TABLE X.

Showing average values obtained on the different series with ARMOEDSVLAKTE *soil.*

Series.	Period of Growth.	Plants per Pot.	Ratio Fresh to dry Weight.	Wt. of Crop.			Water used.			P_2O_5 removed.			Av. lengths			Av. Counts. (Per 20 Plants.)		
				Per Pot.	Per 20 Plants.	Per 100 Litre Water.	Per Pot.	Per 20 Plants.	Per 100 gm. Crop.	Per 100 gm. Crop.	Per 20 Plants.	Per Pot.	of Plant.	of Stem.	of Longest Leaf.	Stems.	Leaves.	Ears.
A.L. Ca................	I	22	5·4	3·6	3·3	36	9·9	9·0	275	·28	9	10	38	19	23	23	147	
A.L. CaKNP.............	,,	21	8·0	15·3	14·6	143	10·7	10·2	70	·98	143	150	62	32	33	48	288	
A.H. Ca...	I	23	5·5	4·4	3·8	38	11·6	10·1	264	·35	13	15	41	20	25	24	149	
A.H. CaKNP..	,,	22	9·7	19·3	17·5	101	19·1	17·4	99	1·31	233	253	65	33	39	60	320	
A.H. CaP...............	,,	24	6·6	21·4	17·8	96	22·2	18·5	104	1·12	199	240	64	48	30	35	240	
A.L. Ca................	II	20	3·4	8·3	8·1	43	19·3	18·9	234	·28	23	23	57	45		29		20
A.L. CaKNP.............	,,	20	2·3	37·8	36·7	94	40·2	39·4	107	·83	305	314	91	76		56		34
A.H. Ca................	II	21	3·5	10·1	9·3	38	26·7	24·6	265	·29	27	29	61	50		31		21
A.H. CaKNP............	,,	20	3·2	43·7	42·8	78	57·2	56·3	103	·98	419	428	102	80		80		27
A.L. Ca................	III	21		9·7	9·1	37	26·2	24·6	271	·30	27	29	54					
A.L. CaKNP.............	,,	20		44·0	42·6	76	58·1	56·7	132	·83	354	363	88					
A.H. Ca................	III	22		12·7	11·4	33	37·9	34·1	298	·31	35	39	56					
A.H. CaKNP.............	,,	21		53·9	49·5	72	74·5	69·1	139	·94	465	507	97					
A.H.O..................	,,	23		8·9	7·8	27	33·3	29·1	376	·20*	16	18	43					
A.H. CaKN..............	,,	25		14·4	11·5	38	37·4	29·9	261	·26	30	38	56					
A.H. CaP...............	,,	22		40·2	35·8	59	68·0	61·7	170	·85	304	343	83					

* Only No. 41 available.

Table XI.

Showing average values obtained on the different series with Shepstone *soil.*

Series.	Period of Growth.	Plants per Pot.	Ratio Fresh to dry Weight.	Wt. of Crop.			Water used.			P_2O_5 removed.			Av. lengths			Av. Counts. (Per 20 Plants.)		
				Per Pot.	Per 20 Plants.	Per 100 Litre Water.	Per Pot.	Per 20 Plants.	Per 100 gm. Crop.	Per 100 gm. Crop.	Per 20 Plants.	Per Pot.	of Plant.	of Stem.	of Longest Leaf.	Stems.	Leaves.	Ears.
S.L. Ca.................	I	26	4·9	1·6	1·2	23	6·9	5·2	431	·28	3	5	24	9	16	20	110	
S.L. CaKNP..............	,,	24	6·0	2·0	1·7	29	6·9	5·8	345	·62	10	12	28	10	20	20	110	
S.H. Ca.................	I	25	4·7	2·3	1·8	24	9·7	7·8	422	·26	4	6	29	11	19	20	117	
S.H. CaKNP..............	,,	24	8·8	11·0	9·2	75	14·6	12·2	133	·84	77	92	56	26	31	47	243	
S.H. CaP................	,,	27	8·1	9·5	7·0	73	13·0	9·6	137	·69	48	66	50	22	30	35	185	
S.L. Ca.................	II	24	2·6	2·1	1·7	21	10·2	8·2	491	·24	4	5	40	29		20		2
S.L. CaKNP..............	,,	24	3·8	7·0	5·6	57	12·2	9·8	174	·60	34	42	62	50	32	26		5
S.H. Ca.................	II	25	2·7	5·3	4·1	27	19·4	15·2	375	·26	11	14	44	34	24	20		7
S.H. CaKNP..............	,,	23	2·8	27·0	22·8	81	33·2	28·0	123	·54	123	146	77	61	40	64		23
S.L. Ca.................	III	24		2·6	2·0	21	12·3	9·9	480	·26*	5	7	36					
S.L. CaKNP..............	,,	21		14·1	13·1	67	20·9	19·3	149	·67	88	95	57					
S.H. Ca.................	III	24		6·1	5·0	24	25·6	21·0	426	·26	13	16	43					
S.H. CaKNP..............	,,	22		31·9	28·3	67	47·9	42·8	151	·53	150	170	75					
S.H.O...................	,,	25		3·1	2·4	13	23·3	18·7	768	·13†	3	4	32					
S.H. CaKN...............	,,	25		6·3	5·0	26	24·4	19·5	391	·22	11	14	47					
S.H. CaP................	,,	25		28·1	21·9	63	44·9	35·1	160	·50	110	141	77					

* Only No. 74 available. † Only No. 71 available.

TABLE XII.

Showing average values obtained on the different series with VERONA EAST *soil.*

Series.	Period of Growth.	Plants per Pot.	Ratio Fresh to dry Weight.	Wt. of Crop.			Water used.			P_2O_5 removed.			Av. lengths			Av. Counts. (Per 20 Plants.)		
				Per Pot.	Per 20 Plants.	Per 100 Litre Water.	Per Pot.	Per 20 Plants.	Per 100 gm. Crop.	Per 100 gm. Crop.	Per 20 Plants.	Per Pot.	of Plant.	of Stem.	of Longest Leaf.	Stems.	Leaves.	Ears.
V.L. Ca................	I	23	6·3	4·6	4·0	59	7·8	6·8	170	·60	24	28	40	20	23	20	146	
V.L. CaKNP..............	,,	24	6·7	3·4	2·8	55	6·2	5·2	182	1·10	31	37	33	14	21	20	120	
V.H. Ca................	I	26	7·0	8·2	6·3	66	12·5	9·6	152	·62	39	51	52	26	29	20	160	
V.H. CaKNP..............	,,	25	8·2	11·5	9·2	88	13·1	10·5	114	1·17	108	135	53	24	32	32	200	
V.L. Ca................	II	21	2·5	10·0	9·3	73	13·7	12·8	137	·49	46	49	63	53	27	25		14
V.L. CaKNP..............	,,	24	3·8	9·1	7·7	69	13·2	11·1	146	·91	70	83	70	56	29	21		5
V.H. Ca................	II	24	3·3	25·3	20·8	69	36·6	30·1	144	·56	116	141	82	73	39	26		23
V.H. CaKNP..............	,,	24	3·8	26·3	22·0	76	34·7	29·1	132	·89	196	233	88	75		33		18
V.L. Ca................	III	24		14·7	12·2	64	23·1	19·3	158	·48	59	71	60					
V.L. CaKNP..............	,,	22		15·4	13·8	75	20·5	18·3	135	·83	115	128	68					
V.H. Ca................	III	25		29·5	23·3	58	50·8	40·3	173	·55	128	163	74					
V.H. CaKNP..............	,,	25		38·2	30·1	68	56·3	44·7	148	·93	280	355	85					
V.H.O..................	,,	24		23·8	20·3	57	41·7	35·6	176	·55	112	131	70					
V.H. CaKN..............	,	25		29·9	24·0	60	50·3	40·2	169	·46	110	138	83					
V.H. CaP.*..............	,,	25		32·0	25·6	61	52·1	41·7	163	1·03	264	330	88					

* Only No. 14 taken.

§7. Discussion of Results.

For the purpose of profitable discussion it was further found necessary to calculate the average figures*, per series (given above in tables X to XII). These figures show more precisely the extent of the differences between the various series, already evident from the recorded observations and strikingly brought out by the photographs. The outstanding differences between these three soils can be summed up in the statement that "*a good crop can be produced on the Shepstone soil only if suitable fertiliser is supplied and a high soil moisture level maintained, whereas the Armoedsvlakte soil needs proper fertiliser equally badly but does not require a high moisture content, and the Verona soil does not stand in immediate need of any fertilising element, although it requires a high soil moisture level.*"

(i) *Crop Yield.*—Taking the 40 per cent. W.H.C. series with Ca only we find by actual observation that the plants on the soil of Armoedsvlakte, making relatively fair growth, initially outstripped those on the other two soils. Within a few weeks, however, the rate of growth on these pots had dropped considerably, so that the Verona plants soon began to catch up with them. The plants on the corresponding Shepstone series fell behind practically from the beginning and as time went on, their inferiority became more and more pronounced. In the light of current and subsequent observations and results, the natural explanation is simply that Armoedsvlakte soil offers very good conditions to the plant for availing itself of the soil moisture and presumably also for root development, etc. The soil is, however, so deficient in certain elements of plant food, notably phosphorus, that the plant soon reaches the stage where it is not able to satisfy its requirements for normal growth, and consequently further increase in size becomes slow. On both the other soils, such good conditions for water-intake, root development, etc., do not exist, so that the initial rate of growth is slower. As in addition to this drawback, the Shepstone soil is exceedingly poor in certain valuable plant food elements (particularly phosphorus), it follows that no relative improvement was possible later on. On the other hand, Verona soil was more or less adequately supplied with plant food and therefore, after the plant roots had reached a certain stage of development and adapted themselves better to their environment, the plants were enabled to make relatively fair growth, catching up with the corresponding Armoedsvlakte plants at an early date and thereafter even gaining appreciably on them.

Let us next consider the pots kept at 80 per cent. W.H.C. and receiving Ca only. By keeping the moisture level so high, the possibility of inadequate water supply was eliminated. If, therefore, the explanation given for the 40 per cent. Ca series be correct, one would now expect relatively large increases over the 40 per cent. for both Shepstone and Verona soils and little or no improvement on the Armoedsvlakte soil. This is precisely what did happen. If we examine the figures given in Tables X to XII, we find that by increasing the water supply on pots receiving Ca only, the final crops were increased by 135 per cent. on the Shepstone soil (2.6 gm. for

* On account of the small number of parallel observations, it was not considered necessary to calculate the "probable error" (*Pfeiffer,* Der Vegetationsversuch: 234 a.f.)

S.L. Ca against 6.1 gm. for S.H. Ca) and 100 per cent. on the Verona soil (14.7 gm. against 29.5 gm.), whereas on the Armoedsvlakte soil the gain was only 31 per cent. (9.7 gm. against 12.7 gm.). That in this series the Verona soil should show up so markedly better than the other soils, is in the main attributable to its higher content of available plant food—although the results might also have been influenced in a minor degree by factors such as air supply to the roots, soil reaction, etc.

If we follow up this line of argument, we would expect to find that, if in addition to an ample water supply, these three soils were given a liberal dressing of soluble plant food, only the two soils which are naturally markedly deficient in one or more ingredients of plant food, would respond strongly to fertilising. In full accordance with this, our experimental results for the final crop show an increase in crop production of 324 per cent. for full fertiliser on the high water content Armoedsvlakte series (12.7 gm. for A.H. Ca against 53.9 gm. for A.H. CaKNP), and 423 per cent. increase for the corresponding Shepstone series (6.1 gm. against 31.9 gm.), whereas on Verona soil full fertiliser only gives 29 per cent. increase (29.5 gm. against 38.2 gm.).

The finding that the relative increase for full fertiliser is greater on Shepstone soil than on Armoedsvlakte, does not necessarily indicate that the former is even more deficient in one or more of the three elements K, N, and P, then the latter; for other factors may equally well have given rise to these results. A comparison of the full fertiliser-high water content series for all three soils show that Armoedsvlakte has given the highest return and Shepstone the lowest. From this it follows that apart from considerations of plant food essentials, soil moisture level and climate, there are other factors at work which make Armoedsvlakte soil the most suited for high crop production. The precise nature of these cannot be discussed, as a detailed laboratory study of these soils has unfortunately not been undertaken yet. Soil reaction might probably have been of some account. Other observations and tests further indicate clearly that the mechanical composition and physical properties of the soils probably influenced the results appreciably. The soil grains of the Shepstone soil were uniformly fine, thus causing the soil to compact itself and hinder proper air circulation, rapid water movement and easy penetration of roots even more than the large percentage of clay did in the case of Verona soil. The sandy nature of the Armoedsvlakte soil, on the other hand, makes high crop production possible, provided favourable conditions of soil moisture and plant food concentration are maintained.

It is a well-known and an obvious fact that in the Verona and Shepstone types of soil, water supply to the plant roots can easily become a " limiting growth factor " if the level of the soil moisture is reduced. This point has already been noted in the discussion of the three L. Ca series. That for Shepstone soil, under the conditions of the experiment, 40 per cent. W.H.C. is actually in the neighbourhood of the absolute limit for growth has been shown on page 1003 and is further evident from the early cessation of growth and smallness of the crop on this soil (S.L. Ca series). If we now consider the L. CaKNP series, it follows that if a large amount of easily soluble fertiliser be added to this type of soil, kept at a relatively low level of soil moisture, the effect would be to lower the water supply available to the plant still further[33a], chiefly as a result of osmotic relationships between plant and soil[34]. Therefore we find for Verona soil a very noticeable depression in growth on addition of KNP to the L. Ca series, the effect of which was still very striking after 6 weeks (cp. Plate III). Ultimately, however, most of the plants succeeded in adapting themselves to the high concentration of the soil solution, so that the final crop on the V.L. CaKNP series was equal to that on V.L. Ca. On the Shepstone pots it was also evident, at first, that the growth was retarded by full fertiliser at a water content of 40 per cent. of the total capacity of the soil. As, however, on the parallel L. Ca series the water supply was already so low as just to permit of a bare maintenance of life, a further cut in the water supply could not show such a marked difference as on the Verona soil, where the soil moisture level on the L. Ca pots was not so near the border line of growth. Moreover, whereas the plants on the S.L. Ca series were subsisting on a "starvation diet" in the S.L. CaKNP series a sufficiency of plant food was available. For these reasons we find that, after an initial period of struggle[35], in which a number of plants succumbed, a few individuals succeeded in adapting[36] themselves so well to the unfavourable concentration of the soil solution as to be able to avail themselves of the plant food offered and to make excellent growth. As an illustration of the great irregularity on these pots (series S.L. CaKNP), No. 94 may be cited. On harvesting this pot at the end of the second growth period (27.XI.23, plants 12 weeks old), it was found that of the total of 25 plants, ten were already quite dead and a further six were very stunted and sickly. The five best plants comprised 60 per cent. of the total (dry) crop weight (i.e., 4.7 gm. out of 7.9 gm. yield). Of these one plant was very superior to any of its mates, being fully equal to the average best plants on the fertilised high water content Shepstone series. It had five well-developed shoots and a dry weight of 2.2 gm., i.e., 28 per cent. of the total weight of the 25 plants.

Reverting back to the question of deficiency of plant food constituents, we next compare the series receiving Ca only with the corresponding ones receiving no fertiliser at all. The crop yields bear out the growth observations already recorded, viz., that $CaCO_3$ acted beneficially on all three soils. In the case of Shepstone soil, this was of course expected, as the soil belonged to the "sour" or acid class. Practically 100 per cent. increase is obtained by liming, although the crop yield is still extremely disappointing. In the case of Armoedsvlakte soil a very definite action of lime is noticeable, too, i.e., 42 per cent. increase. This soil is neutral and fragments of dolomite are quite numerous in it, so that the result was somewhat unexpected. Neither was it expected to obtain any reaction for Ca treatment on the Verona soil, which had an alkaline reaction and contained a fair amount of lime. The fact that even this soil shows 24 per cent. increase in crop yield on treatment with precipitated calcium carbonate, makes it seem probable that the amount of *available* Ca naturally present is not the optimum and that the additional Ca makes more plant food available[37]. The limitations of the space in which the pots were kept unfortunately made it impossible to include a series KNP without Ca, so that further discussion of this point is not possible.

For the same reason we are not in a position to enter into a detailed discussion of the possible deficiency of the soils in nitrogen and potassium. The series CaKN compared with the parallel Ca series clearly show that the combined effect of these two fertilising elements is negligible, so long as the phosphorus content of the soil is not increased. But we have already seen that both Armoedsvlakte and Shepstone soils respond markedly to full fertiliser, hence it follows that they must at least be lacking in phosphorus. As according to the "law of minimum,"[38] the crop return is mainly controlled by the limiting factor, it follows that we can obtain reliable information about the effect of K and N fertiliser, only if the phosphorus level is raised. We have therefore to compare the series CaP with the corresponding CaKNP series. It now becomes evident that there is a slight, though none the less distinct, increase for K and N treatment on these two soils, rather more on the Armoedsvlakte soil (34 per cent. increase of CaKNP over CaP) than on the Shepstone soil (14 per cent.), the former being a very poor sandy soil. In the case of the Verona soil, where P is not a limiting factor to the same extent as on the other two soils, one would expect somewhat similar differences between Ca and CaKN on the one hand, and between CaP and CaKNP on the other. That our figures are not on better agreement with this supposition may simply be due to the unfortunate circumstance that one of the two parallel CaKN pots gave a relatively low yield and that further on the CaP series only one observation could be utilised.

This brings us to the discussion of the phosphorus question. Practically from the start of the experiment it was evident that on Armoedsvlakte and Shepstone soils a marked phosphorus deficiency existed, but that Verona soil was more or less sufficiently supplied with this element. This is also brought out strikingly on some of the reproduced plates. The crop returns for the various cuttings enable us to express the extent of this deficiency more precisely. Although a comparison of the Ca with the CaP series already gives a very fair picture of the relative need of phosphorus on these soils, more reliable information is obtained by comparing the series receiving full fertiliser with those receiving full fertiliser without phosphorus. It is now seen that on Armoedsvlakte soil phosphorus is responsible for an increase in crop yield of 274 per cent.* over the yield given by full fertiliser without P. (i.e. 14.4 gm. for CaKN increased to 53.9 gm. for CaKNP). On Shepstone soil the increase due to P is 406 per cent. (6.3 gm. increased to 31.9 gm.), but on Verona soil it is probably even less than 28 per cent., deduced by comparing the somewhat unreliable figure of 29.9 gm. (CaKN) with the yield on CaKNP (38.2 gm.) *These figures show in a striking way that phosphorus deficiency is the main, if not the only, difference between pica-producing and pica-free soils and are the exact parallel of the figures given elsewhere, showing the increase in growth of animals grazing on pica soils and receiving additional phosphorus in the form of bonemeal.*[39]

For the preceding discussion we have utilised the figures obtained on the final crop. As a rule the figures for the three different growth stages run closely parallel as will be seen from the details in the tables given earlier. Reference has already been made to most of the

* This figure ought probably to be higher, as two of the three A.H. CaKNP pots were somewhat damaged.

series or individual pots which, either in the first, second, or third stages, seemed to be influenced by special factors such as water deficiency, mildew, etc. For the rest it may be of interest to note that in most series the maximum plant production occurred during the second growth period, viz., approximately 45-50 per cent. of the total crop; whereas during the final period of six weeks the production was usually only 15-20 per cent. of the whole and during the first period ± 35 per cent.* There are, however, numerous exceptions to this, the most striking one perhaps being the series S.L. CaKNP, where the high concentration of the available soil solution reversed the growth rate to 15 per cent. during the first six weeks, 35 per cent. during the second six weeks, and 50 per cent. during the final six weeks. In a lesser degree the series V.L. CaKNP shows a similar behaviour. On the S.L. Ca series again, more than 60 per cent. of the whole crop was produced during the first period, the early and large drop in growth rate being mainly due to the premature death of so many of the plants. In many cases it was apparent that K and N treatment tended to prolong growth and to cause a somewhat larger relative production of material in the latter stages of growth (e.g. on V.H. CaKNP 31 per cent. of the crop was produced in the final period; compare also the parallel water requirement curves in plate XIII). Conversely, increased growth in the first period or earlier maturing (compare notes, pages 1009-1011) could be noticed on those series having a good supply of phosphorus, without excess K and N (e.g. A.H. CaP, V.H. O).

Before leaving the discussion of the crop yield, we must still draw attention to the very low returns given by our pots. The maximum figure recorded in this experiment is only 62 gm. of air-dry matter, as against ± 200 gm. recorded by many other workers, mostly for much smaller pots.[40] Although the attack of mildew and the fact that the barley was grown somewhat out of season, may have been responsible for a slight depression in the yield, the writer has little doubt that the smallness of the crop must in the main be attributed to the poor *light* conditions. One need only refer to the experiments of Lemmermann and co-workers,[41] who were able to increase the crop yield three to five times by altering the light conditions from dull to bright, to appreciate the importance of the light factor.

(ii) *Phosphorus Removal.*—As this study is principally concerned with phosphorus deficiency in soil and plant, analysis of the crops for P_2O_5 was also undertaken. The detailed results are given in tables VII to IX, but for the purpose of our discussion the average figures of tables X to XII are utilised. The most outstanding feature is the very considerable difference in P_2O_5 content of the crops for the three soils on those series getting no P fertiliser. Whereas both A. and S. soils produced (in the absence of P fertiliser) crops containing only .25-.30 per cent. P_2O_5, V. soil yielded crops containing .50-.60 per cent. P_2O_5. Even more striking than the percentage figures are the amounts of P_2O_5 removed by the growing plants. For if for each soil we select the series on which the maximum amount of soil phosphorus was removed, we find that Verona soil supplied 163 mgs. P_2O_5 per pot (V.H. Ca), though Armoedsvlakte soil could only supply a quarter of this amount, viz., 39 mgs. (A.H. Ca) and Shepstone

* The figures for the first period are based on the weights of a few plants only and might therefore be less accurate.

barely a tenth, i.e. 16 mgs. (S.H. Ca). The superiority of the Verona soil was already indicated by the results of the chemical analysis, as this soil showed a markedly higher content both of total and of available P_2O_5. That the plants were able to remove appreciably more phosphorus from A. than from S. soil, in spite of the much higher content of total and available P_2O_5 in the latter, merely seems the result of the unfavourable physical conditions prevailing on the Shepstone soil.

In this connection reference might be made to some standards applied by different authorities in judging of the adequacy of the phosphorus supply of the soil from the results of soil analysis. Liebscher[42] took .47 per cent. P_2O_5, soluble in strong hydrochloric acid, as the lower limit for a sufficiency of P_2O_5, whereas Dyer[43] regards .01 per cent. 1 per cent. citric acid soluble P_2O_5 as the border value. Lemmermann and Fresenius[44] again prefer to calculate the ratio between available and total P_2O_5 and place the border value at 25 per cent. Applying these three standards to the three soils under discussion, we find that both A. and S. soils are consistently returned as deficient, but V. soil would appear to approach the border line closely, a forecast which is in thorough agreement with the results of our pot experiments. The following table illustrates this:—

TABLE XIII.

Phosphorus Content.				P_2O_5 Deficiency According to			
Soil.	Total.	Avail.	Ratio.	Liebscher.	Dyer.	Lemmermann.	Pot Experiment.
	Per cent.	Per cent.	Per cent.				
A........	·027	·0014	5	Very great	Very great	Very great	Very great
S........	·051	·0027	5	Distinct	Very great	Very great	Very great
V........	·065	·011	17	Slight	None	Distinct	Slight

König[45] indicates a method of deducing the "true availability" of plant food ingredients by comparing the amounts actually removed by the plants with the amounts extracted from the soil by citric acid. In this way he shows that for soils of different types, different factors have to be used in deducing the actual availability from the citric soluble content. Thus he finds for sandy soil the factor 3.3 per cent. and for loam the factor 4.8 per cent. (of the 2 per cent. citric acid soil extract). In our experiment, the factors deduced from the H. Ca series and the 1 per cent. citric acid extract are rather different, the sandy soil A. coming first with a factor of 8.4 per cent., then the clayey soil V. with a factor of 4.8 per cent., and finally the fine grained soil S. with a factor of only 1.9 per cent. For the fertilised series H. CaKNP, the availability factors run in the same order, but are much lower—presumably because P was present in large excess—values of 4.3, 2.4 and 1.2 per cent. respectively being obtained (on the assumption that all the added P_2O_5 in the monocalcium phosphate would become citric soluble soil phosphorus). The factors deduced from the other series are again different, so that although König's method seems attractive, it would seem that besides the plant grown, the conditions of the experiment, plant food supply, water content of soil, size of pot, etc., are of great importance and must be standardised. A large number of soils of various types would have to be examined before the average factor for a particular soil type could be fixed with any degree of certainty. For this reason the writer is inclined to think that the problem of actual availability could be more profitably investigated along the lines of the newer methods of Greisenegger and Vorbuchner,[46] or of Neubauer and Schneider,[47] which also make use of the agency of the plant roots themselves. Similar experiments conducted with South African soils may be expected to yield valuable results.

On further examining the values obtained on analysis of the crops, we see there is practically no difference in percentage values for P_2O_5 between the L. Ca and H. Ca series, though, especially on heavier soils (S. and V.) the larger water supply was reflected in a greater crop yield and therefore also increased removal of phosphorus from the soil. As would be expected, fertilising with monocalcium phosphate resulted in an enormous increase in the P_2O_5 content of the plant,* as well as in the total amount of phosphorus taken up, but we again notice that on S. soil these values are considerably lower than on the other two soils with the more favourable physical conditions. In these series also more phosphorus was removed on doubling the water content of the soil, though only on V. soil did a clear-cut increase in percentage of P_2O_5 result as well. Addition of KN to Ca seems to have very little influence on the total quantity of phosphorus removed by the crop, as well as on the percentage phosphorus content of the plants; if anything, its effect is to lower the latter value.

It has already been noted that on all these soils the addition of precipitated calcium carbonate caused increased crop production. We further see that the percentage P_2O_5 in the crop also is preceptibly increased by this treatment (except on V. soil) so that the amount of P_2O_5 removed is much larger on the Ca than on the O series. Therefore we can say that on all these soils calcium carbonate has definitely made the soil phosphorus more available.

Finally, a comparison between the different stages of growth reveals the fact that on all series, where P was not particularly deficient, a gradual drop in phosphorus content of the plant is evident as it grows older. The difference between the second and third stages of growth (12 weeks and 18 weeks respectively) is trivial, but between the first and second stages it is in most cases fairly marked. It must be remembered that at the end of the so-called "first stage of growth," the plants were already six weeks old. Actual observations showed that many of the plants on the "no-phosphorus" pots were beginning to develop definite "deficiency symptoms" after three weeks (S. soil) or four weeks (A. soil) growth. There can therefore be no doubt that if the plants had been analysed at the age of three to four weeks very much higher figures[48] for P_2O_5 content would have been found and a more clearly defined drop in P_2O_5 content for increasing age[49] established.

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* We find it very difficult to explain the contrary findings of Richardson ("The Water Requirements of Crops," Reprint from *Journ., Dept. of Agric.*, Vict., Table XV, 1923) that in many cases the crops treated with P. had a lower P.-content than the controls, etc.

(iii) *Water Consumption.*—To enable us to compare the water consumption on the different series and soils better, both the crop yield in gms. per 100 litres water consumed and the number of litres water used up per 100 gms. dry crop produced have been calculated. The nature of the experiment was not such that a definite correction can be made for water lost by evaporation from the soil surface, nor were the pots kept under the best conditions, so our figures give no information about the true transpiration co-efficient (ratio) of barley under normal greenhouse conditions. As they nevertheless show up certain differences due to soil and manurial treatment clearly, a short discussion will not be out of place.

On the Armoedsvlakte soil we find that, on the whole, an increase in the moisture content of the soil has only had a slight effect on the water consumption per unit of dry plant material produced. The slight relative increase in water requirements on the H.W.C. series[49a] is no doubt partly due to the greater evaporation from the moister soil surface, though it might possibly partly be the result of an increased consumption of the more dilute soil solution. On V. soil very much the same result was obtained for the final crop though in the first stage of growth the retarding effect of full fertiliser on a clayey soil in conjunction with low moisture content, was distinctly evident in the less economical use of the available water (i.e. increased transpiration ratio). On S. soil, where 40 per cent. W.H.C. was definitely too low for normal growth, a more pronounced " waste " of water resulted on both L.W.C. series though here too, thanks to the abnormal development of individual plants, the L. CaKNP series just managed to draw level with the H. CaKNP series in the end.

The different nature of the soils is further shown by a comparison of the figures for the H. Ca series. On V. soil 100 litres of soil water were able to produce a final crop of 58 gm., dry material, yet the same quantity of water could, under the identical growth conditions, only produce 33 gm. on A. soil and 24 gm. on S. soil. That these differences are in the main due to the varying amounts of actually available plant food elements in the three soils, is seen from the fact that if excess KNP and water are present, the relative production on the three soils is fairly similar, viz., 68 gm. per 100 litres on V., 67 gm. on S., and 72 gm. on A. The influence of the physical nature of the soil is, however, strongly reflected in the different absolute water consumption, viz., 74.5 litres on A., 56.3 on V., and 47.9 on S., which are again closely comparable with the amount of dry plant matter produced (53.9 gm. on A., 38.2 on V., and 31.9 on S.).

If next we examine the water requirements for the final crop on the five H.W.C. series with different manurial treatment, we see that on all three soils the lowest transpiration ratio, i.e. most economical use of water, occurred on the full fertiliser series. [49b] By the addition of soluble fertiliser, we increase the concentration of the soil solution, so that, speaking generally, the plants can be expected to satisfy their mineral requirements by transpiring a smaller quantity of the enriched soil solution. If, however, a soil is already naturally well stocked with available plant food the transpiration ratio approaches its natural minimum for the type of plant and soil and existing climatic and other conditions. Fertilising cannot therefore now produce a marked drop in relative water consumption, but merely results in an over-consumption of plant food ingredients. This is the explanation for the trivial differences in transpiration ratio for different fertiliser on the Verona soil. On the other hand, if a soil is lacking in some essential element, the plants will transpire much larger quantities of water—if available—in their endeavour to make good the deficit. This is very strikingly illustrated by both Armoedsvlakte and Shepstone soils. On the latter soil, for example, the transpiration ratio of 7,680 is reduced to 4,260 by mere addition of $CaCO_3$, thus confirming the natural lack of lime already shown by the crop figures; the addition of KN caused only a slight further drop in the relative water requirement (partly due to decreased surface evaporation—cp. observations during growth period I, p. 1007), thus indicating that these two elements are not noticeably deficient; addition of P, however, reduces the transpiration ratio from 4,260 to 1,600, a figure which closely approaches the minimum for this soil under our experimental conditions, viz., 1,510. Incidentally it may be pointed out that the transpiration ratio (if the correction for surface evaporation be made, more reliable figures would naturally be obtained) seems to be practically as good a standard for judging of plant food deficiencies as the crop yield itself.

As has already been shown in a previous table and graphs (pp. 1014 and 1037), the water consumption varies with the age of the plant. This is, of course, a well-known fact, which is frequently referred to in the literature,[50] the time of maximum water requirement coinciding with the period of flowering.[51] In our experiment it is seen that in most cases of more or less normal growth this relationship existed too. If we examine the observations and figures for the three series receiving H. CaP treatment, the following is noted:—The average water consumption for a three-weekly period on a uniform rate should be just under 17 per cent., but during the three weeks 10.X to 30.X no less than 29 per cent. of the total water was used on the A.H. CaP series. This was the maximum water requirement for any three weeks' growth on this series and the observations showed that the first ears on this series had appeared on 24.X.23. Both before and after this period, the water requirement was markedly less, falling to 20 per cent. during the period 31.X to 20.XI and to only 7 per cent. during the final three weeks. The corresponding Shepstone series shows a slightly different rate. The first ears were out a few days later, i.e., 28.X, and the development of the plants was definitely more protracted than on Armoedsvlakte soil. In accordance with these observations a less pronounced maximum water requirement of 27 per cent. for the period of "shooting," 10.X to 30.X, followed by 25 per cent. for the ensuing three weeks, is found. On the corresponding Verona series (only one pot!) the first ears appeared even later, i.e. on 3.XI and development was even more protracted than on Shepstone soil. The maximum water consumption in this case was only 25 per cent. and fell somewhat later, in the period 24.X to 13.XI. Over the whole 8 weeks 10.X to 4.XII. the water requirement was very uniform.

A comparison of the above with the H. CaKNP series brings out the effect of KN fertiliser. It is seen that on A. and V. soils the period of maximum water consumption is now considerably later, corresponding to the later development of the plants. For A.H. CaKNP the maximum water consumption of 37 per cent. of the total falls in the three weeks 24.X to 13.XI (first ears 2.XI.23) and on V.H. CaKNP the maximum figure is 25 per cent. and falls in the period 7.XI to 27.XI (first ears 6.XI.23). The fact that Shepstone soil was naturally fairly well supplied with N is presumably the main reason why the development and period of maximum water consumption were not noticeably different on the two series S.H. CaP and S.H. CaKNP.[52]

On most of the other series limiting factors do not allow of similar striking comparisons. On the whole, it is, however, evident that marked differences are due to soil nature, fertiliser treatment and water content of the soil.*

A passing reference must here be made to the extraordinarily high "transpiration ratios" (c.c. water used to produce 1 gm. dry material) found in our experiments. European figures are usually much lower, e.g. 300 (excluding evaporation) to 600.[53] Also American figures, obtained by King[53a] in a humid climate, or in experiments where loss of soil moisture due to evaporation was eliminated,[54] are much lower. Widtsoe[55] emphasises the effect of a dry, hot, atmosphere and gives a figure of about 1,000 for wheat in Utah. Very interesting figures and observations for Victoria (Australia) are given in Richardson's pamphlet referred to already. For summer-grown wheat during a dry year he finds a T.R. of $\pm$ 1,000.[56] If a correction for soil evaporation is made the T.R. is under 900, but the writer does not consider Richardson's method for determining evaporation from the soil reliable. Our own figures for summer-grown barley on three different fertilised soils ranged between 1,300 and 1,700 (including evaporation). We have no doubt, however, that under better conditions of light (assimilation), this figure would have been much reduced. It is, however, quite possible that under our climatic conditions, the T.R. may be higher than in most of the other countries referred to. During the course of the experiment, it was usually quite easy to detect an increased water requirement for hot, dry days or periods, a fact which has been abundantly proved by other workers.[56a]

A reference must still be made to the commonly accepted maxim that "fertilising increases the crop production per unit of water." In our country where inadequacy of soil moisture is often the main stumbling block to crop production, this means of economising on the soil moisture is sometimes advocated. Farming experience, however, shows that it is often unprofitable to try and increase the crop-producing power of the available water by means of fertilising. For if the quantity of soil water is relatively low, a condition which often prevails during part or the whole of the growth period of our field crops, the added fertiliser may increase the concentration of the soil solution to a point to which the osmotic relationship between the plant root and its environment becomes unfavourable for growth, thus resulting in a temporary or permanent setback to the crop. If we refer to Verona soil, low water content series, we see from the figures for the first and second stages of growth that fertilising lowered the crop yield and even caused a certain amount of waste of transpired water. It is not an uncommon farming experience that kraal manure and fertilisers, containing much soluble salts, "burn" the crops if the season is dry. The slight or negative

* On series S.L. Ca, the period of maximum water consumption was apparently the first three weeks of the experiment. This is accounted for by the large surface evaporation, due to frequent sprayings on an impervious soil.

results with potash and full fertiliser in the Bethal potato fertilising experiment, reported on by Hall,[57] may probably (in part at least) find a similar explanation, i.e. not sufficient soil moisture for the amount of fertiliser used.[58]

(iv) *Removal of CaO and N.*—A few determinations of CaO content were done on the series H. O and H. Ca. In the case of the Shepstone soil, the crop on the H. O series contained .47 per cent. CaO = 13 mgs. in the crop of one pot, as against .94 per cent. = 54 mgs. CaO in the crop of an H. Ca pot. There is therefore a very decided increase both in percentage and total CaO due to the application of precipitated calcium carbonate. On the Armoedsvlakte soil liming produced an increase too, but the relative difference between the figures for H. O and H. Ca is much lower. On this soil we find for H. O .85 per cent. = 69 mgs. CaO in the crop, as against 1.01 per cent. = 122 mgs. CaO in the crop for H. Ca. The figures found for Verona soil were respectively .46 per cent. = 109 mgs. CaO for the unlimed and .51 per cent. = 146 mgs. CaO for the limed series, showing that on this soil addition of $CaCO_3$ affected the CaO figures least. Although no very definite deductions can be drawn from these analyses, it seems very probable that a marked Ca deficiency is indicated for the S. soil and only a slight deficiency (if at all) for the V. soil. Of interest is further the fact that whereas on the unlimed V. soil the barley shows a P_2O_5 percentage slightly in excess of the CaO percentage, on both the other soils the ratio between CaO : P_2O_5 is about 4 : 1, a figure which, acording to accepted standards, clearly indicates P. deficiency.[59] On all these soils liming apparently had the effect of increasing the P_2O_5 content of the crop roughly to the same extent as the CaO content.

A few analyses for nitrogen content were carried out on the H.A. series, receiving different fertilisers. The figures show consistently that application of N increases the N content of the plant (e.g. 3.05 per cent. N in series CaKN against 2.34 per cent. N in series Ca) though not necessarily, as was the case with P fertiliser, the crop yield or the total quantity of N removed by the crop (e.g. on series CaP with only 1.60 per cent. N 603 mgs. N were removed by the crops, though on series CaKN with 3.05 per cent. N the crop contained only 418 mgs. N). From this it is again evident that N is not so deficient that its use is urgently indicated, but that P_2O_5 influences the yield most. It is also seen that the ratio $N : P_2O_5$ in the whole plant growing on the unfertilised soil, is approximately 100 : 12, a figure which, according to the normal for P_2O_5 suffciency accepted by Hanamann[60] and others ($N : P_2O_5 = 100 : 30$), indicates pronounced phosphorus deficiency.

(v) *Grain Production.*—The original intention of dividing the final crops into " grain " and " residue " had to be abandoned as the production of grain on most series was so abnormally low. Undoubtedly this was largely the result of the poor light and air conditions under which the pots had to be kept. However, in a number of cases, the ears were separately collected and the grain analysed for P_2O_5 content. Table XIV gives the numbers and weights of the ears, the number of grains and their weights, and the P_2O_5 content of the grain.

Table XIV.

Showing grain and ear production and P_2O_5 content of grain.

Series.	Pot No.	Crop.	Heads.		Grains.			Remarks.
			No.	Wt.	No.	Wt.	P_2O_5.	
A.L. Ca	45	10·2	28	2·1	22	0·55	1·31	Sickly ears.
A.L. CaKNP	59	44·2	46	5·7	42	1·25	1·52	Large empty ears.
A.H. Ca	49	14·0	34	3·25	30	1·0	1·28	Small ears.
A.H. CaKNP	66	62·2	28	5·15	68	1·55	1·34	Large empty ears.
A.H.O.	41	9·6	26	2·4	26	0·8	1·26	Sickly ears.
A.H. CaKN	58	15·0	28	1·95	9	0·3	—	Small empty ears.
A.H. CaP	55	42·6	38	15·35	277	10·25	1·25	Ears large, mostly well filled.
S.L. Ca	74	2·9	—	—	—	—	—	Few immature heads.
S.L. CaKNP	93	17·4	26	4·05	36	1·15	1·41	Mostly small ears; several normal ears.
S.H. Ca	84	6·8	13	0·6	2	0·05	—	Sickly ears.
S.H CaKNP	98	35·0	29	4·7	29	0·75	1·48	Ears fair, but empty.
S.H.O.	71	3·3	—	—	—	—	—	Few sickly ears.
S.H. CaKN	87	6·3	11	0·4	—	—	—	Sickly ears.
S.H. CaP	85	29·4	29	3·6	9	0·25	} 1·35	Ears apparently normal but mostly empty.
S.H. CaP	86	26·7	27	3·2	8	0·2		
V.L. Ca	20	15·5	28	4·1	58	1·7	1·26	Fair, but poorly filled.
V.L. CaKNP	33	17·1	19	2·4	24	0·9	1·35	,, ,,
V.H. Ca	22	31·3	30	13·1	238	8·5	1·22	Many good ears.
V.H. CaKNP	34	39·5	35	4·5	56	1·55	} 1·42	Large ears, but mostly empty.
,,	35	37·5	37	5·1	63	1·9		
V.H.O.	11	23·8	29	8·35	155	4·75	1·30	Many good ears.
V.H. CaKN	27	33·6	38	8·1	117	3·6	1·32	} Ears fair outwardly, but poorly filled.
V.H. CaP	14	32·0	40	7·2	101	3·2	1·37	

A very marked difference is at once evident for the different soils and treatments. Even a cursory examination reveals the natural superiority of the Verona soil, though the highest grain yield was obtained on the Armoedsvlakte series receiving CaP treatment. On not a single Shepstone series is the grain yield satisfactory. The number of ears shows that on this soil only on the three series receiving P was the predisposition for grain formation fairly well developed. The experimental conditions, however, prevented the actual production of grain, so that the ears for the most part remained empty. The fact that on the S. CaKNP series the yield of grain was greater than the the S. CaP series may be taken as an indication of KN (probably mainly K) deficiency, though it is more likely that the difference is merely a chance one, the disturbing influence of the uncontrolled factors being so great as to obscure completely any effect due to a minor factor like K or N deficiency. In fact, as on both the other soils more grain was produced on CaP than on CaKNP series, and on Ca than on CaKN, it rather seems probable that, under the conditions of our experiment, excess KN had a depressing effect upon seed development.[61] That for Shepstone soil, pot 93 (S.L. CaKNP series) gave the best grain crop, is presumably merely due to the fact that on this pot the bulk of the yield consisted of a few very vigorous plants, that had succeeded in adapting themselves ultimately so well to their environment that they could even produce a few normal ears.

We can give no explanation for the relatively low grain production on V.H. CaP (pot 14). The outward appearance of the ears during growth led us to expect one of the highest yields for V. soil on this pot, just as on A. soil the best yield was expected and actually obtained on the CaP series. On finally harvesting, however, it was found that the ears on pot 14 were so badly filled, that this series only took fourth place with 3.2 gm. grain, the first place falling to the H. Ca series with 8.5 gm.

Two subsequent crops have so far been grown on these pots, unfortunately under the same unfavourable conditions. Also other factors have combined to make the results somewhat disappointing. It is, however, intended to publish a short account of this further work elsewhere shortly.

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