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RELATIONS BETWEEN THE POTASH REQUIREMENTS OF CROPS AND METEOROLOGICAL CONDITIONS

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INTRODUCTION

Experience has shown that the growth response of crops to variations in potash supply varies from year to year. It is obvious that this variable behaviour is attributed to differences in weather conditions.

Russell[10] found a negative correlation between the number of hours of sunshine during the period July–October and the depression in the yield of potatoes when application of potash was omitted. The effect of sunshine decreases with adequate applications of potash. This conclusion is based on few data. Russell and Watson[11] found in the case of barley that the availability of soil potash was lower and applications of potash were more effective in dry, sunny years. It proved to be more probable that this difference was due to the decreased humidity of the soil than to the excess of sunshine.

In a comparison of marine clay soils having a high level of available potash with river clay soils having a low level of available potash Ferrari[2] found a clear correlation between yields and weather conditions for the latter kind of soil but not for the former. This might be expected if weather conditions affect the availability of potash as was suggested by this author.

Differences in response to applications of potash may be associated with variations in the moisture content of the soil. In a review of the literature Richards and Wadleigh[9] mention several instances where the uptake of potash from the soil was promoted by higher soil humidity. Ferrrari[3] has found that statistically the potash content of grass grown on sandy soil with a moderate water supply is higher than on soil with a very low water table. He found the reverse to be the case with very humid soil. The latter agrees with the decreased absorption of potash by sugar beet observed by Larson [6] on soils with a very high moisture content. He attributed this to the low oxygen content of these soils.

Schuffelen and Middelburg [12] conclude on the basis of Donnan-equilibriumn considerations, that there will be increased solubility of potassium and decreased solubility of magnesium as soil humidity increases. This has been confirmed experimentally [13].

Recently Dijkshoorn and 't Hart [1] have shown that the cationic content of perennial ryegrass grown under controlled temperature conditions is largely governed by temperature. The potassium content especially increases or decreases considerably after a rise or fall in temperature. These results are in accordance with the field observations of Kemp and 't Hart [5]. The changes observed are closely correlated with the incidence of grass tetany. Hoagland and Broyer [4], working with excised barley roots, had earlier found similar temperature effects.

EXPERIMENTAL

The results from an experimental field, used for the investigation of the effects of potash application, cropped continuously with the same four crops in rotation over a period of 15 years have enabled us to study the relation between the response to potash and weather conditions.

For the investigation of such relationships a suitable general index of weather conditions must be used. Such an index may be the number of rainless days (or days with less than 1 mm of rain); this, according to Post [8], characterizes the type of weather satisfactorily. Data of this kind were available for the meteorological station at Zoutkamp which is 6 km from the experimental field. This index is much more suitable than rainfall in mm, since the latter is strongly affected by heavy showers. A further analysis of the influence of meteorological conditions has not been undertaken, as the available data are too few for a partial regression analysis to be made.

Effective indications of the potash requirements of crops are the differences between yields in the presence or absence of heavy applications of potash, and also the decrease in under-water-weights * of potato tubers after heavy applications of potash, the latter being and index both for dry matter and potash content of the tubers.

The meteorological data for the period May 1st–July 31st were used in the first instance. This period coincides more or less with the growing period of the crops. Whether other periods are more suitable will also be considered.

The relationships between weather conditions and crop response to potash applications are presented graphically and also as correlation coefficients, even though the statistical requirements of a normal distribution are not fulfilled.

The experimental field (Pr 201 at Pieterzijl) is situated in the north of the Netherlands, exactly 20 km north-west of the city of Groningen. It was laid out in 1935 and was continued until 1949. The soil is a light marine clay soil, reclaimed in 1453, still containing 2.3% $CaCO_3$ but rather deficient in potash.

Potatoes, canary grass, beans and spring wheat were grown simultaneously and in rotation on four adjacent strips of the field. Potash was applied as sulphate of potash to plots replicated three times, in quantities corresponding with 0, 40, 80, 120, 180, 300, and 480 kg K_2O per ha: in the first year the highest amounts were only 240 and 300 kg. The quantities applied were always more than sufficient for the attainment of optimum yields but not high enough to guarantee a minimum value for the under-water-weight of potatoes with certainty.

RESULTS

Apart from the first year the cumulative effect of annual applications of potash has been studied. After some years an almost constant level was reached at each level of potash application. Therefore the results obtained in those years are comparable among themselves. This probably does not hold completely for the second and third years when constant levels had not yet been reached. The effect of a somewhat too low level may have been largely

* The under-water-weight is determined by weighing 5 kg of tubers under water. It is an index of the specific weight.

eliminated by the dominating effect of the annual application of potash so that only the results of the first year have been omitted from the calculations. It has not been noticed that during the experiment the potash requirements increased in the case of the plots not receiving a potash dressing. For this reason the first year values for the K_2O-contents of the crops and the under-water-weight of potatoes on plots not receiving potash are not omitted. The yield of grain could not be determined in 1944.

The average results of all years for this fertilizing experiment are presented in Fig. 1. There is a considerable response by beans,

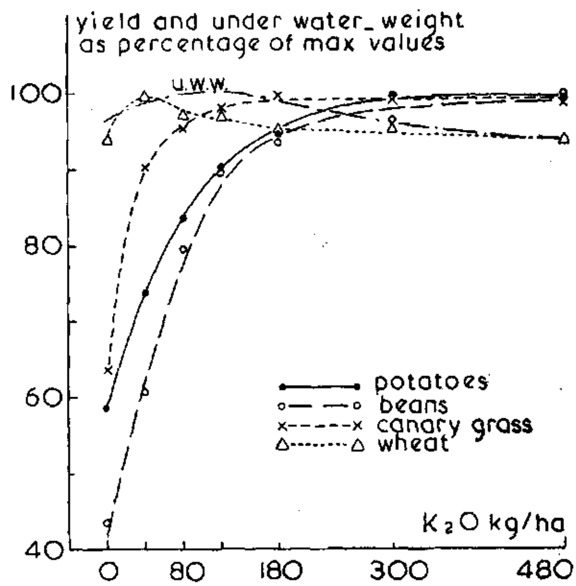

Fig. 1. Relation between the level of annual potash application and the average yields of potatoes, spring wheat, beans and canary grass, and the under-water-weights (u.w.w.) of potatoes (12–14 years). Maximum values are rated at for potatoes (tubers) 100% = 379 q/ha; for wheat (grain) 100% = 33.8 q/ha; for beans (seed) 100% = 31.4 q/ha; for canary grass (grain) 100% = 27.5 q/ha; for under-water-weights 100% = 493 grammes.

potatoes and canary grass. The yield of canary grass reaches a maximum at a rather moderate potash level. The slight increase in wheat yield at the lowest level of potash application is followed by decreasing yields at higher levels. The under-water-weight of potatoes also shows increases at the lower levels of application which are followed by decreases at the higher levels of application.

1. Potatoes

The relation between the number of rainless days and the yields obtained with the highest level of potash application and in the absence of potash application is shown in Fig. 2. From the left-hand parts of the curves it appears that the yield was markedly lower in

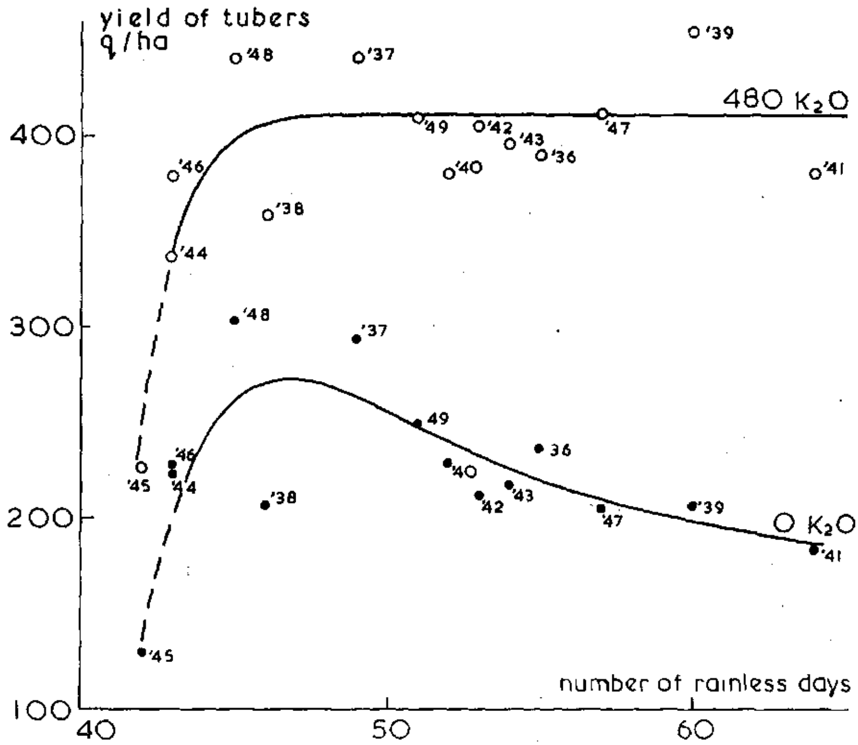

Fig. 2. Relation between the number of rainless days (May–July) and the yield of potato tubers in the presence and absence of heavy applications of potash (480 and 0 kg K_2O per ha).

a very wet year. However, this result does not agree with Russell's [10] observation that the decreased yield (in quintals/ha*) is more pronounced in the absence of potash application than when there are ample dressings of potash. Only relatively as a percentage of the yield obtained when potash is applied, is the yield, in the absence of potash application, in the very wet year 1945 somewhat

* 1 quintal = 100 kg.

lower than in other years. In dry years the yields obtained when potash is applied do not vary appreciably. The yields in the absence of potash application decrease as the number of dry days increases. The difference is thus greatest in dry years.

For comparison of absolute differences between the yields for different years the unfavourable year 1945, with an abnormally low yield, is less suitable and not comparable with the others. Therefore, relative differences will also be taken into consideration.

This positive relation between the maximum increase of the yield of tubers due to potash dressing and the number of rainless days is convincing (Fig. 3). The correlation coefficient (Table I) is 0.84

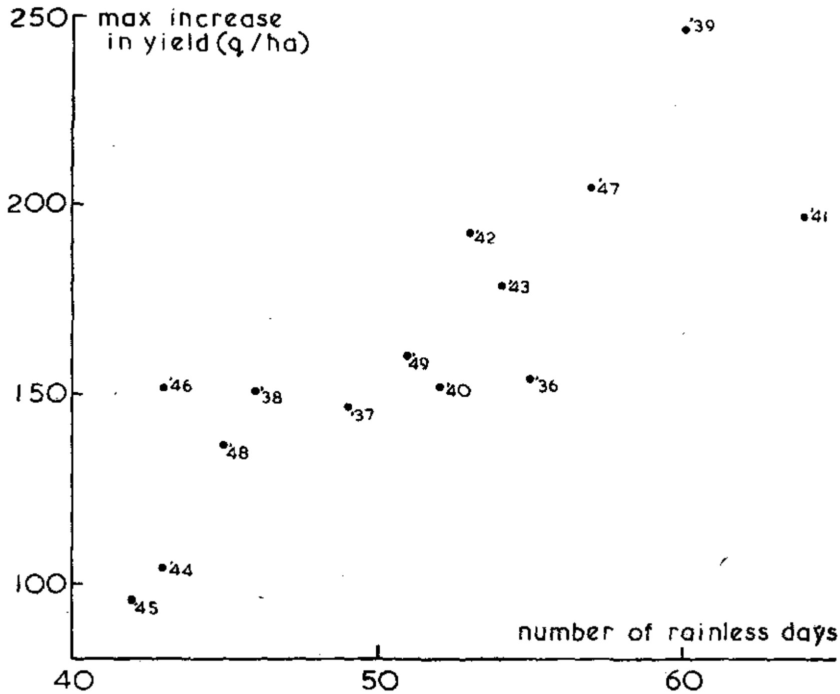

Fig. 3. Relation between the number of rainless days (May–July) and the maximum increases in yields of potato tubers obtained after applications of potash.

(without the results for the year 1945 it is 0.80) and is highly significant. The correlation coefficient for percentage increases in yield is calculated to be −0.74 (without the results for the year

1945 it is −0.80). Evidently the effect of potash dressings is greatest in dry years, which corresponds to a low availability of soil potash.

Rainfall (in mm) shows less correlation with crop response. For the same period the correlation between this factor and the increase in yield is rather weak (r = −0.35). This might be due to the fact that the values for rainfall, having been measured at a distance of 6 km from the experimental field, may not represent the actual

TABLE I

Correlation between number of rainless days in May–July and crop responses to potash applications

Grop	Response	r	p
Potato	Diff. of yields (max.—min.)	0.84	<0.001
	Same without 1945.	0.81	<0.001
	Relative yields without K.	−0.74	0.001
	Same without 1945.	−0.80	0.001
	Depression under-water-weights (max.—min.)	−0.71	<0.01
	Same without 1945.	−0.65	0.02
	Max. K_2O% tubers with K	−0.47	0.09
	Same without 1941.	−0.32	0.30
	Same without 1941 and 1947.	−0.75	<0.01
	K_2O% tubers without K	−0.18	0.53
	Same without 1941.	−0.52	0.06
	Same without 1941 and 1947.	−0.61	0.03
Spring wheat	Diff. of yields (grain) (480—0)	0.69	0.01
	Relative yields (480 in % of O).	0.67	0.01
	Relative yields without K (straw)	−0.16	0.61
Canary grass	Diff. of K_2O-contents (max.—min.) (straw) .	−0.56	0.07
Beans	Relative yields without K (seed + straw) . .	−0.11	0.74

rainfall on this field. A higher correlation (r = −0.52) is indeed found if the mean of the rainfalls for 5 meteorological stations (at distances of 6–20 km) is taken.

With the exception of 1936 and 1945 the relation between level of potash dressing and under-water-weight can be characterized by a curve showing an optimum (the average relation is shown in Fig. 1). From the shape of the curves obtained in 1936 and 1945 it can be concluded that in these years the optimum value must have occurred under conditions where little or no potash was applied. The difference between the optimum values and the minimum values obtained with the highest level of application can be used as an index of potash availability (van der Paauw [7]). A clear correlation is found between this difference in the under-water-weight and the number of rainless days (Table I, Fig. 4). The difference is greatest in wet years. This suggests an abundant potash supply in those years on the plots heavily dressed with potash.

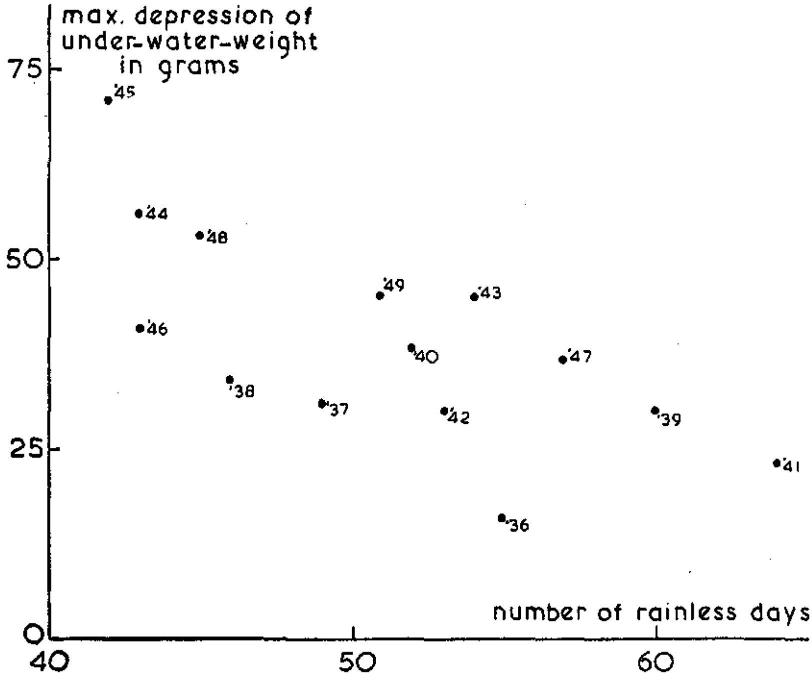

Fig. 4. Relation between the number of rainless days (May–July) and the maximum depression of the under-water-weights of potato tubers caused by high levels of potash application.

It may be noted that the optimum value of the under-water-weight itself is not correlated with the number of rainless days. It seems probable that the optimum values depend not only on potash nutrition but on all the factors influencing the starch content in the different years. In addition the optimum level of potash application varies from year to year.

Relatively low decreases of the under-water-weights were found in the years 1936–1938. This may be fortuitous but it may also be the result of a continuing, somewhat lower potash status during the first few years of the experiment in the case of the plots receiving large applications. Parallel deviations were, however, not found in the case of maximum increase in yield of tubers (Fig. 3) or in the case of K_2O content of tubers (Fig. 5). Therefore, it is probable that the results obtained during these years are comparable with those of other years.

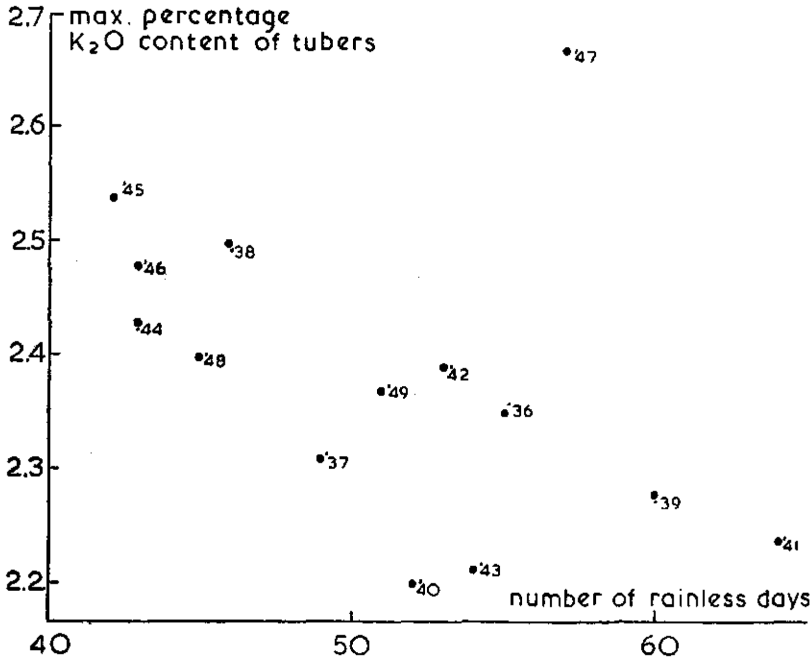

Fig. 5. Relation between the number of rainless days and the K_2O content of potato tubers after high levels of potash application.

A similar trend in the chemical composition of the crop would, however, have been the strongest argument in favour of the assumption of an increased availability of potash in wet years. The correlation coefficient for the relation between K_2O contents of tubers from plots receiving the largest application of potash and the number of dry days is, however, not fully significant (Table I, Fig. 5). It should be mentioned that the result for the year 1941 is rather unreliable. The curve of values for the K_2O contents of tubers plotted against the level of K_2O application (Fig. 6) shows the 1941 values to be very irregular, especially in the case of the K_2O content for tubers grown in the absence of added potash. It seems probable that sampling errors have been made. If the values for 1941 be omitted the correlation coefficient drops from −0.47 to −0.32. The results for 1947 also deviate considerably from the general trend. This year was extremely hot and also dry at the end of the growing season. If the result for 1947 is omitted, then the correlation coefficient rises to −0.75.

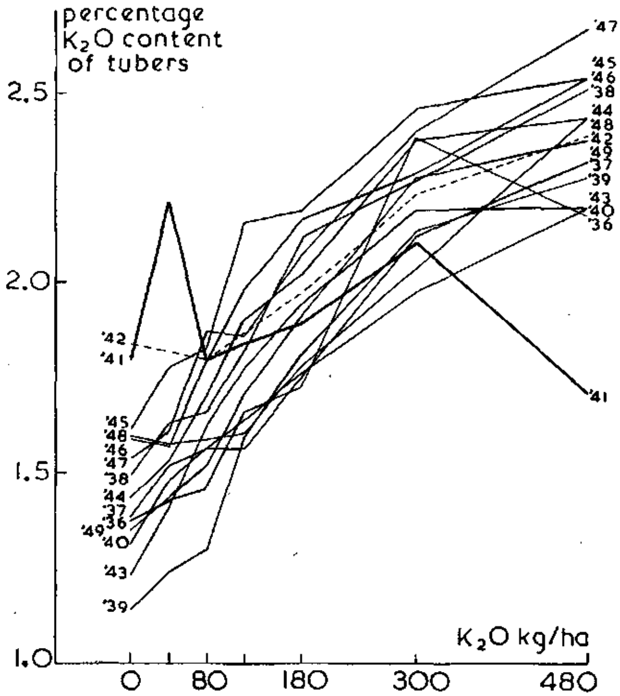

Fig. 6. Relation between the application of increasing amounts of potash and the K_2O content of the potato tubers for all the years of the experiment.

In the case of K_2O contents for tubers grown in the absence of added potash a result obtained in 1935 is also available. The correlation is, however, weak. If, however, the doubtful value for 1941 is omitted, the correlation is greater (Table I).

However, the results from the above data are not sufficiently significant for there to be a definite indication of an increased intake of potash under rainy weather conditions.

2. Spring wheat

The response of this crop to potash applications is much less than in the case of potatoes. In addition the effect of potash on yield is characterized by an optimum in most cases (Fig. 1). In those years when the amount of available potash is low a curve indicating gradual increase in yield with increase in potash application is obtained, in the years when the amount of available potash is high the positive effect of application of potash is slight and the depressing effect on the yield is dominant. It is not easy to

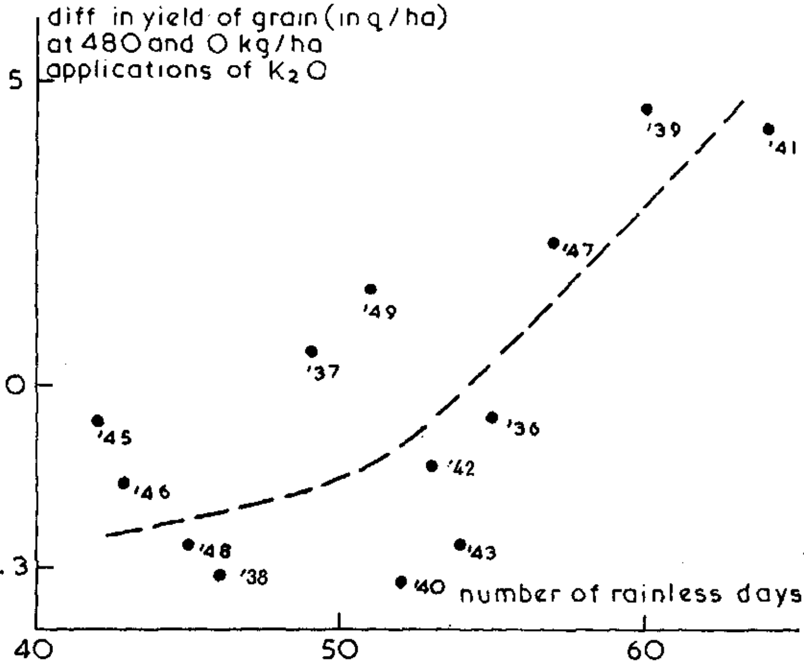

Fig. 7. Relation between the number of rainless days (May–July) and the differences in the yields of wheat obtained in the presence (480 kg/ha) and absence of applications of potash.

characterize such effects by a single index. The yield obtained with the highest dressing is affected positively and negatively. The difference between the yield obtained with the highest potash application and the yield obtained in the absence of a potash dressing appeared to be the most suitable index.

The relation between the number of rainless days and the difference between the yields obtained with and without a potash dressing is shown in Fig. 7. Positive responses to applications of potash have been found in dry years, negative responses especially in wet years. This result points to a higher availability of potash in rainy years and agrees with the result obtained for potatoes.

Probably the relation cannot be represented correctly by a straight line. It seems that the part of the curve nearest the origin has a much less steep slope. This is in agreement with the mean response of this crop to increasing amounts of added potash (Fig. 1). Very high applications of potash did not depress the yield appreciably more than did moderate dressings.

The response of straw to applications of potash does not appear to be noticeably increased in dry years (Table I).

3. Canary grass

Only weak correlations between weather conditions and influence of potash supply on yield were found in the case of this crop. The clearest correlation has been found for the relation between the number of rainless days and the increase in the K_2O content of the straw. This relation is mainly detectable from the variations in the maximum K_2O content of the straw obtained at the highest levels of potash application. The increase in the K_2O content was greatest in wet years.

Although this finding is not fully significant (Table I) it agrees with the results obtained for potatoes and wheat.

4. Beans

No correlations were found in the case of this crop (Table I).

It is curious that the behaviour of this crop, which is very sensitive to potash deficiency, is so different when compared with that of the other crops.

Period of highest sensitivity

In order to determine more accurately the period during which the crop is most sensitive to the meteorological factors affecting the response to potash, correlation coefficients for the relation between the weather index over shorter periods and the response of the crop have been calculated. The increases in yield of potatoes obtained after applications of potash have been taken (Table II) as the measure of crop response.

TABLE II

Correlation between number of rainless days during different periods of the growing season and increases in yields of tubers

Period	r	p
1–30 April	—0.20	0.50
16 April–15 May	0.35	0.23
1–31 May.	0.64	0.01
16 May–15 June	0.77	<0.01
1–30 June.	0.68	<0.01
16 June–15 July	0.12	0.69
1–31 July.	—0.10	0.74
16 July–15 August . . .	—0.32	0.27
1 May–30 June . . .	0.78	0.001
1 June–31 July	0.59	0.02
1 May–31 July.	0.84	<0.001
1 May–15 August . . .	0.71	<0.01

Obviously the correlation coefficient increases until the period 16 May–15 June and then regularly decreases again. This regularity may indicate that the potato crop is especially affected during the period of emergence and early development of the crop.

The highest correlations for the differences in yield of wheat have been obtained for the period 16 May–15 June ($r = 0.41$, $p = 0.17$). No clear correlations were found for May and July. For the period 1 May–31 July the correlation is 0.69 ($p = 0.01$) (Table I).

In the case of canary grass the correlation between the maximum increase in K_2O content of the straw and the number of rainless days is also highest for the period 16 May–15 June ($r = -0.50$, $p = 0.12$). For the period 1 May–31 July a value of -0.56 has been obtained (Table I).

In the case of beans no significant correlations were found for the shorter periods.

The nature of the climatological factor responsible for the crop responses

The correlations found between the weather index and crop response to potash supply do not reveal the real causal effect of climatological factors. The number of rainless days may give an indication of the amount of precipitation and the moisture content of the soil but it may equally well be an indication of hours of sunshine, light intensity, temperature, or other factors. The small number of experimental years does not allow a further analysis to be made.

It might be that differences in moisture content of the soil result in differences in the amounts of available potash (Schuffelen and Middelburg[12], Schuffelen[13]). The increases in K_2O content of crops might be considered to support this hypothesis. It seems feasible that the apparently increased availability of potash is due to an increase in the K-concentration in the soil solution rather than to an increased capacity of the plants to absorb potash. It is generally accepted that good weather conditions (high light intensity) are more favourable for potash absorption by the plants. It appears, however, that a large number of dry days coincides with *low* potash contents in potatoes and canary grass.

Differences in potash absorption may also be due, however, to temperature levels or variations in temperature, as has been shown by Dijkshoorn and 't Hart[1].

SUMMARY

Significant correlations have been found between the response of potatoes, spring wheat, and to some extent canary grass to applications of potash and the number of rainless days during the growing period.

The influence of applications of potash on the tuber yield of potatoes was higher, on the depression of the under-water-weight of the tubers was less, and on the K_2O content of the tubers was lower, in dry years thereby indicating a decreased availability of soil potash in these years.

The positive effect of applications of potash on the grain yield of wheat was highest in dry years. Ample applications of potash were found to depress yields in wet years which is also an indication of higher availability of potash in wet years.

In the case of canary grass greater increases in the K_2O content of the straw after applications of potash were found in wet years.

No significant correlations were found in the case of bean crops.

The influence of weather conditions on the response to potash is probably greatest during emergence and the early phases of growth. In later periods the influence is slight.

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LITERATURE CITED

1 Dijkshoorn, W. and 't Hart, M. L., The effect of temperature upon the cationic composition in perennial ryegrass. Neth. J. Agr. Sci. **5**, 18 (1957).

2 Ferrari, Th. J., An agronomic research with potatoes on the river ridge soils of the Bommelerwaard. Verslag. Landbouwk. Onderzoek. **58.1**, 132 pp. (1952).

3 Ferrari, Th. J., Not yet published.

4 Hoagland, D. R. and Broyer, T. C., General nature of the process of salt accumulation by roots with description of experimental methods. Plant Physiol. **11**, 471 (1936).

5 Kemp, A. en 't Hart, M. L., Grass tetany in grazing milking cows. Neth. J. Agr. Sci. **5**, 4(1957).

6 Larson, W. E., Response of sugar beets to potassium fertilization in relation to soil physical and moisture conditions. Soil Sci. Soc. Am. Proc. **18**, 313 (1954).

7 Paauw, F. van der, Plant analysis as a means of chemical soil tests. Trans. Intern. Congr. Soil Sci. Amsterdam 1950 **I**, 232–235 (1950).

8 Post, J. J., Statistical research on the correlation between the weather, grass-production and milk supply. Kon. Ned. Meteorol. Inst. Mededel. Verhandel. Serie A, no. 55. 's-Gravenhage (1949).

9 Richards, S. A. and Wadleigh, C. H., Soil Water and Plant Growth. Ch. XII. Nutrient accumulation in plants in relation to the soil moisture supply. Pp. 203–206 in: Agronomy. A Series of Monographs. II. Soil physical conditions and plant growth. New York (1952).

10 Russell, J., 85 Jahre Düngungsversuche in Rothamsted. Ernähr. Pflanze **24**, 258 (1928).

11 Russell, E. J. and Watson, D. J., The Rothamsted field experiments on barley 1852–1937. Part. II Empire J. of Exptl. Agr. **6**, 293 (1938).

12 Schuffelen, A. C. and Middelburg, H. A., Ionic exchange interrelationships. Neth. J. Agr. Sci. **1**, 97–100 (1953).

13 Schuffelen, A. C., The absorption of potassium by the plant. *In:* Potassium Symposium, 169–181, Zürich (1954).