the grain straw ratio. For wheat these relationships have been established, it is assumed that these relationships also hold for colza, barley and oats. The effective capacities of combines with a 5.4-m cutter bar have been measured in the crops under average conditions.

6. In view of the prevailing limitations and conditions the choice of the transport equipment is restricted to grain wagons pulled by crawler and wheeled tractors in the field and on the road respectively. Within the limits set by soil trafficability, available tractors and regulations governing agricultural vehicles on the road a grain wagon discharging at the bottom with a volume of 8 m^3 has been developed. These wagons are used in pairs. To minimize the loading time they are loaded on one of the headlands by six combines working in one group.

The conveying capacity of the plants is of considerable importance for the organization of the transport. The investigations show that an efficient transport organization is only possible when the conveying capacity is at least equal to the total net combine capacity.

For the calculation of the required numbers of wheeled tractors and wagons an adapted formula of TISCHLER is used.

7. The costs of the harvest components are based on the farm records and where there are inadequate data on the most accurate estimates possible. All costs are based on 1967 price levels, overhead is not included. Two possibilities for drying and storage of the grain are considered: transshipment plants and storage plants.

A complication is due to the regular movement of the farm through the polders. This means that the average distance to the transshipment plants gradually increases, so that after a given time these have to be moved or the transport capacity would have to be increased. Under certain limitations the total of the costs of grain transport and of the removal of the centres is at a minimum for three transshipment centres which are removed once every 15 years. The average theoretical transport distance is then 11 km.

8. Simulation has been used for the minimization of the total harvest costs. The independent variables taken into account are: the number of combines, the method of operation of the combines (cutting with high or low stubble in wheat), the drying capacity and the ventilated storage capacity.

Other variables as the cropping plan and the maturity dates are introduced as constants. A time limit has been placed on harvesting of each crop, after this date the crop will not be harvested and is considered a partial or total loss. The introduction of the time limit makes it possible to take into account some not yet quantified factors which will tend to increase the costs. The most important time limit, that for wheat, is fixed at October 1. To show the influence of some factors which may change in the future, three levels of field losses and labour costs are introduced: low, medium and high. The following conclusions are drawn from the computations (field losses and labour costs medium).

The ventilated storage capacity required is approximately 8,000 m^3, it is fairly irrespective of the combining and drying capacities. Adding the 4,000 m^3 of dry storage capacity fixes the total storage capacity of the transshipment plants at 12,000 m^3.

At present price levels it is advantageous to cut the wheat at a low stubble. Only if the extra costs involved with high cutting are less than f 36 per ha the high cutting will be preferable.

In the minimum cost range combining with permitted separating losses at 0.5% per ha is preferable to combining with losses at 2% per ha. The decrease in the costs of combining at 2% loss is not sufficient to balance the rise in value of the separating losses.

The minimum total harvest costs are obtained when for each 5.4-m combine are available a drying capacity of one ton h^{-1}, a ventilated storage capacity of 100 m^3 and a dry storage capacity of 50 m^3. One combine can then handle approximately 175 ha per harvest season. The harvest will then on the average be completed on September 10.

From the point of view of the utilization of the harvesting capacity the ratio of the acreages sown with colza, barley and wheat plus oats accordingly must be 1 : 0.6 : 1.6.

To show the effect of the period studied the average total harvest costs are computed for two periods, viz. 1931—1949 and 1949—1967. In the first period the minimum of the costs is obtained with one 5.4-m combine on 215 ha, in the second period the minimum is obtained with one 5.4-m combine on 167 ha due to the less favourable weather during harvesting.

Comparison of the actual progress of the harvesting operations with the simulated progress shows that the operational model may be applied for simulation of the harvesting operations under actual weather conditions.

РЕЗЮМЕ

1. Цель исследования направлена на оптимальную организацию уборки зерна, т.е. на такую организацию, в условиях которой расходы – минимальные. Оказывающими друг на друга взаимное влияние составными частями уборки зерна являются: уборка при помощи комбайнов – загрузка зерноприцепов – транспортировка зерна по полю и по дороге – перегрузка – вентилированное хранение – сушение – хранение сухого зерна.

Необходимая для каждой составной части мощность определяется прежде всего в зависимости от влажности зерна, а также от погоды во время уборки. Это относится специально к комбайновой уборке, к сушению и к временному хранению зерна. В связи с тем, что погода оказывает преобладающее влияние и что она с года в год в значительной степени меняется, в качестве критерия принята минимализация общих среднегодовых расходов по уборке в течение нескольких лет для данного севооборота. Под понятием общих расходов по уборке здесь подразумевается сумма расходуемых на созревшую, включая потери на поле, сельскохозяйственную культуру средств, далее, средств на содержание обслуживающего персонала и на материальные средства уборки. Составные части организации уборки хлеба в настоящее время подвергаются также исследованию; предложена система, в которой расходы по отдельным составным частям – в соответствии с расходами по всей системе – являются минимальными.

Подбор подходящей системы уборки зависит только от того, в какой степени общая организация приспособлена к специфическим условиям данного сельскохозяйственного предприятия. По этим соображениям полученные результаты были применены для минимализации общих расходов по уборке в условиях предприятия, специализированного на выращивание зерновых и занимающего площадь в 20000 га, принимая во внимание действительные условия погоды в период уборки на протяжении 1931–1967 гг.

2. Данное сельскохозяйственное предприятие, специализированное на выращивание зерновых, представляет собой хозяйство по освоению земель, подчиненное Государственной Службе на польдерах Эйселмерского озера. Приведенная Госслужба занимается комплексным освоением из Эйселмерского озера высушенных земель. Одной из этих вытекающих из данной действительности задач является превращение при помощи землечерпательных работ болотистой почвы в почву для преднамеренного назначения.

Одной из важнейших составных частей для данной цели необхо-

димых мероприятий по освоению земель является временная сельскохозяйственная эксплуатация на протяжении, по крайней мере, пяти лет, осуществляемая на полностью высушенной земле. Эти предприятия, специализированные на выращивание зерновых, занимаются разведением следующих культур: рапса, ячменя, овса, пшеницы, люцерны и льна. Рапс и зерновые (приблизительно на площади в 14000 га) почти полностью выращиваются на собственных участках. Связанная с разведением люцерны и льна деятельность переведена на другие сельскохозяйственные предприятия.

Уборка зерна осуществляется при помощи комбайнов, зерноприцепов и оборудования для перегрузки. В установках для перегрузки происходит сушение убранной культуры на минимальную влажность, а именно, до такой степени, чтобы данная культура была способна к перевозке в зернохранилища, находящихся в других местах по всей стране.

На основании влажности зерна, напр., пшеницы, отдельные составные части уборки подразделены следующим образом:

а. влажность $> 28\%$: в мокрых условиях, когда комбайновая уборка непригодна

б. влажность 17–28%: после обмолота до хранения необходимо производить искусственное сушение зерна, причем следует различать два следующих положения:

$б_1$. влажность 19–28%: представляется возможность применения вентилированного хранения зерна, однако, до начала перевозки необходимо произвести сушение зерна

$б_2$. влажность 17–19%: зерно можно перевозить на дальние расстояния; сушить зерно следует до начала хранения

в. влажность $< 17\%$: можно производить перевозку на дальние расстояния и хранение без предварительного сушения зерна.

Подобное подразделение, в условиях иной влажности, имеет место у рапса, ячменя и овса.

3. Культуры созревают в следующей последовательности: рапс, ячмень и пшеница; овес созревает почти одновременно с пшеницей. Подходящая для комбайновой уборки зрелость данной культуры определяется, главным образом, состоянием погоды в период созревания. При помощи данных, полученных от отбора проб, определяют среднее состояние и время созревания. Времена созревания в среднем составляют: у рапса – “22” июля; у ячменя – “7” августа; у пшеницы и овса – “17” августа. Наиболее подхо-

дящее в распоряжении для уборки рапса и ячменя находящееся время составляет, следовательно, 17 и 10 дней.

Для уборки овса и пшеницы в распоряжении находящееся время зависит также от об'ема послеуборочных работ и от имеющегося для данной цели периода. Эти виды работ заключаются, в особенности, в обработке почвы и посеве пшеницы: их необходимо закончить к началу декабря. На основании располагаемой для данной осенней работы мощности стараются, следовательно, завершить уборку приблизительно к середине сентября или, в крайнем случае, до начала октября.

Остальные факторы, оказывающие влияние на находящееся для уборки в распоряжении время, а также на необходимую, из него вытекающую для уборки производительность машин, представляют собой потери культуры в полевых условиях и понижение качества зерна. Потери на поле состоят из следующих частей: выпадание зерна, потери сухого вещества и потери от комбайна (причиненные косилкой и мотовилом). Из исследования этих потерь на полях Эйселмерского озера вытекает, что ежедневные потери нарастают в виде экспоненциальной функции. В условиях "комбайновой" зрелости ежедневные потери на протяжении 36 дней в среднем составляют: у ячменя – 16 кг, у овса – 25 кг, у пшеницы – 15 кг по гектару. По рапсу сведений нет.

В отношении потерь, причиненных понижением качества, известно мало. Приведено доказательство того, что по сравнению с потерями в полевых условиях данного сельскохозяйственного предприятия на польдерах Эйселмерского озера они, по всей вероятности, пренебрежительны.

4. Влияние погоды на влажность зерна у рапса, ячменя, овса и пшеницы подвергалось исследованию на протяжении трех сезонов (1964–1967 гг).

Отбор проб зерна осуществлялся по истечении каждого часа из бункеров, заполненных комбайном одной группы; одновременно производились следующие метеорологические измерения: выпадение осадков, относительная влажность воздуха, температура, скорость ветра и общее сияние. При помощи приведенных данных установлены следующие эмпирические экспоненциальные соотношения:

понижение влажности зерна и общее сияние;

повышение влажности зерна и квадратный корень из продолжительности и количества выпаденных осадков;

повышение влажности зерна вследствие росы и количества ночных часов.

В 1967 г. было произведено измерение влажности зерна и сравнение с влажностью зерна, вычисленной при помощи найденных соотношений; они в приемлемой степени взаимоприменимы. При помощи метеорологических данных из гор. Де Бильт и из гор. Вахенинхен произведен, далее, подсчет влажности зерна на протяжении сезонов уборки от 1931 до 1966 гг. Из этих подсчетов вытекает, что было выведено для комбайнов находящееся в распоряжении время в часах, подразделенное в три класса влажности. Среднее число находящихся для комбайновой уборки в распоряжении часов от "22" июля до "16" сентября составляет 309 ($\tau = 55$). На протяжении половины приведенного количества часов влажность зерна находится в самом низжем классе влажности, причем непосредственное сушение зерна не является необходимым; на протяжении остальных часов влажность зерна столь высока, что его необходимо однажды или дважды подвергать сушению.

5. Подчеркивается, что находящееся для комбайновой уборки пшеницы в распоряжении время можно определить таким образом: начиная с 9 час., и кончая в 19 час., на протяжении которого влажность зерна находится ниже 28% (не принимая во внимание выпадение осадков). Предполагают, что данное определение имеет место также для ячменя, овса и рапса; максимальная граница влажности у рапса составляет 18%.

Под эффективным временем подразумевается такое время, на протяжении которого комбайн производит уборку и обмолот; эффективное вышолнение работ выражается в кг-час. Из хронометража вытекает, что в условиях остаточной технологии эффективное время составляет около 60% чистого рабочего времени. Из измерений также вытекает, что 50% находящегося в распоряжении времени расходуется на вышолнение работы между понедельником, начиная с 9 часов утра, и кончая субботой в 4 часа дня.

На эффективную производительность зернового комбайна оказывает влияние влажность соломы, допустимые потери над грохотом и на очистительных станах, а также соотношение между зерном и соломой. Эти три фактора у пшеницы были подвержены измерению; принято, что эти факторы имеют место также у рапса, ячменя и овса.

Эффективная производительность зернового комбайна, ширина захвата которого равна 5,4 м, определена в средних обстоятельствах для всех поименованных растений.

6. Перевозка зерна в данных обстоятельствах осуществляется при помощи двуосных прицепов, которые перевозятся по полю

тракторами на гусеничном ходу, а по дороге – колесными тракторами.

Для условий, соответствующих данной конфигурации местности, тракторам и законным постановлениям, был сконструирован двуосный зерноприцеп об'емом в 8 куб. метров; данные прицепы агрегатируются один за другим. Для определения самого короткого необходимого для погрузки времени эти два прицепы, наконец, загружали группой машин, состоящей из шести зернокомбайнов, работавшей в качестве, принятой за условную, единицы.

Об'ем разгрузки данных оборудований имеет большое значение для принятой организации транспорта; целесообразность применения всех средств транспорта возможна только в том случае, если об'ем разгрузки равен минимально общей нетто-производительности зерновых комбайнов.

Для расчета надобного транспортного материала применяют подходящим образом приспособленную формулу для транспорта по фан Тишлеру.

7. Расходы на обслуживающий персонал и материал подсчитаны по себестоимости счетоводства сельскохозяйственного предприятия: в случае нехватки учетного материала они зависят от данной оценки. Все издержки обоснованы на уровне цен 1967 года; издержки по непродуктивной части в расчет не включены. Иные возможности переработки зерна рассматриваются в условии применения оборудования по разгрузке и хранению зерна. Компликация возникает в связи с регулярным перемещением сельскохозяйственного предприятия. В соответствии с этим среднее расстояние перевозки к зернохранилищам как правило повышается; после некоторого количества лет необходимо или повысить мощность транспорта или же установки необходимо переместить.

Подчеркивается, что в условиях некоторых ограничений общие расходы по перевозке зерна и по перемещению установок являются минимальными, если именно в качестве исходного положения будут подвергаться эксплуатации три средства разгрузки, перемещение которых осуществляется на протяжении 15 лет однажды. Среднее транспортное расстояние составляет в таком случае 11 км.

8. С целью минимализации расходов произведена симуляция при помощи электронно-вычислительной машины. Независимыми переменными в программе являются: количество комбайнов, низкий или высокий срез пшеницы, производительность сушки и вентилируемого пункта хранения.

Остальные переменные, а также план севооборота и время созревания приняты в качестве постоянных величин. Для окончания уборки каждой культуры в отдельности установлен лимит времени; вследствие того, на убранную до данного времени культуру в качестве потери принято полагать определенные подсчитанные данные. В связи с применением данного предела времени представляется возможность введения в расчеты некоторых факторов, способствующих повышению расходов, но определение которых полностью не представляется возможным. Важнейший предел во времени для пшеницы установлен на "1" октября.

Для того, чтобы подчеркнуть влияние некоторых факторов, которые в будущем в условиях полевых потерь и расходов на работу могут подвергаться изменению, введены, наконец, три классификации, а именно: низкая, нормальная и высокая.

Из расчетов выведены следующие заключения (полевые потери и расходы на работу в "нормальных" условиях).

Необходимые вентилируемые пункты для хранения должны иметь об'ем приблизительно равный 8000 куб.м: если необходимое для хранения сухого зерна пространство должно составлять 4000 куб. м, то это обозначает, что требуемый об'ем складовых средств в общем должен составлять около 12000 куб. метров.

В условиях нынешних положительных соотношений цен предпочитают убирать пшеницу так, чтобы высота стерни составляла приблизительно 20 см. Если же, однако, вследствие того, что чрезвычайные расходы из-за высокого среза находятся ниже 36,– гульденов по гектару, то более высокий срез пшеницы следует предпочитать.

В условиях общих минимальных расходов по уборке допустимые потери в 0,5% по гектару при комбайновой уборке вследствие вытрясания и чистки выгоднее, чем если эти потери составляют 2%. В последнем случае низкие расходы по комбайнированию не превосходят приведенные выше расходы, связанные с потерями при чистке.

Общие расходы по уборке являются минимальными в том случае, если для каждого комбайна шириной захвата в 5,4 м имеются в распоряжении установка для сушения зерна мощностью в 1 тонну в час, вентилируемое зернохранилище об'емом в 100 куб. метров и склад сухого зерна об'емом в 50 куб. метров. Каждый зерновой комбайн, таким образом, может убрать в отдельности зерно из полей площадью в 175 га в течение сезона; уборка в таком случае заканчивается в среднем около "10" сентября. С точки зрения целесообразной работы обслуживающего персонала и применения материала соотношение между площадью рапса, ячменя и пшеницы плюс овса должно составлять, таким образом, 1:0,6:1,6. Влияние рассматриваемого периода на выводы было рассчитано по данным, полученным от двух периодов времени, а именно, 1931–1949 гг. и 1949–1967 гг.

На протяжении периода 1931–1949 гг., эксплуатируя комбайн шириной захвата в 5,4 м, минимальные расходы получены на площади равной 215 га, между тем как на протяжении 1949–1967 гг. – на площади в 167 га; в последнем случае понижение было вызвано плохой погодой.

Из сопоставления действительного исхода уборки в 1968 году с симулируемым вытекает, что предложенная оперативная модель уборки урожая оправдала себя в условиях симуляции исхода уборки с исходом погоды.

SAMENVATTING

1. Het onderzoek is gericht op een optimale organisatie van de graanoogst, dat wil zeggen een organisatie waarbij de kosten minimaal zijn. De opeenvolgende onderdelen van de graanoogst zijn: maaidorsen - vullen der zaadwagens - transport op perceel en weg - lossen - geventileerde opslag - drogen - opslag droog graan.

De benodigde capaciteit voor ieder der opeenvolgende onderdelen wordt voornamelijk bepaald door het vochtgehalte van het graan en dus door het weer tijdens de oogst. Dit geldt speciaal voor de onderdelen maaidorsen, drogen en tijdelijke geventileerde opslag. Daar het weer van overheersende invloed is en van jaar tot jaar aanzienlijk varieert, wordt als criterium gehanteerd: de minimalisatie van de gemiddelde jaarlijkse totale oogstkosten gedurende een reeks van jaren voor een bepaald bouwplan. Onder de totale oogstkosten wordt hier verstaan de som van de verliezen in het rijpe gewas en de kosten van personeel en materieel voor de oogst. De onderdelen der oogstorganisatie zijn tevens onderzocht; een systeem is ontworpen waarbij de kosten der afzonderlijke onderdelen minimaal zijn met inachtneming van de kosten van het gehele systeem.

De keuze van een oogstsysteem kan alleen plaatsvinden indien de gehele organisatie van, en de omstandigheden in een specifiek bedrijf in de beschouwing worden betrokken. Daarom zijn de resultaten gebruikt voor de minimalisatie van de totale oogstkosten op een graanbedrijf van 20 000 ha onder invloed van de werkelijke weersomstandigheden tijdens de oogstperioden van de jaren 1931—1967.

2. Het betreffende graanbedrijf is een onderdeel van het ontginningsbedrijf van de Rijksdienst voor de IJsselmeerpolders. Deze dienst is belast met de integrale ontwikkeling van de drooggevallen polders in het IJsselmeer. Eén der uit deze taakstelling voortvloeiende werkzaamheden is het transformeren van de modder in gronden geschikt voor de uiteindelijke bestemming. Een belangrijk onderdeel van de hiervoor benodigde ontginningsmaatregelen is de ten minste vijf jaar durende tijdelijke landbouwkundige exploitatie welke op de van detailontwatering voorziene gronden wordt uitgeoefend. Op dit graanbedrijf worden de volgende gewassen verbouwd: koolzaad, gerst, haver, tarwe, luzerne en vlas. Koolzaad en granen ($\pm$ 14 000 ha) worden vrijwel geheel in eigen beheer geteeld; de werkzaamheden verbonden aan de teelt van luzerne en vlas worden door anderen verricht.

De graanoogst wordt uitgevoerd met maaidorsers, transportmaterieel en overslaginstallaties. In de overslaginstallaties wordt het gedorste produkt gedroogd tot minstens een zodanig vochtgehalte dat dit produkt kan worden verscheept naar opslaginstallaties elders in het land. Voor de onderdelen van de oogst kan, op basis van het korrelvochtgehalte van bijv. tarwe, de volgende indeling worden opgesteld.

a. vochtgehalte > 28%: te nat voor maaidorsen

b. vochtgehalte 17—28%: na het dorsen is kunstmatige droging nodig voor opslag. De beide volgende situaties worden hierbij onderscheiden:

b_1. vochtgehalte 19—28%: tijdelijk is geventileerde opslag mogelijk, drogen nodig voor verscheping.

b_2. vochtgehalte 17—19%: verscheping mogelijk, droging nodig voor opslag

c. vochtgehalte < 17%: verscheping en opslag mogelijk zonder voorafgaande droging.

Een soortgelijke indeling, bij andere vochtgehalten, geldt voor koolzaad, gerst en haver.

3. De gewassen rijpen in de volgorde koolzaad, gerst en tarwe; haver rijpt vrijwel gelijktijdig met tarwe. Het tijdstip van maaidorsrijpheid der gewassen wordt voornamelijk bepaald door het weer gedurende het groeiseizoen. Met behulp van proefveldgegevens zijn het gemiddelde en de spreiding der rijpheidsdata bepaald; de gemiddelde rijpheidsdata zijn: koolzaad, 22 juli; gerst, 7 augustus ; tarwe en haver, 17 augustus. De beschikbare oogstperioden voor koolzaad en gerst zijn dientengevolge 17 en 10 dagen.

De beschikbare oogsttijd voor haver en tarwe wordt onder meer bepaald door het tijdstip waarop de daaropvolgende werkzaamheden gereed moeten zijn en de daarvoor beschikbare capaciteit. Deze werkzaamheden, voornamelijk bestaande uit grondbewerking en inzaai van tarwe moeten gereed zijn voor 7 december. Op grond van de beschikbare capaciteit voor deze najaarswerkzaamheden wordt ernaar gestreefd de oogst gemiddeld medio september te beëindigen met een mogelijke uitloop tot begin oktober.

Andere factoren die de beschikbare oogstperiode en daarmede de benodigde oogstcapaciteit beinvloeden zijn de veldverliezen in het gewas en de vermindering van de korrelkwaliteit. De veldverliezen bestaan uit: uitval, drogestofverliezen en maaidorserverliezen (veroorzaakt door maaibalk en haspel). Onderzoek naar deze verliezen in de IJsselmeerpolders heeft aangetoond dat de dagelijkse verliezen exponentieel toenemen. De gemiddelde dagelijkse verliezen per ha gedurende ca. 36 dagen na maaidorsrrijpheid zijn: gerst, 16 kg; haver, 25 kg; tarwe, 15 kg. Van koolzaad zijn geen gegevens bekend.

Weinig is bekend omtrent de verliezen welke worden veroorzaakt door de achteruitgang in kwaliteit. Aangetoond wordt dat zij voor dit bedrijf waarschijnlijk te verwaarlozen zijn in vergelijking met de veldverliezen.

4. De invloed van het weer op de korrelvochtgehalten van koolzaad, gerst, haver en tarwe is gedurende drie seizoenen (1964—1967) onderzocht. Zaadmonsters zijn per uur genomen uit de graantanks van een groep maai-

dorsers; tevens zijn de volgende weerkundige metingen uitgevoerd: regenval, relatieve luchtvochtigheid, temperatuur, windsnelheid en circumglobale straling. Met behulp van deze gegevens zijn de volgende empirische exponentiële relaties opgesteld:
verlaging van het korrelvochtgehalte en de circumglobale straling
verhoging van het korrelvochtgehalte en de vierkantswortel uit duur en hoevéelheid van de neerslag
verhoging van korrelvochtgehalte door dauw en het aantal nachtelijke uren

In 1967 zijn de korrelvochtgehalten gemeten en vergeleken met de korrelvochtgehalten berekend met behulp van de gevonden relaties; zij bleken redelijk met elkaar overeen te komen. Vervolgens zijn met weerkundige gegevens van De Bilt en Wageningen de korrelvochtgehalten berekend gedurende de oogstperioden van 1931 tot 1967. Hieruit zijn daarna de beschikbare uren, ingedeeld naar drie vochtklassen, voor maaidorsen afgeleid. Het gemiddeld aantal beschikbare maaidorsuren van 22 juli tot 16 september is 309 ($\sigma \pm 55$). Gedurende de helft van dit aantal uren ligt het korrelvochtgehalte in de laagste vochtklasse waarbij het graan niet direct behoeft te worden gedroogd; in de resterende uren is het vochtgehalte zodanig dat het graan een of twee maal moet worden gedroogd.

5. Aangetoond wordt dat de beschikbare tijd voor maaidorsen van tarwe als volgt kan worden gedefinieerd: de tijd tussen 9 en 19 uur waarin het korrelvochtgehalte beneden 28% is, minus de tijd met neerslag. Aangenomen wordt dat deze definitie ook geldt voor gerst, haver en koolzaad, waarbij de maximum vochtgrens voor koolzaad 18% bedraagt.

De effectieve tijd is de tijd gedurende welke de maaidorser maait en dorst, de prestatie in deze tijd, de effectieve prestatie, wordt uitgedrukt in kg uur^{-1}. Uit tijdmetingen blijkt dat bij de bestaande werkwijze de effectieve tijd ca. 60% van de netto werktijd en 50% van de beschikbare tijd tussen maandag 9 uur en zaterdag 4 uur bedraagt.

De effectieve capaciteit der maaidorser wordt beinvloed door het strovochtgehalte, de toegestane verliezen over schudders en zeven alsmede de zaad stro verhouding. Deze relaties zijn voor tarwe gemeten; aangenomen wordt dat deze relaties ook gelden voor koolzaad, gerst en haver.

De effectieve capaciteit van een maaidorser met een snijbreedte van 5.4-m is onder gemiddelde omstandigheden in alle gewassen bepaald.

6. Bij de heersende omstandigheden dient het graantransport te worden uitgevoerd met zaadwagens welke op het perceel en op de weg worden getrokken door respectievelijk rups- en wieltrekkers. Binnen de beperkingen gesteld door het terrein, de beschikbare trekkers en wettelijke bepalingen is een graanwagen met een inhoud van 8 m^3 ontwikkeld; deze wagens worden in paren gebruikt. Teneinde de laadtijd te beperken worden zij gevuld door een groep van zes als eenheid werkende maaidorsers.

De ontvangstcapaciteit van de installaties is van groot belang voor de transportorganisatie; een efficiënt gebruik van de transportmiddelen is alleen mogelijk indien de ontvangstcapaciteit minstens gelijk is aan de gezamenlijke netto capaciteit der maaidorsers.

Voor de berekening van het benodigde transportmaterieel wordt gebruik gemaakt van een aangepaste transportformule van TISCHLER.

7. De kosten van personeel en materieel zijn gebaseerd op de kostprijzen der bedrijfsboekhouding; in enkele gevallen zijn zij bij gebrek aan gegevens geschat. Alle kosten zijn gebaseerd op het prijsniveau van 1967, kosten van overhead zijn niet ingecalculeerd.

Een tweetal mogelijkheden voor de verwerking van het graan worden beschouwd nl. overslag- en opslaginstallaties. Een complicatie wordt veroorzaakt door de regelmatige verplaatsing van het bedrijf. Hierdoor neemt de gemiddelde transportafstand tot de installaties regelmatig toe; na een aantal jaren moet òf de transportcapaciteit worden vergroot òf moeten de installaties worden verplaatst.

Aangetoond wordt dat, met zekere beperkingen, de gezamenlijke kosten voor graantransport en verplaatsing der installaties minimaal zijn indien wordt uitgegaan van drie overslaginstallaties welke eens in de 15 jaar worden verplaatst. De gemiddelde theoretische transportafstand bedraagt dan 11 km.

8. Voor de kostenminimalisatie is gebruik gemaakt van simulatie door middel van een computer. De onafhankelijke variabelen in het programma zijn: het aantal maaidorsers, laag of hoog maaien in tarwe, de droogcapaciteit en de geventileerde opslagcapaciteit. Andere variabelen zoals het bouwplan en de rijpheidsdata zijn als constanten ingevoerd. Voor het einde van de oogst van elk gewas is een tijdslimiet vastgesteld; het gewas dat dan nog niet is geoogst wordt geheel of gedeeltelijk als verloren beschouwd. Door de invoering van deze tijdslimiet is het mogelijk om bepaalde niet te kwantificeren kostenverhogende factoren in de berekeningen te betrekken. De belangrijkste tijdslimiet, nl. die voor tarwe, is op 1 oktober gesteld.

Teneinde de invloed aan te tonen van enkele factoren, die in de toekomst mogelijk zullen veranderen, zijn voor de veldverliezen en de arbeidskosten een drietal waarden ingevoerd nl.: laag, normaal en hoog.

De volgende conclusies worden uit de berekeningen getrokken (veldverliezen en arbeidskosten „normaal”).

De benodigde geventileerde opslagcapaciteit bedraagt ca. 8 000 m^3; indien de benodigde opslagcapaciteit voor droog graan op 4 000 m^3 wordt gesteld betekent dit dat de totale benodigde opslagcapaciteit der overslaginstallaties ca. 12 000 m^3 moet bedragen.

Bij de huidige prijsverhoudingen is het voordelig om de tarwe op ca. 20 cm hoogte te maaien. Pas als de extra kosten tengevolge van hoog maaien

(45 cm) lager zijn dan f 36 per ha zal het hoog maaien van de tarwe voordeel bieden.

In het traject waar de totale oogstkosten minimaal zijn is het maaidorsen met een toegestaan verlies van 0.5% per ha over schudders en zeven voordeliger dan met een toegestaan verlies van 2%. In het laatste geval wegen de mindere maaidorskosten (tengevolge van de hogere prestatie) niet op tegen de extra reinigingsverliezen.

De totale oogstkosten zijn minimaal indien voor elke 5.4-m maaidorser een droogcapaciteit van een ton per uur, een geventileerde opslagcapaciteit van 100 m^3 en een droge opslagcapaciteit van 50 m^3 ter beschikking staan. Per maaidorser kan dan 175 ha per seizoen worden verwerkt; hierbij eindigt de oogst gemiddeld op 10 september. Bezien vanuit het oogpunt van een zo efficiënt mogelijk gebruik van personeel en materieel voor de oogst moet de oppervlakteverhouding van koolzaad, gerst en tarwe plus haver dan 1 : 0,6 : 1,6 bedragen. De invloed van de beschouwde periode op de conclusies is nagegaan door de berekeningen uit te voeren voor een tweetal perioden nl. 1931—1949 en 1949—1967. In de eerste periode wordt het kostenminimum bereikt bij één 5.4-m maaidorser per 215 ha, in de tweede periode wordt het minimum bereikt bij een 5.4-m maaidorser per 167 ha tengevolge van het minder gunstige oogstweer.

Vergelijking van het werkelijk verloop der oogst in 1968 met het gesimuleerde verloop toont aan dat het ontwikkelde operationeel model van het graanoogstsysteem geschikt is om het verloop van de oogst onder invloed van het weer te simuleren.

REFERENCES

ANONYMUS, 1959, From fisherman's paradise to farmer's pride. *Neth. Gov. Inf. Service*, The Hague.

ANONYMUS, 1965, Work requirement data for farm management purposes. *O.E.C.D.*, no. 72: 17—24.

ANONYMUS, 1966, Rassenlijst, 41e, voor landbouwgewassen. *I.V.R.O.*, Wageningen: 135—172.

ANONYMUS, 1967, Groepsbeproeving maaidorsers met werkbreedtes van 12 of 14 voet. *Inst. Landbouwtechn. Rat., Publ.* 110: 9—13.

ANONYMUS, 1967*a*, Onderzoek inzake opslag en vervoer van goederen. Wageningen-project Suriname. *Nedeco*, The Hague: p. 29.

ANONYMUS, 1968, Circulaires no. O.P. 25, 26, 30. Productschap voor granen, zaden en peulvruchten, The Hague.

ANONYMUS, 1968*a*, Jaarverslag van de landbouwbedrijven in eigen beheer in Oostelijk Flevoland boekjaar 1966—1967. *Rijksd. IJsselm.p.*

BABBITT, J. D., 1949, Observations on the adsorption of water vapour by wheat. *Can. J. of Res.*, 27: 55—72.

BARGEN, K. L. VON, 1965, Systems analysis in hay harvesting. *Am. Soc. Agr. Eng., Paper* 65—164.

BECKER, H. A. AND H. R., SALLANS, 1955, A study of internal moisture movement in the drying of the wheat kernel. *Cer. Chem.*, 32: 212—226.

BECKER, H. A. AND H. R., SALLANS, 1956, A study of the desorption isotherms of wheat at 25° C and 50° C. *Cer. Chem.*, 33: 79—91.

BELDEROK, B., 1965, Einflusz der Witterung vor der Ernte auf die Keimruhedauer und die Auswuchsneigung des Weizens. *Zeitschr. Ack. und Pfl. bau*, 4: 297—313.

BERG, M. OCH L. OTTOSSON, 1949, Skördetröskning vid låg vattenhalt. *Jorbrukstekn. Inst., Med.* 223: 54—57.

X BERGER, C. en J. H. VAN KAMPEN, 1965, Een benadering van de relatie tussen het weer en het vochtgehalte van de tarwekorrel en de hiermede berekende meest gewenste maaidors- en droogcapaciteit voor 5000 ha tarwe. *Rijksd. IJsselm.p., Rapp.* 40.

BERKERS, A. W. en N. F. VAN DER KANT, 1965, Een vergelijking tussen rups- en wieltrekkers bij zaai- en wintervoorploegen. *Rijksd. IJsselm.p., Rapp.* 34.

BOER, H. J. DE., 1960, Berekening van dagsommen van globale straling met behulp van die der circumglobale straling te De Bilt. K.N.M.I., *Wet. Rapp.* 60—8 (III—259), p. 3.

BOONMAN, D. C. M., 1966, Der Transport als Grundlage für die Organisierung und Mechanisierung der Ernte von Agrarprodukten. *Trans. XIIIth Congr. Sc. Work Org. in Agr.*,: 373—416.

BOSMA, W. A., 1962, Het verband tussen de rijping der gronden in de IJsselmeerpolders en de verbouw van landbouwgewassen. *Van Zee Ld.*, 32: 71—97.

BRADBURY, D., J. E. HUBBARD, M. M. MASTERS and F. R. SENTI, 1960, Conditioning wheat for milling. *U.S. Dept. of Agr., Misc. Publ.*, 824: 72—102.

BRENCHLEY, W. E. and A. D. HALL, 1908, The development of the grain of wheat. *J. of Agr. Sci.*, 3: 195—217.

X BRÜCK, J. G. M., 1967, Korrelvocht en weer. *Inst. Landbouwtechn. Rat., Rapp.* 88: 14—16.

CLARK, O. R., 1940, Interception of rainfall by prairiegrasses, weeds and certain crop plants. *Ecologic. Monographs*, 10, no. 2: 243—277.

COOLMAN, F. en G. C. KAPPETEIN, 1966, Oriënterend onderzoek naar de mogelijkheid van het drogen en opslaan van graan e.d. in metalen buitensilo's. *Inst. Landbouwtechn. Rat., Rapp.* 58.

DILLMAN, A. C., 1930, Hygroscopic moisture of flax seed and wheat and its relation to combine harvesting. *J. Am. Soc. Agron.*, 22: 51—74.

DONALDSON, A. F., 1968, Allowing for weather risk in assessing harvest machinery selection. *Am. J. of Agr. Economics*, 50: 24—40.

DRICOT, C. et E. J. PAUWELS, 1960, Etude technique et économique de la moissonneuse-batteuse. Gembloux: 3—10.

DUIN, R. H. A. VAN en T. J. LINTHORST, 1962, De invloed van de grondverzetsafstand op de keus van het transportmiddel. *Inst. Cultuurtechn. Waterhuish., Med.* 51.

ELDEREN, E. VAN, 1966, Task-times and fieldshape. *Trans. XIIIth Congr. Sc. Work Org. in Agr.*,: 105—131.

ELDEREN, E. VAN, 1966*a*, Transport in aansluiting op de oogst. Model geprogrammeerd in Fortran II D. *Inst. Landbouwtechn. Rat., Rapp.* 73.

FAJERSSON, F. and M. KRANTZ, 1965, Studies on resistance to shattering in varieties of winter and spring wheat at Weibullsholm, 1952—1965. *Agr. hort. genet. Landskrona*, 23: 101—171.

FEIFFER, P., 1958, Getreidefeuchtemessung vor dem Mähdrusch. *Dt. Agr. Techn.*, 8: 183—186.

FEIFFER, P., 1962, Näher zur optimalen Leistungsgrenze im Mähdrusch. *Dt. Agr. Techn.*, 12: 18—25.

FIL, L. P., 1963, Moissonnage-battage en grande culture. *Org. et Gestion*, 4: 1—12.

FLEMING, J. A. and J. D. CUNNINGHAM, 1960, Work study report on combine harvesting. *Scott. Agr. Ind. Ltd.*

FREY, K. J., E. RUAN and S. C. WIGGANS, 1958, Dry weights and germination of developing oat seeds. *Agr. J.*, 5: 248—250.

GELS, J. A., 1959, In: Het oogsten, drogen en bewaren van granen in de Noordoostpolder: 50—65.

GERLAGH, M., 1968, Introduction of Ophiobolus graminis into new polders and its decline. *Thesis*, Wageningen.

GESLIN, H., 1944, Etude des lois de croissance d'une plante en fonction des facteurs du climat; contribution à l'étude du climat de blé. Paris.

GESLIN, H. et J. JONARD, 1948, Maturation du blé et climat. *Ann. de la Nutr. et de l'Aliment.*, 3: 361—371.

GOSS, J. R., R. A. KEPNER and L. G. JONES, 1958, Performance characteristics of the grain combine in barley. *Agr. Eng.*, 39: 697—702.

GROENE, A. DE, 1964, De verkoop van de produkten die door de Cultuurtechnische afdeling worden verbouwd. *Van Zee Ld.*, 39: 123—138.

HALTER, A. N. and D. W. DEAN, 1965, Use of simulation in evaluating management policies under uncertainty application to a large-scale ranch. *J. of Farm Economics*, 47: 557—573.

HAM, G. C. J. VAN DER, 1957, De zomers van deze eeuw. *Hemel en Dampkring*, 55: 77—79.

HARLAN, H. V., 1923, Watercontent of barley kernels during growth and maturation *J. of Agr. Res.*, 23: 333—360.

HARTLOPER, B., 1967, Transport in aansluiting op de oogst. Wagentype bij de oogst van graan, aardappelen en bieten. *Scriptie 205, Landbouwh.*, Wageningen.

HAUDE, W., 1955, Zur Bestimmung der Verdünstung auf möglichst einfache Weise. *Mitt. Dt. Wetterd.*, 11.

HELD, E. F. M. VAN DER, 1957, Uber die für das Trocknen wichtigen physikalischen Eigenschaften von Lebensmitteln. *De Ing., Chemische Techn.*, 69: 15—19.

HESSELBACH, J., 1964, Die Ermittlung von Klimadaten für Arbeitskalkulationen. *Rapp. VIe Congres Int. de Génie rural. Tome* 3: 1062—1069.

HESSELBACH, J., 1966, Betriebssimulation in der Landwirtschaft. *Siebte Jahrestagung Gesellsch. für Wirtsch. und Soz. wissenschaften des Landbaues.* Kiel.

HOFMANN, G., 1955, Die Thermodynamik der Taubildung. *Ber. des Dt. Wetterd.*, 18: 10—29.

HORRING, J., 1948, Methode van kostprijsberekening in de landbouw. *Dissertatie,* Emmen: 67—70.

HÜLST, H. VON, 1957, Ergebnisse neuer Untersuchungen an Mähdreschern. *Landtechn.*, 12: 199—202.

HUNT, D., 1965, Farm power and machinery management. Ames, Iowa: 1—20.

JOHNSON, W. H., 1959, Efficiency in combining wheat. *Agr. Eng.*, 40: 16—20.

JOHNSON, W. H., B. J. LAMP and J. E. HENRY, 1963, Corn harvesting performance at various dates. *Trans. Am. Soc. Agr. Eng.*, 6: 268—272.

JONES, C. R., 1949, Observations on the rate of penetration of water into the wheat grain. *Milling*, 113: 80—86.

JONG, D. F. DE, 1965, Een onderzoek naar de invloed van het preventief onderhoud der maaidorsers op aantal en duur der stagnaties tijdens de oogst. *Rijksd. IJsselm.p., Rapp.* 33.

JONG, G. J. DE, 1961, Nu nog wintertarwe zaaien? *Nieuwe Veldb.*, 15: p. 7.

JONG, G. J. DE, 1966, Over de opbrengst van zomergranen bij zeer late uitzaai. *Persbericht Ned. Graancentrum.*

JONG, G. J. DE en L. ZELHORST, 1967, Resultaten van de oogsttijdenproeven met wintertarwe en zomertarwe in 1966. *Rijksd. IJsselm.p., Nota* 62.

JONG, G. D. DE en L. ZELHORST, 1968, Resultaten van de oogsttijdenproeven met granen in 1967. *Rijksd. IJsselm.p.*, to be published.

KAMPEN, J. H. VAN, 1959, Het zwadmaaien van granen. *Rijksd. IJsselm.p., Flevo-Bern.* A. no. 12.

KAMPEN, J. H. VAN, 1964, Technisch onderzoek en ontwikkeling van de machines bij de Cultuurtechnische Afdeling. *Van Zee Ld.* 39: 51—80.

x KAMPEN, J. H. VAN, 1965, Onderzoek naar de mogelijkheden tot minimalisatie van de kosten voor transport en ontvangst der geoogste produkten van het bedrijf der Cultuurtechnische Afdeling. *Rijksd. IJsselm.p., Rapp.* 32.

KAMPEN, J. H. VAN en F. C. ZUIDEMA, 1966, Invloed van het weer op het vochtgehalte van rijp graan in verband met de benodigde maaidors- en droogcapaciteit in Oostelijk Flevoland. *Landbouwk. Tijdschr.*, 78: 53—60.

KAMPEN, J. H. VAN, 1968, De organisatie van de graanoogst op het gezinsbedrijf in Oostelijk Flevoland. *Rijksd. IJsselm.p. Verslag.*

KANT, N. F. VAN DER, 1958, Praktijkwaarnemingen bij zwadmaaien met middenzwaders en dorsen met maaidorsers uit het zwad en van stam gedurende oogst 1958. *Rijksd. IJsselm.p. Verslag.*

KANT, N. F. VAN DER, 1962, De invloed van de te verwerken hoeveelheid stro op het zaadverlies en andere van belang zijnde factoren bij het maaidorsen. *Rijksd. IJsselm.p., Rapp.* 11.

KANT, N. F. VAN DER, 1965, De invloed van de stoppelhoogte op de zaadverliezen en prestaties bij enkele maaidorsers in wintertarwe. *Rijksd. IJsselm.p., Rapp.* 31.

KATE, H. TEN, 1966, Het zeldzaam natte jaar 1965. *Hemel en Dampkring*, 64: 129—131.

KOLLER, H., 1966, Simulation als Methode in der Betriebswirtschaft. *Zeitschr. für Betr. wirtschaft*, 36: 95.

KRAMER, C., 1954, De warmte in de kiemingsperiode van zomergerst. K.N.M.I., *Wet. Rapp.*, 54—001 (III—132): 1—7.

KREHER, G. W., HAMMER und J. HESSELBACH, 1963, Kalkulationsunterlagen für Betriebswirtschaft. Band 1. Frankfurt am Main.

KREYGER, J., 1964, In: Het drogen en bewaren van inlandse granen, zaden en peulvruchten. Wageningen. 70—72.

LENIGER, H. A., 1957, Allgemeine Betrachtungen über das Trocknen von Lebensmitteln. *De Ing., Chemische Techn.*, 69: 1—14.

LERMER, J., 1961, Arbeitspannen und verfügbare Arbeitstage unter dem Einflusz von Klima und Bodenart in niederbayerischen Raum. *Bay. Landwirtsch. Jahrb.*, 38: 157—195.

LERMER, J., 1963, Die Aussenarbeitszeiten unter den verschiedenen klimatischen Verhältnissen Bayerns. *Bay. Landwirtsch. Jahrb.*, 40: 3—10.

LEVINE, G., 1959, Methods of estimating evapotranspiration. *Trans. Am. Soc. Agr. Eng.*, 2: 32—34.

LINK, D. A., 1964, A method for predicting the capabilities of a system of farm field machinery operating under realistic weather and crop conditions. *Rapp. VI^e Congr. Int. de Génie rural. Tome* 3: 1077—1086.

LOMBAERS, H. J. M., 1967, Talen voor simulatie met rekenmachines. *De Ingenieur*, 79: 541—543.

LOMBAERS, H. J. M. en T. DE WIT, 1967, Talen voor simulatie met rekenmachines. *Landbouwk. Tijdschr.*, 79: 365—366.

MARK, A. H., K. J. M. GODLEWSKI and J. L. COLEMAN, 1963, Evaluating combine performance: a global approach. *Agr. Eng.*, 44: 136—137.

MITCHELL, F. S., 1955, The effect of drum setting and crop moisture on the germination of combine harvested wheat. *Nat. Inst. of Agr. Eng., Rep.* no. 51.

MITCHELL, F. S., R. E. ARNOLD, F. Y. K. CALDWELL, A. C. W. DAVIES, 1955*a*, The effect of drum setting and crop moisture content on the germination of combine harvested barley. *Nat. Inst. of Agr. Eng., Rep.* no. 56.

MOENS, A., 1959, Normtijden voor landbouwwerkzaamheden. *Inst. Landbouwtechn. Rat., Publ.* 49.

MONTEITH, J. L., 1957, Dew. *Quart. J. Royal Met. Soc.*, 83: 322—341.

MONTEITH, J. L., 1965, Radiation and crops. *Exp. Agr.*, 4: 241—251.

MONTEITH, J. L. and G. SZEICZ, 1960, The performance of a Gunn-Bellani radiation integrator. *Quart. J. Royal Met. Soc.*, 86: 91—94.

MONTEITH, J. L. and G. SZEICZ, 1961, The radiation balance of bare soil and vegetation. *Quart J. Royal Met. Soc.*, 87: 159—170.

MONTEITH, J. L. and G. SZEICZ, 1962, Radiative temperature in the heat balance of natural surfaces. *Quart. J. Royal Met. Soc.*, 88: 496—507.

MORRIS, W. H. M. and J. A. GROENEWALD, 1968, The utilization of data from work study for decision making in farm management. *XIVth Congr. Sc. Work Org. in Agr.*,: 69—78.

MOULE, C., 1960, Maturation de l'amande et échaudage chez l'avoine cultivée. *Ann. de l'Amélioration de Pl.*, 10: 5—51.

NUTTONSON, M. Y., 1953, Phenology and thermal environment as a means for a physiological classification of wheat varieties and for predicting maturity dates of wheat. Washington.

PAQUET, J., 1964, Phases d'évolution des matières protéiques dans le grain de blé tendre entre la fécondation et la maturité (semis d'automne). *Bull. des anc. élèves de l'école franç. de Meunerie*, 199: 9—13.

PENMAN, H. L., 1948, Natural evaporation from open water, bare soil and grass. *Proc. Royal Soc.*, A 193: 121—145.

POSTMA, G., 1966, Arbeid en planning; de produktiefactor arbeid in het licht van de economische planning in de landbouw. *Inst. Landbouwtechn. Rat. Publ.* 99: 5—15.

POSTMA, G. en E. VAN ELDEREN, 1963, Arbeidsbegroting met behulp van taaktijden. *Inst. Landbouwtechn. Rat., Publ.* 70: 4—6.

PRINS, J. A. en J. J. M. REESINCK, 1948, De totale globale straling te Wageningen en De Bilt. *Meded. Landbouwh.* Wageningen. 49 Verh. 2.

REICHENHEIM, H., 1960, Die Transportraumplanung in der landwirtschaftlichen Praxis. *Dt. Agr. Techn.*, 10: 76—77.

RIGHOLT, J. W., 1962, De invloed van perceelsvorm en perceelsgrootte op arbeidsbehoefte en arbeidsverbruik. *Inst. Cultuurtechn. Waterhuish., Med.* 36.

ROCKWELL, T. H., 1967, Use of simulation methodology for solution of operational system problems. *Trans. Am. Soc. Agr. Eng.*, 10: 291—295.

SCHNEIDER, M., 1952, Summen, Mittel und mittlere Extreme der Temperatur von phänologischen Zeitspannen. *Ber. Dt. Wetterd. U. S. Zône* 42.

SCHOLTE UBING, D. W., 1959, Over stralingsmetingen, de warmtebalans en de verdamping van gras. *Meded. Landbouwh.* Wageningen, no. 10: 21—23.

SEGLER, G. und F. WIENEKE, 1961, Dreschverluste und Leistungsbedarf des Mähdreschers beim Verarbeiten von Getreide mit Grüngutsbesatz. *Landtechn. Forschung*, 11: 141—144.

SIMMONDS, W. H. C., G. T. WARD and E. MCEWEN, 1953, The drying of wheatgrain. Part I: The mechanism of drying. *Trans. Inst. Chem. Engrs.*, 31: 265—278.

STAPLETON, H. N., M. D. CANNON and W. A. LE PORI, 1965, Cotton harvest defoliation scheduling. *Am. Soc. Agr. Eng., Paper* 65—165: 1—3.

STEUBING, L., 1965, Pflanzenökologisches Praktikum; Methoden und Geräte zur Bestimmung wichtiger Standortsfaktoren. Giessen: 16—76.

SZEICZ, G., J. L. MONTEITH and J. M. DOS SANTOS, 1964, Tube solarimeter to measure radiation among plants. *J. Appl. Ecol.*, 1: 169—174.

SZESNY, B., 1963, Probleme der Transportmittelplanung in landwirtschaftlichen Groszbetrieb. *Dt. Agr. Techn.*, 13: 472—475.

THIELEBEIN, M. and O. FISCHNICH, 1957, Mähdrusch, Saatgutqualität und Sortenwahl. In: *Der Mähdrusch. Landwirtschaft, angewandte Wissenschaft*, no. 68: 5—37.

THORNTHWAITE, C. W., 1948. An approach toward a rational classification of climate. *Geogr. Rev.*, 38: 55—94.

TISCHLER, H., 1959, Zur Ermittlung der erförderlichen Zahl von Transportmitteln bei der Flieszernte. *Dt. Agr. Techn.*, 9: 367—370.

TISCHLER, H., 1960, Nochmals „Transportmittelbedarf bei Flieszransport". *Dt. Agr. Techn.*, 10: 315—316.

UHLIG, S., 1954, Berechnung der Verdunstung aus klimatologischen Daten. *Mitt. Dt. Wetterd.*, 6: 19—23.

VENEMA, F., 1961—1967, De in 1961—1967 opgetreden oogstverliezen en opbrengstdervingen bij de in Oostelijk Flevoland door de Cultuurtechnische Afdeling verbouwde granen. *Rijksd. IJsselm.p., Verslagen.*

VERVELDE, G. J., 1962, De ongewisheid van de oogst. Groningen.

VOIGT, V., 1955, Der Kornfeuchtigkeitsverlauf von auf dem Halm stehenden Getreide unter dem Einflusz der Witterung und Folgerungen für den Mähdrusch. *Dissertatie.* Hohenheim: 14—55.

VRIES, D. A. DE, 1955, Solar radiation at Wageningen. *Meded. Landbouwh.* Wageningen, no. 6: 290—294.

WAITE, P. J., 1966, Wet-dry day probabilities. *Iowa Farm Sc.*, 20: 386—388.

WEISS, L. L., 1964, Sequences of wet or dry days described by a Markov chain probability model. *Monthly Weather Rev.*, 92: 169—176.

WIGCHERING, W., 1966, Capaciteit van maaidorsers. *Scriptie* 190, *Landbouwh*, Wageningen.

WILJES, H. G. DE, 1965, Invloed van weer, grond en gewas op de mogelijkheid veldwerk te kunnen uitvoeren. *Inst. Landbouwtechn. Rat., Rapp.* 31.

WIJKEL, H. en J. H. VAN KAMPEN, 1964, Het graantransport van maaidorser naar de ontvangstinstallaties in Oostelijk Flevoland tijdens oogst 1963. *Rijksd. IJsselm.p., Rapp.* 25.

ZIMMERMAN, M., 1967, Field to farmstead transport. *Impl. and Tractor*, 82: 24—25.

ZUIDEMA, F. C., 1965, De invloed van het vochtgehalte van zaad en stro op de prestaties, zaadverliezen en stagnaties bij het maaidorsen tijdens de oogst van 1964 in Oostelijk Flevoland. *Rijksd. IJsselm.p., Rapp.* 36.

ZUIDEMA, F. C., 1965*a*, Enige gegevens over de stijging van het vochtgehalte van het zaad tijdens het dorsen, over het schot en over de korrelbreuk tijdens de oogst 1964 in Oostelijk Flevoland. *Rijksd. IJsselm.p., Verslag.*

X ZUSMAN, P. and A. AMIAD, 1965, Simulation: a tool for farmplanning under conditions of weather uncertainty. *J. of Farm Economics*, 47: 574—594.

APPENDIX I

AVAILABLE COMBINE HOURS IN DIFFERENT MOISTURE RANGES FOR COLZA, BARLEY, OATS AND WHEAT (1931—1967).

Available combine hours for grains are the hours that the kernel moisture content is below 28% less time when rain is falling; for colza the same applies when the kernel moisture content is below 18%. The hours are computed within the following time periods:

July 22 — September 15:	9 a.m. — 7 p.m. (Monday-Friday)
	9 a.m. — 4 p.m. (Saturday)
September 15 — October 1:	10 a.m. — 5 p.m. (Monday-Friday)
	10 a.m. — 4 p.m. (Saturday)

COLZA; HARVESTING PERIOD JULY 22 — AUGUST 7.

	Moisture range (wet basis)			
Year	< 10%	10—14%	14—18%	Total
1931	37	24	19	80
32	24	23	15	62
33	69	8	16	93
34	40	13	15	68
35	123	9	0	132
36	43	15	13	71
37	60	25	24	109
38	84	13	5	102
39	11	33	18	62
40	62	34	10	106
41	57	10	0	67
42	23	29	24	76
43	104	15	0	119
44	52	34	14	100
45	65	24	13	102
46	33	43	42	118
47	109	5	1	115
48	81	10	10	101
49	76	19	7	102
50	19	18	13	50
51	30	39	31	100
52	55	18	18	91
53	74	28	7	109
54	67	3	1	71
55	68	29	9	106
56	28	10	21	59
57	55	26	9	90
58	25	18	20	63
59	48	11	16	75
60	35	25	21	81
61	51	17	7	75
62	75	11	9	95
63	87	14	7	108
64	96	21	4	121
65	37	21	21	79
66	10	22	26	58
Total	2013	717	486	3216
Average	56	20	13	89
σ	± 28	± 10	± 19	± 21

BARLEY; HARVESTING PERIOD AUGUST 7 — AUGUST 17.

Year	Moisture range (wet basis)			
	<19%	19—23%	23—28%	Total
1931	8	11	19	38
32	16	43	12	71
33	40	24	7	71
34	21	10	26	57
35	32	12	17	61
36	5	27	38	70
37	19	10	18	47
38	—	—	—	—[1]
39	2	26	25	53
40	17	19	39	75
41	0	0	0	0
42	15	12	14	41
43	0	10	25	35
44	72	15	0	87
45	5	24	8	37
46	8	6	15	29
47	44	13	7	64
48	0	5	22	27
49	7	22	17	46
50	36	4	17	57
51	0	0	3	3
52	8	17	16	41
53	73	1	0	74
54	0	2	7	9
55	6	15	31	52
56	17	20	5	42
57	8	14	13	35
58	1	8	4	13
59	16	9	14	39
60	6	2	0	8
61	20	27	5	52
62	0	13	21	34
63	9	1	4	14
64	5	11	23	39
65	37	17	18	72
66	10	23	16	49
Total	563	473	506	1542
Average	16	14	14	44
σ	±18	±10	±10	±22

[1] no data available.

OATS; HARVESTING PERIOD AUGUST 17 — SEPTEMBER 6.

	Moisture range (wet basis)				
Year	<17%	<19%	19—23%	23—28%	Total
1931	59	80	34	10	124
32	73	86	13	30	129
33	62	70	23	29	122
34	99	112	8	7	127
35	62	73	30	24	127
36	126	131	2	5	138
37	62	79	17	27	123
38	—	—	—	—	—[1]
39	111	118	8	11	137
40	37	56	33	31	120
41	31	42	31	33	106
42	49	63	33	37	133
43	59	74	17	23	114
44	91	109	11	12	132
45	38	47	10	17	74
46	3	13	36	60	109
47	164	164	0	0	164
48	90	122	22	8	152
49	101	122	14	14	150
50	10	19	31	34	84
51	30	53	22	28	103
52	74	80	3	10	93
53	40	57	31	14	102
54	71	79	9	27	115
55	153	157	—	—	157
56	8	16	24	28	68
57	5	13	29	30	72
58	80	96	11	24	131
59	166	167	0	0	167
60	2	6	16	22	44
61	62	65	2	9	76
62	49	58	38	21	117
63	0	0	5	17	22
64	74	88	16	16	120
65	21	30	13	25	68
66	58	73	10	18	101
Total	2220	2618	602	701	3921
Average	63	75	17	20	112
σ	±44	±44	±11	±12	±33

[1] no data available.

WHEAT; HARVESTING PERIODS AUG 17 — SEPT 6 AND AUG 17 — SEPT 16.

	Aug 17 — Sept 6 Moisture range (wet basis)					Aug 17 — Sept 16 Moisture range (wet basis)				
Year	<17%	<19%	19—23%	23—28%	Total	<17%	<19%	19—23%	23—28%	Total
1931	7	50	70	12	132	7	50	99	38	187
32	28	72	34	24	130	28	72	57	78	207
33	39	60	34	45	139	88	120	34	45	199
34	31	83	40	26	149	44	133	66	32	231
35	33	53	50	33	136	38	79	71	42	192
36	41	104	30	15	149	41	104	48	37	189
37	12	50	42	37	129	12	61	77	50	188
38	—	—	—	—	—	—	—	—	—	—[1]
39	65	109	18	17	144	65	109	18	17	144
40	14	29	55	32	116	27	61	77	33	171
41	6	20	47	52	119	19	49	55	67	171
42	20	43	57	49	149	55	108	60	51	219
43	14	47	45	26	118	36	91	84	26	201
44	46	90	34	16	140	—	—	—	—	—[1]
45	7	33	26	16	75	45	103	33	20	156
46	0	2	41	61	104	0	2	59	96	157
47	153	164	0	0	164	172	207	26	0	233
48	30	81	58	12	151	34	101	99	30	230
49	39	101	39	18	158	45	122	59	48	229
50	4	10	49	43	102	4	10	50	80	140
51	0	20	57	39	116	0	33	110	53	196
52	15	54	26	17	97	27	94	49	24	167
53	15	35	46	20	101	47	80	72	20	172
54	18	51	45	29	125	18	51	77	67	195
55	93	145	12	0	157	93	145	32	23	200
56	0	4	26	37	67	0	4	29	70	103
57	0	0	27	54	81	0	1	42	64	107
58	42	72	27	45	144	49	84	41	73	198
59	136	165	2	0	167	210	242	2	0	244
60	0	0	17	35	52	10	31	41	52	124
61	18	46	17	15	78	18	46	27	32	105
62	26	53	44	30	127	26	61	79	39	179
63	0	0	3	22	25	9	28	26	28	82
64	24	62	38	23	123	27	79	44	47	170
65	7	21	19	26	66	7	25	54	57	136
66	43	50	30	22	102	43	61	54	49	164
Total	1026	1979	1205	948	4132	1344	2647	1751	1488	5986
Average	29	56	34	27	117	40	78	54	44	176
σ	±35	±44	±17	±15	±34	±44	±53	±25	±22	±40

[1] no data available.

APPENDIX II

DEFINITIONS AND SYMBOLS

7.3	*Available time for combining:* in the period July 22 — September 15 that part of the time between 9 a.m. and 7 p.m. that the grain moisture content is less than 28% (colza 18%) and no rain is falling. In the period September 15 — October 1 the definition holds between 10 a.m. and 5 p.m.
4.3	*Circumglobal radiation:* the short wave radiation from sun, sky and earth measured with the Bellani pyranometer
8.3.2	*Effective load capacity:* of grain wagon as loaded in the field; is 96% of load capacity (fully loaded)
7.3	*Effective time:* time the combine is cutting and threshing at an optimum forward speed
7.3	*Field efficiency:* the ratio of the effective time to the net working time expressed as a percentage: 60%
3.4	*Field loss:* sum of dry matter loss, shatter loss and combine header loss (cutterbar and reel) in the mature crop when the harvest is prolonged. In the computer program the field loss includes also the crop not harvested on the time limit (11.2.1.*d*)
10.2 10.4.*b*	*Harvest costs:* the annual operating costs of labour and equipment used for harvesting; value of separating loss included
3.2	*Maturity date:* the date the crop is combine ripe
7.3	*Net working time:* available time between Monday 9 a.m. (10 a.m. from Sept. 15) and Saturday 4 p.m. less time for repairs and operator's off duty time. Net working time averages 85% of the available time
9.3	*Removing frequency:* number of years after which a plant is removed
7.4	*Separating loss:* the kernel losses from straw walkers and shoe at the rear of the combine
3.4.*b*	*Test weight:* weight per unit volume (kg hl^{-1})
8.4	*Theoretical transport distance:* the distance using a harvesting sequence of the fields most favourable for the transport organization
7.3	*Time efficiency:* the ratio of the net working time to the available time expressed as a percentage: 85%
11.2.1.*d*	*Time limit:* date after which the crop standing on the field is assumed not to be harvested
7.1	*Ton:* metric ton (1,000 kg)
4.3	*Total global radiation:* the short wave radiation from sun and sky measured with the Moll-Gorczynski pyranometer
1	*Total harvest costs:* the sum of the harvest costs and the value of the field losses
8.1	*Transport capacity:* number of transport units required

2.3.1 A : annual area to be reclaimed
F : area under cultivation
U : annual area to be allocated to others
x_a : area sown with alfalfa
x_b : „ „ „ barley
x_c : „ „ „ colza
x_f : „ „ „ flax and miscellaneous
x_o : „ „ „ oats
x_w : „ „ „ wheat

8.4 A : number of transport units
A_t : number of wheeled tractors
A_w: number of grain wagons
C : total net combine capacity in tons h^{-1} (combine capacity in wheat with moisture content $< 19\%$).
D : theoretical transport distance in km
L : time for loading, unloading and for (un)hitching in hours
O_t : cycle time of a wheeled tractor in minutes
O_w: cycle time of a pair of grain wagons in minutes
t_{lo} : time for loading a pair of grain wagons in minutes
T : effective load capacity of transport unit in tons of wheat (kernel moisture content $< 19\%$)
V : speed in km h^{-1}
W : waiting time in hours

9.3 $\bar{D}$: mean transport distance
$\bar{b}$: mean cross-wise distance
$\bar{d}$: mean length-wise distance
x : number of drying plants
a : annual movement of the farm
t : year of removal
f : removing frequency of the plants

10.2 A : average annual depreciation
B : cost of labour per harvest period
B_1 : labour costs of one plant per harvest period
C_b : constant of proportionality (labour)
C_e : „ „ „ (energy)
C_o : „ „ „ (building)
d : drying capacity
E : cost of energy
E_1 : cost of energy per ton product for one plant
e_d : building cost for one ton h^{-1} drying capacity
e_w : building cost for one m^3 of storage
f : removing frequency of plants
K : average annual operating costs of plants
N : average gain obtained by storing wheat after the harvest
P : average price increase per ton of stored wheat
R : average annual cost of interest
R_w: interest charge on stored wheat
S_1, S_x: building costs of one and x centres respectively
T : average annual cost of maintenance

w : storage capacity
x : number of plants

11.2.2 C_i = daily supply of grain in moisture range i, $i = 1, 2, 3$
d = drying capacity
t = point of time during the ten hours (at maximum) that grain is brought in from the field
t_o = point of time when no grain of moisture range 3 is present any more in the storage space, therefore $v_3(t) = 0$ for $t > t_o$
t_1, t_3 = points of time when the storage space should become fully occupied, thereafter only a part (μ) of the combines can go on working ($0 \geqslant \mu \leqslant 1$)
t_2 = point of time that the amount of grain in moisture range 3 stored at t_1 has been transferred by drying in moisture range 2
$v_i(t)$ = amount of stored grain in moisture range i on time t
$v(t)$ = total amount of stored grain on time t, $v(t) = v_2(t) + v_3(t)$
m = volume of storage space (90% of actual storage space)
μ = part of the combines that can continue harvesting