CXXX. THE INFLUENCE OF VARIATIONS IN THE SODIUM-POTASSIUM RATIO ON THE NITROGEN AND MINERAL METABOLISM OF THE GROWING PIG. II.

By MARION BROCK RICHARDS, WILLIAM GODDEN AND ALFRED DUDLEY HUSBAND.

From the Rowett Research Institute, Aberdeen.

(*Received June 23rd, 1927.*)

RECENT investigations on the mineral requirements of the growing animal make it increasingly evident that the adjustment of the proportions of the inorganic constituents of a ration requires as much consideration as the absolute amounts of these elements in the diet. Even though a mineral is present in a ration in sufficient amount for the animal's requirements, the presence of other minerals in unsuitable proportions may lead to insufficient assimilation and retention. The importance in animal nutrition of this balancing of the ration has been frequently emphasised by Orr [1924], who quotes various instances of the interdependence of the different mineral elements. Of special interest in this connection are sodium and potassium. The importance of the ratio of these to each other in the diet was discussed by Bunge as long ago as 1873, and since then the ratio has received more attention than the absolute requirements of each. As a matter of fact, in compounding diets the amounts of these are seldom considered. It is assumed, probably rightly, that any ordinary ration will contain sufficient.

Osborne and Mendel [1918], who carried out a series of growth experiments on rats, drew attention to the surprisingly small amounts of some of the minerals which were sufficient to permit growth. Thus less than 0·04 % of Na in the ration sufficed for normal growth, and with only 0·03 % K considerable growth was likewise attained, although the simultaneous reduction of Na and K to these minimum amounts resulted in nutritive failure. Similarly St John [1923] has found that 0·03 % of K in a wheat ration seemed to furnish an approximate maintenance supply. On the other hand, it seems probable that while these small amounts may be sufficient to cover the minimum requirements of the animal, larger amounts (especially of Na) may be necessary for the purposes of optimum growth and well-being. Thus Olson and St John [1925] have found by varying the amounts of Na in a wheat ration that the most satisfactory results, when both growth and reproduction were considered, were obtained with 0·53 % of Na.

The Na : K ratio of the ration.

Though the absolute amounts required are so small, the ratio is of practical importance. The high proportion of K as compared with Na in the most commonly used feeding-stuffs introduces two possible dangers, viz. (1) a Na deficiency may arise not because the small Na requirement of the animal is insufficiently covered by the ration, but because the excessive proportion of K prevents the full utilisation by the animal of the Na actually present, or (2) the excessive proportion of K to Na may cause insufficient assimilation and retention of other elements.

(1) *Effect on* NaCl *content of organism. Bunge's theory.*

The whole question of the sodium-potassium ratio is intimately bound up with the theory of Bunge [1873], which for over 50 years has dominated any reference to the influence of Na and K in nutrition. Bunge, on the ground of very limited experimental data, maintained that excessive intake of potassium salts impoverishes the organism in sodium chloride. He found, in one-day experiments on himself, in which he investigated urinary excretions only, that large doses of K salts caused a large increase in the excretion of Na and Cl, this excessive loss of Na and Cl being however counterbalanced by abnormally low excretion of these elements on the three days following the K intake. Conversely, he found that a dose of sodium citrate caused increased urinary excretion of K with a slight diminution in Cl excretion. Although Bunge himself recognised the incompleteness of his experimental work, pointing out the necessity both for analysing intestinal excretions and for ascertaining the effect of continued high intake of K, he proceeded on this slender foundation to build up and elaborate the theory that has held its ground for half a century. The tendency during this time has been to overlook entirely the limitations of Bunge's experiments, and to regard as a fully demonstrated fact the theory of sodium chloride impoverishment brought about by excess of K salts. Apart from the fact that his data were insufficient to justify the theory even with regard to adult human beings, on whom the experiments were carried out, the hypothesis has been applied indiscriminately both by Bunge and others, and has been generally accepted as true for animals of any species and any age, regardless of the fact that no experimental data whatever were brought forward by him to justify the application of the theory to the young growing animal.

(*a*) *Confirmatory evidence.* Occasionally isolated results have been recorded which appear to support his theory, *e.g.* Luithlen [1912], in feeding a rabbit on green food, obtained a negative balance for Na, along with a retention of Ca, Mg and K. This he regards as an explanation of the herbivores' necessity for sodium chloride, and as a support for Bunge's theory, but the data he presents are too meagre to justify any such general conclusion. Similarly Gérard [1912], working on dogs and mice, believed that he had obtained evidence in support of the theory of the de-sodifying action due to K salts. But the balance experiments reported by him are very short and inconclusive, while his analysis of the organs of the animals is equally inconclusive, in the absence of reliable figures for the normal content of the organs in Na and K. Again, Blum, Aubel and Hausknecht [1921], working on a nephritic patient, found that administration of K salts on a Na-poor diet caused increased excretion of Na, coupled with diuresis. The converse part of Bunge's theory, viz. increased K elimination by intake of Na salts, has also received occasional confirmation, *e.g.* Oehme [1925] states that addition of sodium chloride or sodium bicarbonate to the diet increases the elimination of K, but no details are given in the paper available. Hagentoren and Kozerski, quoted by Shohl [1923], found that sodium citrate (and sodium carbonate) increased the urinary output of K and Cl, but the excessive excretion gradually diminished. Meyer and Cohn [1911], who carried out balance experiments on infants, found that sodium chloride increased the urinary elimination of Cl, Na and K, the K balance being negative. There was a gain in weight which they attributed to a retention of Na and associated water. They found that K salts as a rule, especially the bicarbonate, caused loss of weight and increased elimination of water, Na, K and Cl. These results are quoted from Whelan [1925], the original paper not being available.

(*b*) *Contradictory evidence.* A few results have also been recorded which are not in agreement with the theory, *e.g.* Harnack and Kleine [1899] found that K salts of vegetable acids increased urinary Cl only to a very insignificant extent. Similarly v. Hoesslin [1910], who carried out metabolic experiments on dogs, considered that Bunge's theory was not confirmed. Again, lengthy feeding experiments on heifers carried out by Hart and his associates [1911] offer little support for the theory. They found, in the case of different groups of animals, fed on rations of different cereals but all having free access to salt, that the amount of sodium chloride consumed bore no relationship to the K content of the ration, either when used alone or when supplemented by K salts.

(2) *Effect on general metabolism.*

(*a*) *Calcium assimilation.* In the emphasis which Bunge lays on the Na : K ratio of the diet, and on the effect which changes in this ratio have on the excretion, he takes into account only the dependence of Na and K on each other, and their effect on Cl. But the possibility must not be overlooked that whether or not Bunge's theory is justified, an excessive proportion of K to Na in a ration may have deleterious effects in other directions. This aspect of the matter also seems to have received little attention, judging by the scanty references in the literature. That an excessive K : Na ratio may have a bad effect on Ca assimilation, and thus be the cause of rickets, was suggested by Seemann [1879] and the idea was later supported by Zander [1881]. Aron [1905] also considered it probable that such a ratio interfered with the deposit of Ca and bone formation in cattle, while Zuntz [1912] has recorded that fodders which cause rickets usually show an excessive proportion of K to Na. Adler [1906], on the ground of metabolic experiments carried out on children, considered that Aron's results were not confirmed for human beings, but interpretation of his results is difficult on account of the shortness of the periods, and of the wide variations in the rations used in the different periods. In two of the three experiments reported his results seem rather to support than to contradict Aron's theory, and in the remaining experiment he altered the acid-base ratio of the diet as well as the Na : K ratio by giving the salts as potassium carbonate and sodium chloride, thus making a change which may have had an important effect on the Ca retention.

(*b*) *Growth and general condition.* Of the general effect on growth and welfare of high K feeding, a few experiments recently recorded are conflicting in their results. Sasaki [1924], in his feeding experiments on rats, found 1·5 : 1 to be the optimum ratio for K : Na in the foodstuffs. If the excess of K over Na were greater than this, the animals could not grow perfectly. Miller [1923], however, has stated that a diet containing K and Na in the ratio of 14 : 1 had no deleterious effect on the growth of young rats. St John [1923], in his recent experiments to which we have already made reference, found that excess of K caused loss in weight and prevented reproduction. In the series of experiments carried out in conjunction with Olson [1925], in which the percentage of Na varied from 0·228 to 2·58, we are informed by one of the authors[1] that the percentage of K in the ration was 0·32. From these figures we find that the proportion of K to Na in the ration which gave the most successful results was 0·6 : 1, while a ration in which K : Na was 1·4 : 1 did not give normal growth or successful reproduction. On the other hand, increasing the amount of Na still further led to deleterious effects on growth and reproduction. This series of experiments brings out clearly the importance for growth of suitable adjustment of the Na : K ratio.

In a recently published paper, Redina [1926] attempts to apply Loeb's theory of ion-antagonism to feeding experiments on adult mice, with special reference to the ions Na, K and Ca. He finds that the proportions of Na and K in the diet have a distinct effect on the weight-curves of the animals, but as he works with an unbalanced diet, lacking in fat and carbohydrate as well as minerals, the significance of his experiments with regard to ordinary metabolic work is not easy to determine.

So far as can be ascertained no systematic attempt has been made since the time of Bunge to deal with the question of the Na : K ratio in any of these aspects until the subject was taken up by the present authors and concurrently by Miller [1923–1926], whose work will be referred to later.

In our earlier paper [1924] we recorded experiments in which we investigated the effect, on the metabolism of the growing pig, of increasing the pro-

[1] We are indebted to Mr J. L. St John for his courtesy in supplying this information.

portion of Na to K by the addition of Na salts to a cereal ration. In those experiments it was found that the addition of sodium chloride or sodium citrate led to increased assimilation and retention of N, Ca and P. It is of interest to note that during the experimental periods in which this increased retention took place, the ratios of K : Na were 1·62 : 1 and 1·53 : 1 respectively, figures which approximate closely to the ratio of 1·5 : 1 given by Sasaki as the optimum found in his growth experiments. It was found further that while the increased Na intake did lead to increased urinary excretion of K as found by Bunge, this increase was accompanied by a diminution in faecal K, with the result that the balance showed little deviation from the normal. Thus, Bunge's theory with regard to loss of K caused by increased Na intake did not hold in our experiments on growing pigs.

Present investigation.

The experiments now to be reported, which have been carried out at intervals from 1923–1926, extend this investigation by seeking to determine the effect of increasing the proportion of K to Na by the addition of potassium citrate to the ration. The investigation has thus a twofold object: (1) to determine whether Bunge's theory, in the aspect in which it is generally applied, viz. sodium chloride impoverishment by excessive K intake, is applicable in the case of the young growing pig, and (2) to find whether the increase in the K intake affects in any way the assimilation and retention of N, Ca and P.

Experimental.

Methods. The experiments were carried out on young pigs (3–4 months old) in the manner previously described. The excretions and balances were determined for N, P, Cl, Ca, Na and K.

Basal diet. As in the previous investigation, the basal diet used in the two experiments to be described consisted of maize, oatmeal, barley-meal and blood-meal, in the quantities given below, with various salt additions as shown.

Daily food intake.

Kind of food	Pig I (control) (g.)	Pig II (g.)	Pigs III and IV (g.)
Maize	500	400	300
Oatmeal...	500	400	300
Barley-meal	500	400	300
Blood-meal	50	40	30
$CaCO_3$	27·5	22	7·2
Ca phosphate	18	14·4	—
$CaCl_2$ solution (about 5 % CaO)	—	—	30 cc.
NaCl solution (approx. 20 %)	25 cc.	20 cc.	—

In each experiment the Ca content of the ration was increased by addition of Ca salts. As in the previous experiments, the animals received 10 cc. olive oil daily to assist regular defaecation and in all cases they were given distilled water *ad lib.* In Exp. 1 the ration was further supplemented by addition of calcium phosphate and sodium chloride, in order to make the composition of the ration, with respect to minerals, approximate more closely to that of sow's milk. In Exp. 2 the ration was made exactly similar in composition to that used in the previously reported sodium citrate experiment.

Average composition of the foodstuffs.

	Total N %	P_2O_5 %	Cl %	CaO %	Na_2O %	K_2O %
Maize	1·620	0·658	0·050	0·020	0·184	0·431
Oatmeal	2·130	1·074	0·061	0·087	0·125	0·528
Barley-meal	1·801	0·834	0·110	0·062	0·103	0·648
Blood-meal	13·423	0·315	1·098	0·173	0·987	0·331

The exact intakes of N, P, Cl, etc., in each experiment are stated in the tables giving the experimental data.

Arrangement of experiments. In Exp. 1, pig I was kept as a control, the diet remaining constant for 6 weeks. Pig II, after a preliminary period of 12 days, had potassium citrate added to the ration to the amount of 64 g. daily. On the addition of this large dose of potassium citrate the pig refused to eat its complete ration for 2 days, and the K salt was therefore added in smaller amounts, gradually working up to the full dose. Thus for pig II there is a transition period of 6 days at the beginning of the experimental period (days 13–18) for which the results, being somewhat uncertain, are not included in the table. After 14 days on the full amount of potassium citrate, there followed a post-period of 18 days during which the animal received only the original ration.

In Exp. 2 both pigs were used as experimental animals. After a preliminary period of 14 days for pig III and 10 days for pig IV, each pig received 15 g. potassium citrate for 1 day, and thereafter the full dose of 30 g. daily for 15 days, after which the basal ration was fed for a post-period of 12 days.

The results of the analyses are given in Tables I–IV, and in part in Figs. 1 and 2.

Discussion of results.

I. *Effect on general metabolism.* From these experiments, and from a comparison with the results previously recorded for the Na feeding experiments, it would appear that the administration of potassium citrate has had an adverse effect on the assimilation of N, P and Ca (see Fig. 1), although the response of the individual animals to the introduction of the salt varied somewhat in degree, *e.g.* pig III seemed to be slower than pig IV in showing the effect of the potassium citrate, and to recover more quickly when the salt was withdrawn. In all cases the introduction of potassium citrate had a marked diuretic effect.

Table I. *Exp.* 1. *Pig I* (*control*).

Average daily excretions and balances in g.
Duration of experiment: 42 days.
K : Na in food intake = 2·0 : 1 throughout.

Days (inclusive)	Nitrogen Intake	Urine	Faeces	Total	Balance	P_2O_5 Intake	Urine	Faeces	Total	Balance
1–7	35·05	12·55	10·09	22·64	12·41	20·23	0·25	11·87	12·12	8·11
8–14	35·05	13·17	9·19	22·36	12·69	20·23	0·27	12·28	12·55	7·68
15–21	34·80	13·21	9·21	22·42	12·38	20·23	0·22	12·35	12·57	7·66
22–28	34·48	13·81	8·18	21·99	12·49	20·25	0·21	12·34	12·55	7·70
29–35	34·48	13·75	8·38	22·13	12·35	20·25	0·27	12·78	13·05	7·20
36–42	34·48	13·77	8·22	21·99	12·49	20·25	0·26	12·68	12·94	7·31
			Cl					CaO		
1–7	4·74	4·08	0·37	4·45	0·29	22·94	1·04	13·16	14·20	8·74
8–14	4·74	3·73	0·23	3·96	0·78	22·94	1·06	13·40	14·46	8·48
15–21	4·74	3·89	0·24	4·13	0·61	22·96	0·87	13·56	14·43	8·53
22–28	4·74	3·60	0·25	3·85	0·89	22·99	0·68	14·07	14·75	8·24
29–35	4·74	3·82	0·25	4·07	0·67	22·99	0·74	14·06	14·80	8·19
36–42	4·74	3·70	0·27	3·97	0·77	22·99	0·58	14·45	15·03	7·96
			Na_2O					K_2O		
1–7	4·78	2·07	1·82	3·89	0·89	8·38	4·34	1·97	6·31	2·07
8–14	4·78	1·94	1·49	3·43	1·35	8·38	4·39	1·67	6·06	2·32
15–21	4·81	1·95	1·27	3·22	1·59	8·36	4·44	1·81	6·25	2·11
22–28	4·86	1·72	1·36	3·08	1·78	8·35	4·55	1·56	6·11	2·24
29–35	4·86	1·58	1·38	2·96	1·90	8·35	4·75	1·55	6·30	2·05
36–42	4·86	1·47	1·31	2·78	2·08	8·35	4·64	1·64	6·28	2·07

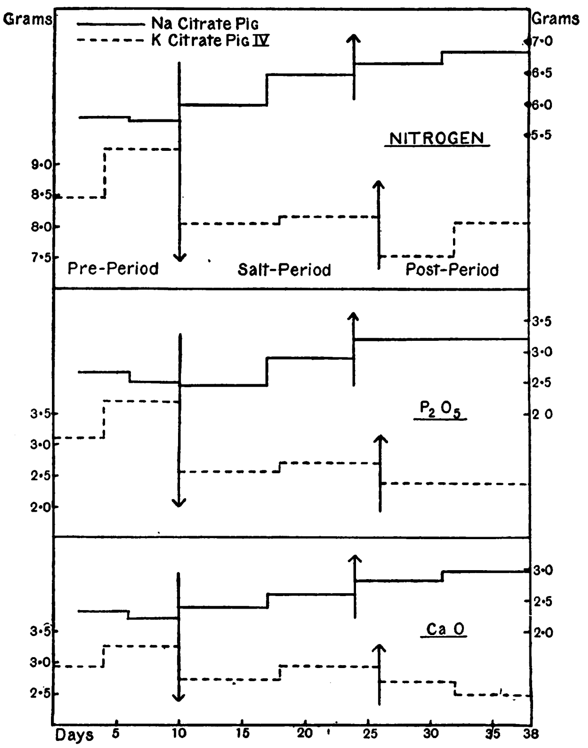

Fig. 1. Nitrogen, P_2O_5, and CaO balances for pigs receiving Na citrate and K citrate respectively, showing the opposite effects of these salts on the general metabolism.

Table II. *Exp.* 1. *Pig II.*

Average daily excretions and balances in g.
Duration of experiment: 50 days.
{K : Na in basal ration = 2·0 : 1.
{K : Na in experimental period = 10·5 : 1.

Days (inclusive)	Nitrogen Intake	Urine	Faeces	Total	Balance	P_2O_5 Intake	Urine	Faeces	Total	Balance
1–6	28·04	9·78	7·97	17·75	10·29	16·18	0·20	10·96	11·16	5·02
7–12	28·04	10·36	7·93	18·29	9·75	16·18	0·23	10·72	10·95	5·23
——→										
*19–25	28·04	11·58	7·07	18·65	9·39	16·18	0·20	11·32	11·52	4·66
26–32	28·04	11·44	7·37	18·81	9·23	16·18	0·26	11·78	12·04	4·14
←——										
33–39	27·71	11·23	7·13	18·36	9·35	16·19	0·20	11·99	12·19	4·00
40–46	27·58	11·05	7·10	18·15	9·43	16·20	0·20	12·53	12·73	3·47
47–50	27·58	11·22	6·73	17·95	9·63	16·20	0·19	12·92	13·11	3·09
			Cl					CaO		
1–6	3·79	3·21	0·29	3·50	0·29	18·35	0·92	12·22	13·14	5·21
7–12	3·79	2·82	0·24	3·06	0·73	18·35	1·65	10·97	12·62	5·73
——→										
19–25	3·79	2·99	0·26	3·25	0·54	18·35	0·70	13·12	13·82	4·53
26–32	3·79	3·09	0·26	3·35	0·44	18·35	0·78	13·14	13·92	4·43
33–39	3·79	2·90	0·24	3·14	0·65	18·38	1·27	12·85	14·12	4·26
←——										
40–46	3·79	2·93	0·28	3·21	0·58	18·39	1·09	13·49	14·58	3·81
47–50	3·79	2·79	0·23	3·02	0·77	18·39	0·77	14·30	15·07	3·32
			Na_2O					K_2O		
1–6	3·82	1·88	1·80	3·68	0·14	6·70	2·81	2·19	5·00	1·70
7–12	3·82	1·95	1·67	3·62	0·20	6·70	2·99	1·89	4·88	1·82
——→										
19–25	3·82	0·90	1·67	2·57	1·25	35·75	29·53	3·34	32·87	2·88
26–32	3·82	0·73	1·17	1·90	1·92	35·75	29·65	3·54	33·19	2·56
←——										
33–39	3·87	1·96	1·20	3·16	0·71	6·68	3·27	2·10	5·37	1·31
40–46	3·88	2·08	1·52	3·60	0·28	6·68	2·92	2·16	5·08	1·60
47–50	3·88	1·62	1·53	3·15	0·73	6·68	2·97	2·08	5·05	1·63

——→ Indicates the introduction of potassium citrate.
←—— Indicates the withdrawal of potassium citrate.
* Days 13–18 omitted. See text.

Nitrogen. In all three pigs the potassium citrate feeding resulted in increased urinary excretion of N, and this increase accounted almost entirely for the diminished N balance. Only in the case of pig IV was the adverse effect on the balance partially due to increase in the faecal N. It is well known [cf. Orr, 1914] that the diuresis consequent on excessive water ingestion leads to increased urinary excretion of N, hence in the present experiments it is probable that the increase in urinary N may be ascribed to the diuresis brought about by the K feeding. This is borne out by the fact that for pig III, which seemed to be less susceptible in general than pig IV to the K salt, it was found that the diuretic effect was also less marked. It is possible, therefore, that the use of natural feeding stuffs containing a high proportion of K, if they caused no diuresis, might have little effect on the N retention.

Phosphorus. With regard to P excretion, in pigs II and IV, in spite of the diuresis, the K feeding had practically no effect on the urinary P, the diminution in balance being due to increased faecal excretion. On the other hand, pig III showed a slight decrease at first in faecal P, and the diminished balance in the second week of the K feeding was due to an increase in urinary P.

Table III. *Exp.* 2. *Pig III.*

Average daily excretions and balances in g.
Duration of experiment: 42 days.
{K : Na in basal ration = 3·0 : 1.
{K : Na in experimental period = 11·6 : 1.

Days (inclusive)	Nitrogen					P_2O_5				
	Intake	Urine	Faeces	Total	Balance	Intake	Urine	Faeces	Total	Balance
1–6	20·41	7·73	4·72	12·45	7·96	8·31	0·15	5·87	6·02	2·29
7–14	20·41	7·22	4·60	11·82	8·59	8·31	0·22	5·78	6·00	2·31
—→										
15–22	20·41	7·57	4·44	12·01	8·40	8·31	0·31	5·51	5·82	2·49
23–30	20·41	8·38	4·31	12·69	7·72	8·31	0·58	5·75	6·33	1·98
←—										
31–36	20·41	8·03	4·12	12·15	8·26	8·31	0·40	5·73	6·13	2·18
37–42	20·41	8·31	4·05	12·36	8·05	8·31	0·55	6·02	6·57	1·74
	Cl					CaO				
1–6	2·97	2·62	0·09	2·71	0·26	6·00	0·29	3·53	3·82	2·18
7–14	2·97	2·52	0·12	2·64	0·33	6·00	0·24	3·41	3·65	2·35
—→										
15–22	2·97	2·52	0·14	2·66	0·31	6·00	0·18	3·18	3·36	2·64
23–30	2·97	2·55	0·16	2·71	0·26	6·00	0·20	3·66	3·86	2·14
←—										
31–36	2·97	2·56	0·13	2·69	0·28	6·00	0·19	3·67	3·86	2·14
37–42	2·97	2·46	0·13	2·59	0·38	6·00	0·23	4·08	4·31	1·69
	Na_2O					K_2O				
1–6	1·79	0·57	0·52	1·09	0·70	4·81	1·19	2·71	3·90	0·91
7–14	1·79	0·63	0·43	1·06	0·73	4·81	1·29	2·50	3·79	1·02
—→										
15–22	1·79	0·22	0·78	1·00	0·79	17·63	12·21	3·32	15·53	2·10
23–30	1·79	0·14	0·61	0·75	1·04	18·49	13·88	2·96	16·84	1·65
←—										
31–36	1·79	0·48	0·53	1·01	0·78	4·81	1·89	2·23	4·12	0·69
37–42	1·79	0·40	0·22	0·62	1·17	4·81	1·40	2·56	3·96	0·85

—→ Indicates introduction of potassium citrate.
←— Indicates withdrawal of potassium citrate.

Calcium. The Ca results agree for all three pigs. In every case, following an increased K intake, there was an increase in the faecal excretion of Ca, accompanied by a diminution in urinary Ca, resulting in a diminished retention. This is exactly the converse of the results obtained in the sodium citrate experiment. In that case the increased Ca balance was accompanied by increased urinary excretion, the amount of urinary Ca increasing progressively during the whole 14 day period of the sodium citrate feeding, a result which seemed to point clearly to increased assimilation of Ca. The figures now reported therefore, taken in conjunction with those of the sodium citrate experiment, seem to indicate that the Na : K ratio of a diet may have a very considerable influence on the Ca assimilation, and they form an interesting justification of the suggestions put forward by Seemann, Zander, Aron and Zuntz, to which reference has already been made.

Chlorine. The present experiments show, if we consider the two-day results, that there is a very distinct effect of the increased K intake on the urinary Cl excretion. The increase of K intake causes increased urinary excretion of Cl and a negative Cl balance for the first two-day period after the intake. This increase is, however, only transitory, being followed by a decreased excretion for the next 2 days, and, if we consider the average figures for the

Table IV. *Exp.* 2. *Pig IV.*

Average daily excretions and balances in g.
Duration of experiment: 38 days.
{K : Na in basal ration = 3·0 : 1.
{K : Na in experimental period = 11·6 : 1.

Days (inclusive)	Nitrogen Intake	Nitrogen Urine	Nitrogen Faeces	Nitrogen Total	Nitrogen Balance	P_2O_5 Intake	P_2O_5 Urine	P_2O_5 Faeces	P_2O_5 Total	P_2O_5 Balance
1–4	20·41	7·23	4·71	11·94	8·47	8·31	0·25	4·96	5·21	3·10
5–10	20·41	7·00	4·15	11·15	9·26	8·31	0·18	4·45	4·63	3·68
——→										
11–18	20·41	7·42	4·95	12·37	8·04	8·31	0·17	5·59	5·76	2·55
19–26	20·41	7·51	4·76	12·27	8·14	8·31	0·30	5·32	5·62	2·69
←——										
27–32	20·41	8·59	4·31	12·90	7·51	8·31	0·19	5·75	5·94	2·37
33–38	20·41	8·02	4·32	12·34	8·07	8·31	0·28	5·66	5·94	2·37
			Cl					CaO		
1–4	2·97	2·19	0·21	2·40	0·57	6·00	0·28	2·79	3·07	2·93
5–10	2·97	2·41	0·22	2·63	0·34	6·00	0·29	2·46	2·75	3·25
——→										
11–18	2·97	2·51	0·13	2·64	0·33	6·00	0·14	3·13	3·27	2·73
19–26	2·97	2·55	0·14	2·69	0·28	6·00	0·15	2·92	3·07	2·93
←——										
27–32	2·97	2·62	0·09	2·71	0·26	6·00	0·17	3·14	3·31	2·69
33–38	2·97	2·51	0·14	2·65	0·32	6·00	0·19	3·32	3·51	2·49
			Na_2O					K_2O		
1–4	1·79	0·62	0·48	1·10	0·69	4·81	1·31	2·16	3·47	1·34
5–10	1·79	0·69	0·40	1·09	0·70	4·81	1·09	2·19	3·28	1·53
——→										
11–18	1·79	0·34	0·99	1·33	0·46	17·63	12·27	3·08	15·35	2·28
19–26	1·79	0·30	0·96	1·26	0·53	18·49	13·23	2·99	16·22	2·27
←——										
27–32	1·79	0·67	0·65	1·32	0·47	4·81	1·78	2·26	4·04	0·77
33–38	1·79	0·58	0·19	0·77	1·02	4·81	1·48	2·30	3·78	1·03

——→ Indicates the introduction of potassium citrate.
←—— Indicates the withdrawal of potassium citrate.

periods, it is found that continued excessive intake of K salts has little effect on excretions and balances. When the K salt is withdrawn there is a reverse transitory effect. Urinary Cl diminishes temporarily, but the organism adjusts itself at once. This transitory influence of increased K intake on urinary Cl is perhaps the most decided effect observed in all the potassium citrate experiments, although again the response of the animals to the change in diet varies in degree. Thus pig III showed a less decided effect when the K salt was withdrawn than pigs II and IV. In pig II the effects are exaggerated by the large dose of K salt. Table V and Fig. 2 show this effect of increased K intake on the urinary excretion of Cl, the figures being two-day excretions.

A comparison of these figures with those of the sodium citrate experiment shows that sodium citrate has the reverse effect on urinary Cl excretion, a point which was not brought out in the previous paper. Table VI and Fig. 2 give these results for the excretions and balances of Cl[1], using the corrected intake.

[1] A correction has to be made in the Cl balance figures as previously published for the Na experiments. More recent work by two of us [Husband and Godden, 1927] on the method of determining Cl in foodstuffs has shown that the method then employed gave results considerably too low in the case of cereal foods. Making this correction for the intake of Cl it will be found that the pigs instead of showing a steady negative balance were really on a small positive balance.

Table V.

	Pig II		Pig III		Pig IV	
	Urinary Cl	Cl balance	Urinary Cl	Cl balance	Urinary Cl	Cl balance
Average for last 8 days of pre-period	5·79	+1·30	5·03	+0·66	4·59	+0·90
Days 1 and 2 of potassium citrate period	9·70	Large neg. balance[1]	5·96	−0·30	5·83	−0·29
Days 3 and 4 of potassium citrate period	0·50	+6·85	4·10	+1·59	4·21	+1·49
Last 8 days of potassium citrate period	6·15	+0·92	5·10	+0·51	5·10	+0·55
Days 1 and 2 of post-period	4·15	+2·97	4·95	+0·73	4·70	+1·05
Days 3 and 4 of post-period	7·47	−0·38	5·22	+0·49	5·83	−0·10

[1] The exact figure here is uncertain, as the animal did not eat the complete ration for 2 days on account of the large dose of potassium citrate, but it may be taken as approximately −4·3.

Table VI.

	Urinary Cl	Cl balance
Last 8 days of pre-period	5·05	+0·46
Days 1 and 2 of sodium citrate period	4·29	+1·30
Days 3 and 4 of sodium citrate period	5·64	−0·17
Last 8 days of sodium citrate period	5·01	+0·51
Days 1 and 2 of post-period	5·26	+0·30
Days 3 and 4 of post-period	5·26	+0·34
Days 5 and 6 of post-period	4·96	+0·65

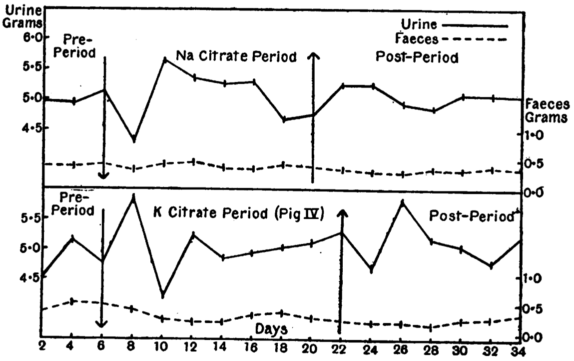

Fig. 2. Urinary and faecal excretions of chlorine for pigs receiving Na citrate and K citrate respectively, showing the opposite effects of these salts on the urinary excretion of chlorine, and the temporary nature of the disturbance.

II. *Bunge's theory of chlorine impoverishment by potassium intake.* It will be seen from a study of the above potassium citrate experiments that while the Cl results agree with those of Bunge in his experiments on himself with regard to the *temporary* increase in Cl excretion caused by increased K intake, they offer no justification of his theory that continued high intake of K may cause impoverishment of the organism in Cl. The immediate increase in urinary Cl is followed at once by decreased excretion when the K salt is withdrawn (see Tables V and VII), as Bunge himself found. We find further that this fall below normal occurs even when the high K intake is continued. From the experimental data available it seems clear that the theory of Cl impoverishment caused by high K intake is quite untenable. On the contrary, the results obtained bring out very strikingly the rapidity with which the organism can adjust itself to sudden changes in the diet, and demonstrate clearly its ability to maintain its Cl balance in spite of large variations in the Na : K ratio of the diet.

Potassium. The increased K intake resulted in an increased K balance for all three pigs, but the excess retained during this period was got rid of in the post-period through the urine, by which also the major portion of the ingested potassium citrate was voided during the experimental period.

Sodium. While the results obtained for the Na excretions and balances in these experiments are not so consistent or so decisive in their nature as those for Cl, yet they cannot be regarded as offering any support for Bunge's theory of Na impoverishment caused by excessive K intake. In considering the results it seems advisable to point out that, owing to the method of Na estimation, the interpretation of small variations in the results is less certain than is the case with other estimations. Since the Na is estimated by difference, it follows that when large amounts of K salt are present in the urine, and consequently small amounts of material have to be taken for analysis, as is the case in the potassium citrate periods, the possibility of error in the final Na result is greatly increased. Hence only *considerable* variations in the Na figures can be accepted as forming any basis for argument.

(*a*) *Urinary sodium excretion.* Although with regard to Cl the figures we have obtained confirm Bunge's findings of a *transient* increase in urinary excretion consequent on increased K intake, we have not obtained the same confirmation as regards the excretion of Na. On only two occasions have we observed a suggestion of such increase. (1) In the transition period of Exp. 1, where the results were however somewhat vitiated by the fact that the large dose of potassium citrate caused pig II to go off its food, the urinary Na increased somewhat for the first 2 days of the period, the daily average being 1·9 g. for the last 2 days of the pre-period, and 2·2 g. for the first 2 days of the experimental period. This small difference is, however, in no way inconsistent with the two-daily variations found during the pre-period, particularly when it is remembered that the animal was not eating well. (2) Another experiment, not otherwise recorded in this paper, was conducted to throw further light on this particular point, attention being paid solely to the intake and excretion of Na and K. The urinary Na for the first day of the K period was 0·51 g. Na_2O as against an average of 0·39 g. for the 8 days of the pre-period. As the excretion for the last 2 days of the pre-period had been rather below normal, this slight increase, while it *may* be due to increased K intake, is again quite in keeping with the ordinary daily fluctuations. In this case the average urinary excretion of Na_2O for 8 days of continued high K feeding was only 0·43 g., as compared with the pre-period average of 0·39 g., and the Na balance for the period showed a slight improvement in spite of the slight increase in urinary excretion.

In no other case did we find even this amount of support of Bunge's findings. Urinary excretion of Na diminished rather than increased during the K-feeding periods, and even when the K salt was given again for 1 day only to pigs III and IV (Table VII), at the end of the post-period recorded in Tables III and IV, no increase in urinary Na was observable, though the Cl effect already referred to was clearly shown.

Table VII.

	Pig III				Pig IV			
	Na_2O		Cl		Na_2O		Cl	
	Urine	Bal.	Urine	Bal.	Urine	Bal.	Urine	Bal.
Daily average for last 6 days of post-period	0·40	1·17	2·46	+0·38	0·58	1·02	2·51	+0·32
Potassium citrate day	0·06	1·30	3·01	−0·18	0·21	1·07	3·12	−0·24
Day after potassium citrate	0·26	1·18	1·33	+1·56	0·35	1·19	1·48	+1·41

(*b*) *Sodium balance.* As regards the Na balance also, the weight of evidence is against Bunge's theory of Na impoverishment by K feeding. In Exp. 2 the decrease in urinary Na for the K period was accompanied by increased faecal excretion of Na (cf. the results of the Na experiments already published in which increased urinary K and decreased faecal K go together). With pig III, as also with pig II, and with the animal in the short experiment already briefly mentioned, there was an improvement in the Na balance for the experimental period, while with pig IV the diminution in balance was due to the largely increased faecal excretion, which more than counterbalanced the diminished urinary excretion. Thus our results do not bear out Bunge's theory of loss of Na from the organism through increased urinary excretion. It must be borne in mind, however, that these experiments were conducted on young growing animals, while Bunge's experiments with an adult human being as subject were carried out under widely different experimental conditions.

Miller [1923–1926] has recently carried out a series of interesting experiments on "Potassium in animal nutrition," to which we have already made some reference. In his first paper, dealing with the influence of K on urinary Na and Cl excretion in pigs, Miller claimed that his results, using a starch diet, a synthetic ration, or a milk diet, agreed with those of Bunge in showing that a sudden increase of K salts in the diet caused an immediate increase in Na and Cl excretion for the following 24-hour period. He found further that the Na and Cl excretion decreased when the high K intake was continued.

From a close study of Miller's data we are unable at times to reconcile the figures in the tables with the conclusions he draws from them, particularly with regard to the effect on Na excretion. Thus in Table II, Nov. 4th, on the starch diet, there is no increase in Na excretion on giving the K salt, although the Cl figure shows the expected increase. In Table VII, on the synthetic ration, there is little or no Na increase for any of the dates on which the K salt was introduced, while in Table IX, giving the results for a pig on milk diet, there is not only no initial increase in Na excretion, but the figures show a distinct decrease for the whole K period. It may be mentioned here that the Cl figures in Table IX agree very closely with those we have obtained both with regard to the initial rise and fall at the beginning of the K period, and also as regards the sudden drop and subsequent increase when the K salt is withdrawn.

Other instances can be found in the tables which do not fit in with Miller's general conclusions, and it seems as if Miller were ready to accept Bunge's statements in preference to the evidence of his own experimental results, instead of recognising how often the two are in conflict. We are inclined therefore to accept the results of Miller's experiments on pigs, which it must be remembered covered only urinary excretions and were not balance experiments, as offering additional support to our conclusions, instead of regarding them as a confirmation of Bunge's results. His later metabolic experiments, in which rats were used as subjects, are scarcely comparable either with his or our experiments on young pigs, or with those of Bunge on himself.

Summary.

1. The addition of potassium citrate to a ration of cereal grain fed to growing pigs, led to decreased assimilation and retention of nitrogen, phosphorus and calcium.

2. The increase of potassium salts in the ration caused an immediate increase in the urinary excretion of chlorine, followed at once by a decrease, after which continued high intake of potassium had little or no effect on the excretion. The withdrawal of the potassium salt, conversely, caused an immediate drop in urinary chlorine, followed by an increase.

3. The results obtained for growing pigs with regard to sodium excretion do not support the theory of sodium impoverishment put forward by Bunge as the result of experiments on himself.

4. For the growing animal it would appear that any adverse effect of excessive potassium content in a ration is due not to impoverishment of the organism in sodium or chlorine, but more probably to the depressing influence on the metabolism of nitrogen, phosphorus, and calcium.

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