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PLANT NUTRITION AND THE HYDROGEN ION II. Potato Scab. and Balanced Cations

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Consideration of soil acidity in terms of the entrance of hydrogen into the clay complex of the soil rather than in terms of the exit therefrom by the nutrient cations has delayed significantly the sppreciation of the seriousness of our declining soil fertility. Plant starvation too often has been interpreted as "disease" and special terminology too often substituted for exact knowledge of the degree of nutritional deficiencies occurring within the plant long before anatomical symptoms indicating these are recognizable. The ancient practices in medicine that struggled against evil spirits attacking the body from without were replaced by attention to human nutrition as a means of preventing disease from within, only after the physiology of immunity became a familiar concept. Increase in knowledge of plant physiology is steadily eliminating the use of poisons as "curatives". It is moving us toward reducing disease incidence by undergirding the plant nutrient supply through soil treatments as a means of producing healthier plants not so vulnerable to disease.

Potato scab long has persisted to the detriment of a significant part of our food production business, and our failure to control it may possibly be charged to the circuitous character of our mental sortie against plant pathogens and soil acidity, when we should have adhered to straight line thinking in plant physiology and soil fertility. It is in support of this charge that the following study of potato scab incidence and potato crop yields in relation to degrees of soil acidity and to levels of the calcium and the potassium in the soil is reported.

PLAN OF EXPERIMENT

Chemical analyses of the crop do not constitute a code of instruction for the rate of application of fertilizers, but the chemical content of the crop in toto tells us what kind and how much of the fertility was mobilized out of the soil. Analyses of the potato tubers impress one immediately with their high content of potassium, particularly when this is so readily associated with its rôle in the production and translocation of carbohydrates within the plants. Insufficient attention has been given, the authors believe, to the chemical analyses of the tops of potato plants. Unnoticed has gone the fact that these are extremely rich in calcium and that they remove large amounts of this nutrient in the crop (10 per cent ash in the tops and 25 per cent of the ash as CaO are not uncommon analyses). The composition of the potato crop as a whole, top and tubers combined, points to the demand by this crop not only for relatively large amounts of potassium per acre, but also for correspondingly large amounts of calcium as well. Recent studies (1) (2) demonstrated that the delivery of calcium by soils was declining to the extent of detriment to crop quality and yield, as well as increased incidence of what is commonly diagnosed as disease rather than plant starvation. This discovery led to the belief that potato scab might well be considered a sympton, suggesting a disturbed calcium-potassium relation in the nutrients offered.

It was in the test of this belief that soils were prepared by means of the colloidal clay technique (3) (4) for controlling the exchangeable nutrients given the plants. There was one series in which the supply of calcium was varied while that of potassium was held constant, and vice versa, at the pH figure of 5.5, which is the reaction much heralded as requisite for the inhibition of potato scab. Likewise, soils were prepared in another series with a constant potassium supply while a variable calcium offering was given in one case with the soils acid, or at a low pH of 5.2, and similarly with the soils neutral, or at a high pH of 6.8. When calcium was held constant, the amount chosen was in relation to the amounts of phosphorus, magnesium, and others held constant throughout all trials. The amount of potassium, when held constant, was similarly chosen in relation to the others or a constant figure. The other conditions of the experiment were maintained at the usual constancy attainable.

In order to assure the presence of the scab fungus, each plant series was well inoculated with suspensions of eight strains of the potato scab organism supplied by Schaal and by Goss*. Replicate plants of the Warba potato variety were grown from March to May and the harvests of five or six plants grown individually were combined to represent the crop per soil treatment.

RESULTS

Crop Yields and Scab Incidence

That the yields of the potatoes, both tubers and tops, are correlated with the levels of calcium, as well as those of potassium, offered is clearly shown in Table 1. On this acid soil at a pH of 5.5 and with constant offerings of 50 M.E. of potassium, the additions of 0, 60, and 100 M.E. of calcium to that already in the natural clay (Columns 1, 2, and 3 in the table) gave the fresh tuber crops of 925, 1313, and 1459 grams; the dry weights of tops as 33.9, 46.5, and 56.4 grams; and the total dry weights of tubers and tops combined of 181.3, 280.4, and 311.3 grams, respectively. All of these yields increased as larger amounts of calcium were supplied.

When the calcium was constant at 60 M.E. and the additions of potassium were 10, 50, and 100 M.E. as shown in columns 4, 5, and 6 of the table, the fresh tuber weights were 780, 1313, and 1073 grams; the figures for the dry tops were 24.3, 46.5, and 41.1 grams; while the values for the total crop weights were 161.8, 280.4, and 219.3 grams, respectively. For these potassium increments, the yield increase was not consistent with the increased allotments of potassium. The heaviest application reduced the potato crop.

Table 1. Potato Crop Yields and Scab Incidence at pH 5.5 With Variable Levels of Exchangeable Calcium and Potassium.

	Variable Calcium Constant Potassium			Variable Potassium Constant Calcium		
Column Number	1	2	3	4	5	6
Calcium added. M.E. (1)	0	60	100	60	60	60
Potassium added. M.E.	50	50	50	10	50	100
Tubers Fresh Wt. gms:	925	1313	1459	780	1313	1073
Tops Dry wt. gms.	33.9	46.5	56.4	24.3	46.5	41.1
Tubers Dry wt. gms.	147.4	233.9	254.9	137.5	233.9	175.2
Total Crop Dry wt. grms.	181.3	280.4	311.3	161.8	280.4	219.3
No. of scabby areas	14	20 (2)	51	9	20 (2)	84 (3)
No. of deep lesions.	3	10	36	5	10	70

(1) Additions of other nutrients, P = 60; N = 60; S = 6; Mg = 6; M.E. per plant.

(2) In addition, one potato had 33% of its surface covered with deep lesions.

(3) In addition, two potatoes were entirely covered by deep lesions.

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When the incidence of scab is related to the nutrients offered, it is most significant to note that giving either liberal amounts of potassium as contrasted to calcium or generous amounts of calcium in contrast to potassium brought about decided scabbiness. The former, namely excess potassium, gave more scabbiness than the latter, namely excess calcium. This is significant, in that the practice with its importance attached to potassium fertilization for yield increase, may be at the same time encouraging potato scab through neglect of balancing this treatment with calcium. It is significant that an increase in yield was obtained without the increase in the scab incidence per unit weight of tuber produced when there was a close similarity in the amounts of exchangeable calcium and potassium added to the soil (columns 1 and 2). When there was the dominance of the calcium over the potassium (column 3) the yield was larger, but the relative scab incidence also larger. Yet even in this case, the scab incidence relative to yield was lower than when potassium was dominant over calcium (column 6). Excessive calcium with very low potassium likewise is less scab provoking than excessive potassium over calcium (column 4), but in this case only a very low yield was produced.

The differences in crop yields can be seen in Figure 1, where the more uniform crop, the larger yields, and the least scabbiness are shown in B and E given 50 M. E. of potassium and 60 M. E. of calcium. In F, with the highest potassium addition, the excessive scabbiness is readily discernible. This combination of potassium at 100 M. E. and calcium at 60 M. E. induced more scab than with calcium at 100 M. E. and potassium at 50 M. E., Figure 1 C. Even though the pH in both cases was at 5.5, considered so commonly as the means of preventing scab.

These data on soils with the pH figure 5.5 -- the figure found serviceable in practice for good yields of more nearly scab-free potatoes -- demonstrate forcefully that potato scab is not wholly a matter of variety and virulence of the infecting organisms, nor necessarily of variety of potato, but rather a matter of proper plant nourishment in terms of the fertility of the soil. They suggest, further, that there must be included in addition to calcium other nutrients, which, as accompaniments to potassium and in proper relation to it, must be given attention for proper plant nutrition as approaches to scab exclusion.

In the attempt at the segregation of the significance of pH in the second series of the trials, the soils of more acid reaction produced the larger yields at all of the nutrient levels, as given in Table 2. The increased yields of fresh tubers from the three acid soils of low pH over the three more nearly neutral soils of high pH were 150, 117, and 147 grams for 30, 60 and 90 M. E. of calcium, respectively, each at 60 M. E. of potassium. These increases represent 11, 9, and 12 per cent as attributable purely to the higher degree of acidity of the soil.

When the incidence of potato scab is examined, it is evident that it is not directly related to the soil acidity. The number of scab areas is lowest in both acid and neutral soils when the levels of the calcium and potassium are not in distorted ratios, and are in amounts similar to those effective in scab reduction in the acid soil trials of Table 1. Quite contrary to the more common belief in the dangers of liming for potatoes, the results show that a liberal calcium supply is not necessarily scab provoking. They show that calcium must be delivered but in an acid soil rather than in a neutral soil for greater efficiency, as the figures in columns (5) and (6) of Table 2 testify. An acid soil with a low supply of calcium encourages scabbiness as well as does a neutral soil, as the solumns (1) and (2) in the tables demonstrate in comparison with the figures in column (5). Scab incidence and reduced crop yield, quite out of accord with some past concepts, may both be a result of calcium deficiency in the soil. Since the hygrogen ion serves to make some of the exchangeable nutrients of the soil more effective, (5) soil acidity in connection with scab inhibition may be playing its role merely as it helps to deliver more nutrients and thus produces healthier plants through which infection is reduced. Soil acidity, whether natural or induced by particular soil treatments, is serving, not directly but indirectly, through improved plant nutrition. That the yield was greater at the lower pH, 5.2 than at the high pH 6.8 regardless of whether the calcium applied was 30, 60, or 90 M.E. in combination with 60 M.E. of potassium is evident when Figures 2, 3, and 4 are closely examined. That the scabbiness is lowest at 60 M.E. of calcium, whether the pH is low or high, is shown in Figure 3. This points to the significance of the fertility of the soil more than to its reaction as a scab preventative. That a neutral soil with deficient calcium encourages scabbiness as does one with similar reaction and extra calcium is shown by contrasting Figures 2 and 4.

Table 2. Potato Crop Yields and Scab Incidence With Constant Potassium and Variable Calcium Levels at Both Low and High pH Values.

Ca added. M. E.	30		60		90	
Potassium added. M. E.	60		60		60	
pH Values	Low	High	Low	High	Low	High
Column Number	1	2	3	4	5	6
Tubers Fresh wt. gms.	1270	1120	1287	1170	1189	1042
Tops Dry wt. gms.	57.9	43.8	58.3	46.5	58.3	45.2
Tubers Dry wt. gms.	224.2	181.0	199.5	191.9	197.8	170.0
Total crop Dry wt. gms.	272.1	224.8	258.8	238.4	256.1	215.2
No. of scabby areas	42	41	6	8 (2)	19 (1)	46 (3)
No. of deep lesions	27	21	2	6	8	38

(1) Three of these lesions were on a single small potato.
(2) In addition, two potatoes have each one-fourth of the surface covered by deep lesions.
(3) In addition, one potato had 50% of its surface covered by deep lesions.

Soil Fertility Levels as Reflected by Composition of the Tops

When the chemical contents of the potato tops grown at pH 5.5 are examined with reference to calcium and potassium in terms of both concentrations and totals in this vegetative part of the crop as given in Table 3, some significan facts are evident.

With the supply of added potassium constant while the calcium was increased to given increased yields (Table 1), there was scarcely significant difference in the calcium concentration in the tops. The percentage figures were 2.38, 2.15, and 2.26, a limited variation as given in columns 1, 2, and 3 in Table 3. However, for the total calcium carried by the tops, the figures increased as more calcium was added to the soil. These were 807, 1003, and 1277 mgms., or a range from a low figure to one more than 50 per cent greater. This increased calcium removal in total from the soil was parallelled by increased yield in both tops and tubers of the crop.

When the supply of added calcium was constant while that of potassium was increased to give a rise and then a decline in yields, the concentration of calcium in the tops declined with successive potassium increments. The lowest calcium concentration in this series of three was not much below any of those in the series where calcium was varied. The highest concentration of calcium in the entire table occurs where the least amount of potassium was offered the plants. This figure of concentration was 3.06 per cent calcium in the tops, though it is well to note that they were not as vigorous of growth as was true of those with the other treatments. It is particularly significant to note that potato tops contain more than 2 per cent of calcium or the equivalent and more than is common in such legume hays as red clover. In terms of the crop of potato tops we may well think of its high need for calcium as we do for the crop of red clover.

Table 3. Concentrations and Totals of Calcium and Potassium in the Tops of Potato Plants as Related to Variable Levels of These Two Plant Nutrients in Exchangeable Forms in a Soil at pH 5.5

Column Number		1	2	3	4	5	6
Ca added. M.E.		0	60	100	60	60	60
Potassium added M.E.		50	50	50	10	50	100
Calcium: Total	:%	2.38	2.15	2.26	3.06	2.15	2.03
	:mgms.	807	1003	1277	896	1003	895
Potassium: Total	:%	2.96	2.92	3.33	2.18	2.92	3.38
	:mgms.	1004	1358	1879	637	1358	1493

The total calcium taken by the tops was not consistently related to the increasing potassium applied. The maximum total calcium was in the crop with 60 M.E. of calcium and 50 M.E. of potassium rather than with the combination of 60 M.E. of the former and 100 M.E. of the latter. This suggests that the excess of potassium is holding down the calcium as total in the tops. This lower total calcium is due to both reduced concentration of calcium and reduced yield of tops in connection with this heavier application of potassium.

As for the contents of potassium in the tops with variable calcium offered, these were similar to their contents of calcium. The concentration was relatively constant for the three levels of calcium, but the total potassium increased as more calcium was available in the soil. When variable potassium was offered, the concentration of this nutrient increased to a figure more than 50 per cent above the lower one, while the total potassium increased from a low figure to one greater by more than 100 per cent. But even this seemingly large figure for total potassium taken from the soil where 100 M.E. of this nutrient were applied in connection with 60 M.E. of calcium was not as large as that taken where only 50 M.E. were applied in conjunction with 100 M.E. of calcium.

These facts become evident when columns 6 and 3 in Table 3 are compared with colum 5. When these three amounts of calcium and potassium applications are considered, it is well to note that the doubling of the applied calcium in conjunction with a moderate amount of potassium was more effective in bringing potassium into the tops than was doubling the potassium application in connection with a moderate calcium application.

For the tops grown at pH 5.2 and pH 6.8, their contents in calcium and potassium show a decided relation to the lower pH figure in contrast to the higher one as given in Table 4. The concentration of calcium is but slightly lower for the higher pH, but increases for either pH with the increments of calcium applied. Much more noticeably the total calcium in the tops is lower as the pH figure represents more nearly neutrality, but in all three cases of this latter reaction the figures for total calcium are lower than the lowest in the more acid soil condition. Again at either pH figure the total calcium increased with the increments of applied calcium.

Table 4. Concentrations of Calcium and Potassium in the Tops of Potato Plants as Related to Variable Levels of These Two Plant Nutrients in Exchangeable Form in One Soil at Low pH 5.2 and Another at High pH 6.8.

Column Number	1	2	3	4	5	6
Ca added. M. E.	30		60		90	
Potassium added. M. E.	60		60		60	
pH Values.	Low	High	Low	High	Low	High
Calcium: Total :%	1.45	1.42	1.74	1.69	1.80	1.76
Calcium: Total :mgms.	840	622	1012	787	1052	798
Potassium: Total :%	3.29	3.68	3.82	3.85	4.60	3.98
Potassium: Total :mgms.	1907	1611	2227	1790	2683	1799

The potassium in the tops, on a percentage basis, increased with increments of calcium applied regardless of the reaction figure as pH. The same held true for the total calcium in the tops. However, the largest figure for total potassium at pH 6.8 was less by more than 6 per cent than the smallest figure at pH 5.2. At the reaction of 5.5 in Table 3, it was shown that increasing applications of calcium which delivered more of this nutrient had associated with them also greater amounts of potassium.

Again in Table 4, the increasing calcium offered was apparently instrumental in bringing larger potassium totals into the tops. Then again as the lower pH figure delivered more calcium than did the higher pH, so correspondingly this greater calcium delivery represented also greater potassium delivery in the tops. Thus, whether by greater applications of exchangeable calcium, or by merely more calcium mobilization through the hydrogen ion associated with it (5), either means of mobilizing more calcium into the tops brought correspondingly more potassium with it. Thus, rather than an "antagonistic" effect by the calcium toward the potassium there is apparently a "synergistic" effect, in that the calcium is associated with movement of potassium into the tops. The reverse effect, or less calcium as more potassium is applied, has already been suggested in the comparisons of columns 5 and 6 with 3 in Table 3. That these soils should demonstrate calcium apparently effective in moving potassium into the tuber tops in relation to yield values of tops and tubers seems paradoxical to some of the past concepts regarding the value of calcium in connection with potato production.

SUMMARY AND CONCLUSIONS

The results in terms of yields of potato tubers, potato tops and incidence of potato scab where the levels of exchangeable calcium and potassium were varied in relation to each other while other nutrients were held constant, all at different degrees of soil acidity, point forcefully to the importance of calcium to potassium in the production of this crop.

In the light of these data, we are forced to take the potato scab problem largely out of the category of pathology with the degree of soil acidity in control and to put it mainly into the category of plant nutrition with soil fertility at the controls. When the increased mobilization of plant nutrients, more particularly certain cations, in the presence of the hygrogen ion in contrast to lowered mobilization in hydrogen absence is appreciated, we shall be solving more rapidly some of the problems of plant "disease", of lowered crop yield, and of reduced crop quality. We shall arrive at these solutions not only by providing the supply of a well balanced soil fertility, but also by appreciating the presence of the hygrogen ion, by discontinuing to regard soil fertility mainly as single nutrient concepts, and by discontinuing to fight hydrogen presence in the soil by excessive carbonate applications. Only through the fuller understanding of the numerous inter-relations between both the complex soil behaviors and the plant behaviors can crop production of the highest order in economic and nutritional aspects be attained.

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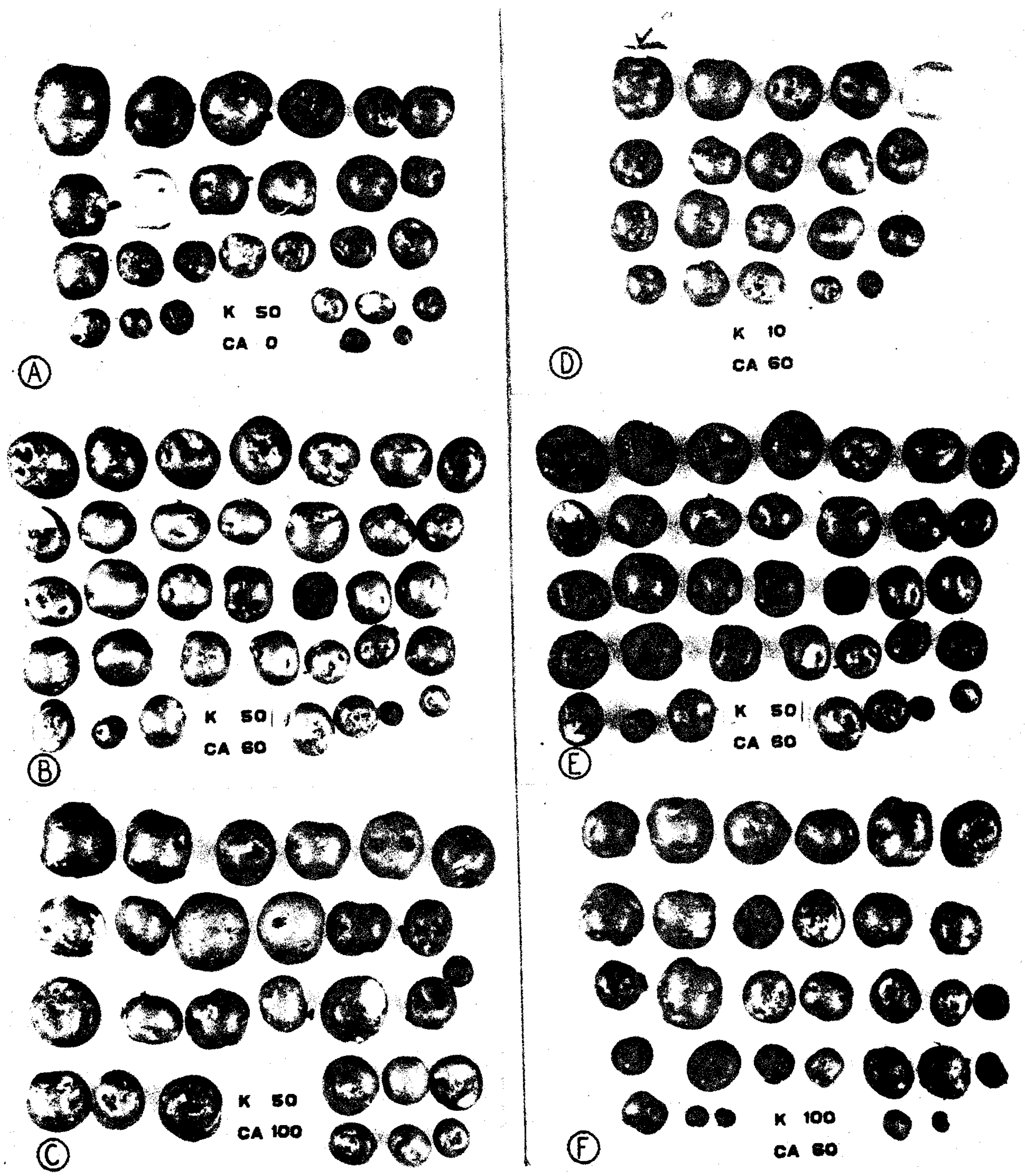
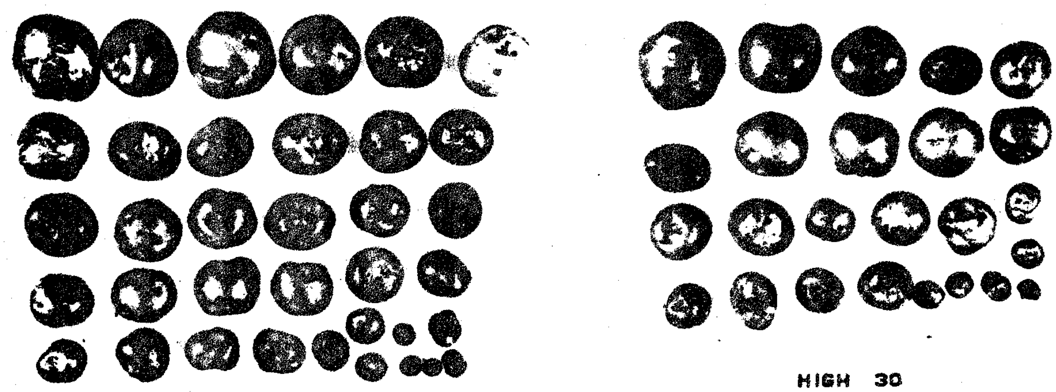
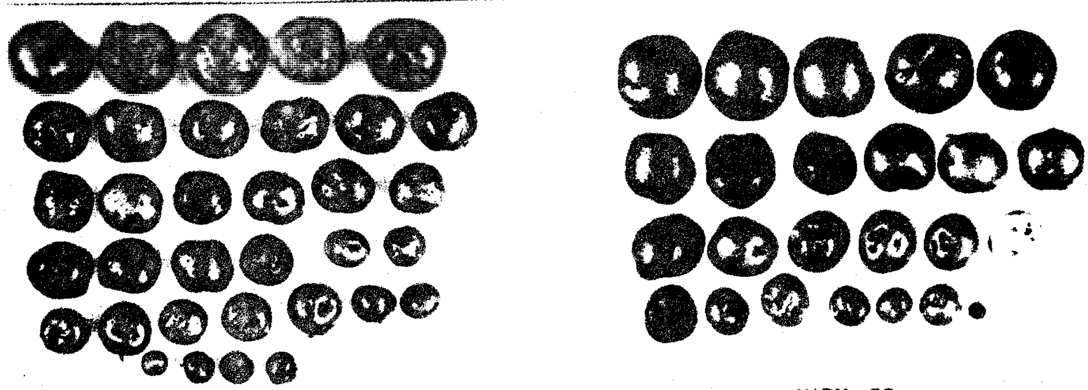


Fig 1



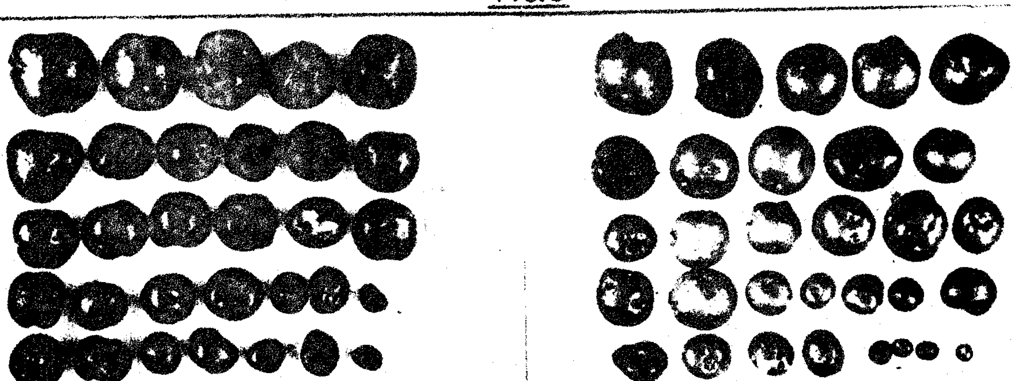
LOW 30 HIGH 30

FIG. 2



LOW 60 HIGH 60

FIG. 3



LOW 90 HIGH 90

FIG. 4