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Relation between total radiation and yield of some field crops in the Netherlands

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Summary

The potential production of a crop surface with optimal water and mineral supply is dependent on the total incoming energy. An attempt was made to test this dependence under field conditions. In treated yield series the variation in the highest yields of various field crops was found to be positively correlated to the variation in the total global radiation per growing period. A further treatment with partial correlations shows that the length of the growing period and the annual yield increase may explain a considerable part of the yield variation.

Introduction

In the Netherlands the growth rate of a crop with optimum water and mineral supply is not limited by temperature during the summer months. It is, however, dependent on the total incoming energy (de Wit, 1959). Total radiation during a 10-day period is perhaps the most varying growth factor for this crop.

Alberda (1962) compared actual growth rates of grass to de Wit's (1959) calculated potential productions. This comparison demonstrated a relation between dry-matter increase per 10-day period and the total light energy received. Makkink (1959) also demonstrated a relation between calculated effective radiation and growth rates of grass, as observed by various authors.

Like this is the case for short periods, total radiation during the whole growing period of a crop in the Netherlands will be the most varying factor from year to year. In growing the same crop every year under optimum water and mineral conditions, the yield should be related to total radiation.

Scholte Ubbing (1959) found a relation between tuber yield of potatoes and radiation during the growing period, and he reported that in some years radiation may be the limiting factor for a maximum tuber yield.

Van der Paauw (1956, 1961), on the other hand, stated that direct weather effects do not cause yield variations, but soil fertility varies under the cumulative effect of meteorological conditions in the preceding period.

Treatment of long term production series of fields with a very good water and mineral supply will give further data on the effect of radiation on the production of other arable crops.

In the present paper the data of a number of such experiments were collected.

Table 1 *Summary of the data and the results of the statistical treatment in partial and multiple correlation coefficients and the yield percentage solved*

1	*2*	*3*			*4*	*5*	*6*	*7*	*8*	*9*	*10*
Crop No	*Figure No*	*Description*			*N*	*Annual trend*	*Number of days*	*Average radiation*	*% solved*	*R*	*Time of radiation*
						r	*r*	*r*			
1	1a	Potatoes	Pr.Lov. 6		14	0.90	0.92	0.76	91	0.96	from 3 weeks after emergence till harvest
2		potatoes	Farms		14	0.65	0.65	0.40	60	0.77	from 3 weeks after emergence till harvest *
3		Sugar-beets	Pr.Lov. 6	(sugar)	14	0.75	0.67	0.79	70	0.84	from 3 weeks after sowing till harvest
4		Sugar-beets	CSM	(d.m.)	17	0.45	—	0.49	29	0.54	from 3 weeks after sowing till harvest
5	1b	Sugar-beets	CSM	(sugar)	17	0.53	—	0.65	45	0.67	from 3 weeks after sowing till harvest
6		Sugar-beets	Beta	(d.m.)	13	0.46	—	0.46	28	0.53	from 3 weeks after sowing till harvest
7		Sugar-beets	Beta	(sugar)	13	0.70	—	0.70	58	0.76	from 3 weeks after sowing till harvest
8	1c	Peas	Pr.Lov. 6		11	0.52	0.43	0.72	56	0.74	from 3 weeks after sowing till harvest
9		Peas	Farms		11	0.79	0.46	0.70	69	0.83	from 3 weeks after sowing till harvest *
10		Peas	Gron.		11	—		0.79	62	0.79	1 April—31 July
11	1d	Wheat	Pr.Lov. 6		12	0.74	—	0.46	55	0.74	from 1 March till harvest
12		Wheat	Gron.		22	0.52		0.44	59	0.77	1 April—31 July
13		Barley	Pr.Lov. 6		10	—		—	—	—	1 April—31 July
14		Barley	Farms		10	0.75		0.65	57	0.76	1 April—31 July
15	1e	Flax	Pr.Lov. 6		12	—	—	—0.74	54	—0.74	from 3 weeks after sowing till harvest
16		Flax	Farms		12	0.65	—	—	42	0.65	from 3 weeks after sowing till harvest *
17	1f	Maize (kernels)			10	0.50		—	25	0.50	1 June—31 August
18		Maize (silage)			10	0.36		—0.45	48	0.68	1 June—31 August

* Growth time according to Pr.Lov. 6.

Origin of the data

The yields indicated as Pr.Lov. 6 (Table 1) are from a long-term experimental field in the Northeast Polder. The experimental field was set out to determine the level of organic matter applications required to keep the productivity of these heavy sandy clay soils in the new polders at the highest possible level (Grootenhuis, 1968a, b). Per crop the treatments with the highest annual yields were selected, irrespective of the level of organic matter or inorganic nitrogen applied. Comparable to these yields are those of three practical fields in the same polder on which the application of organic matter differs per farm. Of these yields the highest annual yield was selected per crop, irrespective of the farm. They are indicated as farm in Table 1.
The sugar yields indicated as CSM and Beta are averages of 35 practical fields, determined by the respective growers associations of that name.
Of the yields of maize variety experiments on drought sensitive sandy soil by Becker (pers. comm.) the highest annual dry matter yields of silage maize and the highest kernel yields of kernel maize were selected, irrespective of the variety.
Van der Paauw's (1961) treated yield data of winter wheat and peas were also taken into consideration and indicated as Gron. It was assumed that these crops were grown on soils on which water was not a limiting factor.
Total global radiation, as measured by the Department of Physics and Meteorology of the Agricultural University at Wageningen, was applied as radiation value, without correcting for locality where the crops were grown.

Calculation of the growing period

For a good comparison between total global radiation per growing period and yield, we attempted to estimate as accurately as possible the length of the period that the field was covered by a closed green crop surface. The Pr.Lov. 6 yields generally were compared to total global radiation during the period three weeks after sowing until harvest. For potatoes this period is from three weeks after emergence until they are killed by spraying.
The sowing dates of the 35 practical fields of sugar beets not being known, the dates of the experimental field Pr.Lov. 6 were used as a standard. The fields were all harvested on the same date, and it is known that the sowing date only varies slightly from year to year. Radiation was assumed to affect growth of winter wheat Pr.Lov. 6 from 1 March and that of winter wheat Gron. from 1 April. Radiation could be accurately totalled until the harvest date of winter wheat Pr.Lov. 6, whereas 31 July was assumed as the harvest date of winter wheat Gron. For barley the period was taken between 1 April and 31 July.
For maize the period from 1 June until 31 August was used, because during this period the crop shows a closed green cover and forms most dry matter.

Graphical presentation of the data and discussion of the results

In the figures in which for the sake of space only part of the results is reflected, the left vertical axis shows the yields and the right vertical axis the total global radiation in cal. cm^{-2} per growing period.

For both series of observations the horizontal line indicates the average value of the concerning years. The scale on the vertical axis was constructed from the level line in units equal to the standard deviation of the single observations.

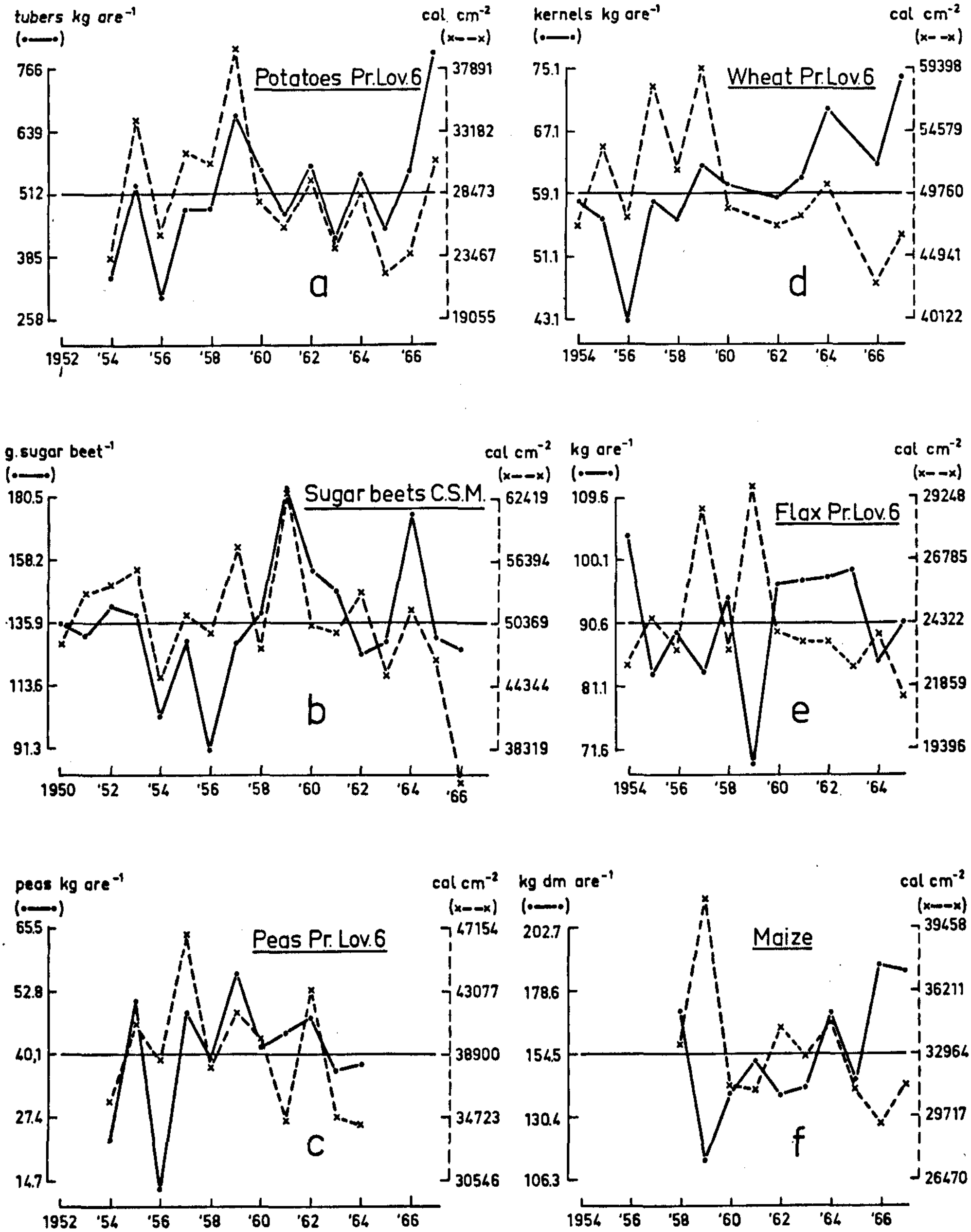

Fig. 1 Relation between incoming light energy per growing period of the crop and yield in the same year.

In all the figures the yields are expressed in the usual units and connected by a drawn line, the values for total global radiation by an interrupted line. In Fig. 1a, for instance, the potato yields of Pr.Lov. 6 from 1954 to 1967 are connected by a drawn line and the values for total incoming energy by an interrupted line.
The lines are more or less similar, but there is no parallelism, because the yields increase with respect to total radiation. Both lines show a top in the extremely dry and sunny year 1959.
For sugar beets the yields of the 35 fields sampled by CSM were used as an example and plotted in Fig. 1b. The yields of the sugar beets of Pr.Lov. 6 and the practical fields showed also a trend and 1959 was a top year in sugar production. Despite the upward deviation of the yields in 1950 and 1958 and the downward deviation in 1962, there is a distinct correlation between total global radiation and yield.
The ups and downs in the yields of peas Pr.Lov. 6 in Fig. 1c practically coincide with those of the incoming energy. Despite the deviations an increase of the yields with respect to total radiation can be inferred.
Fig. 1d reflects the wheat yields and here the relation to total radiation is less distinct than that of the preceding crops. Moreover, the two lines cross each other rather sharply, because of a yield increase in the course of the years, decreasing the similarity in the lines. The comparisons for 1961 and 1965 were omitted, because spring wheat was grown in these years.
The yields of flax including seed are shown in Fig. 1e. Though the flax was grown on the same field where potatoes and sugar beets showed a positive correlation with radiation, the correlation of flax is negative. The year 1959 is striking because of its low yield.
The results of silage maize presented in Fig. 1f also show a negative correlation with respect to total global radiation.

Statistical treatment of the data

The graphs illustrate the effect of total incoming energy on the yields. The figures also show that the yields increase in time with respect to total radiation. However it cannot be seen from the figures to what extent the total incoming energy is due to a high light intensity or to a long growing period.
For a better understanding of these relationships the production series were tested with regression equations. Partial correlation coefficients were calculated of the production series of Table 1 between the yield as a dependent factor and the independent factors:

a. Annual yield increase (annual trend);
b. Number of growing days per season;
c. Radiation intensity (= total global radiation/number of growing days).

In Table 1 the results of the experimental field Pr.Lov. 6 are followed always by one or more examples from practice. When there is a graph of the production series a reference to it can be found in column 2. Column 4 shows the number of observation years.
Column 8 shows the percentage solved by the regression analysis. This percentage indicates the part of the yield variability that can be explained by factors 5, 6 and 7. In column 9 are the multiple correlation coefficients expressing the same idea in another way. These are the correlation coefficients concerning the comparison of cal-

culated and measured yields. Calculated yields in this instance are yields calculated with the regression equation including factors 5, 6 and 7. A —sign in the table indicates that for some reason a correlation could not be calculated.
The partial correlations and the percentage solved are higher for the Pr.Lov. 6 potatoes than for the practical fields. With sugar beets too, the Pr.Lov. 6 yields can best be explained by the 3 factors. The partial correlation coefficients for the sugar beets of the two growers associations are almost equal and higher for sugar than for dry matter. Due to the too small variation in the number of days per growing season this factor was dropped in testing.
In addition to the yields of peas Pr.Lov. 6 used in Fig. 1c, Table 1 shows the correlation coefficients of two other series. The annual trend, reliable for pea yields on a practical scale, could not be demonstrated for the yield series Gron.
The relation of winter wheat yields to average daily radiation was less distinct than that of the preceding crops. For Pr.Lov. 6 factor 6 was dropped, because of a too small variation.
In testing the spring barley yields of Pr.Lov. 6, the yield variations could not be explained by the total radiation from 1 April to 31 July, whereas those of the practical fields did show a close correlation to total radiation.
A correlation coefficient of —0.74 shows the negative effect of high radiation values on flax yields. This is, however, not confirmed by the yields of the practical farms. The correlations for the annual trend are more or less contradictory.
Silage maize, finally, shows a slightly negative correlation between total radiation and yield. The annual trend is not sufficiently reliable because of the small number of observations.

Discussion

The reliability of explaining the yields is related to the accuracy of estimating the period of a closed green crop canopy, afterwards. The close correspondence of the potato yields and total radiation in Fig. 1a and the high correlation coefficients for this crop can be explained by this. Shortly after emergence the soil is completely covered by green leaves until the crop is killed by a chemical spray, and thus the beginning and end of the period are clearly set off. This period is not so distinctly marked for sugar beets, because the period between sowing and complete soil coverage varies from year to year. In cereals, flax and peas the beginning of the period is not clearly set off because initial growth may be more or less slow and the end not, because the leaves start dropping before harvest.
Generally the partial correlation coefficients for the practical farms are somewhat lower than for the experimental field Pr.Lov. 6. Because there are no nitrogen levels on the practical fields, the fields with the most adequate nitrogen supply cannot be selected.
In the production series of potatoes and sugar beets the yields were very high in the extremely dry and sunny year 1959. This shows that water supply was not a distinctly limiting factor for yields on this soil in the Northeast Polder. When flax is grown on the same field where potatoes and sugar beets were grown, the yields in the dry and sunny summers are low, as shown by Fig. 1e. Despite flax being grown on the same field (where potatoes and sugar beets showed a positive correlation of yield and total radiation), the yields are negatively correlated to total annual radia-

tion, as shown by Fig. 1e. The small extent to which this crop covers the soil, including the possibility that the lowest leaves receive sufficient light, suggests that lower light intensities are already sufficient for optimum production. On the other hand, the sensitivity of this crop to dry weather during growth may also be responsible. Other data confirm that rainfall after a drought period increased growth of flax (Grootenhuis, pers. comm.).

The maize yields are less comparable, because they were obtained on drought-sensitive soils in the eastern part of the Netherlands. Nevertheless they are mentioned, since they demonstrate that in dry sunny summers, which are considered favourable for maize because of the higher temperatures, growth is often retarded by water deficiency.

The relation between total radiation and potato yield corresponds to the results of Scholte Ubbing (1958). He demonstrated that with the same water supply higher tuber yields were obtained by higher total radiation. Our results and those of van der Paauw show less agreement, because van der Paauw was more interested in crop growth under sub-optimum conditions. Yields which were obtained under sub-optimum conditions, e.g. maize in this paper, do not show or show to a less extent this relation with total radiation. Further investigations will have to determine to what extent van der Paauw's findings, that yields decrease during rainy periods and increase during sunny periods, can be brought into line with the data in this paper, demonstrating a relation between yields and annual total radiation.

References

Alberda, Th. & L. Sibma, 1962. Dry matter production and light interception of crop surfaces. II. Relation between rate of growth and length of grass. Jaarboek I.B.S. 1962, p. 47–58.

Becker, W. R. & G. H. de Haan. Personal communication.

Grootenhuis, J. A., 1968a. Excursiegids 1968 van de 3 organische stofbedrijven in de Noord-Oostpolder.

Grootenhuis, J. A., 1968b. Excursiegids 1968 Dr. H. J. Lovinkhoeve.

Makkink, G. F., 1959. De potentiële opbrengst van grasland. Jaarboek I.B.S. 1959, p. 117–128.

Paauw, F. van der, 1956. De plaats van de fotosynthese in het produktieproces. *Landbouwk. Tijdschr.* 68: 635–646.

Paauw, F. van der, 1961. Stabielere landbouwproduktie door beheersing van de invloed van het weer op de vruchtbaarheid van de grond. *TNO-Nieuws* 185: 373–376.

Paauw, F. van der, 1967. Het weer en de vruchtbaarheid van de grond. *Landbouwk. Tijdschr.* 79: 75–78.

Scholte Ubbing, D. W., 1958. De invloed van de watervoorziening en de totale instraling op de opbrengst van aardappelen. *Landbouwk. Tijdschr.* 70: 453–464.

Wit, C. T. de, 1959. Potential photosynthesis of crop surfaces. *Neth. J. agric. Sci.* 7: 141–149.

Wit, C. T. de, 1965. Photosynthesis of leaf canopies. *Agric. Res. Rep.* 663.