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On the Growth of the Rice Plant.

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On the growth of the Rice Plant.

By

Shinkichi Suzuki.

Rice has been one of the most important economic crops in Japan. Agricultural Experiment Stations, established in every perfecture of Japan, have, for a number of years, issued reports on many and varied experiments with this crop. The attention of agricultural scientists has been given, in no small measure, to the application of fertilizers and the method of cultivation. Unfortunately, many of these experiments ended only in the ascertainment of empirical facts. It is true that mach valuable scientific rescarch, connected with the cultivation of rice, has been conducted in the Central Agricultural Experiment Station and in the Agricultural College, Tokio, yet there still remain many scientific, and likewise practical questions to be worked out in this Island, where the tropical climate exercises an important influence on the growth of the rice plant.

General Scheme of Experiments.

The present experiments were undertaken with a view to gaining further knowledge of the development and composition of the rice plant at successive stages in the growth. On April 1st, 1913, the young plants, that had been grown in a nursery, were transferred to certain plats, which we will call A, B and C, at the rate of 10,800 bundles per tan (44,068 bundles per acre, i.e. per 4.0804 tan), each bundle consisting of five plants. These plants were cultivated in the usual way, and the manures applied to the three plats were as follws :—

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Table 1. Quantity of Fertilizer.

Plat	Fertilizer	per tan		per acre
			Kwan	lbs.
A	Soy bean Cake	N,	2.5	84.99
	Superphosphate	P_2O_5,	2.0	68.00
	Potassium Carbonate	K_2O,	1.0	34.00
B	Ammonium Sulphate	N,	2.5	84.99
	Superphosphate	P_2O_5,	2.0	68.00
	Potassium Carbonate	K_2O,	1.0	34.00
C	None			

Plants of normal growth and of equal size were carefully selected as samples for analysis. Ten to twenty bundles were uprooted at the desired stages of growth, from each plat, and immediately divided into botanical parts, so as to obtain their weights in a fresh state. The preparation of these samples will be described under the heading "Glucose, Saccharose, Dextrine and Starch Contents". (v. p. 25–28) All these botanical portions were submitted to a chemical analysis.

Total Weight of the Plant when Fresh.

Arendt and Butschneider observed that the oat-plant reached its greatest weight at the time of flowering or heading out, as the following figures show :—

Table 2. Total weight of Oat-plant in a Fresh State.
(Arendt and Butschneider)

Date	per acre
June 19	6,358 lbs.
June 29 (10 days)	10,603 „
July 8 (9 „) Full bloom	16,623 „
July 28 (20 „)	14,981 „
Aug. 6 (9 „) Full ripe	10,622 „

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The submerged rice plant grows in a somewhat different way. The weight remains about constant after the time of flowering, as shown in the following tables :—

Table 3. Total weight of Rice Plant in a Fresh State. (10 bundles).

Date	Plat A	Plat B	Plat C
	gr	gr.	gr.
April 30 (30 days from transplantation)	358.28	297.57	99.66
May 10 (10 days)	857.74	717.13	110.50
May 26 (16 days)	2,137.40	1,941.13	262.80
June 16 (21 days) Full bloom	3,737.80	3,079.80	649.20
July 4 (18 days) Full ripe	3,448.20	3,186.00	667.20

It is clear that variation in weight during maturation depends upon the increase of dry matter and the loss of water contained in the plant body. Evaporation from the swamp rice plants, such as we are experimenting with, may be compensated for by a much more easy and rapid absorption of water than in the case of crops grown in dry fields e. g. oats. Consequently the oat plant is found to have a considerable loss of water in the period of maturation, though the dry matter increases in amount. Thus the weight of the oat-plant decreases towards maturity, while that of the rice plant remains about constant during the same period.

Table 4. Weight of the Parts of the Rice Plant in a Fresh State. (10 bundles)

Plat		May 10	May 26	June 16	June 26	July 4
		gr.	gr.	gr.	gr.	gr
A	Leaves	201.91	479.01	533.70	—	309.40
	Stems ※	432.69	1,208.01	2,533.70	—	2,092.70
	Roots	223.14	450.38	341.00	—	387.80
	Grain			329.40	628.70	658.30
B	Leaves	188.34	420.85	421.50	—	255.20
	Stems	354.04	1,058.60	1,923.70	—	1,886.60
	Roots	1y4.75	461.78	422.50	—	371.70
	Grain			212.10	542.80	672.50
C	Leaves	35.85	64.50	83.20	—	50.70
	Stems	45.87	134.70	403.80	—	393.80
	Roots	38.78	63.60	103.00	—	72.60
	Grain			59.20	—	150.10

※ The word "stems" in the present paper is used for stems and sheaths.

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There is no great difference between the weight of the roots and that of the leaves in the earlier stages of the plant's growth. As a rule, the weight of the vegetative parts increases until the time of flowering, and then begins to diminish; but the weight of the grain increnses very rapidly during maturation. This reduction in the weight of the stem and leaves, which takes place in the period of maturation, is dependent upon the decrease of dry matter and of water. The fresh stems have the greatest weight, at every stage of development, among all the botanical parts of the rice plant, and its weight increases very rapidly, especially befor the time of heading out, as is shown in the following table:—

Table 5. Rate of Increase of the Weight in the Parts of the Rice Plant in a Fresh State.

Plat		May 10	May 26	June 16	June 26	July 4
		%	%	%	%	%
A	Leaves	65.3	154.5	172.5	—	100.0
	Stems	20.7	57.7	121.1	—	100.0
	Roots	57.5	116.1	87.9	—	100.0
	Grain	—	—	50.0	95.5	100.0
B	Leaves	73.8	164.9	165.2	—	100.0
	Stems	18.8	56.2	102.0	—	100.0
	Roots	47.0	124.2	113.7	—	100.0
	Grain	—	—	31.5	80.7	100.0
C	Leaves	70.7	127.2	164.1	—	100.0
	Stems	11.6	34.2	102.5	—	100.0
	Roots	53.4	87.6	141.9	—	100.0
	Grain	—	—	39.4	—	100.0

Amount of Water in the Plant when Fresh.

The absolute quantity of water contained in the live crop is greatest at the flowering stage, and then gradually decreases towards maturity. It may be assumed that the plant needs much water in

the period of vigorous growth, and absorbs a great deal of water through the roots. Yet it must be borne in mind that a good quantity of water is produced by dehydration which occurs in the synthetic process of the higher carbohydrates and protein substances. Leaves also contain the maximum amount of water at the time of flowering, and a remarkable decrease of water takes place in them when the crop is mature. However, it is not certain whether this marked reduction in the amount of water is due to the more active evaporation from the surface of the live leaves during maturation, or to the fact that withered leaves are more abundant in the later part of the plant's life. The amount of water contained in the stems is always much greater than that in the leaves, especially at maturity, for the structure of the stem is such that it retains much water in its tissues, and prevents rapid evaporation. Both when the grain is at an early and at a mature stage, the amount of water does not vary a great deal. Rapid evaporation from the glumes of grain may take place in the early period of maturation, and on the other hand the stems may supply sufficient water to compensate for this loss. In the course of maturation the glumes become hardened, and this hinders rapid evaporation ; but at the same time the upper portion of the stems withers to some extent, and thus the transportation of water to the grain is partly checked. Furthermore, the vigorous synthesis, in the grain, of starch and protain from simpler compounds results in the production of water. Hence the reason for there being a fairly constant weight of water in the grain in its early and in its mature stages becomes clear. The quantities of water in 10 bundles of rice plants are shown in the following list:—

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Table 6. Weight of Water in the Parts of Rice Plant.
(10 bundles)

Plat		May 10	May 26	June 16	June 26	July 4
		gr.	gr.	gr.	gr.	gr.
A	Entire Plant	709.92	1,748.10	2,818.80	—	2,336.10
	Leaves	147.13	348.91	362.50	—	162.80
	Stems	367.18	1,000.11	1,994.00	—	1,688.80
	Roots	195.61	399.08	277.90	—	307.40
	Grain			184.40	—	177.10
B	Entire Plant	577.50	1,542.80	2,263.80	—	2,084.60
	Leaves	134.36	295.35	278.00	—	126.10
	Stems	289.78	856.30	1,459.30	—	1,487.00
	Roots	153.36	391.18	355.70	—	293.40
	Grain			170.80	—	178.10
C	Entire Plant	89.90	212.00	477.50	—	454.20
	Leaves	18.27	45.70	52.80	—	26.30
	Stems	37.59	111.60	304.20	—	322.80
	Roots	34.04	54.70	85.10	—	59.60
	Grain			35.40	—	45.50

It is well known that the percentage of water in a plant is highest, as a rule, during the early stage of its growth. The submerged rice plant (grown in a swamp) seems to be more succulent than cereals that are cultivated in dry fields. The rice crops that were reaped on April 30th, thirty days after transplantation, show that the well-developed young plant on plats A and B contains about 85 % of water; and that the rice plant from plat C, which was unmanured, has a slightly smaller percentage of water, probably owing to its inferior development. Yet from May 10 up to maturity the percentages of water in these plants are practically equal at the same stages of growth. Figures are given below:—

Table 7. Percentage of Water in the Fresh Rice Plant.

Date	Plat A	Plat B	Plat C
	%	%	%
April 30	85.28	85.17	80.78
May 10	82.76	80.54	81.36
May 26	81.80	79.49	80.67
June 16	75.42	73.54	73.55
July 4	67.74	65.43	68.06

All the botanical parts of the rice plant also contain a gradually decreasing percentage of water during the plant's life, with the exception that there is a slight increasing percentage in the stem at the time of maturity. This latter fact is due to the great diminution in the absolute amount of dry matter and the rather less loss of water, that takes place in the stems during maturation. The percentags of water in the parts of the rice plant, at the different stages in its growth, are tabulated below :—

Table 8. Percentage of Water in the Parts of the Fresh Plant.

	Plat	April 30	May 10	May 26	June 16	June 26	July 4
		%	%	%	%	%	%
Leaves	A	—	72.87	72.84	67.92	63.67	52.61
	B	—	71.34	70.18	65.96	63.08	49.42
	C	71.91	70.68	70.89	63.49	59.31	51.88
Stems	A	—	84.86	82.79	78.70	81.02	80.70
	B	—	81.85	80.89	75.86	—	78.82
	C	84.39	81.95	82.86	75.34	—	81.97
Roots	A	—	87.66	88.61	81.50	—	79.26
	B	—	87.78	84.73	84.19	—	78.94
	C	85.11	87.78	86.02	82.63	—	82.10
Grain	A				55.99	32.48	26.91
	B				54.74	—	26.48
	C				59.82	—	30.37

The stems and roots have a larger percentage of water than the grain and leaves, and their percentages do not decrease very greatly throughout the plant's life, varying within 10% only. In the stems the percentage of water is lowest just after the vigorous growth of the vegetative tissues, though a great quantity of water in the stems is found at the same stage, (v. Table 6.). Conseqently it is clear that a much greater amount of dry matter accumulates in the stem in the period of flowering. The difference between the per-

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centages of water in the leaves of May 10 and July 4 is about 20%. This is twice as great as in the case of the stems and roots. However, it should be borne in mind that the percentage of water in the leaves at maturity does not actually represent the water-content of the live leaves, because many of the old leaves begin to wither towards maturity. The mature grain has a lower percentage of water, owing to the great accumulation of dry matter during maturation.

Dry Matter Content.

The continuous increase in the absolute amount of dry matter, and also the rate of increase, are shown in the following table :—

Table 9. Dry Matter of the Rice Plant.

	Plat	April 30	May 10	May 26	June 16	July 4
Dry Matter in	A	gr. 51.90	gr. 147.82	gr. 389.30	gr. 919.00	gr. 1,121.10
10 bundles of	B	44.13	139.63	398.30	816.00	1,101.40
Rice plant.	C	18.88	20.60	50.80	171.70	454.20
Increasing	A	% 4.6	% 13.3	% 35.0	% 82.6	% 100.0
Rate of Dry	B	4.0	12.7	36.2	74.1	100.0
Matter.	C	8.9	9.7	23.8	80.6	100.0

A perusal of the above table shows that the increasing rate of dry matter in the rice plant from the unmanured plat C, is very different from those of the well developed crops cultivated on plat A and B, which were treated with fertilizers. For instance, it is found that the dry matter in the rice plant raised on the nearly exhausted soil of plat C increases only a very little during the early part of its life, because the plant tillers very poorly. Consequently it is clear that the fertility of the soil affects the rate of the accumulation of dry mattar during the plant's life.

Climatic conditions may exert influence on the rate of increase

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of dry matter. But before entering into a discussion on this point, it seems of interest to remark on the relation of climatic conditions to the length of the plant's life. In the summer of 1914, rice grown from similar seed was raised both at Taihoku 臺北, Formosa, and at Shidzuoka 靜岡, 119 miles southwest of Tokio, Japan. The number of days for vegetative growth and maturation are given in the following table :--

Table 10. Number of Days for the Plant's Life.

Variety	Place	Days, transplantation to heading out	Days, heading out to maturity
Tankowhoilé, 短廣花螺, Formosan variety.	Shidzuoka	58	46
	Taihoku	73	31
Wōōkoku, 烏 殼, Formosan variety.	Shidzuoka	60	44
	Taihoku	78	34
Nakamura, 中 村, Japanese variety	Shidzuoka	72	51
	Taihoku	65	33

It is noticed in the above table that the length of the periods, which the rice crops at both places need for their vegetative growth and maturation, is very different. Although the kind of soil and fertilizer and the mode of carrying out the cultivation may have some influence on the development of the rice plant, they are not of sufficient importance to affect the length of the plant's life, when the rice crops are cultivated under normal conditions. However, it is believed that the temperature during the plant's life exercises a very important and direct influence on its growth. All these rice plants at Shizduoka take a greater number of days for their maturation than at Taihoku. The vegetative development of the Japanese variety, "Nakamura," cultivated at Shidzuoka, needs a longer time than at Taihoku, as is very usual when crops of a southern climate

※ The "number of days for the vegetative growth" is used to indicate the period from transplantation to the heading out of the panicles; and "heading out" means the stage, at which about 70 % of the rice plants under consideration produce panicles.

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are raised in a more northern land. It was described in a previous publication, viz: A Study of the Rice Plant produced in Formosa," S. K. S. Suzuki & Y. Ogata, (Agr. Expt. Stat. Formosa, Report No. 10), how the Japanese varieties, "Shiratama" 白玉 and "Miyako" 都 take about 73 days for their vegetative growth and 46 days for maturation, when they are cultivated at Kumamoto 熊本, Japan, whereas they grow for 68 days and mature for 34 days at Taihoku; that is, the northern varieties have a shortened period of growth and maturation in southern climates.

The contrary is the case with the Japanese varieties given in the above Table 10. The two Formosan crops have a shorter period for their vegetative growth in Shidzuoka than at Taihoku, and indeed it seems very probable that these Formosan crops originally belonged to varieties which were shorter lived. The temperature at Shidzuoka may be a very important factor in accounting for the peculiar reaction mentioned, viz: that the vegetative parts of these Formosan plants grow in a shorter period. Temperature during the actual crop seasons at both the places are compared in the following table:—

Table 11. Average Temperature (1914).

Month		Taihoku	Soidzuoka
March	1st ten days.	—	
	2nd „ „	17.2° C. (Transplanted March 18)	
	3rd „ „	21.0° „	
April	1st ten days.	19.3° „	
	2nd „ „	22.5° „	
	3rd „ „	25.3° „	
May	1st ten days.	22.0° „	
	2nd „ „	25.6° „	
	3rd „ „	24.2° „ (Heading out May 30—June 4)	
June	1st ten days.	25.0° „	21.6° C.
	2nd „ „	26.8° „	21.0° „
	3rd „ „	27.3° „	23.0° „ (Transplanted Juue 20)
July	1st ten days.	27.5° „ (Matured July 1—8)	25.9° „
	2nd „ „	27.3° „	25.8° „
	3rd „ „	28.3° „	25.6° „
Aug.	1st ten days.		27.4° „
	2nd „ „		26.0° „ (Heading out Aug. 17)
	3rd „ „		27.2° „
Sept.	1st ten days.		26.0° „
	2nd „ „		24.5° „
	3rd „ „		20.8° „
Oct.	1st ten days.		19.4° „ (Matured Oct. 2)
	2nd „ „		17.5° „
	3rd „ „		16.4° „

It will be noticed from the table that the crops are grown later in the year in Japan, and that the temperatures during the period of vegetative growth are a good deal higher at Shidzuoka, Japan, than at Taihoku, Formosa. Consequently the Formasan varieties cultivated at Shidzuoka, where the temperature is higher, rapidly reach, owing to their special characteristics, the full develop-

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ment of their vegetative organs, and produce panicles early.

Assuming that the nature of the short-life varieties is such that their vegetative organs develop more rapidly at a higher temperature, as is the case with the Formosan crops when raised at Shidzuoka; then if the Japanese short-life crops are cultivated at Taihoku, the duration of their vegetative growth should be longer than it is in their original localities. Yet the variety tests conducted in our Station with these kinds of Japanese crops show that their panicles come out too early and form practically no seed. This negative result appears to be in contradiction with the characteristics of the Formosan crops considered as short-life varieties. However, we may find an explanation in the increasing rate of temperature at Taihoku. At this latter place, the average temperature in the middle of March, when the young seedlings are usually transplanted, is about 17°C., and rises more rapidly than at Shidzuoka. Therefore the Japanese short-life varieties cultivated at Taihoku, must have, at a relatively young stage of growth, met with a higher temperature than that at which, in their original locality, they had become acclimatized, so as eventually to produce panicles. Thus at Taihoku they had too short a period of vegetative growth to yield grain.

Various local crops of the southern part of Formosa were cultivated at different places in 1908. The dates of transplantation, heading out, and maturity, are given in the following table :—

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Table 12. Number of Days for Vegetative Growth and Maturation.

Variety		Dates				Days			
		Akow. ※ (transplanted Feb. 10).		Taihoku (Transplanted April 6)		Akow		Taihoku	
		Heading out	Maturity	Heading out	Maturity	For vegetative growth	For maturation	For vegetative growth	For maturation
Seiyu	清油	April 17	May 22	June 14	July 15	67	35	69	31
Woolieu	烏粒	„ 25	„ 29	„ 16	„ 15	75	34	70	30
Tookow	通興	„ 23	„ 28	„ 15	„ 18	73	35	70	33
Nansisen	楠仔仙	„ 18	„ 20	„ 14	„ 14	68	31	69	30
kokiakhan	紅脚阪	„ 19	„ 22	„ 14	„ 14	69	33	69	30
Seiyu	清油	„ 21	„ 23	„ 17	„ 17	71	32	72	30
Kohikwa	虎皮花	„ 19	„ 21	„ 16	„ 12	69	32	71	26
Woolieu	烏粒	„ 24	„ 28	„ 16	„ 12	74	34	71	26
Rokio	瑯璚	" 26	„ 29	„ 20	„ 20	76	33	75	30
Hakkoku	白穀	„ 21	„ 24	„ 16	„ 15	71	33	71	29
Taiwoo	大烏	„ 20	„ 22	„ 17	„ 15	70	32	72	28
Hakuyo	白葉	„ 30	„ 31	„ 17	„ 15	80	31	72	28

On the whole these southern local crops have a somewhat shorter period for their vegetative growth in the northern climate, and their maturing process is completed in a shorter period than in their native locality. This might seem to run counter to the general observation that vegetation matures earier in southern climates. Yet the fact that the life of the rice plant is shorter in the northern part of Formosa than in the South, is due to the temperature during the actual rice crop season being higher at Taihoku than at Akow, as shown in the following table :—

※ Akow, 阿緱, is 245 miles south of Taihoku.

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Table 13. Average Temperature in the Rice Crop Season.

Month	Taihoku	Akow
February	—	— (Trnsplanted)
March	—	18.3° C.
April	20.8° C. (Transplanted)	22.1° „
May	24.3° „	25.2° „ (Matured)
June	26.3° „	—
July	27.8° „ (Matured)	—

As noted before, the length of vegetative growth and maturation may exert some influence on the increasing rate of accumulation of dry matter during the whole life of the rice plant. Unfortunately we have not sufficient date to enable us to come to definite conclusions on this subject, but a few facts are given below, by means of which the increasing rates of dry-matter accumulation in the entire plant can be compared.

Table 14. Rate of Increase in the Amount of Dry Matter.

Variety	Date	Days	Amount of Dry Matter	Rate of Increase
				%
Tankowhoile, 短廣花螺, (Formosan variety, transptanted April 1, 1913, (Taihoku)	April 30	30		4.3
	May 10	10		13.0
	May 26	16		35.6
	June 16 (Full bloom)	21		78.4
	July 4 (Maturity)	18		100.0
			Per tan	
※ Bungo, 豐後, (Japanese short-life variety)	June 30	9	10,608 Kgr.	1.8
	July 14	14	23,694 „	4.1
	July 28	14	76,840 „	13.3
	Aug. 11 (Heading out)	14	291,263 „	50.2
	Sept. 30 (Maturity)	50	579,305 „	100.0
※ Kowrimasu, 郡益, (Japanesemedium-life variety)	July 14	23	34.610 „	4.0
	July 28	14	123,950 „	14.4
	Aug. 11	14	391,645 „	45.5
	Aug 25 (Heading out)	14	703,579 „	81.7
	Oct. 13 (Maturity)	49	860,910 „	100.0
※ Buzen. 豐前, (Japanese long-life variety)	July 14	23	24,342 „	3.3
	July 28	14	100,290 „	13.5
	Aug 11	14	328,415 „	44.1
	Aug. 25	14	532,123 „	71.5
	Sept. 8 (Heading out)	14	787,050 „	105.7
	Oct. 39 (Maturity)	52	744,687 „	100.0

※ These three crops were transplanted on the 21st of June, 1901. v. "The Amount of Nitrogen in the Rice plant in Relation to its growth," by Matzuoko; Agr. Expt. Stat. Tokio. Report No. 28-p.165.

The dry matter of the above four varieties increases at nearly the same rate until five or six weeks from the time of transplantation. In the next fourteen days, by Aug. 11th, the short, medium and long life varieties reach 50.0%, 45.5% and 44.1% respectively; thus the increasing rates of the Japanese varieties which were cultivated under the same climatic conditions, are not very different in this period. Afterwards, the rates of increase entirely differ from one another, even under the same conditions, probably according to the peculiarities of the different varieties. As a rule the rate of increase in the amount of dry matter during maturation is less rapid than in the period of vegetative growth, the great increase of dry matter in the grain being a little more than counteracted by the very considerable decrease that takes place in the leaves and stems during the period of maturity. This latter fact was explained in the publication previously referred to, (v. p. 10).

It is vsry clearly noticed that the rate of increase of dry matter falls into three distinct periods throughout the rice plant's life.

I. Period of tillering. The increase of dry matter is very slow during the time that the plant tillers freely. In this period the number of panicles may be predicted.

II. Period of vegetative growth, or of increase in height. The dry matter in the plant body accumulates very rapidly up to the time of heading out or flowering.

III. Period of maturation. The dry matter in the grain increases in amount very rapidly, and that in the entire plant has either a gradual or a rapid increase, according to the particular varieties of rice plant.

Therefore these three periods, which farmers recognize by their external appearances, have a very important signification with regard to the formation of dry matter in the rice plant.

The Formosan crop has no such conspicuous distinction in the

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increasing rate of dry matter, as observed in the case of the Japanese varieties. However, it is not impossible to discern the same tendency in the direction of increasing rate. As described above, the Japanese and Formosan varieties have a somewhat similar rate of increase at the young stage of their life, yet in later life the Formosan crop has a very rapid increase in the amount of its dry matter, owing to the higher temperature and the much shorter period of maturation than in Japan.

Table 15. Amount of Dry Matter in the Parts of Rice Plant at Successive Stages of its Growth

Plat	From 10 bundles	April 30	May 10	May 26	June 16	June 26	July 4
		gr.	gr.	gr.	gr.	gr.	gr.
A	Entire Plant	51.99	147.82	389.30	919.00	—	1,112.10
	Leaves	22.63	54.78	130.10	171.20	190.50	146.60
	Stems	22.00	65.51	207.90	539.70	—	403.90
	Roots	7.36	27.53	51.30	63.10	65.90	80.40
	Grain				145.00	—	481.20
B	Entire Plant	44.13	139.63	398.30	816.00	—	1,101.40
	Leaves	18.92	53.98	125.50	143.50	131.50	129.10
	Stems	18.87	64.26	202.30	464.40	—	399.60
	Roots	6.34	21.39	70.50	66.80	57.40	78.30
	Grain				141.30	—	494.40
C	Entire Plant	18.88	20.60	50.80	171.70	—	213.00
	Leaves	7.84	7.58	18.80	30.40	31.80	24.40
	Stems	7.71	8.28	23.10	99.60	—	71.00
	Roots	3.33	4.74	8.90	17.90	—	13.00
	Grain				23.80	—	104.60

The absolute quantity of dry matter in the entire plant increases throughout its life; but in the various parts there are some fluctuations in the amounts at different stages, as the above table shows. The vegetative organs have an increase of dry matter until the time of flowering, but in the period of maturation the dry matter in the stems and leaves considerably diminishes, as the reproductive

organs develop at this stage. It is, therefore, believed that some reserve materials for the formation of grain are accumulated in the stems and leaves during the development of these organs. The nature of dry matter that disappears from these vegetative organs will be described later.

The amount of dry matter in the roots from plat A increases throughout the plant's life, but from plat B it decreases from the time of flowering. The weight of dry matter in the roots from the unmanured plat C also diminishes at the stage of maturity. Although it is very difficult to obtain perfect and complete specimens of the roots, these reductions in amount are too great to be regarded as due to errors in the preparation of the samples. However, we can not decide whether these decreases are due to the destruction of old roots, or to the translocation of nutrients to other organs.

The percentage of dry matter in the leaves, stems, roots and grain is given in the following table, to show the relative distribution at successive stages.

Table 16. Distribution of Dry Matter in the Parts of Rice Plant.

Plat		April 30	May 10	May 26	June 16	June 26	July 4
		%	%	%	%	%	%
A	Entire Plant	100.00	100.00	100.00	100.00	—	100.00
	Leaves	43.53	37.15	33.42	18.62	—	13.18
	Stems	42.31	44.16	53.39	58.72	—	36.31
	Roots	14.15	18.67	13.18	6.86	—	7.23
	Grain				15.77	—	43.26
B	Entire Plant	100.00	100.00	100.00	100.00	—	100.00
	Leaves	42.87	38.65	31.49	17.57	—	11.72
	Stems	42.75	46.02	50.79	56.91	—	36.28
	Roots	14.37	15.32	17.70	8.18	—	7.11
	Grain				17.32	—	44.88
C	Entire Plant	100.00	100.00	100.00	100.00	—	100.00
	Leaves	41.52	36.80	37.03	17.70	—	11.44
	Stems	40.82	40.18	45.38	57.99	—	33.36
	Roots	17.60	23.01	17.58	10.42	—	6.08
	Grain				13.88	—	49.12

It is found in the table that the relative percentage of dry

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matter in the leaves and in the stems do not differ much at the young stage, 30 days after transplantation, but that thence-forward it becomes greater in the stems, reaching a maximum at the time of flowering. A remarkable reduction of the percentage in the stems is noticed at maturity, at which time the grain has the heighest percentage. The percentage in the leaves decreases throughout the development of the rice plant, especially during the period of maturation, just as in the case of the stems. A great reduction in the percentage in the roots takes place after the time of flowering; this means that the roots do not develop so much as the other organs after the flowering season.

The organic constituents of the dry matter which is formed in the rice plant, will be explained in the following pages.

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Protein Content.

The protein substance in the parts of the rice plant was estimated by Stutzer's method, with the following results :—

Table 17. Percentage of Protein Substance in the Parts of the Rice Plant.

Plat			April 30	May 10	May 26	June 16	June 26	July 4
A	Expressed as percentage of dry matter	Entire Plant	% 16.15	% 11.71	% 5.83	% 4.86	% —	% 4.32
		Leaves	23.63	18.94	8.38	9.19	6.13	4.81
		Stems	11.19	7.94	4.56	3.00	2.88	2.38
		Roots	8.88	6.63	4.75	4.81	4.25	4.00
		Grain				6.69	6.31	5.88
	Amount of Protein in 10 bundles	Entire Plant	gr. 8.38	gr. 17.31	gr. 22.70	gr. 44.63	gr. —	gr. 48.00
		Leaves	5.31	10.31	10.88	15.69	11.63	7.00
		Stems	2.44	5.19	9.44	16.19	—	9.56
		Roots	0.63	1.81	2.38	3.06	2.75	3.19
		Grain				9.69	—	28.25
B	Expressed as percentage of dry matter	Entire Plant	% 14.32	% 12.58	% 6.81	% 4.73	% —	% 4.57
		Leaves	20.69	19.56	12.19	8.56	5.50	4.94
		Stems	9.38	8.75	4.13	2.94	2.25	2.75
		Roots	9.69	7.25	5.06	4.56	3.69	3.63
		Grain				6.94	—	6.13
	Amount of Protein in 10 bundles	Entire Plants	gr. 6.32	gr. 17.56	gr. 27.12	gr. 38.63	gr. —	gr. 50.38
		Leaves	3.94	10.50	15.25	12.25	7.19	6.38
		Stems	1.75	5.56	8.31	13.63	—	10.94
		Roots	0.63	1.50	3.56	3.00	2.06	2.81
		Grain				9.75	—	30.25
C	Expressed as percentage of dry matter	Entire Plant	% —	% 9.08	% 6.03	% 4.55	% —	% 5.00
		Leaves	23.63	14.81	9.75	9.69	5.63	6.13
		Stems	11.69	6.19	3.88	2.75	—	2.75
		Roots	—	6.69	4.38	4.25	5.44	3.94
		Grain				6.25	—	6.38
	Amount of Protein in 10 bundles	Entire Plant	gr. —	gr. 1.87	gr. 3.07	gr. 7.82	gr. —	gr. 10.65
		Leaves	1.88	1.06	1.81	2.94	1.79	1.50
		Stems	0.94	0.50	0.88	2.64	—	1.95
		Roots	—	0.31	0.38	0.75	—	0.51
		Grain				1.44	—	6.69

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It was stated in the previous publication (Agr. Expt. Stat. Formosa, Report No. 10, 1915) that the entire plant contained the highest percentage of nitrogen four or five weeks after transplantation. Similarly, in the present axperiments the percentage of protein is found to be highest at the young stage, and to decline rather rapidly when the plant begins vigorously to increase its amount of dry matter. Then, towards the end of maturation, the decrease in percentage is more gradual. Hence it is clear that the rice plant needs a relatively large quantity of protein substance to produce new culms in the period of tillering. Consequently, much nitrogenous manure should be supplied early in the plant's life.

The absolute quantity of protein in the entire plant gradually increases during the plant's development. The increase of protein is not proportionate to the total increase of dry matter, for there is a production of substances other than protein, which yield a larger contribution to the increase of dry matter. At a young stage the increase of protein proceeds more rapidly than that of the other dry matter; but in the period of vegetative growth the case is reversed.

The parts of the rice plant have a decreasing persentage of protein at successive stages of growth. the leaves are always found to have the highest percentage until the time of flowering, but a remarkable reduction in percentage takes place during maturation, owing to the translocation of protein to the stems, as will be described later. The decrease of percentage throughout the plant's life is greater in the leaves than in the stems. And the decrease of percentage in the roots is very slow after the sudden diminution which occurs at the young stage of growth,—(the roots have a rather higher percentage of protein in the period of tillering, new young roots being produced). The decrease in percentage of protein in the stems and leaves before the time of flowering, is dependent on the active production of dry matter other than protein in these organs, yet the reduction which appears during maturation is chiefly

caused by the transference of protein from these tissues.

The leaves, stems and grain are rather rich in protein, but the roots contain a smaller quantity of this nutrient. The absolute quantity of protein in the leaves is always greater than in the stems until the time of flowering. However, there is no great difference between the amounts of protein contained in the stems and in the leaves, when these vegetative organs reach their full development. Throughout the plant's life the absolute amount of protain in the leaves and stems is highest either just before heading out or at the time of flowering, and then it decreases towards the plant's maturity, being transferred to the grain. In the period of maturation the leaves lose a greater amount of protein than the stems, while the stems lose more starch, as will be seen later. Thus the stems do not supply so much protein to the grain, as the leaves do to the stems. Consequently, the leaves may be regarded as the main reserve organ for protein before maturation, and the stems for starch. The protein in the roots increases in amount until the time either of heading out or of flowering, but remains about constant during the later part of the plant's life.

Glucose, Saccharose, Dextrine and Starch Contents.

In the present experiments 9 bundles of representative plants were uprooted at successive stages of growth. Clear days were selected for the collection of the specimens, and the work of sampling in the field was carried out in all cases from 10:00 to 11:00 A.M. as it is a well known fact that the amounts of some of the organic nutrients in a plant vary not a little at different times of day. It may be interesting to give the results of analysis, which show the variation of some of the carbohydrates in the leaves of the rice plant in the morning and in the evening. About a hundred blades of equally well developed leaves, which were attached to the third joints from the top of the stems, were collected at 7:00 A.M. and 4:00

P. M. on the 29th of May, 1913. They were dried at 70°C., and analysed with the following results :—

Table 18. Carbohydrates in Leaves. (Expressed as percentage of dry matter).

	7 : 00 A. M.	4 : 00 P. M.	Difference
	%	%	%
Glucose	1.54	4.26	+ 2.72
Saccharose	2.82	4.43	+ 1.61
Starch	14.72	16.07	+ 1.35
Pentosane	18.96	17.01	— 1.95

We have no direct proofs which enable us to decide positively, whether the main cause of the reduction in the percentages of sugars in the morning, is their transformation into higher compounds or their migration from the leaves. The leaves collected in the evening and on the following morning proved that the weight of dry matter in the leaves is always greater in the evening than in the morning ; this means that the migration of soluble nutrients must be more actively performed in the night. Therefore, perhaps, the main cause of the diminution in the percentage of these carbohydrates in the morning is their translocation from the leaves. Assuming this is the case, then during the day the formation of glucose, saccharose and starch in the leaves, exceeds the amount transferred, and this results in the accumulation of these sugars towards evening. The percentage of pentosane is lower at 4:00 P.M., probably owing to a greater increase of organic matter other than pentosane. More samples were collected at 5:00 A. M. and at 4:00 P. M., when the rice plant was fairly mature. Sugars in the fresh leaves were extracted repeatedly by means of warm alcohol, and then inverted into reducing sugars. The results of analysis are given below :—

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Table 19. Percentage of the Total Reducing Sugars in the Fresh Leaves of the Rice Plant.

	5 : 00 A. M.	4 : 00 P. M.	Difference
Reducing Sugars(expressed as % age of dry matter)	4.46	6.47	+ 2.01
Percent of Water in the Fresh Leaves	65.07	64.56	— 0.51

On the other hand, more samples of the same fresh leaves were dried at 70° C. and analysed with the following results :—

Table 20. Percentage of the Total Reducing Sugar in the Leaves dried at 70° C.

	5 : 00 A. M.	4 : 00 P. M.	Difference
Reducing Sugars(expressed as % age of dry matter)	4.27	5.79	+ 1.52

An examination of the above tables shows that a small amount of the sugars disappear during the drying process at 70° C. Therefore the analysis of the first sample taken on May 29th might give a lower percentage of sugars, because it was dried at 70° C.

The qualitative test showed that the fresh rice plant has some enzymic action, which produces reducing sugars from the starch solution. Consequently, the fresh samples in the present experiment, after the separation of the leaves, grain and roots from the stems, were put in a water oven at 95° C., to check the enzymic action, and were afterwards dried at 70° C. The dried samples were finely ground for analysis.

The determination of sugars, dextrine and starch was carried out as follows. Reducing sugar and saccharose were repeatedly extracted from the finely ground sample, by applying a sufficient amount of warm alcohol (96 %), until the last extract gave no reducing action. The alcoholic extracts, after evaporation, were reduced to a small quantity, and were made up to a definite volume by adding water,

and then filtered so as to separate them from the fatty substances and chlorophyl that were dissolved in the alcohol. An aliquot part of the filtrate was taken in order to estimate, with Fehling's solution, the reducing sugars, and another part was hydrolised with a dilute solution of hydrochloric acid to determine saccharose. The sample treated with warm alcohol for the separation of sugars, was extracted with cold water to obtain the so-called dextrine, which was then inverted into reducing sugars. Finally, the same sample, from which the dextrine had been extracted, was digested with a dilute solution of hydrochloric acid, to convert the starch into reducing sugars. In this way the reducing sugars are produced not only from starch, but from all other hydrolisable carbohydrates which are insoluble in alcohol and cold water. The further procedure of analysis was carried out in the usual way with Fehling's solution.

It is necessary to note here that the roots contain a large amount of iron, which produces ferrous compound in hydrolysis with hydrochloric acid. The presence of the ferrous compound is easily recognized in neutralizing the hydrolised solution of the starch from the roots ; on adding a solution of sodium hydroxide to the hydrolised solution of starch, the precipitates of ferrous hydroxide mixed with ferric hydroxide have a dark green appearance. Morison, C. G. T. and Dayne, H. C., ("Ferrous Iron in Soils," Jour. Agr. Science Vol. IV. p. 97—1914), find that iron compounds in soils yield a large quantity of ferrous iron when the soils are digested with acid in the presence of organic matter. It is, therefore, to be expected that the roots of the rice plant which have a very high percentage of iron, produce ferrous compounds in digestion with acid. In neutralizing the hydrolised solution of starch, the ferrous iron is not precipitated entirely. Thus the reducing sugars, as well as the ferrous salts contained in the filtrate of the neutralized solution, act on the Fehling solution. Therefore a little excess of sodium hydroxide is to be added to the hydrolised solusion of starch until no precipitates are

given. The filtrate separated from hydroxides of iron is faintly re-neutralized, and treated with the Fehling solution in the usual way.

The results of analysis af glucose, saccharose, dextrine and starch are given in the following tables :—

Table 21. Glucose.

Plat			April 30	May 10	May 26	June 16	June 26	July 4
A	Expressed as percentage of dry matter	Entire Plant	2.87 %	2.14 %	2.95 %	2.75 %	— %	0.36 %
		Leaves	4.56	1.81	0.79	2.76	2.15	0.58
		Stems	2.13	3.09	4.92	3.49	1.06	0.73
		Roots	0.00	0.59	0.50	1.12	1.00	0.33
		Grain				0.69	trace	trace
	Amount of Glucose in 10 hundles	Entire Plant	1.49 gr.	3.17 gr.	11.49 gr.	25.25 gr.	— gr.	4.05 gr
		Leaves	1.03	0.99	1.02	4.72	4.09	0.85
		Stems	0.46	2.02	10.22	18.83	—	2.94
		Roots	0.00	0.16	0.25	0.70	0.65	0.26
		Grain				1.00	trace	trace
B	Expressed as percentage of dry matter	Entire Plant	3.31 %	— %	3.58 %	3.56 %	— %	0.47 %
		Leaves	4.47	3.31	4.16	2.61	1.75	0.67
		Stems	2.79	2.20	4.27	5.03	1.43	0.72
		Roots	1.21	—	0.59	1.28	1.17	0.43
		Grain				0.80	trace	0.20
	Amount of Glucose in 10 bundles	Entire Plant	1.46 gr.	— gr.	14.26 gr.	29.08 gr.	— gr.	5.04 gr.
		Leaves	0.85	1.78	5.22	3.74	2.30	0.86
		Stems	0.53	1.41	8.63	23.36	—	2.87
		Roots	0.08	—	0.41	0.85	0.67	0.33
		Grain				1.13	trace	0.98
C	Expressed as percentage of dry matter	Entire Plant	— %	2.43 %	2.54 %	2.98 %	— %	0.48 %
		Leaves	trace	2.23	2.22	2.05	1.06	1.24
		Stems	trace	3.94	3.42	4.07	1.27	0.51
		Roots	0.00	0.47	1.05	1.13	0.67	0.73
		Grain				1.03	trace	0.26
	Amount of Glucose in 10 bundles	Entire Plant	— gr.	0.50 gr	1.29 gr.	5.11 gr.	— gr.	1.02 gr.
		Leaves	trace	0.16	0.41	0.62	—	0.30
		Stems	trace	0.32	0.79	4.05	—	0.36
		Roots	0.00	0.02	0.09	0.20	—	0.09
		Grain				0 24	—	0.27

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Table 22. Saccharose.

Plat			April 30	May 10	May 26	June 16	June 26	July 4
A	Expressed as percentage of dry matter.	Entire Plant	% 0.83	% 1.52	% 1.60	% 2 83	% —	% 0.56
		Leaves	0.84	1.40	0.64	1.78	0.74	0.38
		Stems	1.13	2.10	2.49	3.91	0.62	0.37
		Roots	0.00	0.44	0.45	1.76	0.24	trace
		grain				0.50	0.91	0.88
	Amount of Saccharose in 10 bundles.	Entire Plant	gr. 0.43	gr. 2.25	gr. 6.23	gr. 25.97	gr. —	gr 6.27
		Leaves	0.19	0.76	0.83	3.04	1.40	0.55
		Stems	0.24	1.37	5.17	21.10	—	1.49
		Roots	0.00	0.12	0.23	1.11	0.15	trace
		Grain				0.72	—	4.23
B	Expressed as percentage of dry matter.	Entire Plant	% 1.77	% —	% —	% 4.67	% —	% 0.65
		Leaves	3.01	—	0.63	2.23	0.54	0.44
		Stems	1.00	2.13	—	7.12	2.01	0.81
		Roots	0.00	0.73	0.45	1.47	0.59	0.45
		Grain				0.61	0.95	0.61
	Amount of Saccharose in 10 bnudles,	Entire Plant	gr. 0.76	gr. —	gr. —	gr. 38.10	gr —	gr. 7.16
		Leaves	0.57	—	0.79	3.20	0.71	0.56
		Stems	0.19	1.38	—	33.06	—	3.23
		Roots	0.00	0.15	0.31	0.98	0.33	0.35
		Grain				0.86	—	3.02
C	Expressed as percentage of dry matter.	Entire Plant	% —	% 1.26	% 2.20	% 4.41	% —	% 0.57
		Leaves	trace	0.47	1.44	4.28	1.53	1.19
		Stems	trace	2.66	3.57	5.82	1.89	0.45
		Roots	0.00	0.23	0.34	0.32	0.27	1.06
		Grain				1.89	0.84	0.44
	Amount of Saccharose in 10 bundles.	Entire Plant	gr. —	gr 0.26	gr. 1.12	gr. 7.58	gr. —	gr. 1.21
		Leaves	trace	0.03	0.27	1.30	—	0.29
		Stems	trace	0.22	0.82	5.79	—	0.32
		Roots	0.00	0.01	0.03	0.05	—	0.14
		Grain				0.44	—	0.46

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Table 23. Dextrine.

Plat			April 30	May 10	May 26	June 16	June 26	July 4
A	Expressed as percentage of dry matter	Entire Plant	% 0.00	% 0.00	% 0.92	% 0.88	% —	% 0.35
		Leaves	0.00	0.00	0.72	0.34	0.43	0.44
		Stems	0.00	0.00	1.14	1.26	0.49	0.42
		Roots	0.00	0.00	0.56	0.39	0.34	0.28
		Grain		0.00		0.30	0.40	0.29
	Amount of Dextrine in 10 bundles	Entire Plant	gr. 0.00	gr. 0.00	gr. 3.58	gr. 8.05	gr. —	gr. 3.94
		Leaves	0.00	0.00	0.93	0.58	0.81	0.64
		Stems	0.00	0.00	2.37	6.80	—	1.69
		Roots	0.00	0.00	0.28	0.24	0.22	0.22
		Grain				0.43	—	1.39
B	Expressed as percentage of dry matter	Entire Plant	% 0.00	% 0.34	% 0.59	% 0.61	% —	% 0.35
		Leaves	0.00	0.00	0.79	0.46	0.61	0.28
		Stems	0.00	0.76	0.55	0.76	0.66	0.44
		Roots	0.00	0.00	0.37	0.34	—	0.22
		Grain				0.39	0.33	0.31
	Amount of Dextrine in 10 bundles	Entire Plant	gr. 0.00	gr. 0.48	gr 2.36	gr. 4.95	gr. —	gr. 3.81
		Leaves	0.00	0.00	0.99	0.66	0.80	0.36
		Stems	0.00	0.48	1.11	3.52	—	1.75
		Roots	0.00	0.00	0.26	0.22	—	0.17
		Grain				0.55	—	1.53
C	Expressed as percentage of dry matter	Entire Plant	% —	% 0.49	% 0.77	% 0.77	% —	% 0.38
		Leaves	0.00	0.47	0.80	0.57	trace	0.39
		Stems	0.00	0.67	0.88	0.98	0.61	0.46
		Roots	0.00	0.41	0.48	0.47	0.35	0.31
		Grain				0.47	trace	0.33
	Amount of Dextrine in 10 bundles	Entire Plant	gr. —	gr. 0.10	gr. 0.39	gr. 1.32	gr. —	gr. 0.81
		Leaves	0.00	0.03	0.15	0.17	—	0.10
		Stems	0.00	0.05	0.20	0.97	—	0.33
		Roots	0.00	0.02	0.04	0.08	—	0.04
		Grain				0.10	—	0.35

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Table 24. Starch.

Plat			April 30	May 10	May 26	June 16	June 26	July 4
A	Expressed as percentage of dry matter	Entire Plant	% 14.80	% 20.29	% 22.97	% 26.28	% —	% 39.77
		Leaves	12.02	17.91	16.54	18.67	18.24	22.04
		Stems	15.20	20.68	26.18	26.08	21.94	21.81
		Roots	22.06	24.18	26.34	24.98	24.03	21.00
		Grain				36.60	58.97	63.38
	Amount of Starch in 10 bundles	Entire Plant	gr. 7.68	gr. 30.00	gr. 89.44	gr. 241.54	gr. —	gr. 442.26
		Leaves	2.72	9.81	21.51	31.96	34.74	32.31
		Stems	3.34	13.54	54.42	140.75	—	88.09
		Roots	1.62	6.65	13.51	15.76	15.83	16.88
		Grain				53.07	—	304.98
B	Expressed as percentage of dry matter	Entire Plant	% —	% 21.93	% 22.82	% 27.07	% —	% 40.71
		Leaves	9.98	16.98	17.94	18.87	21.80	21.12
		Stems	22.00	65.72	26.35	26.10	—	23.32
		Roots	—	23.10	21.32	26.78	—	22.18
		Grain				38.76	60.50	62.83
	Amount of Starch in 10 bundles	Entire Plant	gr. 7.98	gr. 30.62	gr. 90.84	gr. 220.91	gr. —	gr 448.43
		Leaves	1.89	9.16	22.51	27.07	28.66	27.26
		Stems	4.15	16.52	53.39	121.20	—	93.18
		Roots	—	4.94	15.03	17.88	—	17.36
		Grain				54.76	—	310.63
C	Expressed as percentage of dry matter	Entire Plant	% 21.50	% 19.08	% 22.81	% 26.34	% —	% 42.26
		Leaves	17.89	15.48	19.96	18.42	—	19.86
		Stems	26.54	20.45	23.86	29.12	—	23.13
		Roots	18.30	22.60	26.28	19.48	—	27.80
		Grain				30.07	—	62.27
	Amount of Starch in 10 bundles	Entire Plant	gr. 4.06	gr. 3.93	gr. 11.59	gr. 45.22	gr. —	gr. 90.01
		Leaves	1.40	1.17	3.75	5.59	—	4.85
		Stems	2.05	1.69	5.51	29.00	—	16.42
		Roots	0.61	1.07	2.33	3.48	—	3.61
		Grain				7.15	—	65.13

The reducing sugar in the plant's body of rice is probably dextrose, its osazone having crystallized in yellow needles which melted at 104°—105° C. The non-reducing sugar crystallized rather easily from the alcoholic extract, and it is called provisionally, in the present paper, "saccharose." These sugars and dextrine are not stored in reserve to such a large extent as are starch, pentosane, cellulose etc., but are transformed into higher compounds during the plant's development. Hence a rather small amount of these carbhydrates are found in the entire plant even at maturity, though other organic substances reach a maximum at this stage. In the later period of the growth of vegetative organs a very vigorous synthesis of soluble carbohydrates takes prace, and a great quantity of insoluble higher carbohydrates accumulate in the vegetative tissues, especially in the stem.

The leaves and stems contain a very high percentage of soluble carbohydrates before maturation, but the grain has a very small percentage. These lower carbohydrates after migrating into the grain, there undergo a fairly complete transformation, and serve as a store of reserve material for the nutriment of seeds. The absolute quantity of these sugars in the stems is always greater than in the leaves. It seems that these soluble substances produced in the leaves enter the stems and accumulate there,—translocation from the leaves being more active than transformation in the stems and migration into the grain.

In comparing the amounts of glucose and saccharose, we find that the latter sugar is more abundantly stored in the stems at the time of blossoming and also in the mature grain. W. P. Kelley and A. R. Thompson, (Hawaii Agr. Expt. Stat Bull. No. 21), obtained 6.53% of reducing sugar and 10.38% of saccharose in the stems of the rice crop collected before the period of flowering. We have no exact knowledge of the process of formation of higher carbohydrates from the lower bodies; however, the greater accumulation of saccha-

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rose in the plant organs, where the soluble sugars change very actively into insoluble nutrients, suggests that in the plant body of rice the transformation of saccharose into higher compounds does not proceed so rapidly as does that of glucose. In a similar way, a great deal of saccharose may be stored in the stems of sugar cane and in the roots of sugar beet.

In maize just after flowering, the percentage of reducing sugar exceeds that of saccharose ; yet the latter sugar is found to have a greater percentage towards maturity. The percentages of these sugars during the maturation of maize are as follows ;

Table 25. Percentage of Carbohydrates in Maize.
(Portelle, Landw. Versuchsstat. XXXII—241—1885)

Date of Harvest	Fructose	Saccharose	Starch
	%	%	%
After flowering	13.61	12.21	27.90
Corn at mealy stage	6.13	8.62	48.88
Corn harden and yellow	2.72	5.83	54.23
When hairs of corn withered	1.43	2.45	54.87
Full ripe	?	0.04	64.26

It is noticed in T. E. Keitt's work entitled "Sweet Potato Investigation," (South Carolina Agr. Expt. Stat. Bull. No. 165--29--1912), that when this crop approaches maturity, there is a similar relation between the amounts of glucose and of saccharose, as observed in the case of ripening maize. Some results of his analysis are given in the following table :—

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Table 26. Percentage of Glucose and Saccharose in Sweet Potato

Name of Variety	Date of Harvest	Glucose	Saccharose
		%	%
Pumpkin yam	Aug. 31—1909	13.03	2.50
	Sept. 10 „	11.98	5.73
	Sept. 21 „	6.18	8.94
	Oct. 10 „	3.95	9.95
	Oct, 26 „	4.50	14.70
Purple yam	Aug. 31— „	8.26	5.51
	Sept. 10 „	9.18	3.51
	Sept. 21 „	3.70	4.76
	Oct. 2 „	6.77	5.18
	Oct. 10 „	2.76	7.55
	Oct. 26 „	4.06	6.50
Polo	Aug. 31 „	6.87	2.32
	Sept. 10 „	6.99	8.88
	Sept. 21 „	6.07	4.16
	Oct. 2 „	4.18	3.06
	Oct. 10 „	3.04	6.01
	Oct. 26 „	3.33	7.61
Brazilian	Aug. 31 „	7.06	5.57
	Sept. 10 „	8.26	3.98
	Sept. 21 „	2.61	7.16
	Oct. 10 „	3.85	7.70
	Oct. 26 „	4.84	8.26

In potato tubers, the percentage of non-reducing sugar always becomes greater than that of the reducing sugar in the process of storing starch. This is shown in the following table :—

Table 27. Percentage of Reducing Sugar and Non-Reducing Sugar in Potatoes.

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(F. Huhngerbuhler, Landw. Versuehsstat. XXX, 381–1886)

Date	Reducing Sugar	Reducing suger after Inversion	Starch
	%	%	%
June 23	6.40	—	56.7
June 30	0.33	4.50	61.3
July 7	0.72	4.69	66.3

All these facts favor the view of a slower transformation of saccharose into higher compounds, although saccharose does not play the same rôle in the development of all other plants, as found in T. Keitt's experiments with the grains of oat-plants, (v. South Carolina Agr. Expt. Stat. Bull. No. 165).

It is observed in Tables 21 and 22, entitled "Glucose" and "Saccharose," that the leaves colled between 10 : 00 and 11 : 00 A. M. contain a greater amount of glucose than saccharose. This is probably due to a more active formation of glucose, than to migration from the leaves. The percentages of these sugars contained in the leaves in the morning and in the evening, are cited again from Table 18, for ready reference, to show the active production of glucose.

Table 28. Percentage of Sugars in Leaves.

	Leaves collected at		Difference
	7 : 00 A. M.	4 : 00 P. M.	
	%	%	
Reducing Sugar	1.54	4.26	2.72
Saccharose	2.82	4.43	1.61

In the morning the leaves contain a much lower percentage of glucose than of saccharose. By evening the glucose and the saccharose have increased by 2.72 % and 1.61 % respectively. The migration and transformation of these sugars must exert a very considerable influence on their accumulation in the leaves. It may be believed that the more active transformation of glucose than of saccharose in the stems and grain, as described above, is also true

of the leaves to some extent; but assuming that the more rapid transformation of glucose occurs in the stems, then the leaves should be expected to supply much glucose for this continous transformation. Thus, the glucose produced in the leaves must enter the stems more rapidly than the saccharose does. Accordingly, if the migration and transformation of glucose contained in the leaves are quicker than the migration and transformation of saccharose, the greater accumuration of glucose found in the leaves at evening must be due to the more active production of glucose during the day.

If these sugars exist in a dissolved state in the cell-sap of the rice plant, the strength of sugar solution at the time of flowering and at maturity should be as follows :—

Table 29. Sugar Solution in the Plant Body.

	Plat		Time of Flowering ; June 16	Maturity ; July 4
			%	%
Glucose	A	Leaves	1.30	0.52
		Stems	0.94	0.17
		Grain	0.54	—
	B	Leaves	1.35	0.68
		Stems	1.60	0.19
		Grain	0.66	0.55
Saccharose	A	Leaves	0.84	0.34
		Stems	1.06	0.09
		Grain	0.39	2.39
	B	Leaves	1.15	0.44
		Stems	2.27	0.22
		Grain	0.50	1.70

It should be borne in mind, however, that these figures are only approximate, because the method of water estimation gives not only the total sum of free and combined water in the plant body but also any substances that are evaporable at 100° C. As explained

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before, the plant body contains a great amount of water at the time of flowering. It was, consequently, expected that cell-sap might be rather dilute at that time. Yet, as a matter of fact, in the leaves and stems the solutions of these sugars are more highly concentrated than at maturity, although the plant body contains a less amount of water at the latter stage. The solution of saccharose in the grain becomes denser towards maturity, owing to the slower transformation or the accumulation of saccharose in the maturing grain, from which much water does not evaporate. Approaching maturity, most of ehe leaves begin to wither and hence to lose water; and by the time of maturity there is but a small amount of water found in them Accordingly, as shown in the above table, the cell-sap in the leaves at maturity is densely impregnated with these sugars, while a dilute solution is observed in the stems, which latter contain a large amount of water and transmit these soluble carbohydrates to the grain.

All the parts of rice plant contain a very small amount of dextrine in comparison with the quantity of soluble sugars. At the young stage of the rice crop dextrine can not be detected, as Table 23, "Dextrine", shows, yet it (dextrine) appears in the various parts of the rice plant when the absolute amount of dry matter in the entire plant begins to increase rapidly. The stems at the time of flowering are found to contain the highest amount of dextrine, and at maturity dextrine decreases in amount, as do the other soluble carbohydrates. Therefore dextrine seems to be easily convertible into higher carbohydrates in the vegetative organs such as the stems and leaves. However, the accumulation of dextrine takes place in the maturing grain. It is not possible to ascertain whether this substance is a compound intermediate between the lower soluble sugars and the higher insoluble carbohydrates in the plant's body, or a by-product of the formation of higher compounds from the sugars.

There is another consideration, viz: that if soluble starch be

present in the plant, as is sometimes the case, it exerts a considerable influence on the analytical estimates of dextrine, because, what we call dextrine, in this paper, represents non-reducing carbohydrates which are insoluble in alcohol of 90% but soluble in cold water. Hence it would appear that, from this point of view, the amount of the so-called dextrine may vary in proportion to the amount of soluble starch in the parts of rice plant.

The percentage of protein has a gradual decrease throughout the plant's life, as is shown in Table 17, under the heading "Protein". On the other hand, the percentage of insoluble starch in the entire plant rises with the increase of dry matter, and the most active production of starch takes place in the maturing grain. In the leaves there is an increasing percentage of starch throughout the plant's life; while the percentage of starch in the stems rises rathar rapidly after the period of tillering,— owing to the vigorous formation of starch in the stems during the period of vegetative growth, – and declines during maturation. The roots resemble the stems with respect to the fluctuations in their percentage of starch.

The absolute quantities of starch contained in the various parts of the rice plant gradually and steadily increase during the period of tillering. But afterwards a rapid increase takes place in ths stems until the flowering stage, while at the same time in the leaves and roots there is only a slow increase. A large amount of starch disappears in the stems after the time of flowering, at which period the highest amount of starch is contained in those organs. It is, therefore, believed that the stems of the rice plant store starch to furnish carbohydrates for the formation of grain. But the leaves do not seem to perform a similar physiological function, at any rate to such a degree that there is a great reduction in the amount of starch in the results given by analysis. Thus, while a decreasing amount of starch is found in the stems during maturation, a conspicuous loss of protein takes place in the leaves, as previously stated.

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Pentosane and Crude Fibre Contents.

Pentosane was estimated by the process of furfurol formation, being calculated from the phloroglucid. The determination of crude fiber was conducted according to Wende's method. The results of analysis at different stages of growth are given in the following tables :--

Table 30. Pentosane.

Plat			April 30	May 10	May 26	June 16	June 26	July 4
A	Expressed as percentage of dry matter	Entire Plant	19.23 %	18.64 %	21.67 %	19.56 %	— %	17.14 %
		Leaves	16.14	17.50	22.32	21.09	22.89	22.68
		Stems	20.41	19.17	20.29	19.21	25.35	25.58
		Roots	25.06	23.37	25.67	25.28	24.23	20.78
		Grain				16.59	8.45	7.78
	Amount of Pentosane in 10 bundles	Entire Plant	9.98 gr.	27.56 gr.	84.37 gr.	179.77 gr.	— gr.	190.65 gr.
		Leaves	3.65	9.58	29.03	36.10	43.60	33.24
		Stems	4.49	12.55	42.18	103.67	—	103.31
		Roots	1.84	5.43	13.16	15.95	15.96	16.67
		Grain				24.05	—	37.43
B	Expressed as percentage of dry matter	Entire Plant	20.82 %	19.38 %	20.06 %	20.15 %	— %	16.90 %
		Leaves	16.60	18.60	21.13	21.59	23.78	23.40
		Stems	19.71	18.84	18.69	19.71	25.30	25.22
		Roots	—	23.04	22.13	24.72	—	21.94
		Grain				18.00	8.89	7.69
	Amount of Pentosane in 10 bundles	Entire Plant	— gr.	27.06 gr.	79.91 gr.	164.45 gr.	— gr.	186.16 gr.
		Leaves	3.14	10.04	26.51	30.98	31.27	30.21
		Stems	3.72	12.10	37.80	91.53	—	100.77
		Roots	—	4.92	15.60	16.51	—	17.17
		Grain				25.43	—	38.01
C	Expressed as percentage of dry matter	Entire Plant	17.85 %	20.78 %	23.09 %	20.56 %	— %	16.29 %
		Leave	15.85	19.19	20.83	21.73	23.50	20.95
		Stems	17.70	19.45	23.16	19.43	25.84	25.52
		Roots	23.12	26.00	27.88	24.63	25.21	27.24
		Grain				20.80	9.30	7.57
	Amount of Pentosane in 10 bundles	Entire Plant	3.37 gr.	4.28 gr.	11.73 gr.	35.30 gr.	— gr.	84.69 gr.
		Leaves	1.24	1.45	3.91	6.60	—	5.11
		Stems	1.36	1.60	5.34	19.35	—	18.12
		Roots	0.77	1.23	2.48	4.40	—	3.54
		Grain				4.95	—	7.92

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Table 31. Crude Fibre.

Plat			April 30	May 10	May 26	June 16	June 26	July 4
A	Expressed as percentage of dry matter	Entire Plant	31.60 %	32.52 %	30.89 %	29.17 %	— %	25.61 %
		Leaves	24.91	27.63	30.61	27.05	30.00	26.80
		Stems	34.13	34.27	30.13	28.96	38.11	38.19
		Roots	44.52	38.10	34.71	28.99	35.93	40.66
		Grain				32.52	—	12.19
	Amount of Crude Fiber in 10 bundles	Entire Plant	16.40 gr.	48.06 gr.	120.26 gr.	268.03 gr.	— gr.	284.86 gr.
		Leaves	5.63	15.13	39.82	46.30	57.15	39.28
		Stems	7.50	22.45	62.64	156.29	—	154.24
		Roots	3.27	10.48	17.80	18.29	23.67	32.69
		Grain				47.15	—	58.65
B	Expressed as percentage of dry matter	Entire Plant	34.15 %	27.09 %	30.27 %	29.81 %	— %	25.16 %
		Leaves	30.41	23.99	27.22	28.26	30.15	29.61
		Stems	34.81	27.64	30.12	30,00	—	36.92
		Roots	43.32	33.38	36.17	33.51	34.90	40.58
		Grain				29.00	14.45	12.06
	Amount of Crude Fiber in 10 bundles	Entire Plant	15.07 gr.	37.83 gr.	120.58 gr.	243.22 gr.	— gr.	277.14 gr.
		Leaves	5.75	12.94	34.16	40.55	39.64	38.22
		Stems	6.57	17.76	60.93	139.32	—	147.53
		Roots	2.75	7.13	25.49	22.38	20.03	31.77
		Grain				40.97	—	59.62
C	Expressed as percentage of dry matter	Entire Plant	31.57 %	28.01 %	28.98 %	29.62 %	— %	24.50 %
		Leaves	27.27	24.81	26.80	26.95	27.99	30.11
		Stems	31.46	27.82	29.24	28.02	36.36	38.93
		Roots	41.76	33.62	33.13	34.88	32.34	31.61
		Grain				35.87	14.62	12.50
	Amount of Crude Fiber in 10 bundles	Entire Plant	5.96 gr.	5.77 gr.	14.72 gr.	50.86 gr.	— gr.	52.18 gr.
		Leaves	2.14	1.88	5.03	8.19	—	7.35
		Stems	2.43	2.30	6.75	27.90	—	27.64
		Roots	1.39	1.59	2.94	6.24	—	4.11
		Grain				8.53	—	13.08

Pentosane and crude fibre constitute a rather high percentage of the entire plant, even at the young stage, and their percentages vary in a different manner from those of starch and protein throughout the plant's life. As described before, starch gradually increases in percentage throughout the life of the rice plant; whereas protein has a gradual decrease after the rather rapid reduction of its percentage which occurs either at an early stage of the plant's life or after

the period of tillering. The entire plant contains about twenty percent of pentosane and thirty percent of crude fibre, from the early stage of growth until the time of flowering, Later, at the time of maturity, there is reduction in the percentage of these carbohydrates. This reduction does not mean that the absolute amount of pentosane and crude fibre produced in the entire plant diminishes, but that a considerable production of starch during maturation lowers the percentage of these carbohydrates. On the whole, the variation in the percentage of pentosane throughout the plant's life seems to have a certain relation to the production of crude fibre. A similar phenomenon is found in the development of some other plants. However, the amounts of these carbohydrates are not always in the same proportions : the ratio of pentosane to crude fibre fluctuates from about 52% to 72%, becoming greater towards maturity.

The percentage of crude fibre in the roots is very high throughout the plant's life. But the percentage of pentosane, which maintains a high rate till the time of flowering, diminishes at maturity, owing to a rather large increase of crude fibre ; yet, be it noted, the absolute amount of pentosane does not decrease during maturation.

The stems are found to have an increase in the absolute amounts of their pentosane and crude fibre at successive stages of growth. The percentage of pentosane contained in the stems is already fairly high in the period of tillering, and drops a little in the course of development, finally increasing again towards maturity to a much greater extent than at the stage of tillering. Such fluctuations are more clearly observed in the percentage of crude fibre in the stems. The increase of these carbohydrates at maturity is caused, in a large degree, by the considerable decrease in the absolute amount of starch that is reserved in the stems. In a word, the fluctuations in the percentages of pentosane and crude fibre are greatly influenced by the amount of protein and starch that are produced in the stems.

Leaves have a gradual increase in the percentage of pentosane throughout the whole life of the rice plant. The percentage of crude fibre in the leaves collected from plat A are not identical with those of the leaves from plat B. However, a somewhat similar variation can be traced in their percentages ; that is, the percentage of crude fibre increases, (though not to so great an extent), when the plant body is vigorously developing, and slightly decreases during maturation. Therefore the variations of percentage of crude fibre in the leaves and in the stems are dissimilar,—(the variation in the stems has been described above) ; and the differences are largely due to the quantities of starch that are produced in these organs. Hoffmeister found, in his investigation on barley and clover, (v. Czapeck : Biochem. d. Pflanz. I Band, p. 657—1913), that the crude fibre in the stems increases throughout the life of these plants, and that the leaves lose a part of this substance towards the end of maturity. In the present experiments the same fact is noticed in the corresponding part of the rice plant. From a physiological stand point, it is very interesting to note that the absolute amount of pentosane and crude fibre in the leaves reaches a maximum at the time of flowering, and decreases in the later period of maturation. This indicates that a part of the pentosane and crude fibre in the leaves undergoes a chemical change towards the end of the plant's life, in spite of the fact that the carcohydrates, which usually constitute the frame work of the plant, are considered to be rather stable compounds. The results of analysis, which show that the stems and roots may either a slight decrease or a great inclease in the absolute amount of these carbohydrates at maturity, do not confirm the supposed impossibility of a transformation of these carbohydrates into other subttances ; because, if the formation of pentosane and crude fibre takes place more actively than the catabolic function, analysis should indicate that there is only an increase of these carbohydrates and never a decrease. From general physiological considerations, assuming that

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the catabolic process in the leaves is a predominant factor during maturation, the decreasing amount of pentosane and crude fibre in the leaves at maturity signifies nothing but the transformation of these stable carbohydrates into other substances. It is, therefore, quite conceivable that the carbohydrates under consideration serve as reserve materials, in certain cases, in the vegetative parts of plant. Cotyledons of Phaseolus vulgaris were found to have a decreasing amount of pentosane, when in a state of germination,—i. e. at the time when the easily convertible reserve materials of the cotyledons are exhausted in furnishing nutrients for the development of the young plant, (v. K. Miyake, Jour. Col. Agr. Tokoku, Vol. IV, No. 8—334). In other words, pentosane is transformed into other substances when the catabolic action predominates in the cotyledons. It might be surmised that there is a decrease of crude fibre in the cotyledons of phaseolus vulgaris at the stage of germination, in which the pentosane is disappearing, as in the case of the leaves of the rice plant.

The grain has an increasing amount of pentosane and crude fibre during maturation, while the percentage of these carbohydrates declines, owing to the increase in the amount of starch and protein. A greater part of these carbohydrates is used in the formation of chaff, but not of husked rice, because the latter usually contains about 1.5 % of pentosane and 1.0 % of crude fibre.

Inorganic Ingredients.

The distribution of inorganic ingredients in the different parts of the rice plant, and the variation of their absolute amounts, at successive stages of the plant's growth, will be discussed in the following pages.

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Table 32. Nitrogen.

Plat			April 30	May 10	May 26	June 16	June 26	July 4
A	Expressed as percentage of dry matter	Entire Plant	3.27 %	2.54 %	1.63 %	0.87 %	— %	0.77 %
		Leaves	4.57	3.88	2.34	1.55	1.15	0.79
		Stems	2.45	1.88	1.36	0.58	0.46	0.43
		Roots	1.75	1.48	0.98	0.77	0.71	0.69
		Grain				1.19	—	1.06
	Amount of Nitrogen in 10 bundles	Entire Plant	1.70 gr.	3.75 gr.	6.36 gr.	7.98 gr.	— gr.	8.53 gr.
		Leaves	1.03	2.12	3.04	2.65	2.19	1.15
		Stems	0.54	1.23	2.82	3.13	—	1.73
		Roots	0.12	0.40	0.50	0.48	0.46	0.55
		Grain				1.72	—	5.10
B	Expressed as percentage of dry matter	Entire Plant	2.79 %	2.18 %	1.31 %	0.90 %	— %	0.77 %
		Leaves	3.95	3.28	2.22	1.64	0.96	0.86
		Stems	2.04	1.53	0.88	0.59	0.46	0.44
		Roots	1.58	1.36	0.92	0.80	0.66	0.62
		Grain				1.21	—	1.03
	Amount of Nitrogen in 10 bundles	Entire Plant	1.23 gr.	3.04 gr.	5.20 gr.	7.31 gr.	— gr.	8.43 gr.
		Leaves	0.75	1.77	2.78	2.35	1.26	1.11
		Stems	0.38	0.98	1.78	2.73	—	1.75
		Roots	0.10	0.29	0.64	0.53	0.37	0.48
		Grain				1.70	—	5.09

Table 33. Phosphoric acid.

Plat			April 30	May 10	May 26	June 16	June 26	July 4
A	Expressed as percentage of dry matter	Entire Plant	— %	0.72 %	0.72 %	— %	— %	0.51 %
		Leaves	—	0.53	0.73	0.46	0.51	0.47
		Stems	1.19	0.97	0.81	0.63	0.51	0.45
		Roots	—	0.52	0.35	0.24	0.28	0.25
		Grain				—	0.62	0.61
	Amount of Phosphoric Acid in 10 bundles	Entire Plant	— gr.	1.07 gr.	2.81 gr.	— gr.	— gr.	5.65 gr.
		Leaves	—	0.29	0.95	0.79	0.97	0.69
		Stems	0.26	0.64	1.68	3.40	—	1.82
		Roots	—	0.14	0.18	0.15	0.18	0.20
		Grain				—	—	2.94
B	Expressed as percentage of dry matter	Entire Plant	— %	0.61 %	0.65 %	0.54 %	— %	0.54 %
		Leaves	0.68	0.57	0.55	0.54	—	0.52
		Stems	1.06	0.77	0.82	0.55	0.47	0.46
		Roots	—	0.25	0.36	0.20	0.28	0.24
		Grain				0.68	0.61	0.65
	Amount of Phosphoric Acid in 10 bundles	Entire Plant	— gr.	0.85 gr.	2.60 gr.	4.41 gr.	— gr.	5.91 gr.
		Leaves	0.13	0.31	0.69	0.77	—	0.67
		Stems	0.20	0.49	1.66	2.55	—	1.84
		Roots	—	0.05	0.25	0.13	0.16	0.19
		Grain				0,96	—	3.21

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Table 34. Potash.

Plat			April 30	May 10	May 26	June 16	June 26	July 4
A	Expressed as percentage of dry matter	Entire Plant	— %	2.35 %	— %	1.68 %	— %	1.36 %
		Leaves	—	2.31	2.84	1.50	1.06	0.73
		Stems	3.65	3.07	2.71	2.18	2.93	2.93
		Roots	—	0.68	—	0.43	0.41	0.39
		Grain				0.60	—	0.40
	Amount of Potash in 10 bundles	Entire Plant	— gr.	3.47 gr.	— gr.	15.48 gr.	— gr.	15.14 gr.
		Leaves	—	1.27	3.69	2.57	2.02	1.07
		Stems	0.80	2.01	5.63	11.77	—	11.84
		Roots	—	0.19	—	0.27	0.27	0.31
		Grain				0.87	—	1.92
B	Expressed as percentage of dry matter	Entire Plant	— %	2.03 %	1.85 %	1.47 %	— %	1.15 %
		Leaves	2.01	2.03	1.83	1.22	0.76	0.68
		Stems	3.02	2.48	2.29	1.95	2.68	2.44
		Roots	—	1.22	0.62	0.40	0.37	0.28
		Grain				0.62	0.44	0.37
	Amount of Potash in 10 bundles	Entire Plant	— gr.	2.95 gr.	7.37 gr.	11.96 gr.	— gr.	12.68 gr.
		Leaves	0.38	1.10	2.30	1.75	1.00	0.88
		Stems	0.57	1.59	4.63	9.06	—	9.75
		Roots	—	0.26	0.44	0.27	0.21	0.22
		Grain				0.88	—	1.83

The percentage of nitrogen in the entire plant as well as in its parts decreases throughout the plant's life. The leaves have always a higher percentage of nitrogen than the stems, while the latter organ contains a greater percentage of phosphoric acid and potash than the leaves. On the whole, all these vegetative parts are very rich in their percentages of nitrogen at early stages; but there is a marked reduction of percentage in the leaves and in the stems of the mature plant. The roots and grain contain gradually decreasing percentages of nitrogen. The percentages of nitrogen in the leaves and in the stems collected from plat A were higher, at the various stages before flowering, than those from plat B, although both plats were treated, as far as possible, in a similar manner. Hence, the physiological functioning in the stems and leaves may be a more delicate and intricate process than is usually supposed.

The total amount of nitrogen in the plant increases up to maturity,—analysis does not show a loss at any stage of growth, as some investigators have maintained. The leaves contain a large amount of nitrogen until the time of the third collection, which was carried out just before heading out; and after this stage the stems also become rich in nitrogen. Thus it is found that there is not a similar variation in the amounts of nitrogen in these parts of the rice plant,—the highest quantity of nitrogen being reached earlier in the leaves than in the stems. Accordingly, it can be asserted that a more active movement of nitrogen from the leaves begins before any large amount of this ingredient in the stems migrates into the panicles. The nitrogen in the grain increases very rapidly during the maturing process, reaching about 60 % of the total amount of nitrogen in the plant; and in the same period the leaves and stems lose a large amount of nitrogen, as described before. A greater decrease of nitrogen is noticed in the leaves than in the stems in the period of maturation. Therefore it is very probable that the leaves transmit a much greater amount of nitrogen to the stems, than the latter organs supply to the grain. The roots do not appear to play an important rôle in the matter of translocation of the reserved nitrogen.

The percentage of phosphoric acid at each stage of growth is always found to be smaller than that of the nitrogen in the corresponding part of the rice plant. Usually there is a decreasing percentage of phosphoric acid in all parts of the plant throughout its life. The percentage of phosphoric acid is a little greater in the stems than in the leaves until the time of flowering, while a greater percentage of nitrogen is contained in the leaves than in the stems. However, at maturity the leaves retain a slightly higher percentage fo phosphoric acid than the stems, owing to the fact that, during maturation, less phosphoric acid migrates from the leaves. The roots contain a much lower percentage of phosphoric acid than of

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nitrogen. The grain contains a fairly constant percentage of phosphoric acid after flowering. In 1914 the nitrogen, phosphoric acid and potash in the grain of the autumnal crop were determined at successive stages during maturation, with the following results :—

Table 35. Percentage of Nitrogen, Phosphoric acid and Potash in the Grain.

Samples	Nitrogen			Phosphoric Acid			Potash		
	Heading out	After flowering	Maturity	Heading out	After flowering	Maturity	Heading out	After flowering	Maturity
	%	%	%	%	%	%	%	%	%
No. 1	1.18	1.07	1.08	0.34	0.61	0.63	0.57	0.31	0.26
„ 2	1.19	1.07	1.10	0.32	0.62	0.65	0.66	0.41	0.26
„ 3	1.17	1.08	1.16	0.27	0.63	0.65	0.67	0.3	0.22

These figures show that the percentage of phosphoric acid is much lower at the time of heading out and increases a great deal up to the time of flowering; afterwards it remains about constant, while the percentage of nitrogen slightly decreases, and that of potash diminishes very markedly. In other words, the amounts of phosphoric acid and nitrogen increase somewhat proportionally to the increase of dry matter in the grain, whereas the amount of potash does not. Hence, it may be presumed that phosphoric acid and nitrogen are very necessary in the grain from the time of heading out till the end of maturity, and that potash plays an important part in the early life of the grain. This leads to the suggestion that phosphoric acid and nitrogen are stored much more in the seed than in the chaff; and also that the potash are very necessary for the formation of chaff, which latter develops when the grain is at a young stage. This will be explained in detail later.

The total amount of phosphoric acid in the plant increases slowly at an early stage of growth, and rather rapidly in the later part of the plant's life. A much smaller amount of phosphoric acid than of nitrogen is absorbed from the soil, especially in the early period of growth, as shown in the following table ;—

Table 36. Amounts of Nitrogen and Phosphoric Acid in the Entire Plant.

Plat	in 10 bundles	April 30	May 10	May 26	June 16	July 4
A	Nitrogen	1.70%	3.75%	6.36%	7.98%	8.53%
	Phos. Acid	—	1.07	2.81	—	5.65
B	Nitrogen	1.23	3.04	5.20	7.31	8.43
	Phos. Acid	—	0.85	2.60	4.41	5.91

Thus, it seems that the young rice plant requires a much larger amount of nitrogen than of phosphoric acid, which latter is taken from the soil rather actively late in the plant's life. The rate of the increase of phosphoric acid in the entire plant is lower than that of nitrogen at each stage, as may be seen from the following figures :—

Table 37. Rates of Increase in the Amounts of Phosphoric Acid and Nitrogen

Plat		April 30	May 10	May 26	June 16	July 4
A	Nitrogen	19.9%	44.0%	74.6%	93.6%	100.0%
	Phos. Acid	—	18.9	49.7	—	100.0
B	Nitrogen	14.6	36.1	61.7	86.7	100.0
	Phos. Acid	—	14.4	44.0	74.6	100.0

The stems always contain a larger quantity of phosphoric acid than the leaves, but this is not the case as regards the nitrogen, as stated before. The amounts of phosphoric acid at each stage, in the stems and in the leaves, bear no definite proportions to the amounts of nitrogen, though these two ingredients are necessary for the formation of protein. The amounts of phosphoric acid in these organs increase till the time of flowering and diminish towards maturity. A greater reduction in the amount of phosphoric acid during maturation takes place in the stems than in the leaves, while the decrease in the amount of nitrogen is greater in the leaves. Much phosphoric acid migrates to the grain in the ripening process, and the mature

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grain contains about 53 % of the total amount of phosphoric acid in the plant.

The percentage of potash, in the entire plant, decreases throughout the plant's life, as in the cases of nitrogen and phosphoric acid. A similar variation takes place in the grain and also in the roots. In the leaves and in the stems the percentages of potash fluctuate in a very different manner to those of the nitrogen and phosphoric acid, which latter decrease at successive stages. The highest percentage of potash in the leaves is found in the period between May 10th and May 26th, when the vegetative portions of the rice plant are in a state of vigorous growth ; afterwards the percentage of potash gradually decreases to the end of the plant's life. In the stems the greatest percentage of potash occurs at an earlier stage than in the case of the leaves, and decreases until the time of heading out, owing to the actual amount of dry matter in the stems increasing more rapidly than potash is stored. On the contrary, in the later part of the plant's life, the potash in the stems increases in percentage ; this is not due to any great increase in the actual amount of potash, but rather to the fact that the dry matter in the stems decreases in amount. As a rule, the stems contain a higher percentage of potash than the leaves at each stage, while it is just the reverse in the case of the nitrogen.

The actual amount of potash varies in a somewhat similar manner as the nitrogen in the same parts of the rice plant. The leaves, in which a vigorous formation of protein takes place, contain a rather large amount of potash, and the stems store the greatest quantity of potash at any stages of growth. The amonut of potash in the stems increases till the time of heading out, but it does not decrease at maturity as in the case of nitrogen, which shows a remarkable reduction at this stage. The actual amount of potash in the roots is very small, not more than 2 % of the total quantity of potash in the plant. The potash in the stems migrates into the

grain during maturation, yet it does not accumulate to such an extent as the nitrogen and phosphoric acid.

Assuming the total amount of each of these three ingredients in the plant at maturity to be 100, then the mature grain contains about 13 % of all the potash in the plant, 60 % of all the nitrogen and 53 % of all the phosphoric acid. Though these figures may be variable, dependent upon the conditions of cultivation, yet their relative order as regards amounts, is, in the case of plants of normal growth, fonnd always to hold good, so far as the author knows.

In this connection, the distribution of these elements amoung the parts of the grain, - that is to say, in the chaff, bran and cleaned rice, - will be explained. At present it is impossible to discuss this problem with any great degree of accuracy, because there are not a sufficient number of reliable analytical data, and moreover because the perfect separation of the bran (seed-coat) from the cleaned rice (endosperm) is not, as yet, a practical possibility. However, the following figures, which are the average percentages of these ingredients contained in the parts of the grain, may give some general idea of the distribution, and serve as data towards an eventual solution of this question.

Table 38. Nitrogen, Phosphoric Acid and Potash in the Parts of Grain.

(Expressed as percentage of dry matter)

	Nitrogen	Phos. Acid	Potash
	%	%	%
Chaff or Glumes	0.47	0.16	0.36
Bran, containing Seed-coat & Embryo	2.69	4.30	1.66
Cleaned Rice or Endosperm	1.43	0.34	0.16

It is noticed in the above table that the bran contains the highest percentage of all these ingredients, among which the percentage of phosphoric acid comes first, and that of nitrogen considerably exceeds that of potash. In the chaff the percentage of nitrogen is

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highest, and that of potash is much greater than that of phosphoric acid. The percentage of potash in the cleaned rice is lowest, and that of nitrogen is much higher than that of phosphoric acid. Thus these three ingredients, contained in each part of the grain, are not in any definite proportions, as the following table shows.

Table 39. Proportion of Nitrogen, Phosphoric acid and Potash in the Parts of Grain.

	Nitrogen	Phos. Acid	Potash
Chaff	100.0	34.0	76.6
Bran	100.0	159.9	61.7
Clened Rice	100.0	23.8	11.2

The percentage of chaff, bran and cleaned rice in the dry matter of the grain were calculated from the results of the experiments carried out in our Station at Taihoku, and they were 27.0 %, 5.8 % and 67.2 % respectively. From these figures the plant foods stored in each portion of the grain were calculated, to show their distribution among the chaff, bran and cleaned rice.

Table 40. Nitrogen, Phosphoric acid and Potash in one Kilogram of the Grain dried at 100° C.

	Nitrogen		Phos. Acid		Potash	
	gr.	%	gr.	%	gr.	%
Chaff	1.269	10.2	0.432	8.3	0.972	32.3
Bran	1.560	12.5	2.494	47.8	0.963	32.0
Cleaned Rice	9.610	77.2	2.285	43.8	1.075	35.7
Total	12.439	100.0	5.211	100.0	3.010	100.0

The above table shows that the distribution of these ingredients is very different in the various parts of the grain. For instance, about 77 % of the total nitrogen in the grain is contained in the cleaned rice, and a little over 10 % in the bran, and a like percentage in the chaff; while 43 % of the total phosphoric acid in the grain is stored in the cleaned rice and about the same percentage

in the bran, but only 8 % in the chaff. And in still greater contrast, about one third of the total potash is accumulated in each of the parts of the grain. Thus, 10% of all the nitrogen in the grain, 8% of all the phosphoric acid, and 32% of all the potash are used for the formation of the chaff.

The percentages of nitrogen, and of phosphoric acid, and of potash, in each part of the rice plants from the plats A and B were compared, and their differences are shown in the following table :—

Table 41. Difference between Percentages of Ingredients in the same Parts of the Rice Plants obtained from Plats B and A.

		April 30	May 10	Moy 26	June 16	June 26	July 4
Nitrogen	Leaves	—0.62	—0.60	—0.12	+0.09	—0.19	+0.07
	Stems	—0.41	—0.35	—0.48	+0.01	±0.00	+0.01
	Roots	—0.17	—0.12	—0.06	+0.03	—0.05	—0.07
	Grain				+0.02	—	+0.03
Phos. Acid	Leaves	—	—0.04	—0.18	+0.08	—	+0.05
	Stems	—0.13	—0.20	+0.01	—0.08	—0.04	+0.01
	Roots	—	—0.27	+0.01	—0.04	±0.00	—0.01
	Grain				—	—0.01	+0.04
Potash	Leaves	—	—0.28	—1.01	—0.28	—0,30	—0.05
	Stems	—0.63	—0.59	—0.42	—0.23	—0.25	—0.49
	Roots	—	+0.54	—	—0.03	—0.04	—0.11
	Grain				+0.02	—	—0.03

This table indicates that at an early stage of growth the percentages of nitrogen, phosphoric acid and potash in the rice plants raised on plat A, on which soy bean cake was used as a nitrogenous fertilizer, are greater than those from plat B, which was manured with ammonium sulphate. On these two plats the percentages of potash, especially in the stems at successive stages of growth, differ in a marked way,— the percentages in the stems from plat A being much greater than those from plat B. Even at maturity the dif-

ference of percentage of potash in the stems from the two plats is great, although the differences between the percentages of nitrogen, and likewise of phosphoric acid, contained in the same parts of the plants from the two plats, become very small towards maturity. It must be borne in mind that in soy bean cake the amount of potash is about 25 % of the quantity of nitrogen. Thus the rice plant could have absorbed a much greater amount of potash from plat A than from plat B, though the plants from the former plat gave a little poorer yield of grain. (v. Table 34 and 15) It is clear from Tables, 32, 33 and 34, that the actual amounts of nitrogen and of phosphoric acid absorbed by the rice plants of these two plats are about the same, but that potash is present in a greater quantity in the entire plant that in grown on plat A. Therefore the potash contained in the soy bean cake may influence the growth of the rice plant, when the soil, as in this experiment, is fertilized at the rate of 34.00 lbs. of potash per acre ; however, the phosphoric acid, of which there is only a small smount in soy bean caks, does not exert so much influence as potash, when 68.00 lbs. of phosphoric acid per acre is applied.

It is very important, as regards fertilizer application, to know that such a surplus amount af potash in the rice plant's body hinders the proper growth of the craps. In the spring of 1915, another experiment was carried out, with a view to ascertaining, (1), the effects of potash fertilizer on the yield of rice and, (2), the potash content in the plant's body at various stages of growth. The soil selected for the experiment was in a nearly exhausted field, on which rice crops had been cultivated eight times in succession, without any fertilizer being applied. This soil showed a slight acidity when treated with a solution of neutral salts. Each plat was fertilized with ammonium sulphate, superphosphate and potassium carbonate, containing respectively nitrogen, phosphoric acid and potash at the following rates per acre :—

Table 42. Amount of Fertilizer per acre.

	Nitrogen	Phos Acid	Potash
	lbs.	lbs.	lbs.
Ist Plat	84.99	68.00	68.00
IInd Plat	84.99	68.00	17.00

Over 50 bundles from each plat were examined, at each collection, in order to find out the average number of culms per bundle. Those bundles which had an average number of culms were cut off level with the surface of the soil. The total yield of 100 bundles, at three different stages of the plant's life, is given in the following table :—

Table 43. Total Weight of 100 Bundles.

	Dry matter	May 20	June 11	July 1
		gr.	gr.	gr.
Ist Plat	Straw	1,909.	3,449.	2,491.
	Gain			1,979.
IInd Plat	Straw	1,823.	3,712.	2,691.
	Grain			2,230.

It is clear from this table that the production of grain from the first plat is about 11 % less than that from the second plat, which was fertilized with a smaller amount of potash ; and the straw is found also to be less in the first plat, to which a greater amount of potash was applied. This is in the agreement with the results of other experiments on fertilizer, which had been conducted for many years in our Station. Pot experiments, in 1912 and in 1914, with spring rice crops were carried out in the Experimental Farm of the Akow Agricultural Association, and gave similar results.

From a physiological standpoint, it seems that when the nutrients absorbed from the soil have a certain balance in the plant's body, there results an excellent development of the rice plant. But a surplus absorption of potash seems to disturb the balance of the

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nutrients and to hinder the normal physiological functions of the plant, and thus leads to a poor yield.

The rice plants under consideration were analyzed with the following results, as regards nitrogen, phosphoric acid and potash.

Table 44. Percentage of Nitrogen, Phosphoric Acid and Potash.

(Expressed as percentage of dry matter)

	Dry matter	Plat	May 20	June 10	July 1
Nitogen	Straw	Ist Plat	1.53 %	0.88 %	0.62 %
		IInd „	1.36	0.93	0.57
	Grain	Ist „			1.20
		IInd „			1.09
Phos. Acid	Straw	Ist „	0.74	0.53	0.27
		IInd „	0.70	0.53	0.23
	Grain	Ist „			0.59
		IInd „			0.57
Potash	Straw	Ist „	1.84	1.29	1.56
		IInd „	1.35	1.02	1.26
	Grain	Ist „			0.24
		IInd „			0.27

Table 45. Amount of Nitrogen, Phosphoric Acid and Potash in 100 Bundles of the Mature Plant.

	Nitrogen	Phos. Acid	Potash
Ist Plat	39.1 gr.	18.4 gr.	43.6 gr.
IInd Plat	39.3	18.9	39.9

Table 46. Ratios of Nitrogen, Phosphoric Acid and Potash.

	Nitrogen	Phos. Acid	Potash
Ist Plat	212.4	100.0	237.0
IIndPlat	208.0	100.0	211.1

The percentages of potash in the straw from each plat have greater differences than those of the other ingredients, as remarked before. The plants which produce a greater amount of straw and grain contain a lower percentage of potash, and the actual amount of potash is also found to be smaller in the rice crop that gives a better yield. Thus the ratios of these ingredients shows the greatest differences in the "Potash" column of Table 46.

A somewhat similar fact can be seen by examining the results of the manure experiments by W. P. Kelley and Alice R. Thompson, (Hawaii Agr. Expt. Stat. Bull. No. 24). The complete fertilizer plat was treated with 60 lbs. of nitrogen, 45 lbs. of phosphoric acid and 60 lbs. of potash, per acre, derived respectively from Ammonium sulphate, superphosphate and potassium carbonate. The nitrogen plat was treated with 60 lbs. of nitrogen from ammonium sulphate. The following tables are prepared and elaborated from Kelley and Thompson's figures.

Table 47. Nitrogen, Phosphoric Acid, Potash and Dry Matter.

		Nitrogen	Phos. Acid	Potash	Dry matter, per acre
		%	%	%	lbs
Leaves	Complete fert. Plat	0.56	0.16	1.29	1235.
	Nitrogen „	0.62	0.18	1.33	1222.
Stems	Complete fert. „	0.43	0.15	3.06	2345.
	Nitrogen „	0.38	0.14	2.62	2362.
Roots	Complete fert. „	0.71	1.07	0.94	313.
	Nitrogen „	0.84	1.14	0.73	347.
Chaff	Complete fert. „	0.51	0.32	1.12	996.
	Nitrogen „	0.43	0.26	1.06	982.
Kernel	Complete fert. „	1.22	0.83	0.39	3610.
	Nitrogen „	1.36	0.87	0.46	3783.

Table 48. Amount of Nitrogen, Phosphoric Acid and Potash in the Entire Plant. (per acre).

	Nitrogen	Phos. Acid	Potash	Dry matter, per acre
	lbs.	lbs.	lbs.	lbs.
Complete fertilizer Plat	68.4	42.0	115.9	8,499.
Nitrogen Plat	74.9	45.1	108.4	8,696.

Table 49. Ratio of Nitrogen, Phosphoric Acid and Potash.

	Nitrogen	Phos. Acid	Potash
Complete fertilizer Plat	162.9	100.0	276.0
Nitrogen Plat	166.0	100.0	240.4

Both the percentage and the actual amount of potash are greater in the rice plant cultivated on the complete fertilizer plat, which has a poorer yield of grain and straw.— as proved in our experiments. The greatest difference in the percentages of potash is, again in this experiment, found in the stems from the two plats, while nitrogen and phosphoric acid show only slight differences in the corresponding parts of the plants. The ratios of these three ingredients agree in showing that potash has the greatest difference. (v. Table 49) Therefore it seems that an excess of potassium in the plant's body exerts a by no means negligible influence on the yield of rice, disturbing as it does the balance of nutrients.

However, repeated experiments with the autumn crop in our Station, proved that the plats which were rich in potash gave a better yield. In the autumn of 1914 the experiment was carried out again, and it confirmed the above fact, as may be seen in the following table:—

Table 50. Dry matter in 100 Bundles of the Autumnal crop.

			Before flowering	Maturity
			gr.	gr.
Ist Plat	68. lbs. of Nitrogen, per acre, (Ammonium Sulphate).	Leaves	787.	642.
		Stems	2,742.	1,631.
	51. lbs. of Phos. Acid, per acre, (Superphosphate).	Roots	292.	261.
	68. lbs. of Potash, per acre, (potassium Carbonate).	Grain	389.	1,992.
		Total	4,210.	4,526.
IInd Plat	68. lbs. of Nitrogen, per acre, (Ammonium Sulphate).	Leaves	669.	584.
		Stems	2,433.	1,507.
	51. lbs. of Phos. Acid, per acre, (Superphosphate).	Roots	245.	208.
	17. lbs. of Potash, per acre, (Potassium Carbonate).	Grain	331.	1,808.
		Total	3,678.	4,107.

The table shows that greater amounts of dry matter in each part of the rice plant, both before flowering and at maturity, were produced from the first plat, which was fertilized with much potash. But the spring crop gave a better yield from the plat containing a less amount of potash, as explained before. These samples of the autumn crop were analyzed to ascertain their contents of nitrogen, phosphoric acid and potash. The results are given below :—

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Table 51. Percentage of Nitrogen, Phosphoric acid and Potash in the Autumn Crop.

	Dry Matter		Before flowering	Maturity
			%	%
Nitrogen	Leaves	Ist Plat	1.29	0.54
		IInd „	1.40	0.56
	Stems	Ist „	0.49	0.43
		IInd „	0.53	0.47
	Roots	Ist „	0.69	0.70
		IInd „	0.70	0.74
	Grain	Ist „	1.18	1.08
		IInd „	1.19	1.10
Phos. Acid	Leaves	Ist „	0.31	0.09
		IInd „	0.32	0.10
	Stems	Ist „	0.45	0.22
		IInd „	0.47	0.18
	Roots	Ist „	0.25	0.19
		IInd „	0.18	0.22
	Grain	Ist „	0.34	0.63
		IInd „	0.32	0.65
Potash	Leaves	Ist „	1.13	0.21
		IInd „	1.00	0.26
	Stems	Ist „	1.02	1.96
		IInd „	1.04	1.87
	Roots	Ist „	0.49	0.32
		IInd „	0.45	0.35
	Grain	Ist „	0.57	0.26
		IInd „	0.66	0.26

Table 52. Amount of Nitrogen, Phosphoric Acid and Potash, at Maturity in 100 Bundles of the Autumn Crop.

	Nitrogen	Phos. Acid	Potash
	gr.	gr.	gr.
Ist Plat	33.8	17.2	39.4
IInd Plat	32.2	15.4	35.0

The percentages of the same ingredients, in corresponding parts of the plants from each plat, show but slight differences. But it is the first plat, fertilized with 68.0 lbs. of potash, that has a rather lower percentage in each case, and yet which produces, as said before, the larger crop. However, the potash in the stems from the first plat has a slightly higher percentage than from the second plat, and its actual amount in the entire plant is also greater. This is just the reverse to the results of experiments with spring crops, which were described above. Therefore the autumn and the spring crops may each have some particular balance of nutrients proper to their respective developments. As observed in Bulletin No. 10,—(previously referred in this paper, v. p. 10),—fertilizer experiments proved that the rice plant absorbed a greater quantity of phosphoric acid from carbonized bone,—(which is prepared by the Formosan farmers in some localities),—than from superphosphate, and gave a poorer yield in the former case. Thus, a surplus of this ingredient in this plant's body might also disturb rhe physiological functions necessary for the proper development of the plant. (These subjects were discussed in the following bulletins :— Agr. Expt. Stat. Formosa, Publication No. 95 ; S. K. Suzuki, "Absorption of Phosphoric Acid from carbonized Bone," and No. 120, S. K. Suzuki; "Effect of the Over-absorption of Potash on the Growth of Rice Plant.")

It is noticed in Table 47, that, according to Kelley and Thompson's figures, there was a much higher percentage of phosphoric acid in the roots than shown either by the present experiments, (v.

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Table 33.) or by the examination of samples from rice plant raised at Taihoku in 1913 and 1914. Herewith some figures for the latter, the samples having been taken from various plats :--

Some roots from 1913 spring crop contained 0.25% of phosphoric acid,
other " " " " " " 0.24% " " ,
some " " 1914 " " " 0.19% " " ,
other " " " " " " 0.22% " " ,
other " " " " " " 0.25% " " ,

P. L. Gille and J. O. Carrero obtained 0.15 % of phosphoric acid in the roots of upland rice plants, (Jour. Agr. Research. vol. V, No. 9, Nov. 1915). Our preliminary test showed that ash from the roots contained much more iron than could be precipitated by the phosphoric acid of the ash in the process of ash analysis. Consequently, as the ordinary method of ash analysis was not suitable for determining the amount of phosphoric acid in the roots, the molybdate method was in the present experiments, used for making the required estimates.

Table 53. Soda

Plat			April 30	May 10	May 26	June 16	June 26	July 4
A	Expressed as percentage of dry mater	Entire Plant	— %	0.49 %	— %	0.28 %	— %	0.19 %
		Leaves	—	0.22	0.24	0.12	0.09	0.08
		Stems	0.69	0.54	0.44	0.39	0.35	0.39
		Roots	—	0.93	—	0.29	0.43	0.38
		Grain				0.04	—	0.01
	Amount of Soda in 10 bundles	Entire Plant	— gr.	0.73 gr.	— gr.	2.55 gr.	— gr.	2.06 gr.
		Leaves	—	0.12	0.31	0.21	0.17	0.12
		Stems	0.15	0.35	0.91	2.10	—	1.58
		Roots	—	0.26	—	0.18	0.28	0.31
		Grain				0.06	—	0.05
B	Expressed as percentage of dry matter	Entire Plant	— %	0.66 %	0.49 %	0.21 %	— %	0.17 %
		Leaves	0.91	0.43	0.15	0.09	0.13	0.11
		Stems	1.71	0.70	0.67	0.24	0.32	0.33
		Roots	—	1.11	0.59	0.48	0.30	0.38
		Grain				0.09	0.03	0.02
	Amount of Soda in 10 bundles	Entire Plant	— gr.	0.92 gr.	1.97 gr.	1.68 gr.	— gr.	1.86 gr.
		Leaves	0.17	0.23	0.19	0.13	0.17	0.14
		Stems	0.32	0.45	1.36	1.11	—	1.32
		Roots	—	0.24	0.42	0.32	0.17	0.30
		Grain				0.12	—	0.10

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Table 54. Lime.

Plat			April 30	May 10	May 26	June 16	June 26	July 4
A	Expressed as percentage of dry matter	Entire Plant	— %	0.45 %	0.42 %	0.36 %	— %	0.32 %
		Leaves	—	0.87	0.81	1.11	1.30	1.31
		Stems	0.20	0.18	0.21	0.19	0.27	0.30
		Roots	—	0.25	0.28	0.33	0.31	0.27
		Grain				0.11	0.05	0.05
	Amount of Lime in 10 bundles	Entire Plant	— gr.	0.67 gr.	1.63 gr.	3.30 gr.	— gr.	3.59 gr.
		Leaves	—	0.48	1.05	1.90	2.48	1.92
		Stems	0.04	0.12	0.44	1.03	—	1.21
		Roots	—	0.07	0.14	0.21	0.20	0.22
		Grain				0.16	—	0.24
B	Expressed as percentage of dry matter	Entire Plant	— %	0.39 %	0.38 %	0.32 %	— %	0.27 %
		Leaves	0.76	0.72	0.80	1.03	1.14	1.14
		Stems	0.23	0.17	0.16	0.17	0.23	0.25
		Roots	—	0.21	0.25	0.25	0.25	0.27
		Grain				0.12	0.05	0.05
	Amount of Lime in 10 bundles	Entire Plant	— gr.	0.54 gr.	1.50 gr.	2.61 gr.	— gr.	2.93 gr.
		Leaves	0.14	0.39	1.00	1.48	1.50	1.47
		Stems	0.04	0.11	0.32	0.79	—	1.00
		Roots	—	0.04	0.18	0.17	0.14	0.21
		Grain				0.17	—	0.25

Table 55. Magnesia.

Plat			April 30	May 10	May 26	June 16	June 26	July 4
A	Expressed as percentage of dry matter	Entire Plant	— %	0.28 %	0.27 %	0.22 %	— %	0.28 %
		Leaves	—	0.30	0.30	0.29	0.31	0.61
		Stems	0.33	0.29	0.28	0.24	0.22	0.22
		Roots	—	0.24	0.18	0.13	0.16	0.32
		Grain				0.12	0.19	0.22
	Amount of Magnesia in 10 bundles	Entire Plant	— gr	0.42 gr.	1.06 gr.	2.05 gr	— gr.	3.09 gr.
		Leaaes	—	0.16	0.39	0.50	0.59	0.88
		Stems	0.07	0.19	0.58	1.30	—	0.89
		Roots	—	0.07	0.09	0.08	0.11	0.26
		Grain				0.17	—	1.06
B	Expressed of percentage of dry matter	Entire Plant	— %	0.25 %	0.26 %	0.22 %	— %	0.24 %
		Leaves	0.36	0.31	0.27	0.30	0.41	0.54
		Stems	0.33	0.21	0.25	0.21	0.20	0.20
		Roots	—	0.23	0.27	0.18	0.20	0.25
		Grain				0.20	0.18	0.19
	Amount of Magnesia in 10 bundles	Entire Plant	— gr.	0.35 gr.	1.04 gr.	1.81 gr.	— gr.	2.64 gr.
		Leaves	0.07	0.17	0.34	0.43	0.54	0.70
		Stems	0.06	0.13	0.51	0.98	—	0.80
		Roots	—	0.05	0.19	0.12	0.11	0.20
		Grain				0.28	—	0.94

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Table 56. Ferric Oxide.

Plat			April 30	May 10	May 26	June 16	June 26	July 4
A	Expressed as percentage of dry matter	Entire Plant	— %	1.32 %	1.06 %	— %	— %	0.66 %
		Leaves	—	0.28	0.15	0.19	0.33	0.40
		Stems	0.98	0.86	0.64	0.22	0.30	0.38
		Roots	—	4.51	5.06	—	5.17	6.43
		Grain				0.03	0.01	Trace
	Amount of Ferric oxide in 10 bundles	Entire Plant	— gr.	1.95 gr.	4.13 gr.	— gr.	— gr.	7.31 gr.
		Leaves	—	0.15	0.20	0.33	0.63	0.59
		Stems	0.22	0.56	1.33	1.19	—	1.53
		Roots	—	1.24	2.60	—	3.41	5.17
		Grain				0.04	—	0.02
B	Expressed as percentage of dry matter	Entire Plant	— %	0.78 %	1.02 %	0.61 %	— %	0.52 %
		Leaves	0.23	0.17	0.25	0.40	0.41	0.42
		Stems	0.93	0.56	0.73	0.26	0.28	0.37
		Roots	—	2.99	3.21	4.64	—	4.59
		Grain				0.06	0.04	0.03
	Amount of Ferric oxide in 10 bundles	Entire Plant	— gr.	1.09 gr.	4.05 gr.	4.96 gr.	— gr.	5.76 gr.
		Leaves	0.04	0.09	0.31	0.57	0.54	0.54
		Stems	0.18	0.36	1.48	1.21	—	1.48
		Roots	—	0.64	2.26	3.10	—	3.59
		Grain				0.08	—	0.15

Soda, although it may not be essential to the growth of the rice plant, is distributed in all its parts. The greatest quantity and also the highest percentage are found in the stems, as was to be expected, for this ingredient is usually present in abundance in the succulent portions of plants. The variations of the quantity of soda throughout the plant's life, somewhat resemble those of potash.

The percentage of lime in the entire plant decreases very gradually in the course of the plant's life, but the leaves and stems have increasing percentages. The highest percentages of lime are always found in the leaves,— as was the case with nitrogen, which was described before. Many investigators have proved that those parts of a plant which are rich in chlorophyll contain a considerable amount of lime. And this is also found to hold good as regards the stems and leaves of the rice plant. The actual amount of lime

contained in these organs increases towards maturity, though at this same stage nitrogen and phosphoric acid decrease in amount, owing to their migration to the grain. It does not seem that the lime in the vegetative tissues migrates much to, or takes any very active part in, the formation of the grain, for this latter is very poor in lime. Twelve samples of grain taken from other experimental plats, each of which had been supplied with a different amount of lime, were analyzed, and the differences in percentage of lime contained in the grain from the various plats were found to be very small, and the average percentage of lime was 0.078.

The percentage of magnesia in the entire plant is, in this case, practically constant throughout the plant's life, as shown in Table 55. However, another experiment proved that the entire plant had a decreasing percentage of magnesia throughout its life, dependent upon the production of dry matter in the plant's body. The percentage of magnesia in the leaves has a sudden rise at maturity, owing to the fact that the dry matter of the leaves decreases while the actual amount of magnesia increase during maturation. The stems have a gradual decrease in the percentage of magnesis, which latter migrates to the grain to a greater extent than the lime does. And there occurs a reduction in the amount of magnesia in the stems at maturity. A fair amount of magnesia is deposited in the grain, as is often found to be the case among the gramineæ. The plants which developed better on plat B absorbed smaller quantities of soda, lime, magnesia and potash than those on plat A, while the nitrogen and phosphoric acid in the plants from both plats were abont the same. It might thus seem that the surplus of potash present in the rice plants from plat A, accelerates the absorption of soda, lime and magnesia. Yet this is very doubtful, for no such phenomenon occurred in a similar experiment with the same variety of spring crop, as may be seen from the following figures :— (v. p. 50)

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Table 57. Amount of Inorganic Ingredients in 100 Bundles of the Rice Plant, 1915.

	Fertilizer, per acre	Dry Matter	Nitrogen	Phos. Acid	Potash	Lime	Magnesia
		gr.	gr.	gr.	gr.	gr.	gr.
Ist Plat	Nitrogen, 68 lbs. Phos. Acid, 51 „ Potash, 68 „	4,470.	39.1	18.4	43.6	11.9	10.1
IInd Plat	Nitrogen, 68 „ Phos. Acid, 51 „ Potash, 17 „	4,921.	39.3	18.9	39.9	14.8	12.0

The percentage of ferric oxide contained in the entire plant gradually decreases in the course of the plant's life. On the whole, the leaves and roots have increasing percentages of ferric oxide, and the roots become particularly rich with this ingredient during the later part of plant's life. The old roots are always found to be of a reddish brown colour, probably owing to the adherence of ferric oxide, of which the larger portion can easily be extracted by means of a very dilute solution of hydrochloric acid. The percentage of ferric oxide in the stems gradually decreases until the time of flowering, at which stage an abrupt decrease takes place, caused by a rapid increase of dry matter and also a reduction in the actual amount of ferric oxide. The grain contains a very little ferric oxide. This ingredient accumulates in the leaves and roots throughout the plant's life, but it decreases appreciably in the stems at the time of flowering, although at this stage they (stems) possess a maximum amount of the other ash ingredients. A certain amount of ferric oxide in the stems migrates to the grain, but perhaps this may not be of a sufficient amount to account for the comparatively great reduction of this ingredient in the stems. However, it is not clear whether the ferric oxide deposited in the stems migrates to the leaves and roots before the time of flowering, or whether this reduction of ferric oxide in the stems is incidental.

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On the Growth of the Rice Plant.

BY

SHINKICHI SUZUKI.
