SOME ASPECTS OF THE NUTRITION AND STORAGE OF CELERY

by

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SUMMARY

Twenty-seven fertilizer treatments with celery were set out in duplicate on muck soil on 1/57.6 acre plots. The yields were recorded by weight, and analysed by the analysis of variance. Nitrogen, phosphorus and potash all gave very significant increases over the nil treatment. Doubling the phosphorus and potash in the basic treatment resulted in further increments in yield.

Celery was grown in quartz sand in the greenhouse and nutrients approximating the fertilizers used in the field were applied as nutrient solutions. The effect of nitrogen, phosphorus and potash on the growth of tops and roots and on the number of leaves is discussed together with top/root ratios. The basic treatment gave the tallest plants. The basic treatment with an additional 16 per cent of potash gave the greatest weight of tops as well as the greatest weight of roots. Potash did not influence either the weight or the length of roots.

The field fertilizer treatments were repeated in the greenhouse on muck and mineral soil. Phosphorus was the limiting factor throughout the growing season, while

nitrogen and potash showed up only towards the end of the growing season. The 8-8-16 fertilizer resulted in the best growth on muck soil. On the mineral soil, nitrogen and potash had a detrimental effect on the growth. Phosphorus slightly improved the results.

Cold storage studies were undertaken in an attempt to determine what effects the different fertilizers had on the keeping quality of celery. Pithiness did not increase with senescence. The green colour decreased and breakdown increased with the length of the storage period. Large well-formed plants kept the best in storage.

Studies were conducted on the quantity and changes in quantity of sugar in celery by means of the osmotic concentrations. Eight per cent of nitrogen and no phosphorus or potash gave the highest sugar contents. High sugar content cannot be considered a criterion of high quality.

The cold storage and laboratory studies were linked together by calculating various correlation coefficients. High sugar content was associated with darker green colour, more pithiness, more breakdown and decreased yield.

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GENERAL INTRODUCTION

Considerable experimental work has been done on problems connected with the production of celery in the field. Experiments are being carried on by the Division of Horticulture, Experimental Farm, Ottawa; Macdonald College and many other institutions to determine which fertilizer or fertilizer mixture produces the best results when applied to the different soil types in different localities. Similar experiments have been and are being conducted in other parts of Canada, and in the United States as well as in other countries of the world. This is necessary because of the differences which exist in climate, soil types, varieties, methods of culture and the time the crop is marketed.

The celery acreage for the Province of Quebec has increased from 169 acres in 1930 to 760 acres in 1936. McKibbin and Stobbe (1936) have shown that there are 40,000 to 50,000 acres of peat and muck soils within a radius of 45 to 60 miles of Montreal. Most of this area could produce good celery.

Table 1 shows the number of carloads of celery brought into Montreal from Ontario, California, Florida, Bermuda and the West Indies.

TABLE 1

Number of carloads of celery brought into Montreal annually.

Year	Number of carloads
1930	294
1931	246
1932	351
1933	280¾
1934	217
1935	283
1936	309
1937	301
Average	285.21

This gives an average for the eight years of 285.21 carloads. These figures apply only to celery brought in by train. Any that may have arrived by truck has not been recorded.

A car holds 350 crates, which is an average yield from an acre of celery. Therefore, Montreal imports annually the produce of at least 285 acres. A great deal of this imported celery could be replaced by the local product if it were properly grown, packed and successfully stored to meet the market demands during the early winter months. However, there are many problems to be taken care of before this can be done.

It was for the purpose of solving some of these that the present studies were undertaken. When the proper balance of fertilizer has been determined to produce a good yielding crop that will keep well, then the Quebec farmers will have a better chance of competing against imported produce.

Table 2 shows the time of the first arrivals of California and Florida celery on the Montreal market.

TABLE 2

First arrivals of California and Florida celery

Season	California	Florida
1931-2	--	Feb. 14
1932-3	Dec. 4	Feb. 12
1933-4	Dec. 3	Feb. 5
1934-5	Dec.27	Feb. 18
1935-6	Dec.16	Feb. 17
1936-7	Dec.21	--
1937-8	Dec. 6	Jan. 19
1938-9	Nov.23	--

The Florida product does not compete with our local celery at present because it arrives on the market after the normal time of holding local celery in storage has passed. California celery, on the other hand may come in early in December in some years. As soon as it arrives, the price of Quebec celery is likely to drop. If good celery were produced and good storage facilities were available, there is no reason why the local product could not be sold at a good price even in the face of this competition.

The results from studies in the storage undertaken with the view of determining the cause, time and extent of the development of fungal organisms, would seem to indicate that at least some of the troubles are due to secondary organisms which enter that plant after it has been injured either by mechanical means, or by freezing or after physiological breakdown has set in.

The Sections of Horticulture, Soils, Botany and Entomology of the Michigan Station (1938) state that celery plants at harvest must be carefully handled to prevent bruising.

Binkley (1934) cites the conclusions drawn from an experiment where some plants were handled very carefully to prevent bruising so that only healthy and whole plants were obtained, and where other plants were handled ordinarily. Both groups were placed in storage. When they were examined there was a difference amounting to 15 to 20 per cent in favour of the plants which had been carefully handled at the time of harvest and storage.

Thompson (1917) states that when the crates are badly broken, the celery stalks are often crushed and the injured portions form courts of infections for decay-producing organisms.

Platenius, Jamison and Thompson (1934) point out that frost injury is a type of physiological breakdown. Ice crystals forming in the intercellular spaces rupture the cells and this is usually followed by rapid decay.

From these statements we would conclude that the grower should and can guard against all freezing and mechanical injuries. More information is needed on the causes of physiological breakdown. Without question certain types of this disorder can be traced to cultural practices which include the use of commercial fertilizers as mineral nutrients. However, more experimental work is needed before definite recommendations can be made to our growers who are growing celery for cold storage purposes.

In an attempt to obtain more information on this question certain aspects of the problem relative to the fertilizer requirements of celery were studied by several well planned experiments, undertaken in both field and greenhouse. Cold storage observations were made periodically using the celery from the field experiment. This material was afterward tested in the laboratory for sugar by the osmotic pressure method. Careful observations were also made of the plants growing in the greenhouse.

This experimental work is now presented in detail together with the results, discussion and summary.

PART I.

FERTILIZER REQUIREMENTS

Introduction

The fertilizer requirements of plants vary considerably with the type of plant, the type of soil, length of growing season, amount of rainfall, temperature, and many other environmental factors. The fertilizer requirements for one locality cannot be adopted indiscriminately in another district. The fertilizer requirement of a particular soil can be determined only by trial. Furthermore, the cropping system plays a very important part in influencing what elements should be added for a particular crop, because one crop may tend to deplete the soil of some elements more than others. In order to find how much of each element is present in the soil, samples of soil may be taken and analysed chemically. This is likely to give a value much greater than what the plant would be able to take up from the soil.

The Neubauer method as described by Thornton (1935), seems to be gaining popularity in determing the amount of available phosphorus and potash in the soil. A certain portion of soil (either by weight or by volume) is taken, and one hundred selected and weighed rye seeds are sown and germinated. At the end of a 17-day vegetation period, the plants are harvested and the amount of P_2O_5 and K_2O are determined chemically. It is assumed that at the end of this vegetation period the plants will have exhausted all available plant food.

When the amount of plant food present in the soil has been determined, the requirement of the particular crop has to be found. Thus a field experiment is in order. Various fertilizer mixtures may be applied and the yield results obtained. In this way, a fertilizer which results in the best growth will be found. However, the results found from an experiment of this nature will, strictly speaking, apply only to that portion of land upon which the experiment was conducted. Seasonal variations may cause the results to differ markedly from year to year, hence an experiment of this type should be repeated for several years to smooth out such seasonal variations before recommendations can be made for the crop in a certain locality. It must be kept in mind that such recommendations are only approximate, since it is impossible to lay down any definite rules for the application of fertilizers for maximum growth or maximum fruit production.

Review of Literature

Abell (1922) found that high nitrogen content of the soil was necessary for high quality celery.

Norton (1917) states that celery, being a foliaceous crop, responds more readily to soil dosages of nitrogen than to other forms of plant food.

Knott (1931) recommends that New York State growers use 2000 pounds of a 4-8-12 fertilizer per acre for wide-spaced celery (30 to 42 inches between the rows) on muck soil.

Edmond (1926) suggests that manure can be ommitted for celery grown on muck soil, since commercial fertilizers usually give better results. He recommends for Michigan 1000 to 1800 pounds of a 3-8-24 analysis or a 0-8-24 analysis, with 200-300 pounds of nitrate of soda or sulphate of ammonia as a side-dressing. The application of such an amount of a nitrogen carrier should be made about the time of banking if the weather is cold.

McCool, Grantham and Harmer (1930), in their fertilizer recommendations for Michigan, advise the use of lime-stone or of marl before the application of fertilizer to "low-lime," or very strongly acid, mucks. On this type of muck they believe early celery should receive 1200 to 1800 pounds of a 4-8-28 or a 3-9-18 analysis. The high-lime mucks (not acid to medium-acid) are divided into a deep, a medium, and a shallow group. The former is subdivided further into mucks requiring both potash and phosphate, and those showing little or no benefit from phosphate in the mixture. Late celery should receive 1200 to 2000 pounds of a 4-8-28 on both these or an 0-8-24 on the former and an 0-8-32 on the latter. Early celery should receive 1200 to 1800 pounds of a 3-9-18 on both these or a 2-8-10 on the former and a 2-8-16 on the latter. A 3-9-18 or a 2-8-10 analysis is suggested for shallow muck, to be used in conjunction with manure or with a green manure crop; this to be added to the muck some time in the rotation. These investigators state further: "If no manure has been applied, an application of available nitrogen fertilizer is often beneficial during a cold or a wet period. If manure has been applied, no nitrogen is needed in the fertilizer mixture."

Comin (1930) reports on a fertilizing experiment which has been under way since 1925 in Ohio. The largest yields were obtained from the heaviest treatment. This consisted of 1000 pounds to the acre of a 2-8-16 fertilizer before setting, and 500 pounds of the same analysis applied as a side-dressing three weeks, and again six weeks, after the plants were set.

Comin (1931) found that all nitrogen supplemental treatments in his test produced average increased yields of celery with only one decrease in five years. The average increases were in the neighbourhood of 8 per cent. Doubling the phosphorus applied in the basic treatment (1000 pounds per acre of 2-8-16) increased the yields every years by 7.4 per cent. Doubling the potassium applied in this basic treatment increased the yield by 8.6 per cent. He considers potash to be of most value on muck soils.

Binkley (1934) states that commercial fertilizers have been used on celery in Colorado but, so far, these have not produced sufficient increases in yield to make any general recommendations.

The Sections of Horticulture, Soils, Botany and Entomology of the Michigan Station (1938) recommend the use of a commercial fertilizer mixture containing some phosphate but high in potash to produce a better yield and better quality of celery than can be obtained by manure alone. The proper ratio of phosphate to potash in the mixture depends chiefly on the time of producing the crop and on the reaction of the soil. For early celery a good supply of phosphate in the fertilizer mixture tends to bring along the crop faster so that it will reach maturity in the shortest possible time. An excess of phosphate, however, is likely to result in an under-sized crop. In view of the fact that phosphate gradually accumulates in organic soils, this phosphate effect is more likely to be seen on old mucks rather than on a newly reclaimed one. In growing midseason and late crops of celery, it is advisable to use more potash in order to produce a larger stalk and to have improved eating and keeping quality. Thus, while a 3-12-15 mixture is suitable for an early crop of celery, an 0-8-24 generally will produce the best results on the late crop.

Hoare (1937) recommends a 4-10-6 fertilizer on the black lands of England. When manure is applied, phosphorus at the rate of 500 to 600 pounds per acre should be added.

Hoare (1938) states that potash is not regarded as being of such importance for celery as either nitrogen or phosphorus, and demonstrations in Staffordshire have shown that, by increasing the potash in the fertilizer mixture, the growth of the plants was retarded and the attacks of Leaf Spot were more severe.

Comin (1936) obtained the largest yield increase from a 6-24-48 fertilizer.

Beattie (1922) recommends the application of 1400 to 1800 pounds of a 4-8-6 or 4-8-7 fertilizer for celery.

Wilson and Townsend (1931) pointed out that field and laboratory studies with a number of muck soils showed them to accumlate nitrate nitrogen rapidly, the nitrates often reaching quantities of considerable magnitude. Accumulations were found to be larger in newly cleared muck than in that which had been cropped annually for more than twenty years. The extent to which nitrates accumulated in the soils used in some investigations suggests that the large quantities of nitrogen which are often applied to muck soils may be excessive, and possibly injurious to the proper development of certain crops, particularly on newly cleared mucks.

Skinner and Ruprecht (1930) used a number of different fertilizers and concluded that yield, size and quality of celery are influenced largely by commercial fertilizers and that amounts as high as 8,000 to 10,000 pounds per acre can be used profitably. Nitrogen and potash are effective in producing growth and quality, sufficient nitrogen is required to maintain a rapid growth during the entire growing season. The best results were secured with mixtures containing 6 to 8 per cent nitrogen. When the nitrogen needs of the crop is satisfied, potash is effective in producing yield and good quality, these increasing with the increase of potash up to 8 to 10 per cent in the fertilizer mixture. Phosphoric acid had but little effect on the growth or yield of celery in the experiments, but if omitted from the fertilizer mixture, malnutrition disturbances would likely occur with detrimental results. A fertilizer analysing 6 per cent ammonia, 2 per cent phosphoric acid and 8 per cent potash gave the largest yields.

Section A. Field Studies

Materials and Methods

For the field studies of the fertilizer requirements of celery, a section in the muck area around Ste. Clothilde de Chateauguay was selected in 1937 and used during the summer of 1938. This land, on Mr. O. Bourdon's farm, consisted of about an acre that had not been broken up for quite a number of years. The land was ploughed in the fall of 1937 and in the following spring all debris, such as partly decayed tree stumps, roots, etc., was picked off by hand. The land was harrowed several times and finally rolled before planting.

Three levels each of nitrogen, phosphorus and potash were employed in the fertilizer mixtures, namely, 0, 1 and 2 as shown in the following scheme.

Figure 1. Layout of the fertilizer treatments.

0N

	0P	1P	2P
0K	0-0	1-0	2-0
1K	0-1	1-1	2-1
2K	0-2	1-2	2-2

1N

	0P	1P	2P
0K	0-0	1-0	2-0
1K	0-1	1-1	2-1
2K	0-2	1-2	2-2

2N

	0P	1P	2P
0K	0-0	1-0	2-0
1K	0-1	1-1	2-1
2K	0-2	1-2	2-2

This gave 27 treatments. A fertilizer with a 4-8-16 analysis at one ton per acre was used as the basic treatment since it corresponded closely to the usual fertilizer recommendation, 3-8-15, in use for celery on muck soil in this part of the country. The 4-8-16 fertilizer was designated as the 1-1-1 treatment for convenience.

Table 3 shows an elaboration of the symbol combinations as well as the amounts of nitrate of soda, superphosphate and muriate of potash used.

Muck soil is considered to be relatively homogeneous, therefore, only two replications were used, giving a total of 54 plots.

Figure 2 shows the field plan. Each plot was 42 feet long by 18 feet wide. This gave five rows for harvesting and a guard row between adjacent plots. One foot was taken from each end of each plot at harvest to do away with border effect. The area of each plot was 1/57.6 acre. The area harvested was 1/72.6 acre.

The area was divided into six blocks, three in each replication. The plots were randomized within each replicate in such a way as to confound the triple interaction. Fisher (1937) proves that the accuracy of the error is increased at the expense of limiting the information which could be drawn from the triple interaction which was presumed to be of lesser value than some of the other interactions.

TABLE 3

Fertilizer treatments showing formulae and active ingredients in pounds per acre.

Treat-ment	Formula	Nitrate of soda	Superphos-phate	Muriate of potash
0-0-0	0-0-0	0	0	0
0-0-1	0-0-16	0	0	666.6
0-0-2	0-0-32	0	0	1333.3
0-1-0	0-8-0	0	800	0
0-1-1	0-8-16	0	800	666.6
0-1-2	0-8-32	0	800	1333.3
0-2-0	0-16-0	0	1600	0
0-2-1	0-16-16	0	1600	666.6
0-2-2	0-16-32	0	1600	1333.3
1-0-0	4-0-0	533.3	0	0
1-0-1	4-0-16	533.3	0	666.6
1-0-2	4-0-32	533.3	0	1333.3
1-1-0	4-8-0	533.3	800	0
1-1-1	4-8-16	533.3	800	666.6
1-1-2	4-8-32	533.3	800	1333.3
1-2-0	4-16-0	533.3	1600	0
1-2-1	4-16-16	533.3	1600	666.6
1-2-2	4-16-32	533.3	1600	1333.3
2-0-0	8-0-0	1066.6	0	0
2-0-1	8-0-16	1066.6	0	666.6
2-0-2	8-0-32	1066.6	0	1333.3
2-1-0	8-8-0	1066.6	800	0
2-1-1	8-8-16	1066.6	800	666.6
2-1-2	8-8-32	1066.6	800	1333.3
2-2-0	8-16-0	1066.6	1600	0
2-2-1	8-16-16	1066.6	1600	666.6
2-2-2	8-16-32	1066.6	1600	1333.3

Figure 2. Field plan of the celery fertilizer experiment

0-2-2	2-0-1	0-0-0	1-0-0	1-2-2	2-0-2
1-0-2	1-1-0	1-2-1	0-2-0	2-1-0	1-1-1
0-1-1	2-1-2	2-2-0	0-0-1	2-2-1	0-1-2
1-2-2	2-0-2	0-0-1	1-0-1	2-1-1	1-2-0
2-1-0	0-2-0	1-1-1	2-0-0	2-2-2	0-1-0
1-0-0	2-2-1	0-1-2	1-1-2	0-0-2	0-2-1
0-2-1	2-0-0	1-2-0	0-2-2	0-0-0	1-2-1
1-0-1	2-2-2	0-0-2	2-2-0	2-0-1	1-0-2
2-1-1	0-1-0	1-1-2	0-1-1	1-1-0	2-1-2

The rows were spaced 3 feet apart and the plants were set 6 inches apart in the row. However, local help was employed to set the plants in the field and they soon threw away the measuring sticks which they found inconvenient to use and used their own judgment which was somewhat erratic and their six inches more often than not were equal to 8 to 10 inches. This produced great variations in the number of plants per plot. The harvest yields were adjusted to partially overcome this discrepancy by the use of the Analysis of Covariance, as described by Fisher (1936).

Field planting started on July 4 and continued until July 8. Cultivation and spraying were practised throughout the summer as the occasion demanded.

Harvesting commenced on October 5 and finished on October 12. There were several days in between these dates when no harvesting was done as the plants had been rather severely frozen and it was decided to give them a chance to recuperate before finishing the harvest.

The weight of the trimmed plants was recorded. These, as already pointed out, were adjusted for the number of plants by the Analysis of Covariance before the data were analysed.

Since the plants had been frozen on two consecutive nights by 17 degrees of frost, it was considered that it would be worthless to try to conduct storage and laboratory studies on this material since it could not be expected to keep long in storage.

Experimental Results

Table 4 gives the yields of trimmed celery in pounds per plot and in pounds per acre for the two replicates, and the average yield in pounds per acre.

It is interesting to note that the standard error for the adjusted yields is 27.86 while that for the unadjusted yields was 33.23. The accuracy of the experiment was increased by 16 per cent by adjusting the yields.

Table 5 gives the analysis of variance for the celery yields.

Variation due to blocks was not sufficiently large to give any significant differences. This means that the muck soil on which the experiment was placed was sufficiently homogeneous to justify the use of only two replications.

TABLE 4

Celery yields (Oct., 1938) adjusted by regression

Treatment	Pounds per plot 1	Pounds per plot 2	Pounds per acre 1	Pounds per acre 2	Average yield per acre (lbs.)
0-0-0	80.6	77.7	5,852	5,641	5,746
0-0-1	143.8	150.1	10,440	10,897	10,669
0-0-2	284.2	178.2	20,633	12,937	16,785
0-1-0	103.9	163.8	7,543	11,892	9,718
0-1-1	339.6	215.8	24,655	15,667	20,161
0-1-2	279.8	317.9	20,313	23,080	21,697
0-2-0	103.5	170.0	7,514	12,342	9,928
0-2-1	223.4	289.2	16,219	20,996	18,608
0-2-2	314.0	283.9	22,796	20,611	21,704
1-0-0	130.3	175.8	9,460	12,763	11,114
1-0-1	256.7	130.3	18,636	9,460	14,048
1-0-2	220.7	251.1	16,023	18,230	17,127
1-1-0	172.5	144.4	12,524	10,483	11,504
1-1-1	330.2	330.8	23,973	24,016	23,995
1-1-2	291.1	284.3	21,134	20,640	20,887
1-2-0	144.7	176.8	10,505	12,836	11,621
1-2-1	391.5	354.1	28,423	25,708	27,065
1-2-2	408.0	402.4	29,621	29,214	29,418
2-0-0	140.2	120.4	10,179	8,741	9,460
2-0-1	231.2	238.5	16,785	17,315	17,050
2-0-2	229.1	231.9	16,633	16,836	16,735
2-1-0	128.5	217.8	9,329	15,812	12,571
2-1-1	269.4	323.9	19,558	23,515	21,537
2-1-2	425.6	300.4	30.899	21,809	26,354
2-2-0	189.6	184.5	13,765	13,395	13,580
2-2-1	340.8	365.8	24,742	26,557	25,650
2-2-2	436.3	358.1	31,675	25,998	28,837

Standard error of a single plot 27.86

TABLE 5

Adjusted celery yields - Ste. Clothilde, October, 1938

					Z value		
Source	D.F.	S.S.	Variance	$\frac{1}{2}\log_e$	Obtained	P .05	P .01
Blocks	5	13,127.00	2,625.40	.4835	.2875	.4817	
Treatments	24	437,036.30	18,209.85	1.4507	1.2547	.3425	.4890
N	2	33,555.78	16,777.89	1.4107	1.2147	.6123	.8626
N vs no N)	1	33,475.92	33,475.92	1.7558	1.5598	.7246	1.0285
Rates of N)	1	79.86	79.86	-	-		
P	2	103,839.56	51,919.78	1.9746	1.7786	.6123	.8626
P vs no P)	1	87,090.27	87,090.27	2.2335	2.0375	.7246	1.0285
Rates of P)	1	16,749.29	16,749.29	1.4127	1.2167	.7246	1.0285
K	2	256,858.78	128,429.39	2.4255	2.2295	.6123	.8626
K vs no K)	1	247,920.79	247,920.79	2.7567	2.5607	.7246	1.0285
Rates of K)	1	8,937.99	8,937.99	1.0953	.8993	.7246	1.0285
N x P	4	6,008.60	1,502.15	-	-		
N x K	4	2,753.85	688.46	-	-		
P x K	4	19,678.34	4,919.58	.7966	.6006	.5106	.7197
N x P x K	6	14,341.39	2,390.23	.4356	.2396	.4598	.6496
Error	24	35,631.47	1,484.64	.1960			
TOTAL	53	485,794.77					

Standard error 39.4035

Presence versus absence of nitrogen was highly significant though rate of nitrogen was not of importance. This is shown up clearly in Table 6 which consists of the total yields for the different levels of the different elements.

TABLE 6

Effect of nitrogen, phosphorus and potash on the yield of celery in the field.

0	N	3719	0	P	3270	0	K	2624
4%	N	4595	8%	P	4639	16%	K	4925
8%	N	4731	16%	P	5136	32%	K	5497

The difference required for significance is 327.6.

The analysis of variance further reveals that presence versus absence of phosphorus and rates of phosphorus were highly significant in increasing yields.

Presence versus absence of potash was exceedingly important. Rates of potash had a significance greater than the P .05 level. In other words, the possibility of obtaining increases in the yield such as was shown between 16 per cent and 32 per cent K would occur by chance only once in more than twenty times.

TABLE 7

Percentage increases in yields over the zero treatments due to increases of nitrogen, phosphorus and potash.

Increase due to	Per cent increase
4% N	23.55
8% N	27.21
8% P	41.86
16% P	57.06
16% K	87.69
32% K	109.48

These figures show large increases in yield due to increasing the amounts of phosphorus and potash. Nitrogen did not increase the yield quite as much as the other two elements. However, the increases due to nitrogen were very significant.

Reference to Table 6 will show that under the conditions of this experiment the 4-16-32 fertilizer produced the best results. The 8-16-32 produced the largest yield but the increase in yield due to doubling the quantity of nitrogen was not sufficiently large to justify the expense of purchasing and applying the extra nitrate.

The interaction of nitrogen on phosphorus, and nitrogen on potash did not influence the growth substantially. The interaction of phosphorus on potash was just significant.

Discussion

Muck soil has been considered to be quite homogeneous by many workers. That is, fertility and structural gradients do not appear within an area of muck to the same extent that they do in mineral soil. The fact that the variance due to blocks in this experiment is not significant, falls in line with other investigations on soil of this type. This muck is rather woody in nature but is fairly well decomposed.

Muck soils in different areas may well be quite different due to the type of growth which once prevailed. This would affect the composition and acidity of the soil. Muck or peat that is submerged in water would not be as well decomposed as a drier soil would be since the soil bacteria require a certain amount of aeration before their activity becomes noticeable.

This explains why the present results do not conform to those of the experimental results obtained by workers in other localities. However, in the main, increase of nitrogen, phosphorus and potash increased the yields quite considerably.

The increases of yield shown in Table 7 are of very great importance when it is considered that not only is the weight in pounds per acre increased but the size of the plants is also affected. Consequently, the marketability value of high quality produce is substantially increased.

Norton (1917) found that celery responded more readily to increment of nitrogen than to other forms of plant food. Under the conditions of this experiment it was found that potash was the most important, with phosphorus running a close second.

Hoare (1938) states that potash is not as important for the growth of celery as either nitrogen or phosphorus.

Doubling the nitrogen content of the basic treatment gave an increase of 2.95%. Doubling phosphorus gave an increase of 10.71 per cent while double potash resulted in 11.61 per cent increase.

In view of the increases recorded, the 1-2-2 combination might be recommended. This contains 80 pounds N, 320 pounds P_2O_5 and 640 pounds K_2O. This might be supplied by 3500 pounds of a 2-8-16 fertilizer made up from nitrate of soda (15%), superphosphate (20%) and muriate of potash (50%) with no filler added.

The increases due to phosphorus and potash are somewhat of the order that Comin (1931) suggests, only larger amounts of fertilizer have to be applied to get the results.

Section B. Greenhouse Studies

Introduction

The field studies gave an insight into the needs of the celery plant *in situ.* These needs will vary with the soil and its locality. An attempt was made to determine the actual needs of the celery plant. For this purpose quartz sand was the medium in which the plants were grown, the fertilizers being applied as nutrient solutions. Attempts were made to determine the needs of celery on different soil types. Muck and mineral soils were used, applying commercial fertilizers at the same rates as in the field. In the subsequent report the quartz sand experiment will be designated Experiment 1 and the muck and mineral soils experiments will be designated Experiment 2 and Experiment 3 respectively.

Materials and Methods

Experiment 1

Quartz sand was obtained and placed in boxes in the greenhouse bed. These boxes were two feet long, one foot wide and eight inches deep. The boxes contained no bottoms and were set on a good layer of cinders to facilitate drainage. Later, three plants were transplanted into each box and the treatments randomized.

The seedlings, after they were one inch high, were transplanted into flats containing quartz sand and were watered each week with a general nutrient solution made up as in Table 8. The plants were watered when necessary with distilled water.

This formulae together with the quantities of solutions used was the same as that employed by the Horticulture Division, Central Experimental Farm, Ottawa.

TABLE 8

General nutrient solution for small seedlings

Calcium nitrate	$CaNO_3$	102.30	grams
Magnesium sulphate	$MgSO_4, 7H_2O$	40.70	"
Superphosphate (16%)		63.34	"
Muriate of potash		15.97	"
Boric acid	H_3BO_3	0.257	"
Manganese sulphate	$MnSO_4, 4H_2O$	0.037	"
Water		40.00	gallons

When the seedlings were about two inches high (May 27, 1938), they were set out in the sand beds. The first feeding was made on the following day.

The solutions were made up in such a way that after 13 weeks' growth the plants would have received in total nutrients an amount equivalent to that which the plants received while growing in the field.

Table 9 shows the amount of elements in parts per million received weekly by the plants for the first four weeks.

TABLE 9

Parts per million of elements in solution for the first four weeks

N	44.5
P	39.0
K	142.5
Mg	96.4
Ca	400.0
S	203.0
Cl	706.0
Mn	0.2
Zn	0.1
Fe	8.3
Cu	0.1
B	1.5

TABLE 10

Concentration of stock solutions and the amount of each used in making up the 1-1-1 treatment

Chemical	Grams per litre	Amount of stock solution in 5000 ccs. distilled water
NH_4NO_3	90.0	7.06 ccs.
KH_2PO_4	35.0	24.44
K_2SO_4	50.0	41.46
$MgSO_4, 7H_2O$	70.0	69.75
$CaCl_2$	75.0	73.80
$MnSO_4, 2H_2O$	0.62	5.50
$CuSO_4, 5H_2O$	0.333	3.77
$ZnSO_4$	0.25	4.97
$FeCl_3, 6H_2O$	5.0	24.20
H_3BO_3	1.0	42.88

Table 10 represents the solution which was applied to the 1-1-1 treatment. Solutions for the other treatments were made up by varying the amounts of nitrogen, phosphorus and potash. In the case of the no potash treatments,phosphorus was supplied as orthophosphoric acid since both K and P are present in potassium phosphate. This is made up by diluting 10 ccs. of the acid to 1000 ccs. and applying 39.31 ccs. of stock solution for the single application.

In the case of 0-2-1, 1-2-1 and 2-2-1, increasing the level of phosphorus to 2 would supply too much potash from the potassium phosphate. To overcome this difficulty, a single level of phosphorus was supplied as KH_2PO_4 and the remainder as H_3PO_4. In treatments receiving no K_2SO_4, the sulphur content was necessarily lowered. This was brought up to normal by adding sufficient sodium sulphate. In the case of the double application of K, the sulphur was a little higher than in the rest of the treatments. This was the only element that fluctuated apart from N, P and K. However, this fluctuation was not considered to be of great importance.

At the end of the first four weeks' growth, the concentration of N, P and K was increased 2.45 times and so maintained for the remaining nine weeks.

The pH of the solutions was adjusted to 5.5 by adding the appropriate amount of N/10 NaOH to each solution.

These solutions were applied each week to the plants at the rate of 600 ccs. of solution per plant.

The total number of leaves more than one inch high in each treatment was counted on July 5.

Measurements of height of the plants were made on July 5, July 19 and August 1.

The length and weight of the roots were determined at harvest on August 1 after the roots had been carefully washed out of the sand.

Experiment 2

The muck soil used in the greenhouse experiments was brought by truck from the field next to the one in which the field fertilizer experiment was conducted at Ste. Clothilde.

Boxes two feet along, one foot wide and one foot deep were built into the greenhouse bench. These were filled with muck soil and the twenty-seven fertilizer treatments that were used in the field were employed at the same rate. Three plants were placed in each box on November 30, 1938.

Measurements were made on the height of the plants on February 9, February 22, March 8 and March 22. The number of leaves was counted on the first three dates but not on the last because the plants were badly affected with heart-rot which necessarily reduced the number of heart leaves. The plants were watered with tap water when necessary.

Experiment 3

The same procedure was followed as in Experiment 2 except that instead of muck soil, mineral soil was placed in the boxes. This mineral soil was a good quality greenhouse compost made up of garden loam and well decayed manure.

Since there was a temperature gradient throughout the greenhouse, the muck and mineral soil plots were randomized as well as the treatments on each of the two soil types.

Review of Literature

Experiment 1

Blake, Nightingale and Davidson (1937) found that apple trees lacking potassium developed as rapidly during the first two months of the experiment as those lacking phosphorus and magnesium. Later, these trees began to be superior to those in the latter treatments. They did not grow so rapidly nor so vigorously as those receiving a complete nutrient solution.

Davis, Hill and Johnson (1934) grew strawberry plants under normal conditions for one season and then subjected them to low potassium conditions. These plants were able to cope with the situation to an almost efficient degree, but such was not the case with regard to phosphorus or magnesium.

Gregory (1937) found that the effect of deficiency in reducing both tiller number and leaf area occurred in the decreasing order of N, P, K. Decrease in potassium in all series studied led to an increase in sodium uptake.

Experimental Results

Experiment 1

Influence of treatment on growth

Height

The presence of nitrogen showed up throughout the whole growing period as being extremely necessary for the growth in height of the plants.

TABLE 12

Effect of nitrogen on growth of plants in sand culture

Treatment	July 5	July 19	August 1
0 N	59.2	54.6	169.6
4% N	116.3	174.6	545.6
8% N	128.4	184.0	569.8
Significant difference	21.9	39.3	124.1

It can be seen from the above table that 4 per cent N gave significant increases in growth over the zero treatment but doubling the nitrogen did not result in much better growth.

TABLE 11

Height of plants in greenhouse quartz sand
(total of 3 plants per plot)

Treatment	July 5 cms.	July 19 cms.	August 1 cms.
0-0-0	14.9	15.2	24.4
0-0-1	8.4	15.2	17.2
0-0-2	19.0	18.5	23.4
0-1-0	15.2	15.2	17.9
0-1-1	16.5	15.2	16.1
0-1-2	19.0	18.5	19.3
0-2-0	16.5	7.6	15.1
0-2-1	21.5	19.0	20.9
0-2-2	19.0	15.2	15.3
1-0-0	22.8	21.0	22.2
1-0-1	24.1	26.2	29.5
1-0-2	25.4	19.8	23.4
1-1-0	38.1	52.8	62.7
1-1-1	30.5	59.7	76.6
1-1-2	47.0	88.4	113.9
1-2-0	25.4	26.7	28.9
1-2-1	41.4	76.9	91.4
1-2-2	40.6	71.9	97.0
2-0-0	20.3	19.0	16.8
2-0-1	17.8	18.5	21.2
2-0-2	19.0	19.8	20.5
2-1-0	36.3	41.4	40.3
2-1-1	56.6	93.9	116.2
2-1-2	53.3	82.5	113.9
2-2-0	27.9	24.9	21.6
2-2-1	41.5	75.7	104.1
2-2-2	52.8	91.4	115.2

TABLE 13

Effect of phosphorus on growth of plants in sand culture

Treatment	July 5	July 19	August 1
0 P	67.7	68.3	198.6
8% P	123.1	184.2	576.9
16% P	113.1	160.7	509.5
Significant difference	21.9	39.3	124.1

Eight per cent of phosphorus increased the growth markedly over the nil treatment. It is interesting to note that 16 per cent or the double application has a detrimental effect throughout the whole growing season.

TABLE 14

Effect of potash on the growth of plants in sand culture

Treatment	July 5	July 19	August 1
,0 K	85.7	88.2	249.9
16% K	101.9	157.2	493.2
32% K	116.3	167.8	541.9
Significant difference	21.9	39.3	124.1

On July 5, the single application of potash did not increase the growth significantly over the nil treatment, it being necessary to apply 32 per cent potash to give a sufficient increase to be apparent. From these figures and from the appearance of the treatments receiving no potash during the first five weeks, it would appear that during this stage of growth the plants were quite capable of carrying on the necessary metabolic processes without the addition of any more potash. The seedlings received a general nutrient solution weekly before being transplanted into the sand beds, so it looks as though the young plants had stored up sufficient potash in their tissues to tide them over a period in which they received no further potash.

After July 5, potash deficiency began to show up as evinced by the readings of July 19 and August 1. On these two dates the addition of 16 per cent K significantly increased the height of the plants. Doubling the application did not result in marked increases. Apparently, 16 per cent potash supplied sufficient potassium to bring about metabolism within the plant leading to protein and carbohydrate synthesis.

The N x K interaction is the only one of significance. This showed up about the middle of July.

TABLE 15

Weight of plants at harvest and number of leaves on three plants in each treatment on July 5.

Treatment	Weight in gms.	No. of leaves
0-0-0	1.2	5
0-0-1	0.6	4
0-0-2	1.3	5
0-1-0	0.7	7
0-1-1	0.8	7
0-1-2	1.1	6
0-2-0	0.6	6
0-2-1	1.2	6
0-2-2	0.5	9
1-0-0	1.4	11
1-0-1	4.1	13
1-0-2	2.2	8
1-1-0	24.9	18
1-1-1	46.9	16
1-1-2	159.2	19
1-2-0	3.8	13
1-2-1	67.5	17
1-2-2	101.1	18
2-0-0	0.2	8
2-0-1	1.1	7
2-0-2	1.0	8
2-1-0	9.1	17
2-1-1	148.0	19
2-1-2	129.0	18
2-2-0	0.9	17
2-2-1	77.0	16
2-2-2	202.9	21

Weight

Table 15 gives the weight of the plants grown in the sand culture and also the number of leaves on three plants in each treatment on July 5.

TABLE 16

Effect of nitrogen, phosphorus and potash on the weight of tops taken at harvest of plants grown in sand culture

0	N	8.0	0	P	13.1	0	K	42.8
4%	N	411.1	8%	P	519.7	16%	K	347.2
8%	N	569.2	16%	P	455.5	32%	K	598.3

The difference required for significance is 314.3. The presence versus absence of nitrogen, phosphorus and potash is highly significant. It is interesting to note that 0 potash gave somewhat better results than 0 nitrogen and 0 phosphorus, but 16 per cent potash did not result in an increase of significant proportion. The combination of 4 per cent nitrogen, 8 per cent phosphorus and 32 per cent potash brought about the greatest significant weight. The double application of phosphorus had a slightly depressing effect on the weight of the plants and there were no interactions of significance.

Influence of treatments on number of leaves

The leaf count was taken only once but it sheds some interesting light on the development of the plant under the conditions of the different treatments.

The 4 per cent nitrogen and 8 per cent phosphorus treatments resulted in increased number of leaves over the zero treatment.(Table 17). The double applications of N and P had a very slight depressing effect. There is no significant difference between presence and absence of potash, thus suggesting that the plants had stored up enough of this element when in the seedling stage.

TABLE 17

Effect of nitrogen, phosphorus and potash on the leaf count of plants grown in sand culture on July 5

0 N	55	0 P	69	0 K	102
4% N	133	8% P	127	16% K	105
8% N	131	16% P	123	32% K	112

The difference required for significance is 13.7

Ratios and correlations

The ratio of length of top to length of root varied with the different treatments. The ratio was greater than unity in most cases only when the three elements were present.

The ratio of weight of top to weight of root varied considerably more than the length ratio. This is presumably due to the fact that the roots were air-dried at room temperature overnight before being weighed. Since some of the root systems were much larger and more bushy than the others, they maintained more moisture and thus influenced the results. However, even here the ratios are larger when all three elements were present, than when only one or two of the three elements studied were present (Table 18).

The correlation of length of top to length of root is highly significant with a coefficient of 0.9180.

The correlation of weight of top to weight of root is just as significant with a coefficient of 0.9116.

Thus for each small change in the size of the root, there is a corresponding change in the size of the top. This is of great importance inasmuch as any factor that affects the root adversely, results in a much decreased growth (Plate 1).

TABLE 18

Ratios of length and weight of top to root.

Treatment	Length ratio top:root	Weight ratio top:root
0-0-0	1.16	0.66
0-0-1	0.84	0.37
0-0-2	0.72	0.37
0-1-0	0.75	0.58
0-1-1	0.53	0.27
0-1-2	0.79	0.52
0-2-0	0.73	0.55
0-2-1	0.62	0.41
0-2-2	0.82	1.00
1-0-0	0.97	2.33
1-0-1	0.81	0.92
1-0-2	0.91	2.20
1-1-0	0.89	6.10
1-1-1	1.29	4.39
1-1-2	1.79	10.62
1-2-0	1.20	1.65
1-2-1	1.47	4.98
1-2-2	1.53	5.37
2-0-0	0.67	0.40
2-0-1	1.01	1.00
2-0-2	1.45	2.50
2-1-0	0.88	1.44
2-1-1	1.88	5.76
2-1-2	1.81	6.41
2-2-0	0.82	0.81
2-2-1	1.79	5.13
2-2-2	1.79	3.52

Effect of treatments on the development of the roots

Length

Table 19 gives the length and weight of the roots of plants grown in different nutrient solutions in pure quartz sand in the greenhouse.

TABLE 20

Effect of nitrogen, phosphorus and potash on length of roots of plants grown in sand culture

0	N	224.1	0	P	227.4	0	K	294.7
4%	N	443.0	8%	P	444.1	16%	K	386.2
8%	N	383.0	16%	P	379.4	32%	K	370.0

The difference required for significance is 100.88. From the above figures it can be seen that 4 per cent nitrogen and 8 per cent phosphorus have the greatest length of roots. Doubling these applications decreased the ultimate length achieved by the roots. Potash did not significantly increase the length of roots.

TABLE 19

Length and weight of roots in sand.

Treatment	Length in cms.	Weight in gms.
0-0-0	22.3	1.8
0-0-1	19.0	1.6
0-0-2	32.5	3.5
0-1-0	24.6	1.2
0-1-1	30.3	2.9
0-1-2	25.0	2.1
0-2-0	20.9	1.1
0-2-1	33.4	2.9
0-2-2	16.1	0.5
1-0-0	27.3	0.6
1-0-1	36.8	4.6
1-0-2	26.4	1.0
1-1-0	70.9	3.9
1-1-1	59.2	10.4
1-1-2	63.5	14.6
1-2-0	32.2	2.3
1-2-1	62.1	14.2
1-2-2	64.6	20.8
2-0-0	24.7	0.5
2-0-1	24.3	1.1
2-0-2	14.1	0.4
2-1-0	45.9	5.3
2-1-1	61.6	26.5
2-1-2	63.1	20.0
2-2-0	25.9	1.1
2-2-1	59.5	16.5
2-2-2	64.7	57.9

Weight

TABLE 21

Effect of nitrogen, phosphorus and potash on the weight of roots in sand

0 N	17.6	0 P	15.1	0 K	17.8
4% N	72.4	8% P	86.9	16% K	80.7
8% N	129.3	16% P	117.3	32% K	120.8

The difference required for significance is 76.55. It was necessary to double the application of the elements before the weight of the roots would increase significantly.

Condition of roots

The lack of nitrogen, phosphorus and potash tended to produce small brownish root systems. When all three ingredients were present, the root systems were large, succulent and white.

The analysis for length of roots showed that potash did not affect the length, but on the other hand an analysis for weight showed that a heavy application of potash was necessary before the weight was significantly increased. A further examination of the root system showed something of considerable interest. The length and weight of the roots may not have been unduly affected by potash but potash had a decided effect on texture. Plate 1 shows the difference between a root system from the cultures lacking potash and one from the cultures with potash. This shows clearly that the 1-1-0 root system consisted of long, stringy, coarse roots with very few short, stubby rootlets, and the 1-1-1 root system, which contained potash, consisted of many fine rootlets which penetrated throughout the soil in all directions supplying the plant with an abundance of water and soil nutrients.

Deficiency symptoms

Nitrogen

In the treatments lacking nitrogen but possessing both phosphorus and potash the plants were small, pale green to colourless and of no value. This was on July 16.

Phosphorus

Phosphorus deficient plants were small and of a pale green colour. Many of the leaves had a mottling of bronze.

Potash

The plants in the potash deficient treatments grew normally till about the fifth of July before the deficiency became noticeable. This deficiency was characterized by pale green to yellow leaves and weak stems which were unable to support the leaves, consequently they had a droopy appearance. Treatments high in nitrogen but lacking potash seem to be the first to show deficiency symptoms. Once the reserve potash was used up, the plants very quickly deteriorated.

Condition of plants

The following treatments at the time of harvest were small and of no value:

0-0-0	1-0-0
0-0-1	1-0-1
0-0-2	1-0-2
0-1-0	1-2-0
0-1-1	2-0-0
0-1-2	2-0-1
0-2-0	2-0-2
0-2-1	2-1-0
0-2-2	2-2-0

It is interesting to note that in the treatments on the previous page there are no more than two elements in any one treatment. There seems to be a balance required before normal growth can take place. An excess of one element will not make up for the lack of another.

The following treatments had good vigorous plants at the time of harvest:

1-1-0	2-1-1
1-1-1	2-1-2
1-1-2	2-2-1
1-2-1	2-2-2
1-2-2	

The 1-1-0 treatment was lacking in potash but seemed to be able to keep up a good growth with the amounts of nitrogen and phosphorus present. Possibly when two elements are properly balanced, the deficiency of the third is not quite so noticeable.

Maximov (1930) cites Mitscherlich as suggesting that the increase in one of the nutrient elements slightly augments the effect of the other nutrient substances. Thus, in the case of nitrate deficiency, a potash fertilizer may increase the yield, though according to the law of the minimum this should not be the case.

Since the potassium can be replaced by sodium to some extent, the explanation for the continued growth of the 1-1-0 treatment might be found. In making up the nutrient solutions, the sulphur content was maintained in the absence of potassium sulphate by adding an appropriate amount of sodium sulphate. The sodium added here may have been enough along with nitrogen and phosphorus to give good growth.

Experiment 2

Effect of treatments on plants

The treatments used on the muck soil in the greenhouse were the same as those used in the field experiment in Section A and the muck soil came from the adjoining field. In many respects the results from these indoor plats were quite different.

TABLE 23

Effect of nitrogen on height of plants grown on muck soil in the greenhouse

	Feb. 9	Feb. 22	March 8	March 22
0 N	253.0	332.7	450.7	661.6
4% N	253.9	348.1	469.8	677.5
8% N	234.7	327.2	460.7	712.5
Significant difference	28.26	35.92	34.18	44.37

TABLE 22

Height (in cms.) of plants in greenhouse on muck soil.

Treatment	Feb. 9	Feb. 22	March 8	March 22
0-0-0	12.3	14.5	16.1	25.0
0-0-1	12.2	16.2	20.6	32.2
0-0-2	13.1	19.3	25.2	41.1
0-1-0	37.6	45.3	65.0	97.7
0-1-1	40.8	51.8	69.4	91.3
0-1-2	40.4	47.4	64.2	94.1
0-2-0	37.9	50.6	65.0	97.6
0-2-1	27.0	39.0	58.9	91.7
0-2-2	31.7	48.6	66.3	90.9
1-0-0	9.7	11.7	13.7	20.7
1-0-1	14.1	20.1	25.3	37.7
1-0-2	13.5	17.0	22.1	35.9
1-1-0	42.8	52.6	69.6	88.6
1-1-1	36.3	52.6	65.7	98.2
1-1-2	28.8	43.1	69.0	100.8
1-2-0	42.8	58.2	70.9	91.8
1-2-1	33.7	49.7	66.4	98.8
1-2-2	32.2	43.1	67.1	105.0
2-0-0	10.9	12.5	14.6	22.5
2-0-1	17.3	25.0	37.7	60.5
2-0-2	9.2	14.2	17.9	27.2
2-1-0	33.9	48.9	66.3	104.3
2-1-1	31.5	43.4	65.3	102.2
2-1-2	27.5	41.1	61.2	91.5
2-2-0	34.7	48.2	66.3	105.1
2-2-1	35.9	52.0	72.5	113.1
2-2-2	33.8	41.9	58.9	86.1

The only significant difference here is shown at harvest when the double application of nitrogen gave an increased yield over the nil treatment.

TABLE 24

Effect of phosphorus on height of plants grown on muck soil in the greenhouse

	Feb. 9	Feb. 22	March 8	March 22
0 P	112.3	150.3	193.2	302.8
8% P	319.6	426.2	595.7	868.7
16% P	309.7	431.3	592.3	880.1
Significant difference	28.26	35.92	34.18	44.37

From February 9 until harvest, the addition of 8 per cent of phosphorus gave a very marked increase in the size of the plants but the double application did not make any improvement in the yield.

TABLE 25

Effect of potash on height of plants grown on muck soil in the greenhouse

	Feb. 9	Feb. 22	March 8	March 22
0 K	262.6	342.5	447.5	653.3
16% K	248.8	349.8	481.8	725.7
32% K	230.2	315.7	451.9	672.6
Significant difference	28.26	35.92	34.18	44.37

The only effect due to the addition of potash made itself known by height at harvest when 16 per cent potash gave a significant increase over the zero treatment. At the other three dates potash did not improve the size as measured by height of plant.

The muck soil used in the greenhouse was very low in potash. Morgan's Universal Soil Testing System (1937) revealed the fact that the soil contained less than 150 pounds of potash per acre.

Plate 2 shows the size of the plants in the 0-0-0, 0-0-1 and 0-0-2 treatments at harvest. The background is laid out in two inch squares.

Plate 3 shows the effect of adding phosphorus to the treatments in Plate 2.

In Plate 4, nitrogen was added to the treatments in Plate 2. The increase in size is almost negligible.

The addition of phosphorus in Plate 5 to the treatments in Plate 4 resulted in a very great increase in growth.

Plates 6 to 10 show the effects on size of plants by doubling nitrogen and phosphorus.

Effect of treatments on leaf count

Leaf counts were made on February 9, February 22 and on March 8, but not on March 22 because heart rot at this date greatly cut down the number of leaves in the heart that might have otherwise been counted.

TABLE 26

Effect of nitrogen on leaf count on plants grown on muck soil in the greenhouse

	Feb. 9	Feb. 22	March 8
0 N	187	228	283
4% N	200	235	311
8% N	178	228	300
Significant difference	28.9	34.1	43.7

The addition of nitrogen did not increase the number of leaves. The 8 per cent application slightly decreased the number.

TABLE 27

Effect of phosphorus on leaf count on plants grown on muck soil in the greenhouse

	Feb. 9	Feb. 22	March 8
0 P	109	138	163
8% P	230	280	373
16% P	226	273	358
Significant difference	28.9	34.1	43.7

Eight per cent of phosphorus increased the number of leaves but 16 per cent had a slight depressing effect.

TABLE 28

Effect of potash on leaf count on plants grown on muck soil in the greenhouse

	Feb. 9	Feb. 22	March 8
0 K	183	216	283
16% K	195	244	315
32% K	187	231	296
Significant difference	28.9	34.1	43.7

Potash did not increase the number of leaves on the plants until March 8.

Since the effects of nitrogen, phosphorus and potash were identical on both the height and number of leaves on the plants, it would seem that there was a very definite relation between the size of the plant and the number of leaves produced.

Experiment 3

Effect of treatments on plants

Mineral soil, as would be expected, gave very different results of the fertilizer treatments from what was obtained on muck soil.

Table 29 gives the measurements of height of the celery plants at four dates. These measurements are the total of the height of three plants in each treatment.

TABLE 30

Effect of nitrogen on height of plants grown on mineral soil in the greenhouse

	Feb. 9	Feb. 9	March 8	March 22
0 N	239.7	353.9	528.3	859.5
4% N	216.2	336.3	482.1	780.8
8% N	209.8	312.6	446.4	754.6
Significant difference	34.98	43.11	66.70	85.50

TABLE 29

Height (in cms.) of three plants per treatment on mineral soil in the greenhouse.

Treat-ment	Feb. 9	Feb. 22	March 8	March 22
0-0-0	26.6	37.9	57.6	93.6
0-0-1	28.6	39.2	61.3	99.9
0-0-2	23.6	39.3	57.5	101.7
0-1-0	29.4	43.6	65.0	91.3
0-1-1	24.6	35.3	53.5	89.9
0-1-2	30.6	45.7	66.7	106.7
0-2-0	36.7	50.4	72.8	111.7
0-2-1	26.5	41.7	56.8	95.8
0-2-2	13.1	20.8	37.1	68.9
1-0-0	30.7	47.0	65.8	99.4
1-0-1	23.0	37.3	54.4	91.1
1-0-2	14.3	26.4	36.3	72.9
1-1-0	34.6	49.1	72.9	111.5
1-1-1	27.7	41.1	54.8	87.3
1-1-2	16.1	30.1	42.9	77.3
1-2-0	34.3	52.6	78.0	110.8
1-2-1	25.9	37.4	53.0	78.7
1-2-2	9.6	15.3	24.0	51.8
2-0-0	27.6	37.9	56.1	91.7
2-0-1	17.3	23.6	35.6	61.6
2-0-2	11.4	18.1	27.3	57.2
2-1-0	29.4	43.6	59.4	99.4
2-1-1	27.7	41.4	54.2	80.0
2-1-2	23.0	36.6	46.9	82.3
2-2-0	28.9	42.2	60.5	98.3
2-2-1	27.7	41.0	62.9	105.8
2-2-2	16.8	28.2	43.5	78.3

Eight per cent nitrogen gave significant decreases in height on March 8 and 22. On the first two dates the decrease reached almost to the odds of 20:1.

TABLE 31.

Effect of phosphorus on height of plants grown on mineral soil in the greenhouse

	Feb. 9	Feb. 22	March 8	March 22
0 P	203.1	306.7	451.9	769.1
8% P	243.1	366.5	516.3	825.7
16% P	219.5	329.6	488.6	800.1
Significant difference	34.98	43.11	66.70	85.50

On February 9 and 22, the addition of phosphorus increased the height. On March 8, the increase was hardly significant, while on March 22, phosphorus did not produce any significant difference.

TABLE 32

Effect of potash on height of plants grown on mineral soil in the greenhouse

	Feb. 9	Feb. 22	March 8	March 22
0 K	278.2	404.3	588.1	907.7
16% K	229.0	338.0	486.5	790.1
32% K	158.5	260.5	382.2	697.1
Significant difference	34.98	43.11	66.70	85.50

Potash gave the most striking results of all on the mineral soil. Good yields were obtained without any additional potash. The addition of 16 per cent decreased the yields significantly while a further addition of 16 per cent gave another significant decrease.

Effect of treatments on leaf count

Leaf counts were made on the same three dates as with the plants grown on muck soil.

TABLE 33

Effect of nitrogen on leaf count on plants grown on mineral soil in the greenhouse

	Feb. 9	Feb. 22	March 8
0 N	209	255	347
4% N	196	246	336
8% N	182	231	324
Significant difference	33.5	33.9	48.8

Nitrogen did not affect the leaf count markedly, though it had a slight depressing influence.

TABLE 34

Effect of phosphorus on leaf count on plants grown on mineral soil in the greenhouse

	Feb. 9	Feb. 22	March 8
0 P	176	219	300
8% P	221	269	373
16% P	190	244	334
Significant difference	33.5	33.9	48.8

The addition of 8 per cent of phosphorus increased the number of leaves. Sixteen per cent decreased the number.

TABLE 35

Effect of potash on leaf count on plants grown on mineral soil in the greenhouse

	Feb. 9	Feb. 22	March 8
0 K	237	291	390
16% K	205	250	347
32% K	145	191	270
Significant difference	33.5	33.9	48.8

Increasing potash to 16 per cent and to 32 per cent decreased the number of leaves very markedly each time.

The figures on the leaf count as well as those on height measurements would suggest that the mineral soil already had sufficient nitrogen and potash. Further additions decreased the yield. An 8 per cent application of phosphorus improved the size of the plants. Since greenhouse compost, containing manure, was used, these results would indicate that this mineral soil, with a good application of manure, would require only an application of 800 pounds of superphosphate. It is quite possible that a smaller application of phosphorus might have given a greater response, since there are some indications that increasing the phosphorus decreased the yield somewhat.

These results on the mineral soil are very strikingly brought out in photographs (Plates 11-19).

From these photographs, it can be seen that the depressing influence of potash occurred more markedly when nitrogen was present, and as the nitrogen was increased the effect became greater.

Prevalence of heart-rot.

No detailed studies were made on heart-rot, but certain observations were made which in all probability are worthy of mention.

Affected plants were first noticed on the muck soil. Later, this condition, which is believed to be physiological, developed on the mineral soil plots and ultimately surpassed the muck soil plots in number of plants affected. The reason for this is that the plants on the mineral soil were larger and more plants contained hearts.

TABLE 36

Number of plants affected with heart-rot on muck and mineral soils in the greenhouse

Soil	March 3	March 8	March 20
Muck soil	21	42	53
Mineral soil	11	24	60

Discussion

Experiment 1

Four per cent nitrogen, eight per cent phosphorus and sixteen per cent potash gave the best results with celery growing in quartz sand.

Potash applications did not bring about any improvement during the first five weeks. Apparently the plants had stored up sufficient quantities of this element during the seedling stage to tide them over a part of the experimental period when they were receiving no potash in the nutrient solutions. This was in keeping with the results of Blake et al (1937) and Davis et al (1934).

Potash deficiency symptoms in celery compare somewhat with those in potatoes as pointed out by Rohde (1935), e.g., yellowing of older leaves, dwarfing of the plant, a weakened root formation, a marked development of deficiency symptoms in the presence of an abundance of nitrogen.

Crist and Stout (1929) found that the top/root ration of lettuce varied with experimental conditions between the extremes of 0.79 and 12.96. Various fertilizers increased the top/root ratio. In the present work, the top/root ratio varied from 0.27 to 10.62 (Table 16), depending on the fertilizer.

Crist and Stout found that the coefficient of correlation of weight of top to weight of root in lettuce was 0.521, in radish 0.728 and in tomato 0.885. With celery, the coefficient of correlation between length of top and length of root was found to be 0.9180 and of weight of top to weight of root was 0.9116.

There seems to be no question but that nitrogen, phosphorus and potash are necessary for the formation of strong, healthy, well-developed root systems.

Experiment 2

The muck soil used in the greenhouse was from the same locality in which the field experiment was conducted. The results of the greenhouse and field experiments differ quite considerably. This is to be expected to some extent as the conditions of light, temperature, amount of soil and moisture existing in the greenhouse were quite different to those existing in the field. The question is, however, could these differences in environment be directly responsible for the differences in growth as exhibited by the plants growing under the different fertilizer treatments? The plants inside were grown during the winter months in a house where the temperature fluctuated between 50 and 65 degrees a good part of the time, while often it was below 60 during the day.

Experiment 3

On the mineral soil, both potash and nitrogen had a depressing effect on growth. Apparently there was an abundance of these elements already in the soil.

PART II.

COLD STORAGE STUDIES

Introduction

Certain fertilizers may produce excellent yields of celery in the field but these same fertilizers may not be the best for celery culture from the standpoint of keeping quality. This is the other aspect of the problem so it is the purpose of these storage studies to attempt to find which fertilizer will produce a good crop which deteriorates the least in cold storage.

The criteria by which keeping quality was measured were percentage breakdown, pithiness and changes in colour.

Review of Literature

Sandsten and White (1902) and Austin and White (1904) found that pithiness is hereditary and dates back to the parent plant.

Norton (1917) states that pithiness is characterized by a lack of parenchyma, due in self-blanching varieties to heredity, to the propagation of an undesirable strain or to reversion. He states further that in other forms it is probably due to unfavourable cultural methods and conditions.

Mills (1923) associates pithiness with early maturity in the field and too high a temperature in the store house.

Sayre (1929) states that pithiness evidently is correlated with a breaking down of the parenchyma which leaves large open spaces through the centre of the stalk.

Emsweller (1932) describes two kinds of pithiness. There is the type which is found throughout all the petioles, even in the young plants, and which is caused by a single dominant gene. The second type develops with maturity in the outer petioles.

Binkley (1934) attributes pithiness to growth checks, poorly selected seed, too rapid a growth following a growth check, and to severe injury by late blight and web-worm.

White-Stevens (1938) states that pithiness develops rapidly after the plants have attained the culmination of their growth but points out that in the cold storage it progresses more slowly. He also finds that the appearance of pithiness is preceded by a decline in the osmotic value of the cells concerned.

Certain English authors, notably Hoare (1937, 1938) and Quarrell (1938), state that nitrogenous fertilizers should be applied judiciously since excessive amounts encourage the production of pithy plants.

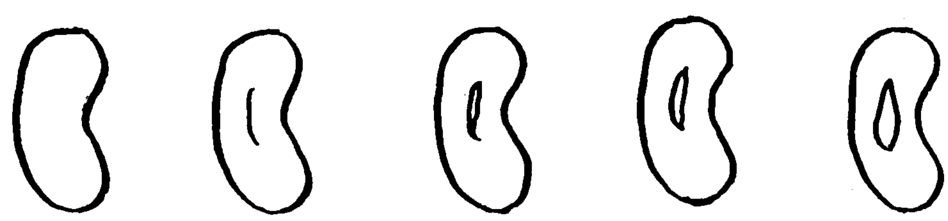
Materials and Methods

The material used in the cold storage studies was obtained in 1937 from an experiment similar to the one outlined in Part I, Section A.

The celery was placed in cold storage on October 1. Readings were taken on pithiness, colour changes and breakdown at 50, 71, 96, 106 and 120 days after the material was placed in storage.

Pithiness was measured by giving a number according to the size of the cavity. For instance: solid petioles 0, faint trace 1, cavity just discernible 2, cavity of fair size 3, and cavity large 4.

Figure 3. Pithiness standards



0 1 2 3 4

The plants were cut across about two inches from the crown, thus exposing the cross-section of both outer and inner petioles. It was easy to see at a glance the amount of pithiness present and so to evaluate it.

Earlier workers, particularly Austin and White (1904) required that considerable pithiness be present before the plant was considered pithy. A plant was not counted pithy unless the whole heart as well as the outer part was pithy. When three or four outer petioles were somewhat pithy and the heart was solid, the plant was counted solid.

In the present work, an attempt was made to differentiate between pithiness and non-pithiness. Even a single petiole showing only a trace of pithiness was recorded. In this way it was hoped that pithiness could be determined whether due to treatments, senescence or position of the petiole on the plant.

Colour was rated according to numerical standards, e.g., dark green 4, green 3, light green 2, and blanched 1.

Breakdown was determined by weighing before and after trimming off the unmarketable parts. If a part of a petiole was rotted or had become soft and worthless through wilting, only the worthless part was removed, not the whole petiole as would have been done in commercial trimming. Each plant should have been weighed at the time it went into storage and the difference between this and the final trimmed weight used in estimating the percentage breakdown. However this was not done and the author had to be content with weighing the plant as it came from storage.

There were no plants of the 2-0-0 treatment after the first of the year since only two crates had been put in storage and they were, unfortunately, used for another purpose. However, the three remaining readings for this treatment were estimated by a method derived by Yates (1933) to restore orthogonality and to make the estimate of the error more valid.

The storage temperature was found to be 32.1 $\pm$ 4.06. This was determined by a recording thermometer which operated for a period of about four weeks between November 17 and December 10. It was impossible to determine the relative humidity accurately with the hydro-thermograph employed, but it flucturated between 93% and 97%.

The celery, at the time that it was placed in the storage, was remarkably free from disease.

The data were analysed by Fisher's Analysis of Variance (1936, 1937) and the significance tested by the Distribution of Z.

Experimental Results

Pithiness

The data indicate that the position of the petiole on the plant, whether inner or outer, was highly significant. The outer petioles showed more pithiness than the inner. (Table 37.)

TABLE 37

Pithiness of celery in storage

Treat-ment	Nov.19 O	Nov.19 I	Dec.10 O	Dec.10 I	Jan. 4 O	Jan. 4 I	Jan.14 O	Jan.14 I	Jan.28 O	Jan.28 I	Total O	Total I	Average O	Average I	Grand Total
0-0-0	1.2	.2	.8	.3	1.5	.3	1.4	.6	1.6	.8	6.5	2.2	1.30	.44	8.7
0-0-1	.4	.1	.1	0	1.1	.2	.7	.1	.9	.1	3.2	.5	.64	.10	3.7
0-0-2	2.7	1.2	1.4	.6	2.6	1.6	.8	.2	2.8	1.8	10.3	5.4	2.06	1.08	15.7
0-1-0	.9	0	.4	.1	.8	.2	.2	0	.6	.1	2.9	.4	.58	.08	3.3
0-1-1	.4	0	.1	0	.7	0	1.0	1.0	.8	.2	3.0	1.2	.60	.24	4.2
0-1-2	.1	0	.4	.1	.5	0	.2	0	.6	0	1.8	.1	.36	.02	1.9
0-2-0	1.5	.6	.9	.2	.7	.3	.4	.1	.7	.1	4.2	1.3	.84	.26	5.5
0-2-1	.3	0	.2	0	.4	0	.6	0	0	0	1.5	0	.30	0	1.5
0-2-2	.2	0	.5	.1	.1	0	0	0	.5	0	1.3	.1	.26	.02	1.4
1-0-0	.3	0	.4	0	2.0	1.0	2.8	1.8	2.6	1.8	8.1	4.6	1.62	.92	12.7
1-0-1	.9	.6	.3	0	1.4	.9	.4	.1	1.2	.7	4.2	2.3	.84	.56	6.5
1-0-2	.7	.1	.6	.1	.6	.2	.2	0	.6	.3	2.7	.7	.54	.14	3.4
1-1-0	1.0	.2	.4	0	1.2	.3	.6	.2	1.2	.3	4.4	1.0	.88	.20	5.4
1-1-1	.7	0	.3	.1	1.4	.7	.2	0	.2	0	2.8	.8	.56	.16	3.6
1-1-2	0	0	1.0	.4	0	0	.7	.2	.5	0	2.2	.6	.44	.12	2.8
1-2-0	.7	.1	.9	.3	.8	.1	.2	.4	.2	0	2.8	.9	.56	.18	3.7
1-2-1	.1	0	.2	0	.1	0	.4	.1	.8	.1	1.6	.2	.32	.04	1.8
1-2-2	.6	0	.6	0	.6	.1	.4	0	.4	.2	2.6	.3	.52	.06	2.9
2-0-0	.2	0	0	0	.3	.2	.2	.2	.4	.2	1.1	.6	.22	.12	1.7
2-0-1	1.9	.1	1.8	.8	2.7	1.6	2.7	2.0	2.2	1.4	11.3	5.9	2.28	1.18	17.2
2-0-2	.4	0	1.0	.1	1.4	.5	2.7	1.5	2.6	1.4	8.1	3.5	1.62	.70	11.6
2-1-0	.4	0	.6	.1	.3	0	1.0	.4	1.0	.4	3.3	.9	.66	.18	4.2
2-1-1	.1	0	.3	0	.3	0	.8	.2	.2	0	1.7	.2	.34	.02	1.9
2-1-2	.2	0	.4	0	0	0	.2	0	0	0	.8	0	.16	0	.8
2-2-0	.7	.2	.8	.2	.4	0	0	.1	.2	0	2.1	.5	.42	.10	2.6
2-2-1	.1	0	.5	0	.2	.1	0	0	.4	.2	1.2	.3	.24	.06	1.5
2-2-2	.2	0	.3	0	.4	.2	0	0	.1	.1	1.0	.3	.20	.06	1.3
Total	16.9	3.4	15.2	3.5	22.5	8.5	18.8	9.2	23.3	10.2	96.7	34.8	19.36	7.04	131.5
Mean	.625	.125	.562	.129	.833	.314	.696	.340	.862	.377	3.585	1.307	.717	.260	4.892

O - Outer petiole
I - Inner petiole

TABLE 38

The average amount of pithiness for all treatments in inner and outer petioles

Date	Outer petioles	Inner petioles
Nov. 19	.625	.125
Dec. 10	.562	.129
Jan. 4	.833	.314
Jan. 14	.696	.340
Jan. 28	.862	.377

Reference to Figure 3 will show that the amount of pithiness present was not extensive.

There was a slight increase in pithihess from November 19 to January 28 but this increase was not significant, hence it can be concluded that pithiness did not increase with maturity or senescence as was the case with Emsweller's second type of pithiness.

TABLE 39

Effect of nitrogen, phosphorus and potash on pithiness

0	N	45.9	0	P	81.2	0	K	47.8
4%	N	42.8	8%	P	28.1	16%	K	41.9
8%	N	42.9	16%	P	22.2	32%	K	41.8

The difference required for significance is 10.03. The different levels of nitrogen and potash had no effect on the amount of pithiness present. The 8 per cent of phosphorus showed a very significant decrease from the zero treatment. An additional 8 per cent did not bring about any further reduction.

The interactions of P x K, P x N and N x K were highly significant. This means that although nitrogen and potash singly did not affect pithiness, yet when in combination with each other and with phosphorus they produced a noticeable effect on the amount of pithiness, decreasing the amount.

Colour

Colour changes of the petiole were observed in the cold storage over a period of four months. The results are tabulated in Table 40.

Figure 4. Average colour values

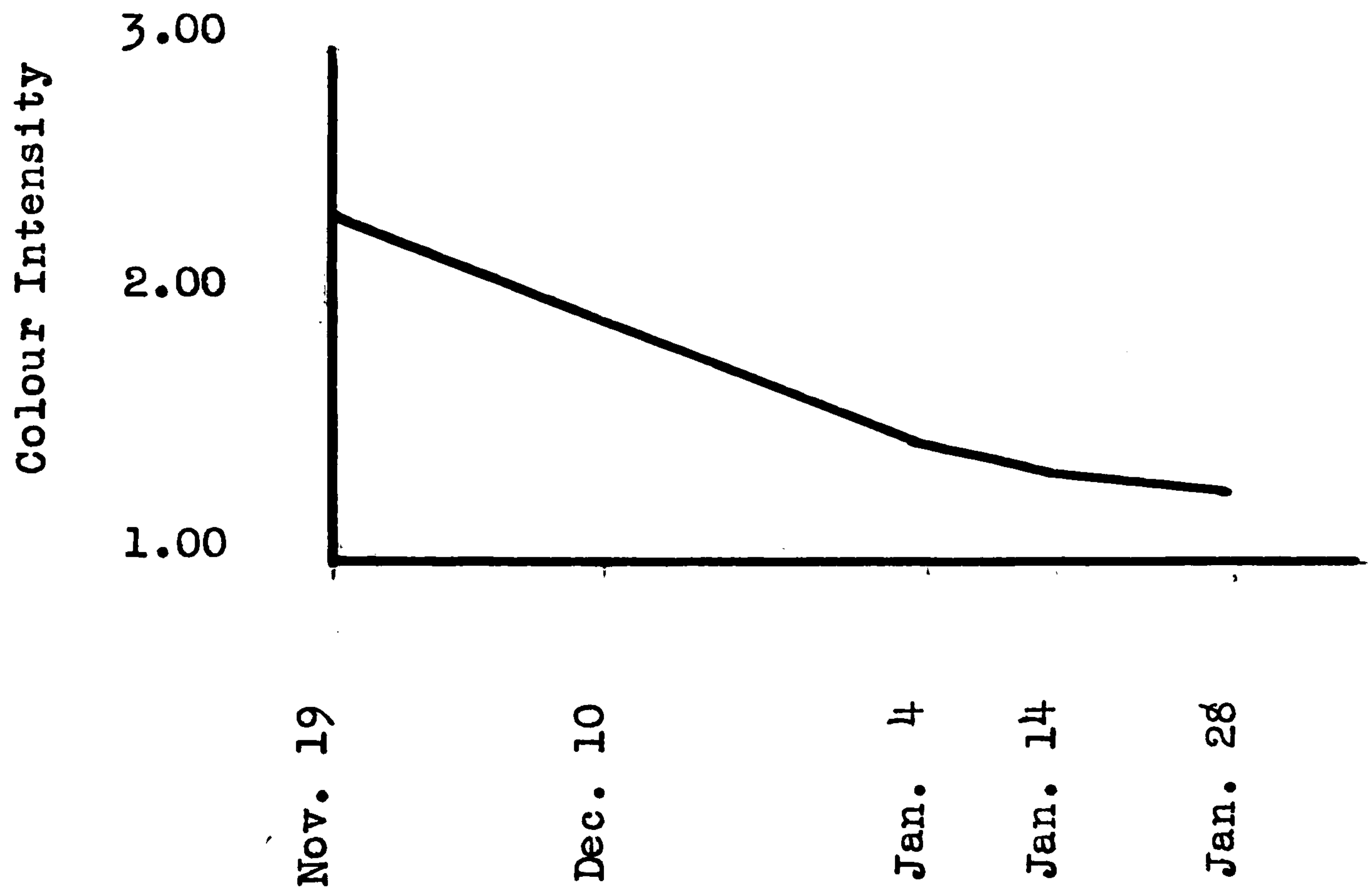


Figure 4 shows that there was a steady decline from November 19 to January 4 in the colour intensity of the plants. From then until the end of the storage period, the rate of blanching was reduced.

TABLE 40

Colour values of the external petioles from different treatments at different dates.

Treat-ment	Nov. 19th	Dec. 10th	Jan. 4th	Jan. 14th	Jan. 28th	Total	Average
0-0-0	2.4	2.4	1.9	2.0	1.9	10.6	2.12
0-0-1	2.2	2.2	1.8	2.0	1.5	9.7	1.94
0-0-2	4.0	2.4	1.6	1.5	1.9	11.4	2.28
0-1-0	2.2	2.6	1.9	1.6	1.6	9.9	1.98
0-1-1	2.0	2.6	1.7	1.2	1.0	8.5	1.70
0-1-2	2.0	1.2	1.6	1.3	1.1	7.2	1.44
0-2-0	2.0	2.2	1.4	1.2	1.0	7.8	1.56
0-2-1	2.0	2.0	1.5	1.6	1.0	8.1	1.62
0-2-2	2.0	1.8	1.4	1.1	1.0	7.3	1.46
1-0-0	3.0	2.8	2.0	2.0	2.0	11.8	2.36
1-0-1	3.0	2.2	2.0	1.8	1.1	10.1	2.02
1-0-2	2.0	1.2	1.1	1.0	1.2	6.5	1.30
1-1-0	2.2	1.8	1.4	1.3	1.1	7.8	1.56
1-1-1	2.0	1.0	1.1	1.2	1.0	6.3	1.26
1-1-2	2.0	1.8	1.1	1.0	1.4	7.3	1.46
1-2-0	2.4	2.0	1.3	1.3	1.1	8.1	1.62
1-2-1	2.0	1.2	1.0	1.1	1.2	6.5	1.30
1-2-2	2.0	1.3	1.0	1.1	1.0	6.4	1.28
2-0-0	3.0	2.2	2.0	1.9	1.8	10.9	2.18
2-0-1	3.0	2.0	1.7	1.7	1.6	10.0	2.00
2-0-2	2.8	2.0	1.9	1.9	1.5	10.1	2.02
2-1-0	2.8	2.0	1.4	1.3	1.2	8.7	1.74
2-1-1	2.0	1.5	1.2	1.0	1.0	6.7	1.34
2-1-2	2.2	1.6	1.3	1.1	1.0	7.2	1.44
2-2-0	2.2	2.0	1.4	1.0	1.0	7.6	1.52
2-2-1	2.0	1.6	1.0	1.0	1.0	6.6	1.32
2-2-2	2.2	1.0	1.0	1.0	1.0	6.2	1.42
Total	63.6	50.6	39.7	37.2	34.2	225.3	45.06
Mean	2.355	1.874	1.470	1.377	1.266	8.344	1.668

TABLE 41

Effect of nitrogen, phosphorus and potash on colour of petioles

0	N	80.5	0	P	91.1	0	K	83.2
4%	N	70.8	8%	P	69.6	16%	K	72.5
8%	N	74.0	16%	P	64.6	32%	K	69.6

The difference required for significance is 6.90. Four per cent nitrogen, eight per cent phosphorus and sixteen per cent potash gave significantly lower intensities of colour than the respective zero treatments. Double applications of these elements did not change the colour significantly.

Plants receiving such percentages of the elements concerned would be comparatively large, thus a certain amount of blanching would have taken place in the field due to the more abundant foliage.

On the other hand plants receiving no fertilizer were relatively small and green and maintained their green colour throughout the storage period.

Breakdown

The percentages of breakdown for the various elements calculated for the five sampling dates are given in Table 42.

TABLE 42

Breakdown percentages.

Treat-ment	Nov. 19th	Dec. 10th	Jan. 4th	Jan. 14th	Jan. 28th	Total
0-0-0	0	24.46	34.62	43.07	42.54	144.69
0-0-1	4.73	30.76	35.80	45.76	48.09	165.14
0-0-2	6.46	41.66	46.61	44.21	59.86	198.80
0-1-0	20.68	25.29	37.06	40.24	25.81	149.08
0-1-1	4.47	25.24	35.87	45.46	46.99	158.03
0-1-2	5.72	19.80	37.23	37.86	42.59	143.20
0-2-0	5.13	20.75	44.30	45.60	41.48	157.26
0-2-1	5.53	18.11	30.51	32.30	35.88	122.33
0-2-2	20.73	24.15	41.36	30.58	31.88	148.70
1-0-0	12.84	26.22	37.60	53.74	58.06	188.46
1-0-1	18.43	28.42	36.78	44.65	43.01	171.29
1-0-2	8.87	28.53	29.64	41.64	46.14	154.82
1-1-0	18.94	22.11	27.12	42.29	50.46	160.92
1-1-1	7.88	38.91	31.07	42.88	53.05	173.79
1-1-2	14.25	22.76	33.08	38.37	20.56	129.02
1-2-0	7.45	29.78	31.61	40.25	47.39	156.48
1-2-1	6.66	10.75	20.00	34.00	40.83	112.24
1-2-2	10.10	24.10	37.25	41.16	44.40	157.01
2-0-0	10.01-	23.07	40.26	51.99	54.11	179.44
2-0-1	11.20	30.48	39.87	47.39	50.44	179.38
2-0-2	0.39	30.43	34.32	41.40	45.86	152.40
2-1-0	13.04	24.05	28.18	36.57	31.28	133.12
2-1-1	6.29	22.30	28.74	39.83	42.40	139.56
2-1-2	2.81	14.90	26.61	34.43	36.39	115.14
2-2-0	0	24.22	29.56	44.56	36.85	135.19
2-2-1	0	12.48	21.77	42.13	29.04	105.42
2-2-2	0	17.52	32.40	28.06	33.96	111.94
Total	222.61	661.25	909.22	1110.42	1139.35	4042.85
Mean	8.24	24.49	33.67	41.12	42.19	

The average percentage breakdown is portrayed in Figure 5. There was a steady increase of breakdown until the middle of January. During the following two weeks the rate of breakdown decreased quite appreciably.

Figure 5. Average percentage breakdown

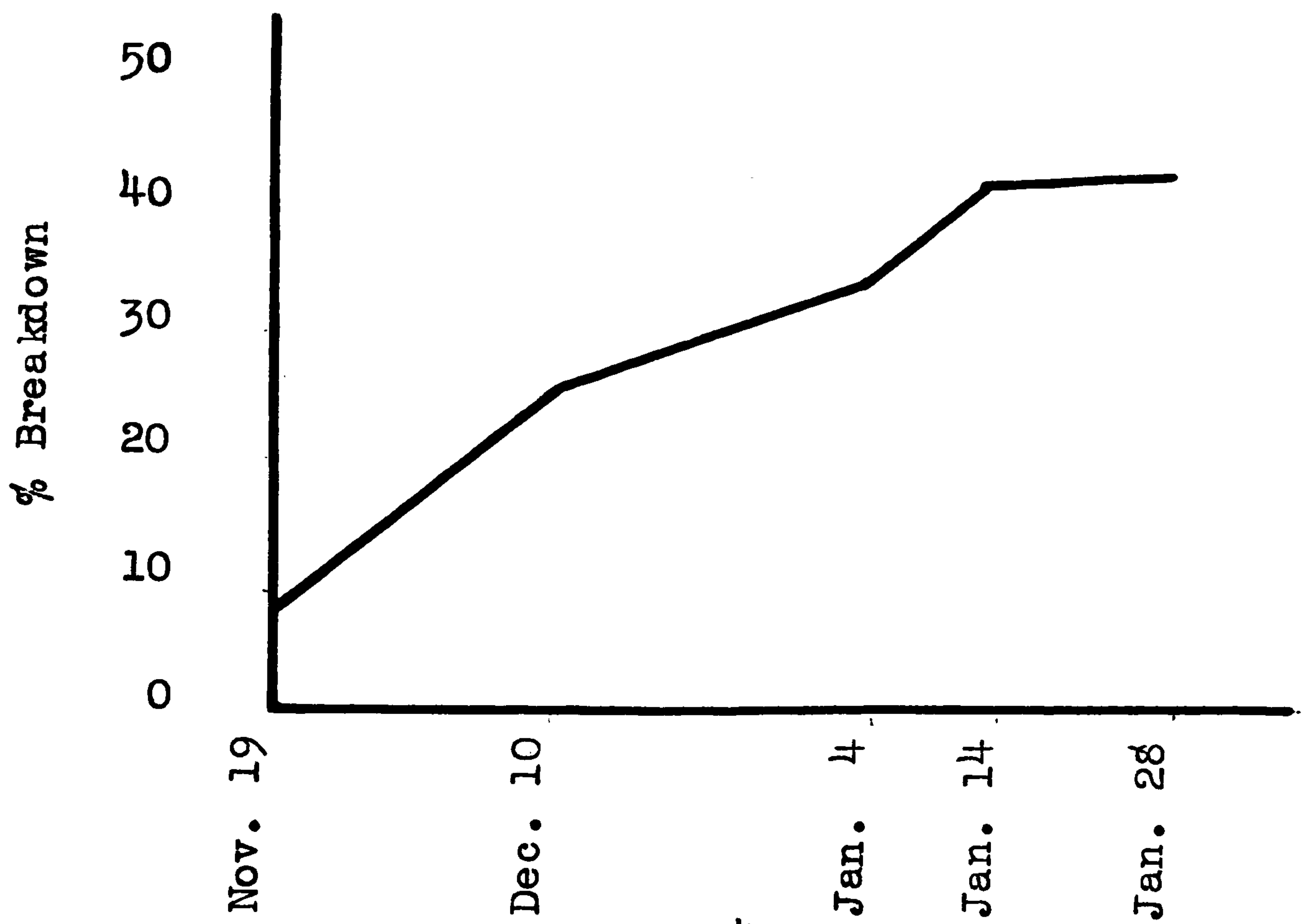


TABLE 43

Effect of nitrogen, phosphorus and potash on breakdown

0	N	1387.23	0	P	1534.42	0	K	1404.64
4%	N	1404.03	8%	P	1301.86	16%	K	1327.18
8%	N	1251.59	16%	P	1206.57	32%	K	1311.03

The difference required for significance is 108.82. Eight per cent nitrogen and 8 per cent phosphorus gave the lowest significant percentages of breakdown. Plants from the plots receiving such amounts of nitrogen and phosphorus would be comparatively large and consequently considerable trimming could take place before the size of the plant would be appreciably affected. It is noticeable that the levels of potash did not produce any significant differences in the amount of breakdown, though 32 per cent potash approached the odds of 20:1.

Discussion

Pithiness

Sandsten and White (1902), Austin and White (1904) and Emsweller (1932) have traced pithiness to the genetical make-up of the plant. If such is the sole cause of pithiness, then the seed used to produce the plants for the work under review must have been of a very high order, since of all the plants studied there was no outstanding quantity of pithiness.

Maturity did not bring with it more pithiness as Emsweller (1932) and White-Stevens (1938) found.

The fact that nitrogen did not increase pithiness is in accord with the results of White-Stevens (1935) but is in disagreement with the claims of Hoare (1937, 1938) and Quarrell (1938) who suggest that excessive nitrogenous fertilizers produce pithy plants. It would seem that 8 per cent of nitrogen on muck soil would be considered an excess since good growth is obtained with a much smaller quantity.

Colour

Celery petioles are blanched in the field by banking, placing boards or heavy paper along the rows close to the plants in order to exclude light or by very close spacing of rows.

The colour in plant cells is due to the presence of plastids, chromoplasts being coloured and leucoplants colourless. Eames and MacDaniels (1925) state that of the chromoplasts, the most important are the green chloroplasts which are contained in the cortical parenchyma and collenchyma cells.

The various cell types in the cortex serve various functions, but it is evident that the cortex is primarily a protective layer with such functions as support, photosynthesis and storage being secondary.

That all the plastids are alike in nature is clear from the readiness with which they are transformed from one into another. For example, the chloroplasts of young fruit and of developing petals may become the chromoplasts of the ripe fruit and of the mature flower respectively and the leucoplasts of a potato tuber become chloroplasts on exposure to light.

Since the Golden Self Blanching variety was used, the natural shading of the petioles by the leaves may have transformed the chloroplasts into leucoplasts, thus accounting for the blanching process.

Knudson (1939) agrees with this transformation of chloroplasts into leucoplasts. He states further that, in view of recent work, the production of ethylene in the plants itself may be a factor in the blanching process, varieties which blanch most rapidly producing a greater quantity of ethylene.

Miller (1931) states that the lack of potassium gives rise, so far as can be observed, to no pathological condition of the chloroplasts, and under conditions of K deficiency they remained normal for two months and even increased in number. The loss of the power of synthesis by green plants in the absence of K has been observed by Stocklasca which possibly explains why treatments lacking potash maintained a strong intensity of green colour throughout the storage period and resulted in small unmarketable plants.

Breakdown

Storage conditions have not yet been brought to the point where produce can be kept for prolonged periods without some deterioration. A steady increase of breakdown took place until about 41 per cent had been reached by the middle of January. It is quite noticeable that when large plants free from disease, frost and mechanical injuries, are placed in cold storage, a large heart in sound condition may be had even as late as the middle of January.

The fact that potash did not effect breakdown is rather strange because potash seems to be a necessary constituent of the fertilizer if large well-filled stalks (Part 1, Section A), are to be found in the plants growing in the field.

However, as potash is passive in its effect on breakdown and necessary for field growth the amount giving the best field results should be recommended for use.

PART III.

LABORATORY STUDIES

Introduction

In the cold storage studies changes were observed in phenomena relative to the keeping quality of celery. However, these studies did not reveal sufficient information concerning celery behaviour in cold storage. Since celery high in sugar was thought to be of better quality than celery containing a smaller quantity of this substance, the analysis of the plants at different dates was planned in an attempt to determine which fertilizer resulted in the sweetest product and when the product was at its best. For this purpose the osmotic concentration was decided upon since it would give a quick, accurate, comparative measure of the sugar content. A detailed description of this method is given under Materials and Methods.

Review of Literature

Dixon and Atkins (1915) state that the major part of the osmotic pressure of tissues is due to dissolved carbohydrates.

Variation of the sugar content closely followed the variation of the osmotic pressures, according to Lewis and Tuttle (1920). They also found that the sugars show a decided concentration during the winter months.

Magness (1922) and others have reported a slight increase in the total quantity of sugar in the apple between the time of harvest and the time when the fruit became soft.

Maximov (1930) states that in some plants osmotic pressure is induced chiefly by sugars and organic acids. When starch is hydrolysed into sugar, the osmotic pressure is increased considerably. Furthermore, it has been found that in the majority of halophytes with an extraordinarily high pressure, the substances are most frequently either sodium chloride or some other mineral salts.

The osmotic pressure in the cell is not constant. It varies continually, depending on the chemical processes of the cell. Thus when starch is hydrolysed into sugar, the pressure is increased considerably, and likewise is decreased as a result of the reverse process, that is, the accumulation of starch at the expense of sugar. The imperfect oxidation of sugar, accompanied by an accumulation of organic acids of small molecular weight, as for example, oxalic acid, also leads to an increased osmotic pressure.

Materials and Methods

Before any attempt was made to measure quality in stored celery, it was necessary first to establish a criterion by which to judge the quality, maturity and senescence.

White-Stevens (1936) determined the changes in pectin during the storage period. From his work, he concluded that there appeared no definite correlation between pectic hydrolysis and storage maturity.

Both White-Stevens (1935) and Bourque (1937a) working on the sugar changes occurring in celery during storage concluded that such changes were a reliable criterion of quality and storage maturity. These workers found that there was an increase in sugar content up to a maximum and then a decline. The decline in sugar content was accompanied by a general deterioration of the celery. They found that it was not advisable to keep the celery in the storage after the maximum sugar content had been attained.

The laboratory studies in connection with this present work were based on an acceptance in principle of this conclusion. However because of the necessary materials, the number of samples, and time required to make a chemical analysis for sugars, the method used by White-Stevens and by

Bourque could not be used in this case. Another method, known as the osmotic pressure method or De Vries plasmolytic method, was used. This method is accurate as well as being rapid and is independent of the fluctuation of the water content of the cells. It was devised in 1884 and is based on the following considerations as outlined by Maximov (1930). The higher the osmotic pressure of the external solution above the osmotic pressure of the cell sap, the greater is the shrinkage of the protoplasm. On the other hand, the smaller the decrease in the volume of the protoplasmic sac, the less it will withdraw from the cell wall, thus showing a smaller difference between the two pressures. If a concentration of the outer solution is found which causes but an incipient shrinking of the protoplasm, which is usually observed in some corner of the cell, one may then assume that this concentration of the outer solution balances the concentration of the cell sap within. Since the concentration of the outer solution is known, it is easy to calculate its osmotic pressure and from this the almost equal osmotic pressure of the cell sap.

The problem is then to find a concentration of the external solution that produces only incipient plasmolysis. For this purpose, a series of solutions of increasing concentrations was prepared, differing from one another by the same magnitude, for instance, by 0.01 mol. Thin sections of celery were placed in these different solutions.

The highest concentrations induced strong plasmolysis (Plate 20) and the weakest showed no plasmolysis at all (Plate 21). Somewhere in between, a concentration was found which induced only the incipient stages of plasmolysis (Plate 22). This concentration corresponds closely to the molecular concentration of the cell sap.

Ernest (1935) disagrees with the use of this method in determining the osmotic values of plant cells because as she points out the cells are injured in sectioning. She suggests that the plasmolysis which is seen is not a real plasmolysis but rather a pseudo-plasmolysis, induced by pathological actions. However, since the plasmolytic method gives the same results as the cryoscopic method, it was accepted as giving results of sufficient reliability.

Solutions were made up in concentrations from 0.15 M to 0.30 M, each differing by 0.01 mol. Solutions of sodium chloride and calcium chloride were made up in different concentrations. In order to prevent staining of the cell wall, a mixture of nine parts of sodium chloride to one part of calcium chloride was employed. Since these two chlorides at the same concentration do not have equal osmotic pressures as expressed in atmospheres, the concentrations of the calcium chloride were adopted as the concentrations of the final solutions. Sodium chloride solutions having an osmotic pressure in atmospheres equivalent to the 0.15, 0.16, 0.17, etc. concentrations of the calcium chloride were made up and thoroughly mixed with the correct proportions of calcium chloride.

These solutions were placed in small vials which were kept corked to prevent evaporation, thus maintaining the correct concentration.

Samplings were made simultaneously with the storage examinations. Five plants were taken at random from the plants of each fertilizer treatment at each sampling. An inner and an outer petiole were taken from each plant and thin sections of tissue were cut with a sectioning razor, from approximately one inch below the first node of the petiole. These were placed in a neutral red solution for staining. They were then placed in the solutions of different concentration and left for fifteen minutes after which they were examined nicroscopically. The solution which brought about incipient plasmolysis was considered as being isotonic with the cell sap.

Experimental Results

Incipient plasmolysis, the stage at which 50 per cent of the cells showed signs of plansmolysis and 50 per cent did not, was brought about by a certain concentration of the salt solution. This concentration was considered to be isotonic with the sugar solution within the cells.

Maximov (1930) shows that the isotonic value at incipient plasmolysis is necessarily a little higher than normal, due to the slight contraction of the cell walls and protoplasm. However, since this difference was common to all the readings, this method was accepted without change as a measure of osmotic concentration.

Table 44 gives the osmotic values for the outer and inner petioles. These values are the average of the five readings of both inner and outer petioles taken at each sampling.

Lewis and Tuttle (1920) and others claim that there is a rise in the osmotic pressure until it reaches a certain maximum after which it gradually falls off. Some treatments showed a rise, a fall and then a rise to a maximum, before the final decline. Others showed an almost steady decline beginning early in the season. However, when the average of the treatments was considered, a curve representing this was plotted which had its maximum about the tenth of December (Figure 6). This means that

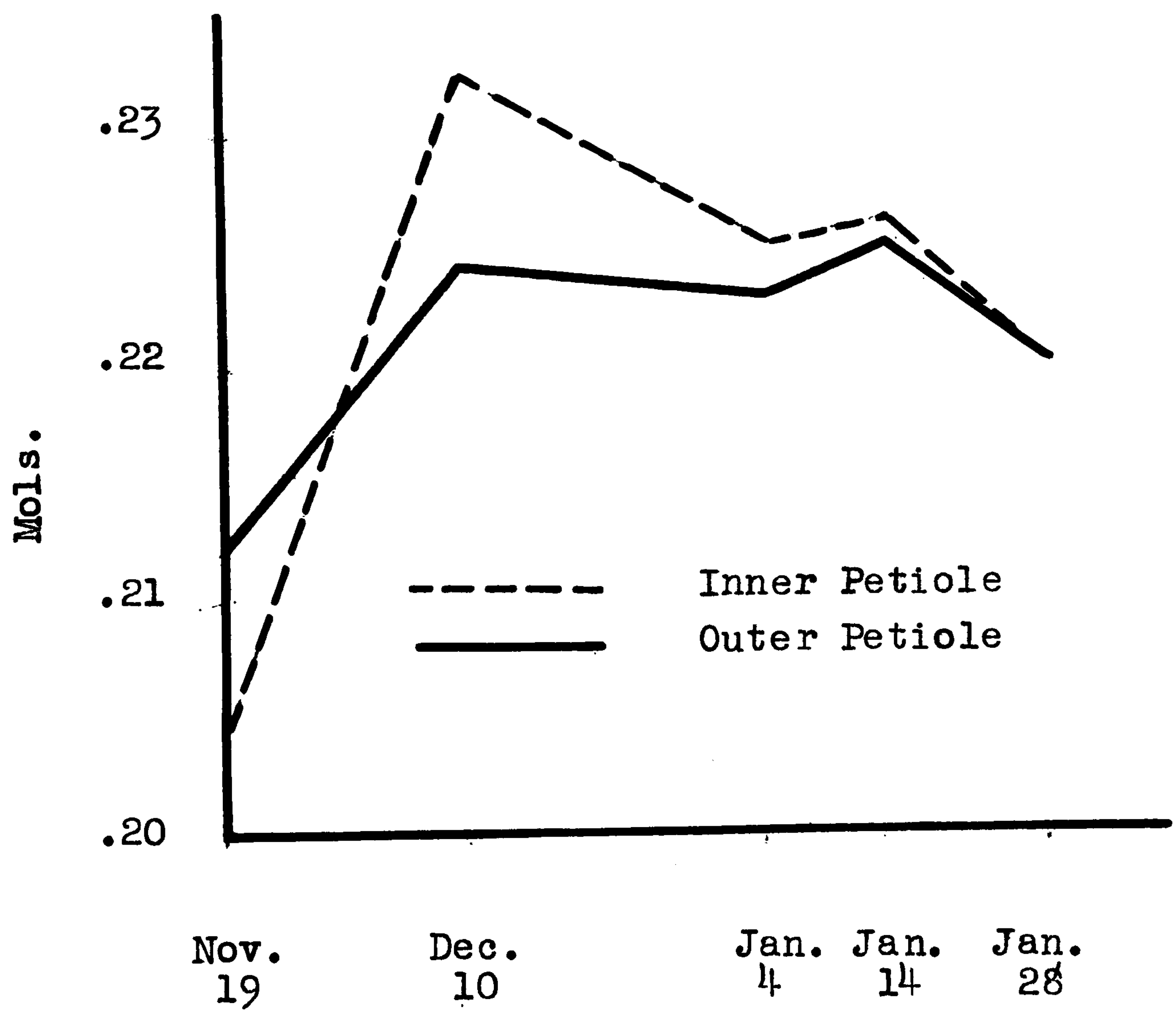
TABLE 44

Osmotic values of inner and outer petioles of plants from the different fertilizer treatments at different dates.

Treat-ment	Nov.19 O	Nov.19 I	Dec.10 O	Dec.10 I	Jan. 4 O	Jan. 4 I	Jan.14 O	Jan.14 I	Jan.28 O	Jan.28 I
0-0-0	.24	.21	.23	.23	.22	.22	.23	.23	.22	.21
0-0-1	.22	.19	.21	.22	.21	.22	.23	.23	.23	.22
0-0-2	.18	.20	.24	.25	.23	.23	.24	.23	.25	.25
0-1-0	.20	.18	.21	.23	.22	.23	.21	.22	.21	.21
0-1-1	.18	.17	.21	.22	.21	.22	.22	.20	.22	.22
0-1-2	.20	.17	.21	.22	.22	.22	.21	.21	.22	.22
0-2-0	.21	.21	.22	.23	.22	.22	.23	.23	.23	.23
0-2-1	.22	.21	.21	.23	.22	.22	.24	.24	.22	.22
0-2-2	.22	.21	.23	.24	.22	.22	.22	.23	.21	.21
1-0-0	.22	.22	.25	.25	.24	.25	.25	.25	.25	.25
1-0-1	.22	.22	.25	.25	.25	.25	.25	.25	.24	.24
1-0-2	.21	.20	.20	.21	.23	.22	.21	.21	.20	.20
1-1-0	.20	.21	.24	.25	.24	.25	.24	.24	.23	.23
1-1-1	.21	.20	.20	.20	.20	.21	.21	.21	.21	.20
1-1-2	.21	.20	.20	.20	.22	.21	.20	.21	.20	.19
1-2-0	.20	.19	.21	.22	.21	.21	.21	.21	.20	.20
1-2-1	.19	.19	.22	.23	.20	.21	.22	.21	.20	.20
1-2-2	.21	.21	.22	.23	.23	.22	.22	.21	.21	.21
2-0-0	.23	.23	.23	.24	.23	.24	.24	.24	.23	.24
2-0-1	.23	.22	.24	.25	.25	.26	.26	.27	.26	.26
2-0-2	.22	.23	.24	.26	.23	.23	.23	.23	.23	.23
2-1-0	.21	.20	.23	.24	.22	.22	.23	.24	.23	.23
2-1-1	.21	.21	.22	.23	.24	.24	.24	.24	.23	.23
2-1-2	.21	.22	.22	.22	.20	.20	.20	.21	.18	.19
2-2-0	.23	.22	.24	.25	.25	.25	.24	.24	.23	.24
2-2-1	.22	.19	.24	.25	.21	.21	.22	.22	.23	.23
2-2-2	.23	.22	.23	.24	.21	.21	.20	.21	.19	.19
Total	5.73	5.53	6.05	6.29	6.03	6.09	6.10	6.12	5.96	5.95
Mean	2.12	2.04	2.24	2.32	2.23	2.25	2.25	2.26	2.20	2.20

the sugar content is at its highest about the tenth of December after which it falls off. It is quite possible that the climacteric may be some days later than the tenth, but since no readings were taken between this date and the fourth of January, there is no available data with which to support this possibility.

Figure 6. Average osmotic concentration



A careful study of Table 44 will reveal that there was considerable fluctuation in the osmotic values of the different treatments taken at the different dates. There seems to be little consistency in the data as they stand, but after a statistical analysis the picture becomes clearer and the results are quite definite.

The difference in osmotic concentration between the inner and outer petioles was not significant.

Corbett and Thompson (1925) have suggested that a progressive translocation of sugars proceeds from the external petioles to the heart during the storage of celery.

White-Stevens (1938) found that the hexose sugars decline in the outer petioles and crowns but increase in the inner petioles. Disaccharides decrease quite rapidly in both outer and inner petioles, while in the crowns they increase markedly at first and then decline in the same manner.

The analysis of variance showed that there was no significant different in osmotic concentration between the outer and inner petioles. But an examination of Figure 6 will show that there was a marked increase in the value for the inner petioles on December 10 followed by a decrease. At this time it would be well to call attention to the fact that the data used in this analysis of variance was the combined data from all treatments, from all dates and would thus tend to smooth out any irregularities.

The length of the storage period is an important factor in the keeping of celery (totals of Table 44 and Figure 6). These data show the changes in sugar contents for all the treatments at the different dates. Using sugar content as a measure of quality, the results show a marked decline after the tenth of December.

TABLE 45

Average osmotic concentration

Date	Outer petiole	Inner petiole
Nov. 19	.212	.204
Dec. 10	.224	.232
Jan. 4	.223	.225
Jan. 14	.225	.226
Jan. 28	.220	.220

TABLE 46

Effect of nitrogen, phosphorus and potash on osmotic concentrations

0	N	168	0	P	284	0	K	240
4%	N	166	8%	P	130	16%	K	203
8%	N	251	16%	P	171	32%	K	142.

The difference required for significance is 29.4. Eight per cent nitrogen, zero phosphorus and zero potash gave the highest yields of sugar as measured by the osmotic concentration.

Since the celery receiving this treatment in the field was comparatively small and stringy, it is obvious that plants containing the greatest amount of sugar cannot be considered as possessing the highest quality. Quality is based on stringiness, pithiness, succulence or crispness and other factors as well as on sugar content. It will be pointed out within the next few pages that there is a correlation between sugar content and the other criteria of quality. Thus it will be seen that under these circumstances high sugar is not associated with high quality.

The interactions of N x P, N x K, and P x K are all highly significant, thus showing that although phosphorus and potash did not have any influence when alone, their effect is quite different when they are combined with each other and with nitrogen.

Correlations

A number of correlations were calculated, using the formula:

$$r \quad \frac{S(xy) - \bar{y}\ (Sx)}{\overline{S(x^2) - \bar{x}\ (Sx)}\quad \overline{S(y^2) - \bar{y}\ (Sy)}}$$

Fisher (1936) shows that the method of calculation is derived from the considerations that the correlation of the population is the geometric mean of the two regression coefficients.

The figures pertaining to the yield of the fertilizer plots were taken from a report by Bourque (1937b), Quebec bursary student working under the supervision of the Working Committee of the Quebec Refrigeration Committee.

The correlation coefficients obtained(Table 47) were tested by Fisher's Table VA (1937).

TABLE 47

Correlation Table

Correlation between	Correlation coefficient
Osmotic concentration and breakdown	0.448
" " " yield	-0.438
" " " pithiness	0.509
" " " colour	0.623
Yield and colour	-0.804
Yield and pithiness	-0.602
Colour and pithiness	0.694

The P .02 and P .01 values are 0.4451 and 0.4869 respectively.

The negative correlations obtained between yield and osmotic concentration, yield and colour intensity, and yield and pithiness, show that where yield may increase, sugars, colour and pithiness decrease. This means that where large sound plants are produced, the colour is lighter, pithiness is noticeably decreased or entirely absent, and sugar content is lowered.

This is of extreme importance. When the sugar content is high, the size of the plant is small. Therefore, it would seem that the highest sugar content does not mean highest quality as there is more to quality than taste, but rather a plant of inferior marketability. Sweetness is an important consideration of quality, as opposed to the bitterness of the immature produce. However, the results of this experiment would tend to show that the plants can be sufficiently sweet and of good quality without having a high sugar content.

Breakdown, colour and pithiness are all increased with increased osmotic concentration. Not only is a poor plant produced which has high sugar content but it also possesses inferior storage possibilities.

Plants which maintained their green colour to a greater extent throughout the storage were smaller and seemed to be more pithy than those which went through the normal process of blanching.

Discussion

The amount of nitrogen in the dry substance of a plant ranges from 1 to 3 per cent. Nitrogen is an indispensable constituent of the protein molecule and of the protoplasm.

Sulphur, phosphorus and nitrogen are found combined with the most important organic substances of the protoplasm, namely, the proteins, nucleoproteins, phosphatides, lecithins, etc. The metals on the other hand are present in the plant as free ions. This is especially true with regard to potassium of which 90 to 98 per cent is found in the plant in ionic form, and may be extracted from the dry substance by water. Maximov (1930) states that the metallic elements play the role of regulators of vital processes.

Like the proteins, the lecithins and phosphatides form indispensable compounds of the protoplasm. Moreover, they seem to play an important role in determining the osmotic properties of the cell.

Many investigators have put forward the theory that the permeability of the protoplasmic membrance to salts and sugars in solution is due to the presence of lipoids, proteins, etc., which being colloids, readily permit of swelling in water. The amount of swelling and consequently the resultant control over permeability depends upon the supply of nitrogen and phosphorus at hand which goes into the formation of these colloids.

By means of certain irritations, the permeability of protoplasm may be greatly augmented. Thus, for instance, narcotics and light increase the permeability of protoplasm, while strong solutions considerably decrease it.

This being the case, permeability would seem to be dependent on the amount and on the chemical composition of the proteins, lipoids and other substances present in the protoplasmic membrane..

The material used in these studies was grown on organic soil which, supposedly, is rich in nitrogen. In peat-bog soils (muck), even this nitrogen is often so firmly bound that it is unavailable to the roots of the plant. This is confirmed because an additional eight per cent of nitrogen in the fertilizer mixture gave the highest osmotic pressures.

The treatments lacking phosphorus gave higher osmotic values than those with phosphorus. Presumably nitrogenous substances in the protoplasm are more active in making the cell impermeable than are the phosphatic substances.

Potassium is closely connected with the vital activity of protoplasm, since most of it is found in the meristem of the young organs, the cells of which are rich in protoplasm. An important role is ascribed to potassium in the general metabolism of the cell, especially in the formation of carbohydrates and proteins.

However, when these studies relating to osmotic pressure were undertaken the proteins and carbohydrates had already been formed. The changes observed in the osmotic concentrations were due to the transformation of starch to sugar and vice versa. If the potassium was still active at this stage, then it would seem that an increase in the amount of potash applied in the fertilizer mixture favoured the production of starch at the expense of sugar, since increased potash gave decreased osmotic values.

GENERAL DISCUSSION

A short discussion covering each section of the work has already been presented. It now remains to coordinate these various aspects of the problem under one general review.

From the point of view of plant nutrition it is evident that nitrogen, phosphorus and potash are all necessary for the general growth of celery. Quantity, and balance of the different important elements will vary with the growing media and with the different environmental conditions.

The results obtained from the greenhouse plots were quite different to those obtained from the outdoor plots of the same experiment. In the greenhouse oh the muck soil, phosphorus was the limiting factor, good growth being obtained only when it was present. Varying the quantity of potash under different conditions of phosphorus supply did not result in marked changes in growth. Subsequent to the carrying out of the experiment described in this paper, celery plants were placed in glazed pots in muck soil from two different sources. The following fertilizers were applied: 1-0-1, 1-0-2, 1-1-1, 1-1-0 and 1-2-0. Though the plants are still young at the time of writing, quite noticeable growth is resulting in favour of phosphorus. The plants in the 1-1-0 treatment are just as large as those in the 1-1-1 treatment, while plants receiving the 1-2-0 fertilizer are larger. The plants in the 1-0-1 and 1-0-2 treatments are quite small. In the field, the best growth was obtained when large amounts of potash were supplied along with phosphorus. This is surprising because the muck soil used in the greenhouse came from the field adjoining the one where the outdoor experiment was conducted during the summer. This might be accounted for in part by the differences in growing conditions which existed between the greenhouse and the outdoor cultures. These were quite different.

In the greenhouse on muck soil the effect of nitrogen and potash did not show up until the end of the growing season. The best results were obtained with lower levels of phosphorus and potash and higher levels of nitrogen. On the mineral soil any application of nitrogen and potash reduced the height of the plants, while phosphorus increased the height very slightly.

In the various stages of the storage and laboratory experiments, all three of the elements, nitrogen, phosphorus and potash, played different roles. The most important conclusion is that the largest plants put into storage are likely to give the greatest amount of marketable product (after trimming) at any given time, other conditions being equal. This means that the fertilizer mixture giving the most vigorous growth in the field is for the present, the one to be recommended.

CONCLUSIONS

1. Under the conditions of the field fertilizer experiment, the 4-16-32 fertilizer gave the best results. This contains 80 pounds of nitrogen, 320 pounds of P_2O_5 and 640 pounds of K_2O.

2. Muck soil was found to be quite uniform in composition since the variance for the blocks was not significant.

3. Growing plants in quartz sand revealed that nitrogen, phosphorus and potash are all necessary for good growth, the 4-8-16 giving the best results.

4. In the greenhouse experiment on muck soil, phosphorus was the limiting factor.

5. In the greenhouse experiment on mineral soil, additions of both nitrogen and potash adversely affected the growth of the plants.

6. Nitrogen did not increase pithiness in the petioles nor did pithiness increase with senescence. There was more pithiness in the outer than in the inner petioles.

7. The blanching of celery in storage seems to depend somewhat on the size of the plant; the larger the plant, the more complete was the blanching. This applies to the Golden Self Blanching varieties.

8. Percentage breakdown was lessened when nitrogen and phosphorus were applied. The application of potash did not affect it appreciably.

9. High nitrogen and no phosphorus or potash gave the highest osmotic concentrations.

10. There was no significant difference between the osmotic concentration of inner and of the outer petioles.

11. The sugar content of celery had reached its highest point about the tenth of December.

12. High sugar content does not mean high quality since the plants showing high sugars came from treatments which produced a small and unmarketable crop which deteriorated rapidly in storage.

13. In many instances increasing phosphorus beyond a certain limit had a detrimental effect on growth.

14. In some of the studies, increasing potash did not improve yield or quality but it had no detrimental effect on growth except when it was applied to the mineral soil plots in the greenhouse.

15. A proper balance of nitrogen, phosphorus and potash is required to give the best results. This balance can be ascertained only by trial on the different types of soil and under the different climatic conditions which are likely to exist from year to year.

RECOMMENDATIONS

1. For a uniform muck soil well supplied with moisture, a 4-16-32 fertilizer on the basis of one tone per acre or a 2-8-16 at 3500 pounds per acre may be recommended. This is equivalent to 80 pounds of nitrogen, 320 pounds of P_2O_5 and 640 pounds of K_2O per acre.

2. Highest sugar content should not be a criterion for highest quality since the results of this work prove quite the opposite.

3. A good healthy, vigorous crop should be grown in the field so that the produce will keep well in storage.

These recommendations are not final and should be changed when evidence warrants it.

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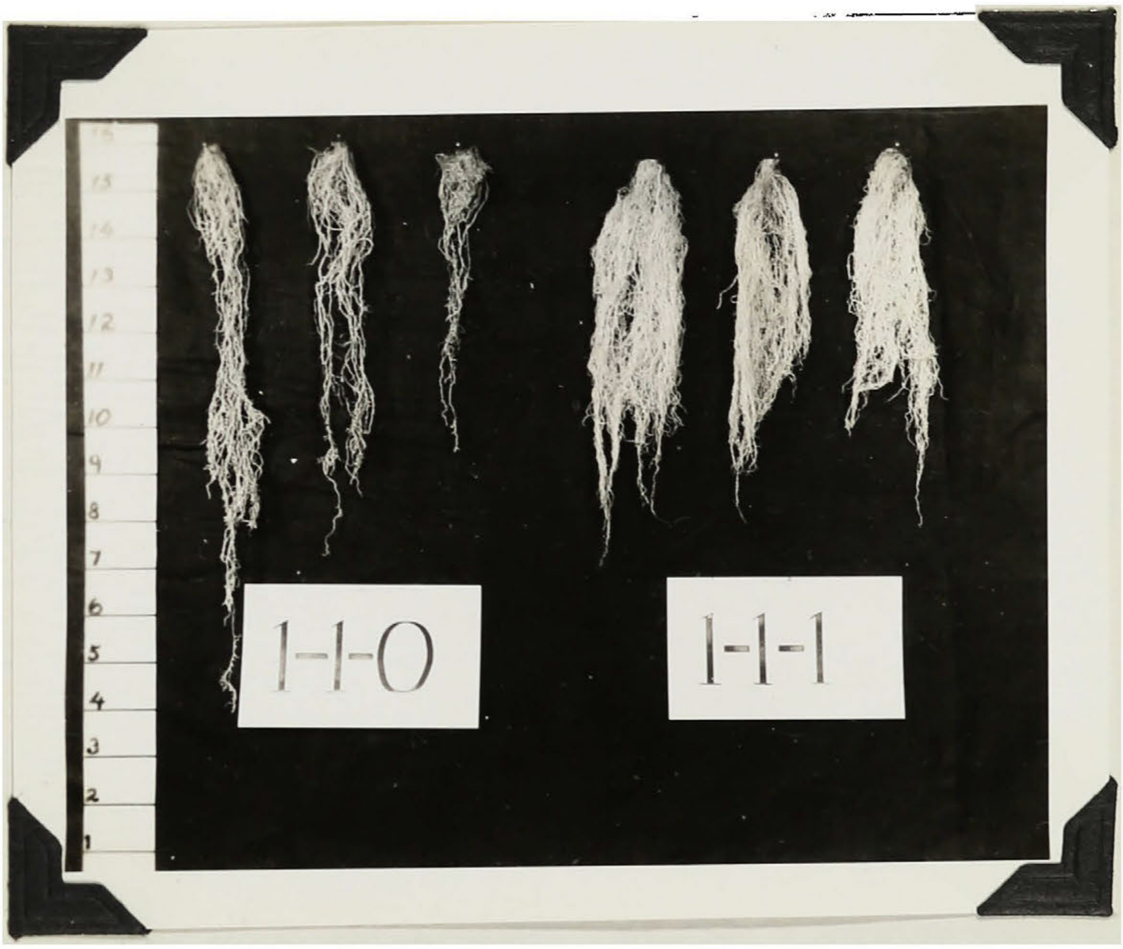

Plate 1. Showing the difference between absence and presence of potash.

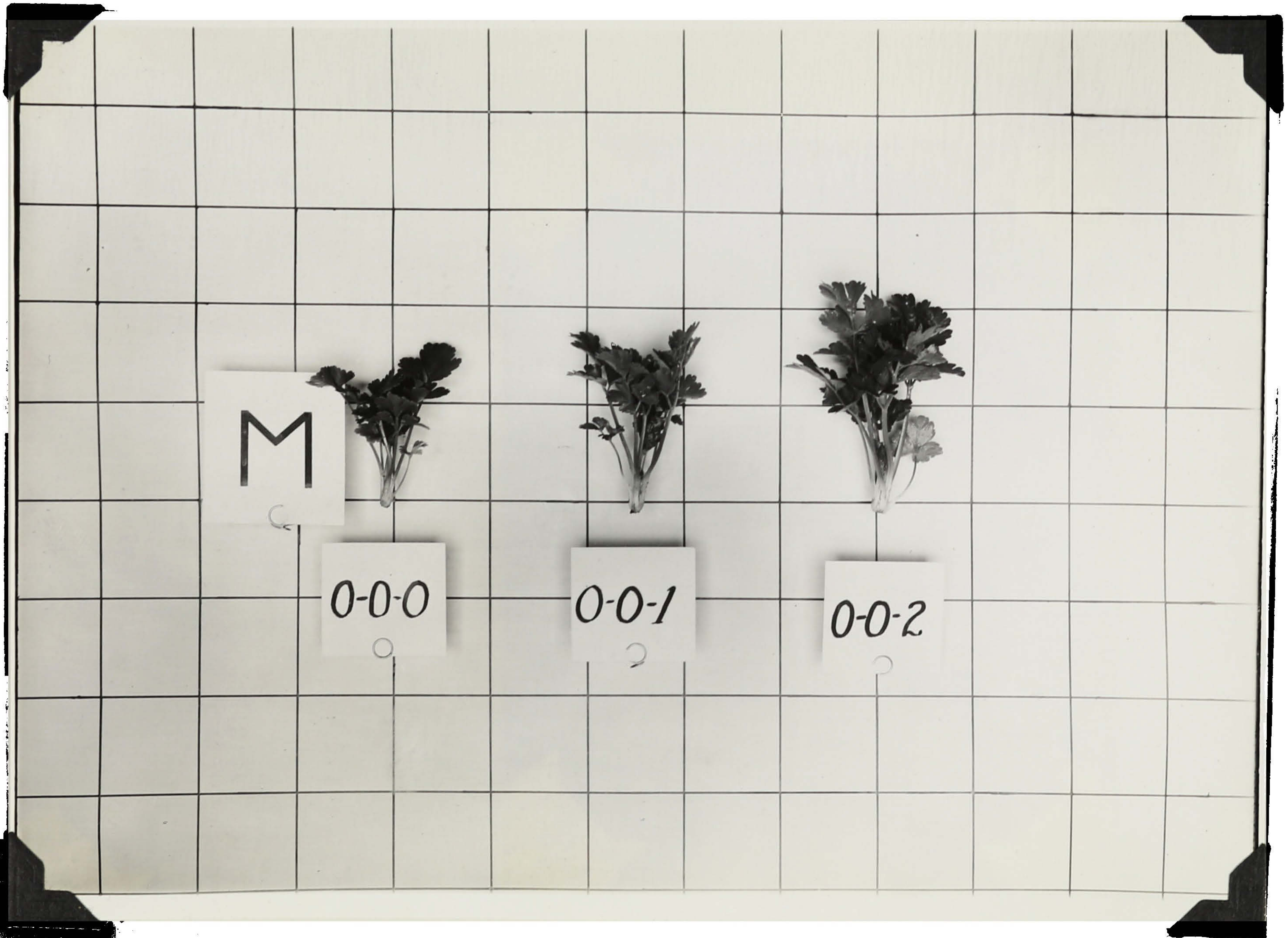

Plate 2. Treatments on muck soil in the greenhouse

Plate 3. Treatments on muck soil in the greenhouse

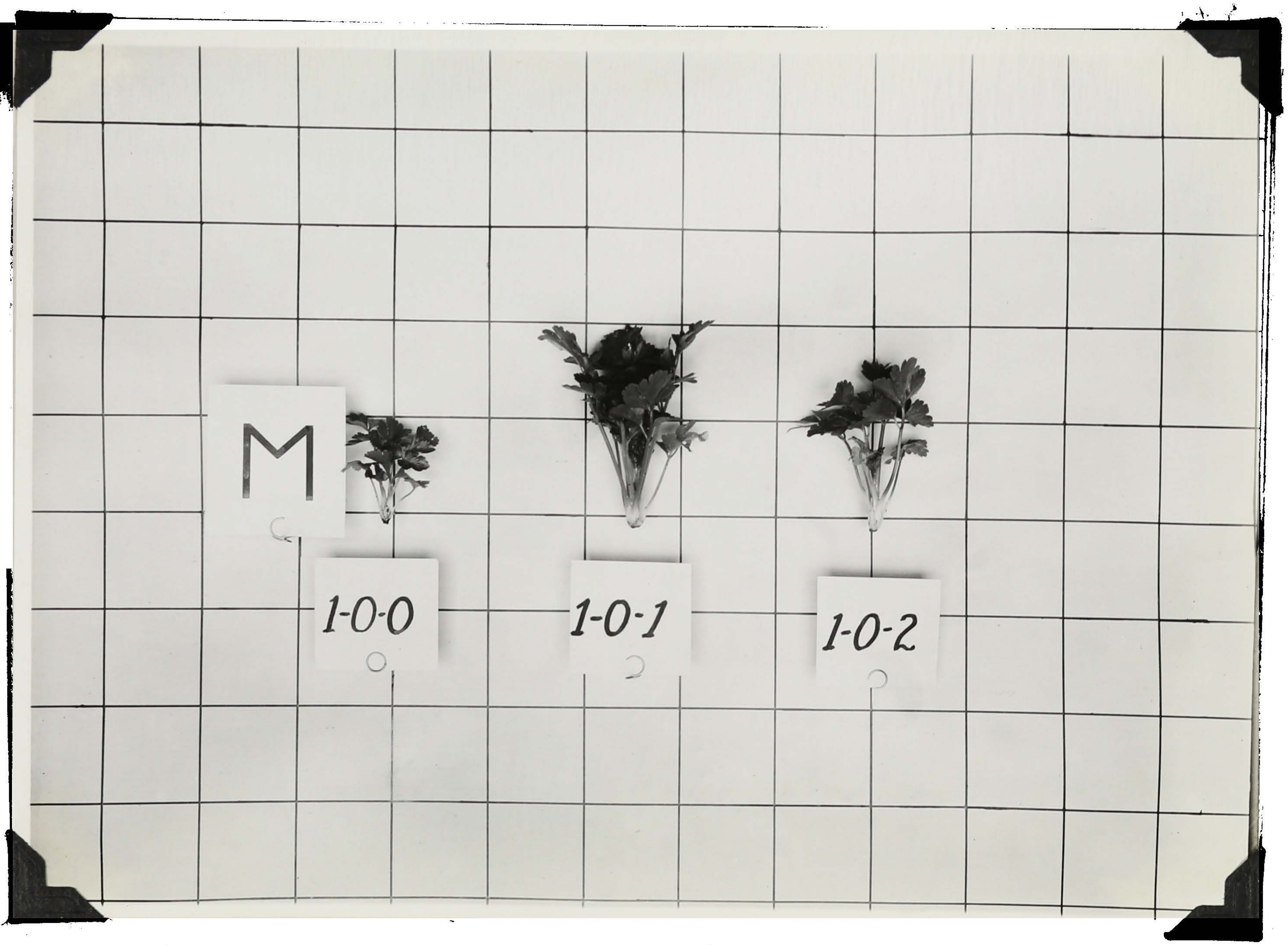

Plate 4. Treatments on muck soil in the greenhouse

Plate 5. Treatments on muck soil in the greenhouse

Plate 6. Treatments on muck soil in the greenhouse

Plate 7. Treatments on muck soil in the greenhouse

Plate 8. Treatments on muck soil in the greenhouse

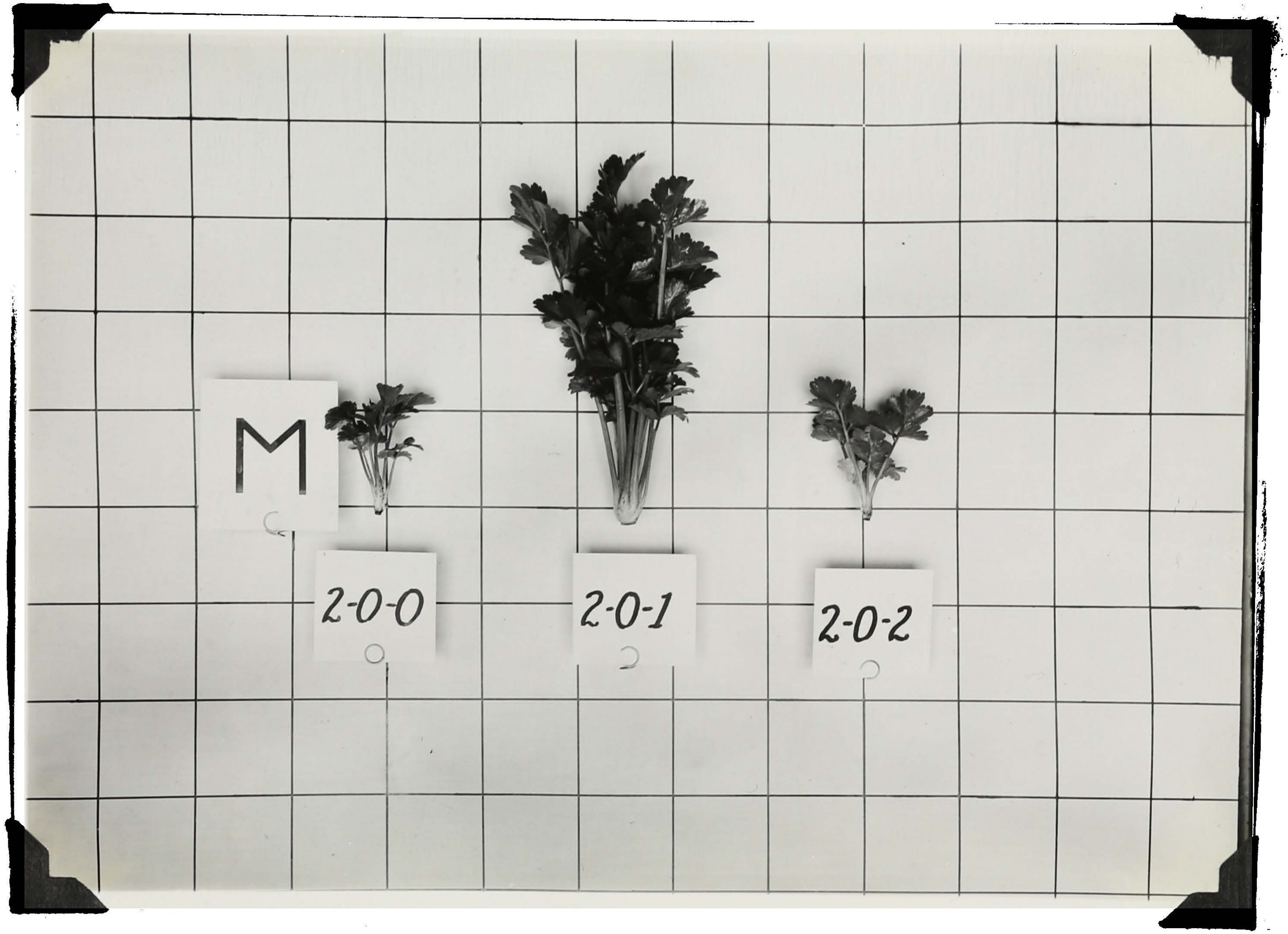

Plate 9. Treatments on muck soil in the greenhouse

Plate 10. Treatments on muck soil in the greenhouse

Plate 11. Treatments on mineral soil in the greenhouse

Plate 12. Treatments on mineral soil in the greenhouse

Plate 13. Treatments on mineral soil in the greenhouse

Plate 14. Treatments on mineral soil in the greenhouse

Plate 15. Treatments on mineral soil in the greenhouse

Plate 16. Treatments on mineral soil in the greenhouse

Plate 17. Treatments on mineral soil in the greenhouse

Plate 18. Treatments on mineral soil in the greenhouse

Plate 19. Treatments on mineral soil in the greenhouse

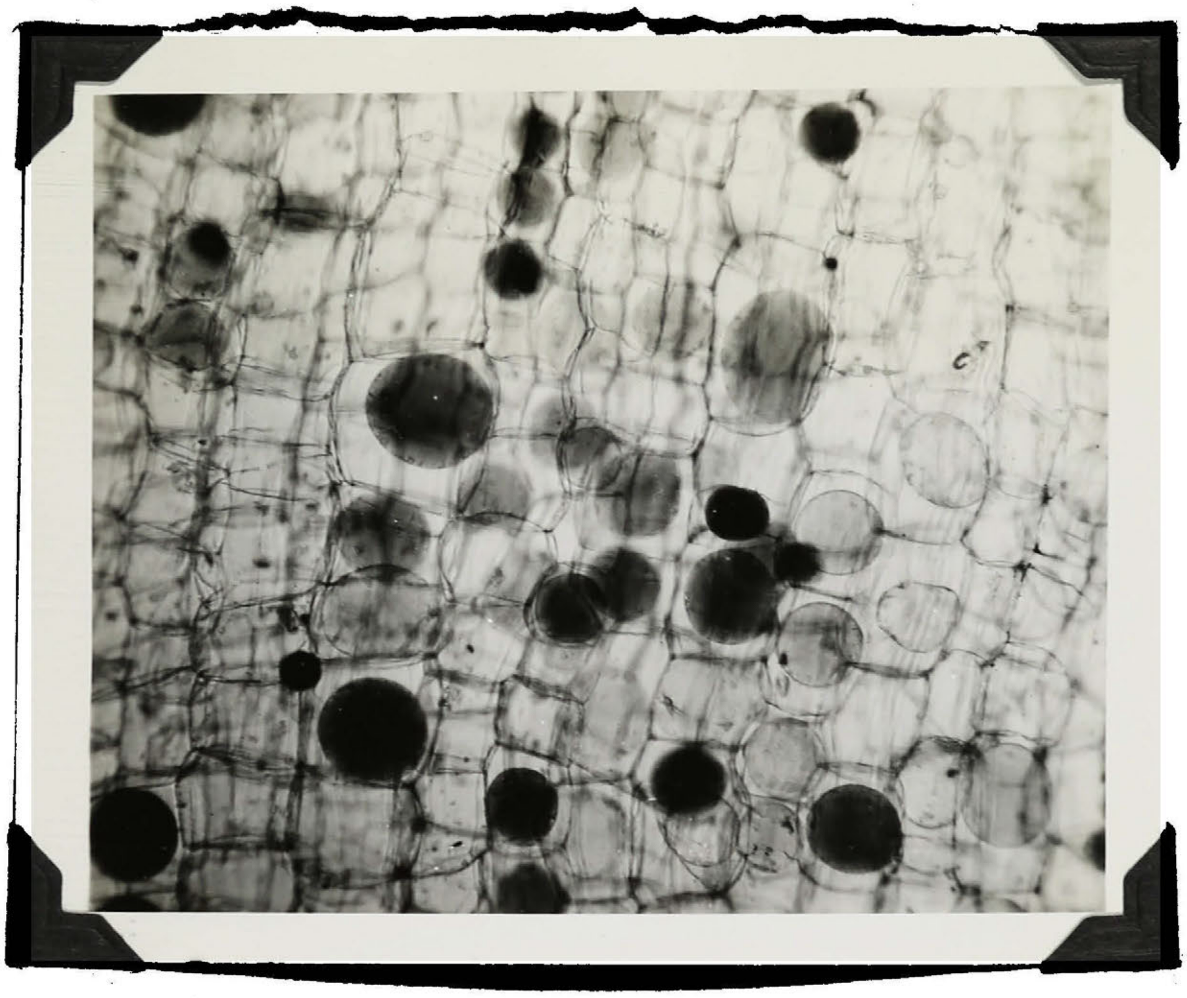

Plate 20. Strongly plasmolysed cells

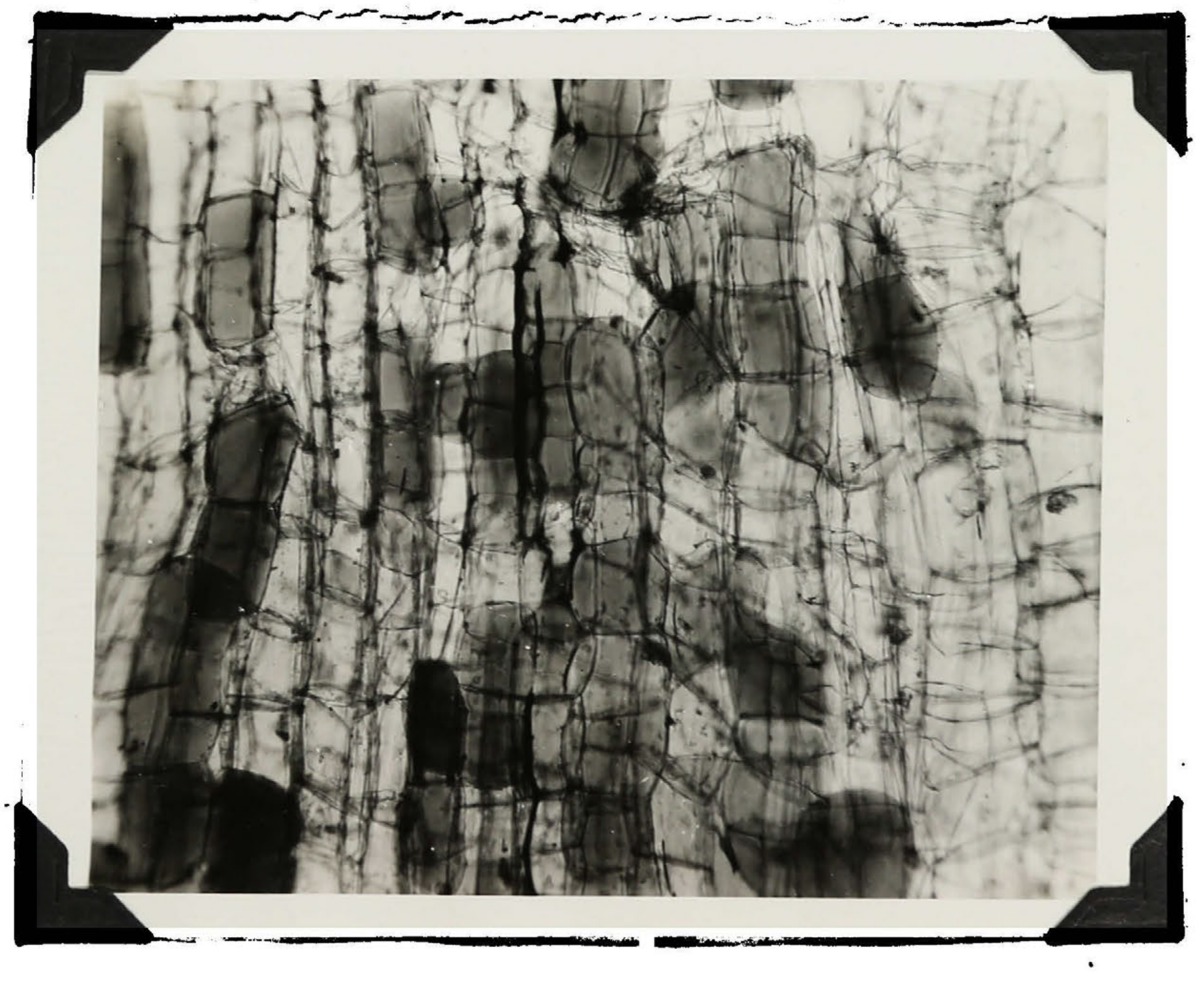

Plate 21. Normal cells - no plasmolysis

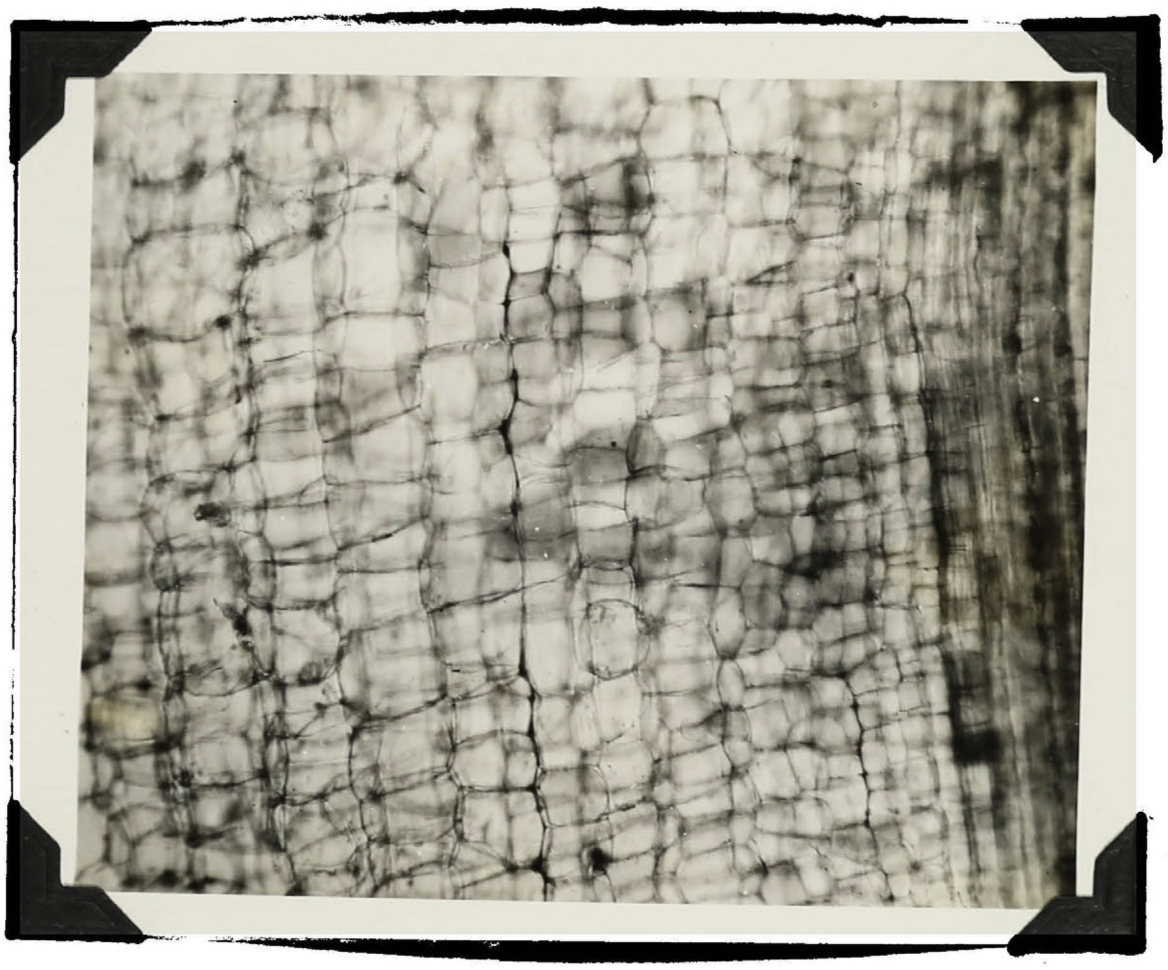

Plate 22. Cells showing incipient plasmolysis