NUTRIENT LEVELS AS AFFECTING STRINGINESS IN CELERY

by

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Nutrient Levels as Affecting Stringiness in Celery

Abstract

Findings are presented indicating the effects of nutrient solutions containing combinations of nitrogen, phosphorus, and potassium at different levels, on the tissues causing stringiness in celery petioles. These tissues are the collenchyma strands and the vascular bundles.

High applications of nitrogen stimulated succulent growth and hence retarded maturity and development of stringiness in the collenchyma, and to a lesser extent in the vascular bundles. Phosphorus had no direct effect on stringiness. Potassium had a marked effect in increasing stringiness when applied in large amounts.

The cell walls of the collenchyma strands became thicker as maturity progressed. This thickening of the cell walls of collenchyma tissue resulted in their increased stringiness. The size of the collenchyma strands was no indication of amount of string present but maturity was an indication since stringiness increased with age. Cell size in the larger collenchyma strands was usually greater than in smaller collenchyma strands.

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INTRODUCTION

Origin and Habitat of Celery

A history of the development of celery would reach back into antiquity to a time when it was used as a medicinal herb. The wild forebearers of celery, all members of the genus Apium, are described by Bailey (1927) as belonging to fifteen or twenty species, of which Apium graveolens is the only one of importance for human consumption. In its wild state the various species of Apium have been found in marshy low lying areas throughout the temperate regions of Europe and Asia. The uncultivated predecessors produced furrowed stalks, compound leaves with wedge shaped leaflets, and the whole plant possessed a rank taste and peculiar smell.

Celery as a vegetable was not appreciated until relatively modern times when through selection and cultivation an improved plant type appeared. Paralleling the advances in celery are those in other present day vegetables, all of which can be attributed to scientific methods of vegetable breeding, producing, and marketing.

The advent of commercial truck farming introduced celery as a vegetable economically within the reach of all, whereas formerly it had been looked on as a luxury. When grown in soils to which it is adapted, with fertilizers supplying the requisite nutrients, an inexpensive crop of good quality can be harvested regularly. Exclusion of light from the stalks adds to the quality by producing a blanched type which is much in demand.

Nutritional Value

Vegetable producers keeping in step with nutritional discoveries are endeavouring to increase vitamin and nutritive content. This may be accomplished by breeding and selection of superior varieties. A comparison of white and green varieties of celery by Osterman (1938) is given in Table I.

TABLE I

Milligrams of Ascorbic Acid Found in 100-gram portions of different parts of Celery

Variety	Sample	Outer Stalks	Inner Stalks	Juice of Stalks	Leaves
Green Utah	I	6.78	8.58	1.10	22.35
		6.69	8.40	1.09	22.16
	II	4.34	7.60	1.10	24.92
		4.26	7.27	1.05	24.77
	III	7.66	8.20	1.26	31.25
		7.63	8.03	1.25	30.65
					27.30
					23.95
White California	I	4.60	6.56	0.78	22.54
		4.57	6.49	0.77	21.68
					16.95
					14.55
	II	4.76	7.92	0.75	17.86
		4.73	7.86	0.72	15.90
					22.04*
					20.65*
	III	4.98	9.35	0.78	29.52*
		4.90	9.27	0.78	29.30*
	IV				23.62
					23.44

*Samples from which all traces of stem were removed.

Here green Utah celery is shown to be slightly higher in vitamin C (ascorbic acid) than are blanched California varieties. Taylor (1942) found that a celery heart weighing 62 grams uncooked, contained .8 grams of protein, 51 milligrams of calcium, .4 milligrams of iron, 15 International Units of vitamin A, .022 milligrams of vitamin B_1 (thiamin), 4 milligrams of vitamin C (ascorbic acid), and .027 milligrams of vitamin G (riboflavin). Calcium can be seen here to be present in moderate amounts but vitamin values appear to be rather low as compared to leafy vegetables.

Criteria of Quality

Quality in celery is associated with stalks firm and crisp in texture, but which are also tender and stringless. The flavour and aroma have been best described as nut-like. Of these properties the degree of freedom from stringiness is the more important.

Maintenance and expansion of market demand depends upon production of high quality crops. Hence amongst commercial celery growers quality has ever been a primary consideration. Being a specialized crop celery is produced on a large scale only where climate and soil are favorable. Optimum conditions for celery culture could be stated as a cool equable summer with small day and night temperature variations, uniform soil moisture conditions, and adequate soil nutrients especially nitrogen

to promote succulent vegetative growth. Mineral nutrition is the one non-environmental factor which can in some measure be controlled by the grower. Therefore, if all other factors other than mineral nutrition are maintained at the optimum level then quality, particularly stringiness, should bear a relationship to the amounts and kinds of nutrients applied in the fertilizers. Thus variations in combinations of different elements in the mineral nutrients may produce a corresponding variation in the degree of stringiness that develops. An investigation of this aspect of celery growing should prove of value to commercial growers, to seed companies, to plant breeders, and to the general consuming public. With this idea in mind the following investigation dealing with mineral nutrition of celery as related to development of stringiness was undertaken.

STATEMENT OF THE PROBLEM

As a relationship appears to exist between mineral nutrition and its physiological effect on quality in so far as stringiness is concerned, a study of this specific problem has been undertaken. To carry on such an investigation all possible combinations of mineral nutrients should be studied. These must be applied to plants growing under optimum conditions in order that other physiological factors affecting stringiness may be reduced to a minimum.

The substratum in which growth is to take place must be devoid of available mineral nutrients in order to eliminate errors from this source. One of the more satisfactory substrata used in studying effects of the major plant elements has been found to be clean river or finely ground sand. Hence for this project in which it was undertaken to investigate the correlation of varying mineral nutritive balances and their physiological effects on stringiness, sand has been chosen for a growing medium.

GENERAL REVIEW OF LITERATURE

White-Stevens (1937) in an extensive study of fertilizer treatments on celery grown in muck soils found that a nutrient combination high in nitrogen such as 8-8-10, gave a significantly greater yield than other fertilizers containing less nitrogen.

Bourque (1937) however, in another fertilizer experiment on celery grown in muck soil failed to find significant results when nitrogen as high as fourteen per cent of the total fertilizer material was added. It must be noted in this connection that Bourque and White-Stevens were working in different localities with muck soils at different stages of decomposition.

Crandall (1937) in a study of fertilizer and manure applications on mineral soils showed that increased nitrogen gave significantly greater yields, and decreased nitrogen reduced yields. To a lesser extent potassium had the same effect. Phosphorus treatments showed negative results. Apparently celery can succeed within a wide range of available phosphorus.

A fertilizer experiment conducted at the Bathurst Experimental Farm in New South Wales (1937) in which celery was grown in alluvial loam high in organic matter, was found to be successful when treated with a combination of superphosphate and sulphate of ammonia. When the latter

was replaced with nitrate of soda a poorer growth resulted.

Parker (1939), experimenting on celery fertilizers in Eastern Virginia found that two tons of 6-6-5 fertilizer per acre were insufficient to produce maximum yield and foliage colour. However, a further application of 300 pounds per acre of nitrogen applied in the form of a solution from the overhead irrigation water gave increased growth and normal foliage colour.

A survey of fertilizers used for celery on the sawgrass peet soils of the Florida everglades convinced Beckenbach (1939) that the Florida winter crop could be stimulated by the addition of 200 pounds per acre of nitrate of soda or nitrate of potassium. This was of particular value when the weather was wet or cold, as without this side dressing, growth was slow and of poor quality.

Thompson (1939) suggested 4-8-12 fertilizer at 2000 to 2500 pounds per acre on old muck with additional side dressings of nitrogen when needed. Watts and Watts (1939) preferred combinations of 4-12-4, 4-10-6, or 5-10-5 for upland soils, and 4-8-12, 3-12-15 or 2-8-16 for mucks. Here again top or side dressings of nitrogen were to be added as required by the crop.

Beaupre (1941) in an analysis of nutrition of

spinach found potassium gave significant increases in yield and that increases of nitrogen fertilizers produced increases of soluble nitrogen in the plant tissue. These increases of soluble nitrogen however retarded uptake of phosphorus.

Filman (1942) studying celery, once again demonstrated the importance of nitrogen and potassium in increasing crop yields.

Bourque (1939) from his work on celery nutrition concluded that normal growth would result if any two of the three requisite plant elements namely nitrogen, phosphorus, and potassium are included in a fertilizer.

Both Knott (1931) and Comin (1931) mention the use of fertilizers in celery production and each advised 1000 pounds of 4-8-12 or 2-8-16 fertilizer per acre with added dressings of nitrogen when required.

MATERIALS AND METHODS

Design of Experiment

The crocks used throughout the experiment were of a glazed earthenware material and of one imperial gallon capacity. An outlet one half inch in diameter in the bottom of each, stoppered with glass wool, allowed for drainage but withheld the sand. The latter a gray river washed sand was rendered devoid of nutritive value prior to use. This was accomplished by filling barrels with the sand to approximately one quarter of their capacity and leaching them with water several times a day for a period of a week. By forcing a stream of water to the bottom of each barrel any sediment present was brought to the top. Repeated leaching and removal of the sediment until no more appeared on the surface provided an inert sub-stratum for the roots of the plants. An analysis of the size of the sand particles is presented in Table II.

TABLE II

A Physical Analysis of the Sand Using the U.S. Standard Sieve Series

Not passing a 20 mesh sieve	12.80%
Passing a 20 mesh but not a 30 mesh sieve	62.51%
Passing a 30 mesh but not a 40 mesh sieve	4.16%
Passing a 40 mesh but not a 60 mesh sieve	16.60%
Passing a 60 mesh but not a 80 mesh sieve	2.63%
Passing a 80 mesh but not a 100 mesh sieve	.39%
Passing a 100 mesh sieve	.87%

The statistical plan of the experiment was that of a 3 x 3 x 3 factorial design with randomization of the crocks in each of the three arbitrarily chosen stages all of which were replicated once. As a 3 x 3 x 3 factorial arrangement allows for 27 possible combinations the three stages in duplicate give a total of 162 crocks. The plan of randomization within each stage and its duplicate replication are shown in Table III. The three stages chosen are indicative of the condition of celery, when respectively half mature, three-quarters mature, and fully mature.

TABLE III

Plan of Randomization

Stage One			
2-3-3	2-1-1	1-2-3	3-2-1
2-2-2	3-3-2	1-1-2	2-2-3
1-3-2	3-1-3	1-1-3	3-2-2
1-3-3	1-2-2	3-3-3	3-1-1
3-2-3	2-1-3	1-2-1	2-2-1
1-1-1	2-1-2	3-1-2	3-3-1
Filler	1-3-1	2-3-2	2-3-1

Stage One Replicate			
3-3-3	3-1-2	1-1-1	2-1-1
2-3-1	1-3-2	2-3-3	1-3-3
1-1-3	1-3-1	2-2-1	1-2-2
3-2-1	2-1-2	2-3-2	1-2-3
3-2-2	2-2-3	3-3-1	3-3-2
3-1-3	3-1-1	1-1-2	1-2-1
Filler	2-2-2	3-2-3	2-1-3

Stage Two			
2-2-3	3-1-1	3-2-1	3-3-1
2-1-2	2-2-1	1-1-1	2-3-1
3-2-2	2-1-1	1-2-3	3-3-2
2-2-2	1-1-2	3-2-3	1-3-3
3-1-2	2-3-3	1-2-2	3-3-3
2-3-2	3-1-3	1-3-1	2-1-3
Filler	1-2-1	1-1-3	1-3-2

Stage Two Replicate			
2-3-1	1-1-3	3-1-1	1-1-1
2-2-3	1-1-2	3-3-1	3-1-2
1-2-3	1-3-2	2-2-1	2-2-2
3-2-2	3-1-3	2-1-1	3-3-3
2-3-2	3-2-1	2-1-2	3-2-3
1-3-1	2-1-3	2-3-3	1-2-1
Filler	3-3-2	1-2-2	1-3-3

Stage Three			
3-3-2	2-2-3	3-1-2	3-2-2
3-3-1	2-3-1	2-1-3	1-2-1
1-1-3	1-3-3	3-2-3	3-2-1
2-2-1	2-1-2	1-2-3	1-1-2
2-1-1	1-3-2	1-2-2	3-1-1
2-2-2	3-3-3	1-1-1	2-3-2
Filler	1-3-1	2-3-3	3-1-3

Stage Three Replicate			
3-1-2	1-2-3	1-1-1	2-3-3
1-2-2	2-1-2	3-3-3	3-3-1
2-3-2	3-1-3	2-3-1	3-2-1
2-1-3	1-1-2	3-1-1	3-3-2
2-2-1	2-2-2	2-1-1	2-2-3
3-2-2	3-2-3	1-3-1	1-3-2
Filler	1-3-3	1-2-1	1-1-3

Establishment of the Seedling Plants

Celery of the variety Golden Self Blanching (tall strain) was sown in seedling flats of soil in the greenhouse on March 15, 1943. On April 29th it was transplanted to other flats at a distance of two inches apart each way. On June 2nd these flats were removed from the greenhouse and hardened off outside in cold frames. On June 11th the young plants, now 4-5 inches high, were again transplanted this time to the previously prepared earthenware crocks of sand.

To first establish the young plants in the sand a balanced starter solution of the composition given in Table IV was applied at the rate of 450 c.c. per crock every third day for a period of ten days. Tap water was added as required. The entire array of properly randomized crocks were placed outside on a raised bench.

TABLE IV

General Nutrient Solution for Small Seedlings

Calcium nitrate, $Ca(NO_3)_2$	102.30 gms.
Magnesium sulphate, $MgSO_4.7H_2O$	40.70 gms.
Superphosphate (16%)	63.34 gms.
Muriate of potash	15.97 gms.
Boric acid, H_3BO_3	0.257 gms.
Manganese sulphate $MnSO_4.4H_2O$	0.037 gms.
Water	40.00 gals.

Preparation of Nutrient Solutions.

The nutrient solutions used throughout the experiment were based on those of Hill (1940) and Beaupre (1941) although some modifications were required to achieve the desired combinations of nitrogen phosphorus and potassium. Table V shows Hill and Beaupre's solution.

TABLE V

Hill and Beaupre's Solution

Compound	No. of grams in 5000 c.c. of H_2O
Potassium dihydrogen phosphate (KH_2PO_4)	2.676
Magnesium sulphate ($MgSO_4.7H_2O$)	4.881
Calcium chloride ($CaCl_2$)	5.546
Potassium nitrate (KNO_3)	4.0078
Ammonium nitrate (NH_4NO_3)	7.356
Manganous sulphate ($MnSO_4$)	.00268
Boric Acid (H_3BO_3)	.0283
Ferric Chloride ($FeCl_3.6H_2O$)	.250

The elements arbitrarily divided as major and minor and calculated in parts per million (p.p.m.) are given in Table VI.

TABLE VI

Major and Minor Elements

Major Elements		Minor Elements	
Nitrogen	626 p.p.m.	Manganese	1.8 p.p.m.
Phosphorus	122 p.p.m.	Boron	1.0 p.p.m.
Potassium	464 p.p.m.	Iron	3.44 p.p.m.
Calcium	400 p.p.m.		
Sulphur	127 p.p.m.		
Magnesium	96 p.p.m.		

In order to use a 3-3-3 factorial design twenty-seven combinations of the elements nitrogen, phosphorus and potassium shown in Table VI are required. Hence three levels of each were utilized, the second and third level in each case being respectively one half and one quarter of the original. These when arranged factorialy give the total twenty-seven combination. The amounts given in parts per million are presented in Table VII.

TABLE VII

Nutrient Combinations in Parts per Million

Treatment		Parts per Million of									
No.	Formula	N	P	K	Mg.	Ca	S	Mn	B	Fe	Total
1	4N4P4K	626	122	464	96	400	127	1.8	1.0	3.44	1841.24
2	4N2P4K	626	61	464	96	400	127	1.8	1.0	3.44	1780.24
3	4N1P4K	626	30.5	464	96	400	127	1.8	1.0	3.44	1749.74
4	2N4P4K	313	122	464	96	400	127	1.8	1.0	3.44	1528.24
5	2N2P4K	313	61	464	96	400	127	1.8	1.0	3.44	1467.24
6	2N1P4K	313	30.5	464	96	400	127	1.8	1.0	3.44	1436.74
7	1N4P4K	156.5	122	464	96	400	127	1.8	1.0	3.44	1371.74
8	1N2P4K	156.5	61	464	96	400	127	1.8	1.0	3.44	1310.74
9	1N1P4K	156.5	30.5	464	96	400	127	1.8	1.0	3.44	1280.24
10	4N4P2K	626	122	232	96	400	127	1.8	1.0	3.44	1609.24
11	4N2P2K	626	61	232	96	400	127	1.8	1.0	3.44	1548.24
12	4N1P2K	626	30.5	232	96	400	127	1.8	1.0	3.44	1517.74
13	2N4P2K	313	122	232	96	400	127	1.8	1.0	3.44	1296.24
14	2N2P2K	313	61	232	96	400	127	1.8	1.0	3.44	1235.24
15	2N1P2K	313	30.5	232	96	400	127	1.8	1.0	3.44	1204.74
16	1N4P2K	156.5	122	232	96	400	127	1.8	1.0	3.44	1139.74
17	1N2P2K	156.5	61	232	96	400	127	1.8	1.0	3.44	1078.74
18	1N1P2K	156.5	30.5	232	96	400	127	1.8	1.0	3.44	1048.24
19	4N4P1K	626	122	116	96	400	127	1.8	1.0	3.44	1493.24
20	4N2P1K	626	61	116	96	400	127	1.8	1.0	3.44	1432.24
21	4N1P1K	626	30.5	116	96	400	127	1.8	1.0	3.44	1401.74
22	2N4P1K	313	122	116	96	400	127	1.8	1.0	3.44	1180.24
23	2N2P1K	313	61	116	96	400	127	1.8	1.0	3.44	1119.24
24	2N1P1K	313	30.5	116	96	400	127	1.8	1.0	3.44	1088.74
25	1N4P1K	156.5	122	116	96	400	127	1.8	1.0	3.44	1023.74
26	1N2P1K	156.5	61	116	96	400	127	1.8	1.0	3.44	962.74
27	1N1P1K	156.5	30.5	116	96	400	127	1.8	1.0	3.44	932.24

When adjusting combinations of the basic solution to obtain the desired levels it must be remembered that some of the salts used possess more than one of the desired elements. The required adjustments are carried on in the following manner: If the quantity of phosphorus is to be reduced to one quarter that of the basic solution only a quarter of the amount of potassium dihydrogen phosphate would be used. But this latter compound adds potassium to the solution which must be taken into consideration when further potassium is added in the form of potassium nitrate. Likewise when adding ammonium nitrate for the required level of nitrogen, the amount of nitrogen in the potassium nitrate must be allowed for. In this manner varying combinations of nitrogen, phosphorus, and potassium can be obtained without altering levels of the other elements.

An example of the mathematical calculations used to obtain the quantities of the elements shown in Table VIII is given here.

It is required that 5000 c.c of the nutrient solution contain 61 p.p.m. of phosphorus.

Then 5,000,000 c.c of solution will contain $5 \times 61 = 305$ parts of phosphorus.

Now 136.12 is the molecular weight of KH_2PO_4 and 31.02 is the atomic weight of phosphorus.

Therefore, $\frac{136.12 \times 305}{31.02}$ = 1338 gms. of KH_2PO_4.

Now 1338 gms. of KH_2PO_4 is the amount in 5,000,000 c.c.of nutrient solutions. Therefore, in 5,000 c.c. of nutrient solution there are 1.338 gms. of KH_2PO_4.

1.338 gms. of KH_2PO_4 contain 77 p.p.m. of potassium. The total required amount of potassium is 464 p.p.m. The difference, 387 p.p.m., is added in the form of KNO_3.

This is calculated in a similar fashion and is found to amount to 4.0078 gms. However, 4.0078 gms. of KNO_3 contain in addition 111 p.p.m. of nitrogen. The necessary amount to make up the required 626 p.p.m. is supplied in the form of NH_4NO_3. Further calculation shows this desired amount of NH_4NO_3 to be 7.356 gms. In three cases which involve the combinations of 4N4P1K, 2N4P1K, and 1N4P1K, it was found that even when no KNO_3 was used the amounts of potassium supplied by the KH_2PO_4 exceeded the desired level. Hence, another source of phosphorus not containing potassium had to be found. Ammonium dihydrogen phosphate ($NH_4H_2PO_4$) fulfilled the requirement and in the three above mentioned combinations this substance was substituted for KH_2PO_4. The calculations required to obtain nitrogen, phosphorus and potassium levels in these three cases are of the same nature as those given in the example. Table VIII expressed in grams shows all twenty-seven combinations in the required amounts.

TABLE VIII

Nutrient Combinations in Grams

Treatment		Grams in 5000 c.c. of water							
No.	Formula	KH_2PO_4	KNO_3	NH_4NO_3	$MgSO_4$	$CaCl_2$	$MnSO_4$	H_3BO_3	$FeCl_3$
1	4N4P4K	2.676	4.0078	7.356	4.881	5.546	.00268	.0283	.250
2	4N2P4K	1.338	5.0041	6.972	4.881	5.546	.00268	.0283	.250
3	4N1P4K	0.669	5.5019	6.772	4.881	5.546	.00268	.0283	.250
4	2N4P4K	2.676	4.0078	2.886	4.881	5.546	.00268	.0283	.250
5	2N2P4K	1.338	5.0041	2.500	4.881	5.546	.00268	.0283	.250
6	2N1P4K	0.669	5.5019	2.300	4.881	5.546	.00268	.0283	.250
7	1N4P4K	2.676	4.0078	0.650	4.881	5.546	.00268	.0283	.250
8	1N2P4K	1.338	5.0041	0.264	4.881	5.546	.00268	.0283	.250
9	1N1P4K	0.669	5.5019	0.064	4.881	5.546	.00268	.0283	.250
10	4N4P2K	2.676	1.0085	8.543	4.881	5.546	.00268	.0283	.250
11	4N2P2K	1.338	2.0040	8.157	4.881	5.546	.00268	.0283	.250
12	4N1P2K	0.669	2.5020	7.957	4.881	5.546	.00268	.0283	.250
13	2N4P2K	2.676	1.0085	4.071	4.881	5.546	.00268	.0283	.250
14	2N2P2K	1.338	2.0040	3.686	4.881	5.546	.00268	.0283	.250
15	2N1P2K	0.669	2.5020	3.485	4.881	5.546	.00268	.0283	.250
16	1N4P2K	2.676	1.0085	1.829	4.881	5.546	.00268	.0283	.250
17	1N2P2K	1.338	2.0040	1.450	4.881	5.546	.00268	.0283	.250
18	1N1P2K	0.669	2.5020	1.250	4.881	5.546	.00268	.0283	.250
19	4N4P1K	2.263*	1.4999	7.585	4.881	5.546	.00268	.0283	.250
20	4N2P1K	1.338	0.5042	8.743	4.881	5.546	.00268	.0283	.250
21	4N1P1K	0.669	1.0085	8.543	4.881	5.546	.00268	.0283	.250
22	2N4P1K	2.263*	1.4999	3.119	4.881	5.546	.00268	.0283	.250
23	2N2P1K	1.338	0.5042	4.271	4.881	5.546	.00268	.0283	.250
24	2N1P1K	0.669	1.0085	4.071	4.881	5.546	.00268	.0283	.250
25	1N4P1K	2.263*	1.4999	0.886	4.881	5.546	.00268	.0283	.250
26	1N2P1K	1.338	0.5042	2.036	4.881	5.546	.00268	.0283	.250
27	1N1P1K	0.669	1.0085	1.836	4.881	5.546	.00268	.0283	.250

* $NH_4H_2PO_4$

Application of Nutrients

Nutrient solutions including potassium dihydrogen phosphate, potassium nitrate, ammonium nitrate, ammonium dihydrogen phosphate, magnesium sulphate, calcium chloride, manganous sulphate, and boric acid, were made up to concentrations of 5%. In order to keep ferric chloride in solution it was made up to a strength of only .5%.

Table IX presents the amounts of stock solutions for all combinations of nitrogen phosphorus and potassium.

TABLE IX

Amount of Stock Solution Required to Make up 2000 c.c of Nutrient Solution (made to volume with tap water)

Treatment No.	Treatment Formula	KH_2PO_4 c.c.	KNO_3 c.c.	NH_4NO_3 c.c.	$MgSO_4$ c.c.	$CaCl_2$ c.c.	$MnSO_4$ c.c.	H_3BO_3 c.c.	$FeCl_3$ c.c.
1	4N4P4K	22	32	59	39	44	.05	.45	4
2	4N2P4K	11	40	55	39	44	.05	.45	4
3	4N1P4K	5.5	44	54	39	44	.05	.45	4
4	2N4P4K	22	32	23	39	44	.05	.45	4
5	2N2P4K	11	40	20	39	44	.05	.45	4
6	2N1P4K	5.5	44	18	39	44	.05	.45	4
7	1N4P4K	22	31	5.5	39	44	.05	.45	4
8	1N2P4K	11	40	2	39	44	.05	.45	4
9	1N1P4K	5.5	44	-	39	44	.05	.45	4
10	4N4P2K	22	8	68	39	44	.05	.45	4
11	4N2P2K	11	16	65	39	44	.05	.45	4
12	4N1P2K	5.5	20	63	39	44	.05	.45	4
13	2N4P2K	22	8	32	39	44	.05	.45	4
14	2N2P2K	11	16	29	39	44	.05	.45	4
15	2N1P2K	5.5	20	27	39	44	.05	.45	4
16	1N4P2K	22	8	15	39	44	.05	.45	4
17	1N2P2K	11	16	11	39	44	.05	.45	4
18	1N1P2K	5.5	20	10	39	44	.05	.45	4
19	4N4P1K	19*	12	60	39	44	.05	.45	4
20	4N2P1K	11	4	70	39	44	.05	.45	4
21	4N1P1K	5.5	8	68	39	44	.05	.45	4
22	2N4P1K	19*	12	24.5	39	44	.05	.45	4
23	2N2P1K	11	4	34	39	44	.05	.45	4
24	2N1P1K	5.5	8	32	39	44	.05	.45	4
25	1N4P1K	19*	12	7	39	44	.05	.45	4
26	1N2P1K	11	4	16	39	44	.05	.45	4
27	1N1P1K	5.5	8	15	39	44	.05	.45	4

* $NH_4H_2PO_4$

The young plants after becoming established by the starter solution in the crocks of sand were given the first application of nutrients on June 14th, 1943 and thereafter every five days. Applications were made at the rate of 450 c.c. per crock, this being the amount required to thoroughly soak the sand. Tap water was added as needed, varying from day to day. Hence the nutrient solutions were applied in constant amounts whereas watering was conducted only as required by reduction in the moisture level of the sand.

EXPERIMENTAL PROCEDURE

Review of Literature

Loomis (1932) enlarged upon Kraus and Kraybill's (1918) study of carbohydrate-nitrogen ratios in plant growth by including a study of growth-differentiation balance vs. carbohydrate-nitrogen ratios. Loomis divided plant development into two phases namely growth and differentiation. At high temperatures he found growth depended on moisture supply and protoplasmic synthesizing materials, whereas differentiation depended mainly on the sugar concentration of the cell sap. Growth-differentiation balance compared with carbohydrate-nitrogen ratios varied in that the former laid more stress upon the importance of moisture, temperature, factors other than nitrogen limiting the synthesis of protoplasm, and the importance of active carbohydrates as opposed to storage forms. Kraus and Kraybill considered princibly the ratios of carbohydrates and nitrogen as they affected fruiting, i.e. differentiation, although they did briefly mention moisture and mineral nutrients as less important factors.

Essau (1936) in a study of the ontogeny of celery petioles showed that the condition known as stringiness is caused by the toughness and tensile strength of two types of tissues namely collenchyma and fibro-vascular bundles. She demonstrated by the use of a specially

adapted balance that collenchyma tissue is from two to four times stronger than vascular tissue. The latter she found to be composed of xylem in the form of spiral vessels and phloem made up of weak parenchymatous tissue.

Determinations of toughness and stringiness in celery go back to Ambronn (1881) who used an adaptation of the devise of an even earlier worker, Schwendener (1874). Ambronn's equipment was composed of a clamp which supported a strand of tissue to which weights were added. A scale and pointer operated by the weights, indicated elongation and breaking point. Ambronn came to the conclusion that collenchyma is of particular value as a supporting tissue in the more actively growing regions of plants.

Mills (1923) suggested several factors causing stringiness in celery including mineral nutrition, too much or too little light, checking of growth by excess moisture, exposure to disease, or excessive banking in the blanching process. Wilted petioles were found by Mills to be stringier than those maintained in a turgid condition, and blanched petioles to be more crisp, of better flavour, and less stringy than the unblanched petioles.

Sayre (1929) has shown that variety and environment are both important measures of quality in celery.

In this connection Haberlandt(1914) says, "Generally speaking both qualitative and quantitative development of the mechanical system are included among the hereditary characteristics of the species. Nevertheless a certain amount of direct accommodation to external conditions on the part of the mechanical system may take place during the life of the individual plant". Sayre demonstrated after studying several widely grown varieties that the size of the vascular string is not associated with the degree of stringiness. In fact, in Sutton's Giant Red, one of the most tender varieties he found unusually large bundles, and conversely in Rose Ribbed Self Blanching, a tough stringy variety, medium to small vascular bundles. The variations in the number of bundles per petiole also showed no significant effect on stringiness. Lignin content of the tracheal vessels composing the vascular system has often been considered a factor in estimating stringiness. Sayre's work indicated that the lignin content of the vascular tissue was not excessive, and hence not a factor to be considered in this regard. However, Sayre did find a relation between stringiness and collenchyma tissue, although the actual size of collenchyma string was not a measure of strength of string. The governing factor here was hardness of the collenchyma tissue, the varieties that were most stringy having the hardest collenchyma and those that were most tender having the softest collenchyma.

Corbett and Thompson (1935) studying the effect of cold storage on celery used a breaking test to detect stringiness, in which by means of a given leverage, the weight necessary to break sections of petioles one half inch in diameter was recorded. These workers reported a constant decrease in strength of string during the first ten days of storage, particularly in plants having received high applications of nitrogenous fertilizer. A change from insoluble to soluble pectic compounds was noted during this period corresponding to some extent with the decrease in stringiness.

Curtis (1938a) found collenchyma strands to be stronger, less tensile and more difficult to separate from surrounding parenchyma than were vascular bundles. The increase in brittleness with maturity in collenchyma, was attributed by Curtis to a hardening of the cell walls. This caused a contraction of the wall tissue due to its inability to absorb as much water as at earlier periods of growth when more pectin was contained in the wall. Curtis differs from Corbett and Thompson and also from Mills in finding that harvested celery plants showed no decrease in tensile strength of string during the immediate period after harvesting. However, Curtis held his plants at a temperature of 70°F whereas both Corbett and Thompson, and also Mills, used plants kept in cold storage for a

period of ten days. Other plants stored by Curtis under refrigeration at 32°F possessed essentially the same degree of stringiness after five months cold storage as at the time of harvesting. High moisture supply in the growing plants produced a colloidal hardening of collenchyma walls which in turn increased strength of string whereas low moisture supply reduced it. The reverse effect was noted in vascular tissue. Curtis (1938b) also ascribed to collenchyma tissue a tendency to shatter and break when removed from the petiole.

Norton (1917) enumerated the factors affecting quality in celery and included nutrition, ratio of parenchymous to fibrous tissue, soil moisture, rate of growth, pest control, warmth and blanching. Being a foliaceous plant, celery was found to respond more readily to nitrogen than to phosphorus or potassium fertilizers. Slow or checked growth increased stringiness. Intense light produced a dwarfed, tough, crop, half light a crop of good quality, and low light a crop that was long stemmed, watery and subject to disease attack.

Crandall and Odland (1939) associated quality in celery with crispness and stringiness. In what they admit to be a crude experiment they found no effects on these two factors as caused by varying levels of nitrogen, phosphorus or potassium in the fertilizers applied.

Physical Analyses

Selection of Petioles

At three stages of growth arbitrarily selected as half mature, three-fourths mature, and wholly mature, petioles were removed from the plants to test the collenchyma and vascular tissues for stringiness. One-third of the total number of plants was used during each stage. Therefore fifty-four plants were available at each stage as each comprised a series of twenty-seven plants replicated once. Plants used for the first stage were discarded after carrying out the required tests, as were those used for the second stage. Consequently only fifty-four plants of the original one hundred and sixty-two were grown to full maturity.

By August 4, 1943 the crop had attained sufficient growth to be considered half mature. Plate I gives some indication of the degree of maturity at the first stage. Plate II shows individual petioles at this time. All the plates depict plants and petioles chosen from respectively low, intermediate, and high nutrients treatments. Nitrogen deficiency was evident at all stages in the low (1-1-1) treatments. The high treatments throughout the series of plates are incorrectly labelled 3-3-3 whereas they should read 4-4-4. To conserve photographic material they were left unchanged. Plates III and IV are indicative of the second stage one month later, September 5, 1943, and plates V and VI of the third stage photographed after a similar period on October 3, 1943.

PLATE I

Plants At Stage One (Half Mature) Showing Effects of
Respectively Low, Intermediate, and High Nutrient Treatments.

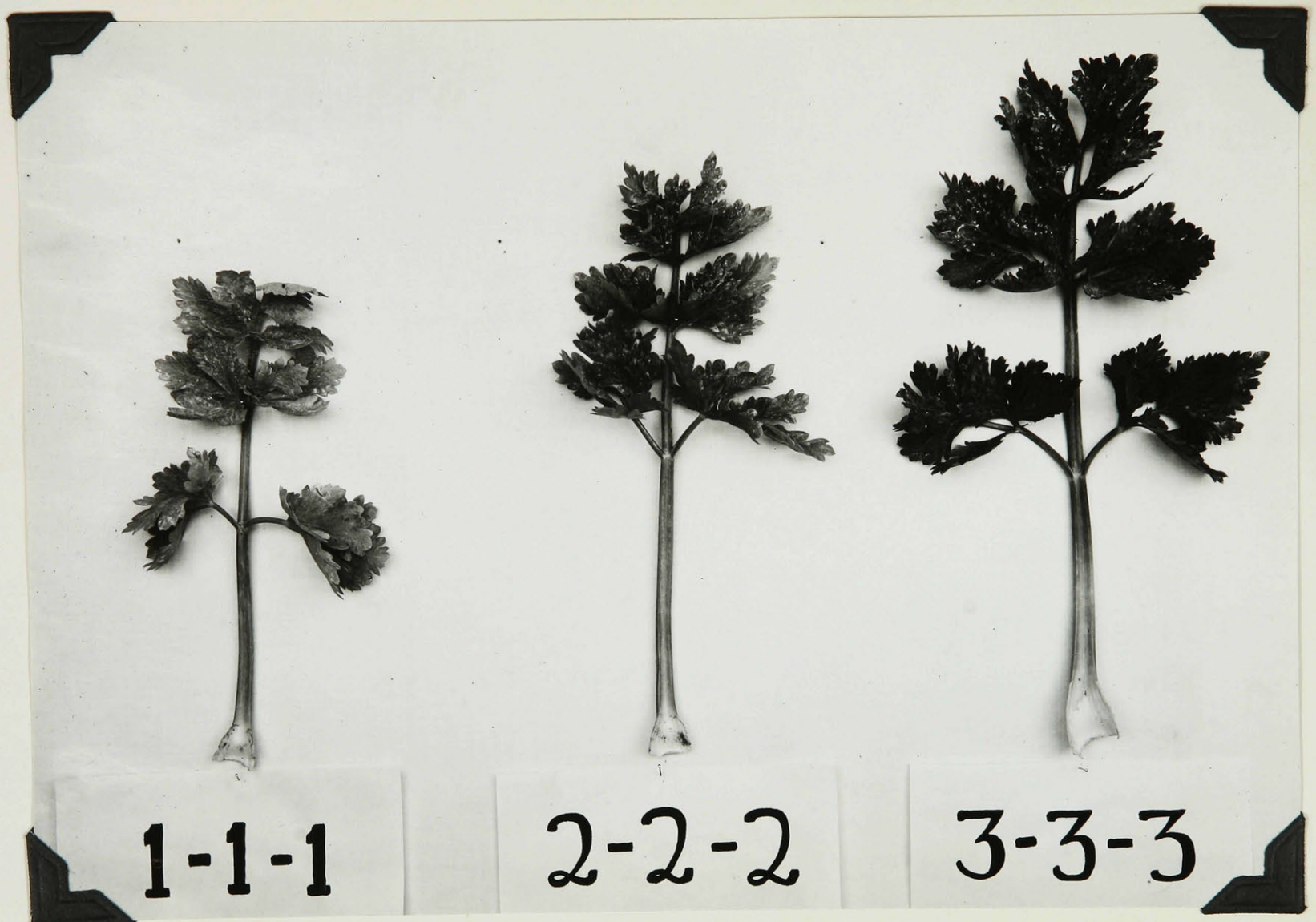

PLATE II

Petioles At Stage One (Half Mature) Showing Effects Of
Respectively Low, Intermediate, and High Nutrient Treatments.

PLATE III

Plants At Stage Two (Three-fourths Mature) Showing Effects of Respectively Low, Intermediate and High Nutrient Treatments.

PLATE IV

Petioles at Stage Two (Three-fourths Mature) Showing Effects Of Respectively Low, Intermediate and High Nutrient Treatments.

PLATE V

Plants At Stage Three (Fully Mature) Showing Effects Of Respectively Low, Intermediate and High Nutrient Treatments.

PLATE VI

Petioles At Stage Three (Fully Mature) Showing Effects Of Respectively Low, Intermediate, and High Nutrient Treatments.

Maximum turgor in the plants was assured by an adequate watering applied an hour or so before removal of petioles for testing. The actual selection of the petioles to be used involved a careful inspection of every plant and from each, two outer heart petioles as much alike as possible were chosen. To assure turgidity these were not removed until immediately before the test for stringiness was made. From either end of all petioles a portion about one centimetre in length was removed and placed in formalin acetic acid alcohol fixing solution for later microscopic study. Petioles on being taken from the plants were placed in a humidity chamber at a R.H. of 50% ± 5% at room temperature, and they were only removed while collenchyma or vascular strands were selected from them.

Removal of Tissues

Three vascular bundles and three collenchyma strands were used from each petiole. The collenchyma strands chosen were always those in the same radius as the bundles. Both types of tissue separated readily from the surrounding parenchyma with the aid of a scalpel and with gentle pulling. The vascular bundles came away particularly cleanly. On removal the bundles had a tendency to curl like coiled springs. The collenchyma tissue especially in the second and third stages was inclined to split or shatter unless care was taken in its removal. By stripping it slowly from the

growing point down towards the base of the stem, rather than in the opposite direction, shattering was reduced to a negligible minimum.

Breaking Tests

The device used to test strength of celery strands was a modification of that used by Essau (1936) and also by Curtis (1938a). This apparatus, based on the principle of a scale balance is shown in Plate VII. On one side of the balance two smooth parallel bars 1.5 c.m. apart provided for attachment of the collenchyma or vascular strands. This attachment was done in such a manner that the strands, which, in general averaged 12 c.m. in length, were bound securely about the two bars with 1.5 c.m. left between them. The precaution was taken that the last loop about each bar overlapped on other turns of the tissue rather than on the bare wood of the bar. This overcame any possibility of the strands breaking from contact or friction with the wood. The lower bar was firmly fixed to the base below. Suspended on the opposite end of the beam of the balance was a beaker into which water could be buretted. On placing a strand in position between the two bars water was permitted to flow into the beaker at a constant rate of 240 c.c. per minute until the strand parted. The weight of the beaker and water in grams was considered the breaking load of that strand. Six

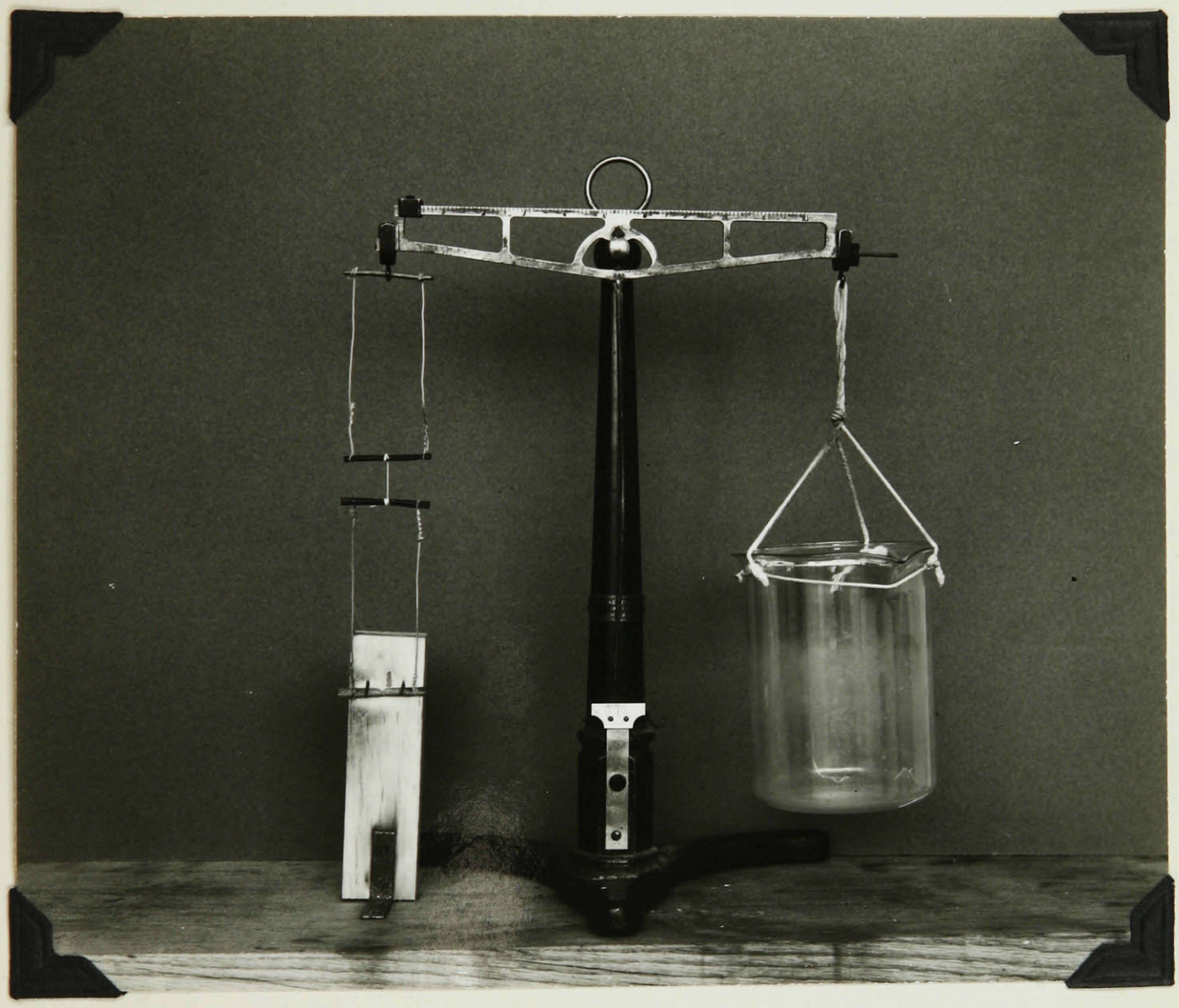

PLATE VII

The Device Used For Testing
Breaking strength of celery Strands.
A Collenchyma Strand is Shown in
Position Between the Parallel Bars.

breaking tests were carried out on each petiole, three for vascular bundles and three for collenchyma strands. Two petioles were used from each plant at each stage.

Microscopic Analyses

Micrometer Studies

It has been suggested that a relationship exists between the strength of the strands and their cross sectional areas, although other workers have not found this to be the case. To determine such a relationship, fresh sections were cut from either end of the petioles prior to the breaking tests made on the collenchyma and vascular strands. These sections when stained with the biological stain, neutral red, were suitable for microscopic study. Both collenchyma and vascular bundles in cross section are of relatively constant shapes so micrometer diameter measurements could be used as a method of calculating areas. Eight diameters were recorded for each strand. As half of them were from the small end of the petiole and half from the large end, it was necessary to average the calculations in order to estimate the approximate area. The sectioning of tissue was done in such a manner that the diameters and the areas calculated from them could be associated with breaking loads of the corresponding strands from which the measurements were taken.

RESULTS

Statistical

A statistical analysis of the effect of fertilizer nutrition on the degree of stringiness was carried on after the manner described by Fisher (1936), Goulden (1937), and Paterson (1939). Table I (appendix) presents the average breaking loads for groups of three vascular bundles or collenchyma strands tested during each of the three stages of growth and for all twenty-seven treatments. From this table the basic data for the treatment totals shown in Table X was obtained, and from it in turn has been taken the information required for the Analysis of Variance in Table XI.

TABLE X

Treatment Totals Collected from Table I (Appendix) for Calculation of Sums of Squares

	Stage 1				Stage 2				Stage 3				Total			
	1K	2K	4K	Total	1K	2K	4K	Total	1K	2K	4K	Total	1K	2K	4K	Total
1P	2222	2148	2044	6414	1532	1830	2458	5820	1507	1878	1873	5258	5261	5856	6375	17492
1N 2P	1856	2044	2005	5905	1687	1992	2292	5971	1736	1790	2099	5625	5279	5826	6396	17501
4P	2173	2742	2279	7194	1867	1640	2345	5852	1709	1858	1913	5480	5749	6240	6537	18526
Total	6251	6934	6328	19513	5086	5462	7095	17643	4952	5526	5885	16363	16289	17922	19308	53519
1P	1783	2559	1678	6020	1480	1704	2315	5499	1570	1390	1879	4839	4833	5653	5872	16358
2N 2P	1916	2145	2068	6129	1658	1927	2194	5779	1595	1611	1913	5119	5169	5683	6175	17027
4P	2126	2322	1736	6184	1474	1594	2558	5626	1570	1660	1693	4923	5170	5576	5987	16733
Total	5825	7026	5482	18333	4612	5225	7067	16904	4735	4661	5485	14881	15172	16912	18034	50118
1P	1725	2411	2059	6195	1526	2078	2172	5776	1575	1466	1610	4651	4826	5955	5841	16622
4N 2P	1959	2128	1956	6043	1387	2254	2343	5984	1367	1464	1646	4477	4713	5846	5945	16504
4P	2087	1999	1884	5970	1320	2101	1781	5202	1165	1827	1849	4841	4572	5927	5514	16013
Total	5771	6538	5899	18208	4233	6433	6296	16962	4107	4757	5105	13969	14111	17728	17300	49139
Total K	17847	20498	17709	56054	13931	17120	20458	51509	13794	14944	16475	45213	45572	52562	54642	152776

TABLE XI

Analysis of Variance of Experiment

Source	D.F.	Variance Stage 1	Variance Stage 2	Variance Stage 3	D.F.	Variance Total
N	2	14403	4691	40552	2	48934**
P	2	11283	7831	2177	2	1560
K	2	68636**	295896**	50251	2	209030**
N x P	4	12760*	4002	2576	4	7137
N x K	4	5937	30903**	3453	4	10335*
P x K	4	9309	4794	4941	4	1875
N x P x K	8	11547*	8869*	6296	8	765
Tissues	1	2596160**	2620817**	2484265**	1	7701242**
Stages					2	274419**
Stages x Tissues					2	519
Stages x N					4	5356
Stages x P					4	9865*
Stages x K					4	102877**
Stages x N x P					8	6101
Stages x N x K					8	14979**
Stages x P x K					8	8584*
Stages x N x P x K					16	12973**
Tissues x Treatments	26	4980	5020	3001	26	3723
Stages x Tissues x Treatments					52	4379
Error	54	4575	3480	13991	162	3791
Total	107				323	
Standard Error of Experiment		67.64	58.98	153.26		61.57

Difference required for sig. between totals of	Stage 1	Stage 2	Stage 3	Total
108 plots	-	-	-	1773.83
36 plots	1124.17	980.25	2547.18	1023.33
12 plots	649.34	566.20	1471.29	591.07
4 plots	374.05	326.16	845.99	-

* Significant
** Highly significant

From this latter Table of the Analysis of Variance and using the P.05 point as significant and the P.01 point as highly significant it can be seen that under the conditions of the experiment: -

1. The highly significant difference for stages of growth indicated that real differences occurred between stages in the amounts of stringiness occurring.

2. The difference between the collenchyma and vascular tissues, taken as a whole and also at stages one, two, and three showed highly significant differences. The histogram in Plate VIII expressed in F values gives some indication of the striking degree of significance found between tissues at the three separate stages of growth. The collenchyma strands were stronger than the vascular bundles, requiring approximately twice the breaking load of the latter. This can be seen from a study of Table I (appendix) where in general the breaking load of collenchyma in grams is twice that of vascular tissue.

3. Treatments when taken collectively unseparated into stages of growth showed a number of highly significant variations. However, when broken down, the separate elements at the different stages varied greatly.

a. Nitrogen taken separately at the three stages of growth showed no significant effect on development of stringiness.

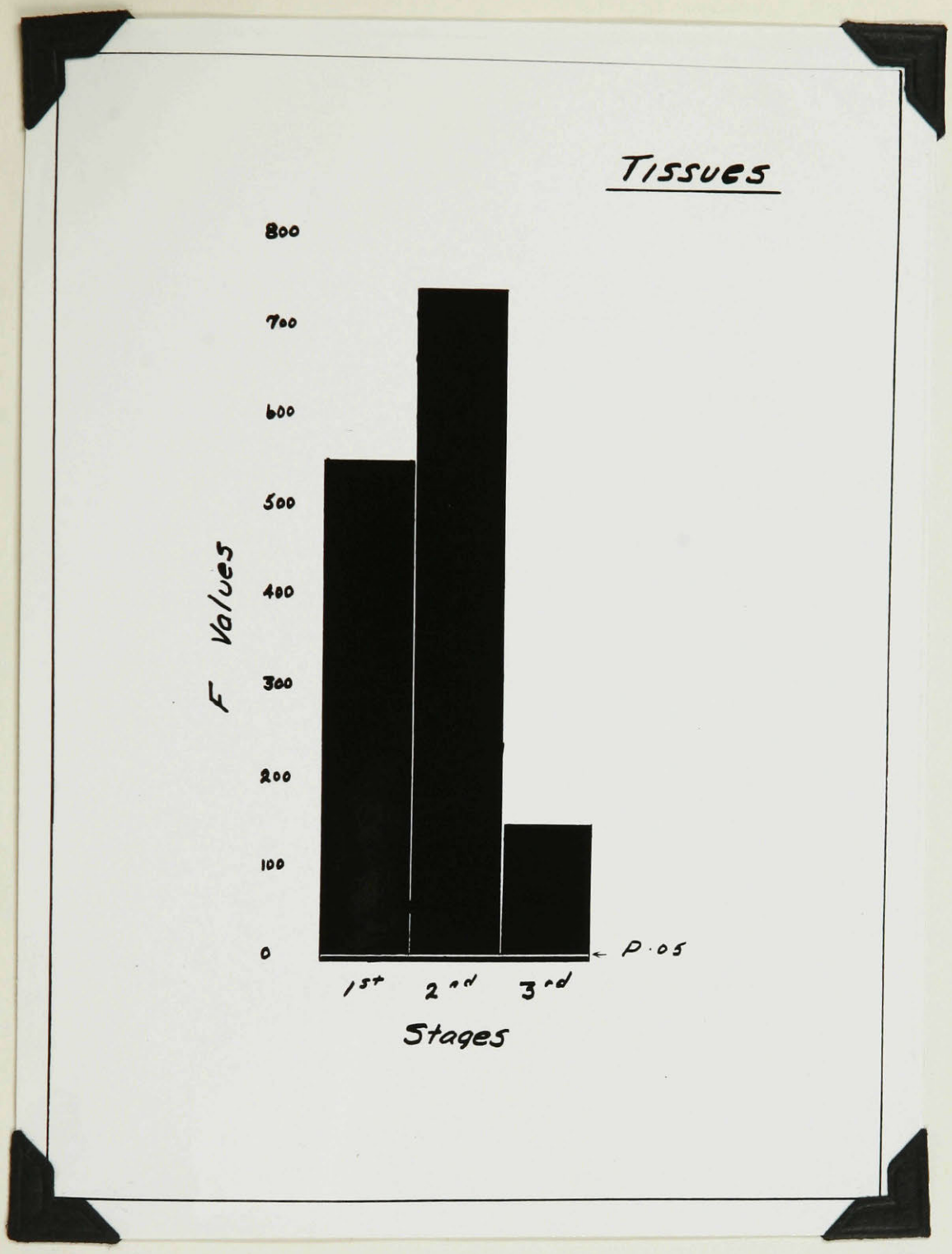

PLATE VIII

The Effects of Tissues Expressed In F values at Stages One, Two, and Three.

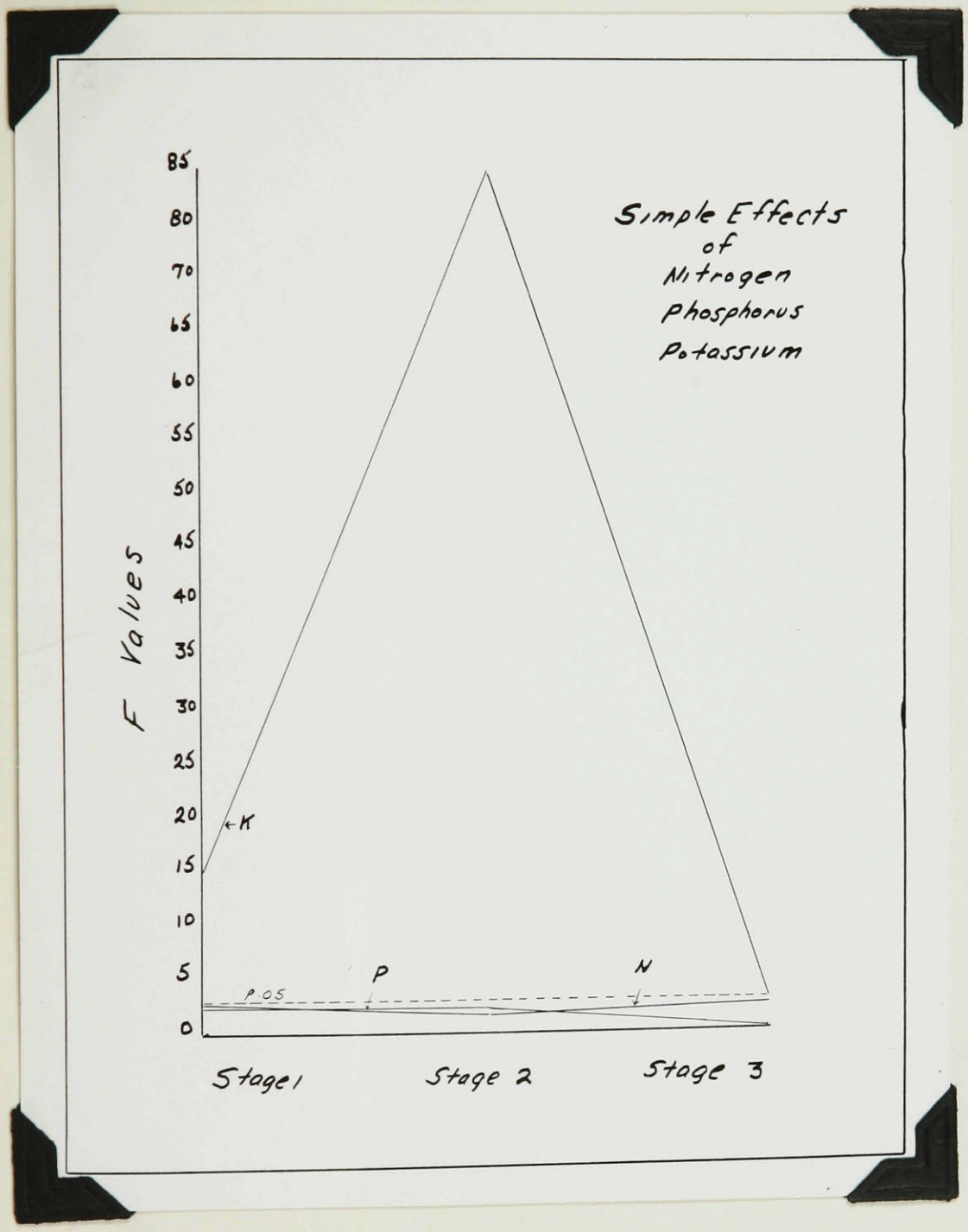

PLATE IX

The Simple Effects Expressed In F Values of Nitrogen, Phosphorus and Potassium at Stages One, Two and Three.

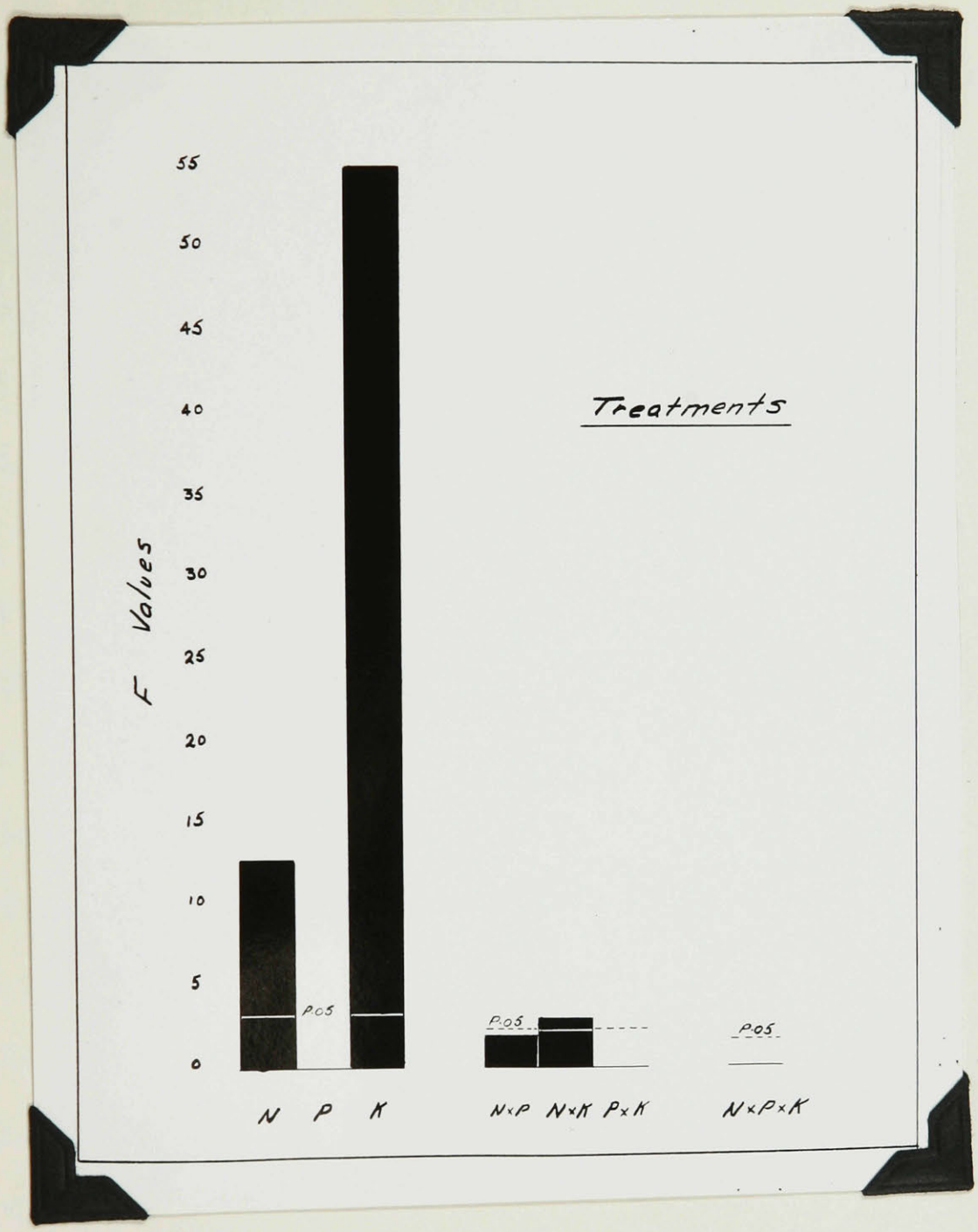

PLATE X

The Effect of Treatments Expressed In F Values for the Experiment Taken Collectively (Stages Unseparated).

When nitrogen was considered collectively for the whole experiment it possessed a highly significant negative effect as the histogram in Plate X shows.

b. In no case did phosphorus affect stringiness, either when taken for the experiment as a whole (Plate X) or when split up into stages of growth (Plate IX).

c. Potassium showed marked influence on the degree of stringiness at all times. This highly significant potassium effect is readily seen in the histogram in Plate X and in the graph in Plate IX. It will be noted that the graph rose from a highly significant F value of 15 in stage one, to a greatly increased F value of 85 at stage two, only to break abruptly and drop in stage three to bare significance.

d. The first order interaction of nitrogen on phosphorus is seen in the histogram of Plate X to be non-significant for the combined stages effect of the experiment as a whole. However, when the effects were split up into stages of growth as in Plate XI, the first stage was significant whereas the second and third stages were non-significant.

e. Interaction of nitrogen on potassium for the experiment as a whole reached the P.05 point but not the

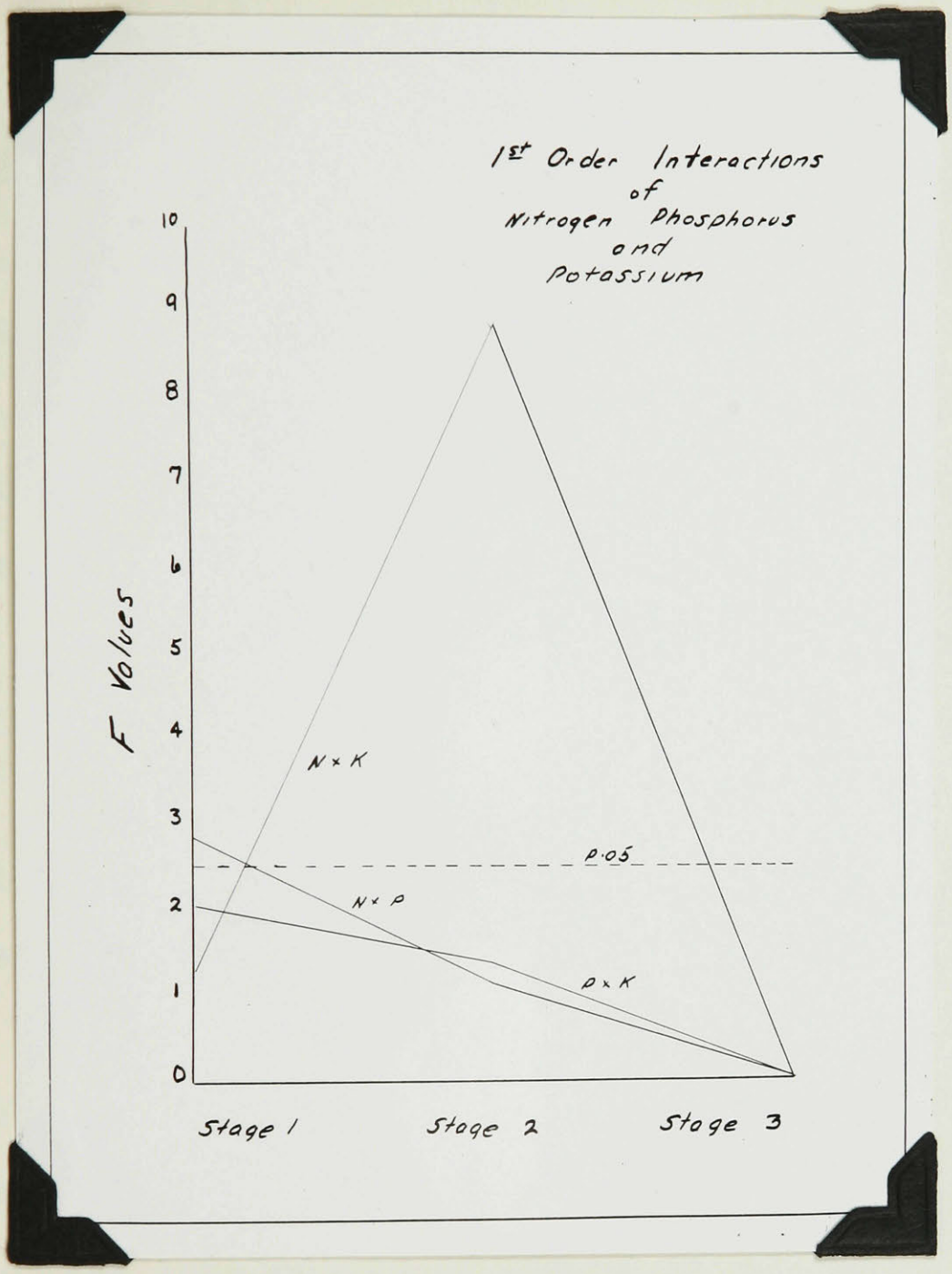

PLATE XI

The Effect of 1st Order Interactions of Nitrogen, Phosphorus, and Potassium, Expressed in F Values, at Stages One, Two, and Three.

P.01 point, Plate X. On dividing them up, the second stage, Plate XI, indicated high significance only to drop to non-significance again at the final stage.

f. The interaction of phosphorus on potassium was non-significant at all times, neither the histogram in Plate X, nor the graph in Plate XI showing a rise to the P.05 point.

g. The second order interaction, nitrogen on phosphorus on potassium, when considered undivided for the entire experiment indicated no effect, Plate X, but separating it out, stages one and two reached significance.

4. The interactions of stages on treatments showed that at the different stages of growth the varying treatments acted differently. When broken down into the effects of stages of growth on the individual elements these variations could be more closely studied. The histogram of Plate XII shows these effects of stages on the various treatments as follows -

a. The interaction of stages of growth on nitrogen gave no significance whatever.

b. The interaction of stages of growth on phosphorus showed a significant but not a highly significant effect.

c. The interaction of stages of growth on potassium as can be seen in the histogram in Plate XII had a very highly significant effect.

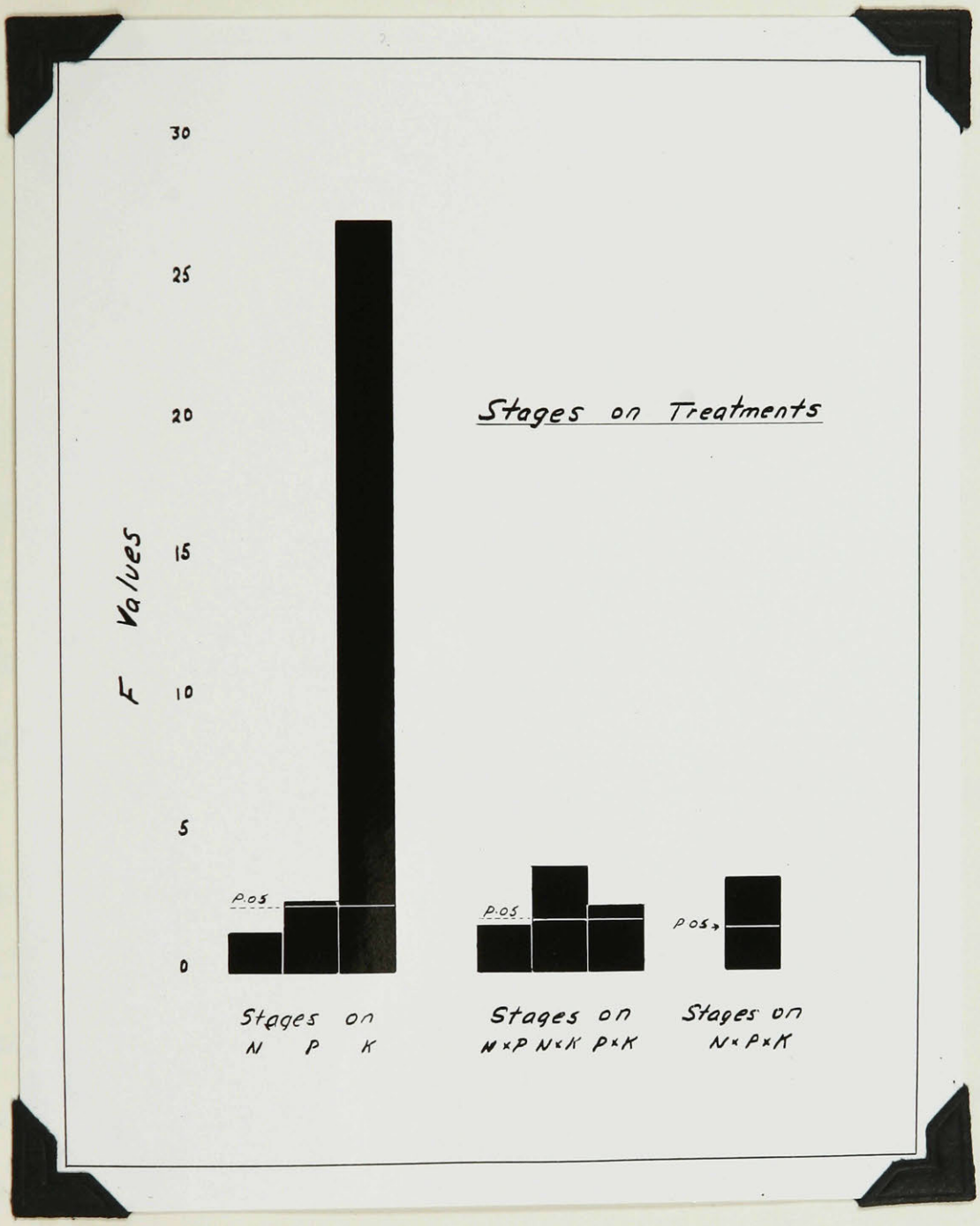

PLATE XII

The Effect of Stages On Treatments Expressed In F Values.

d. The second order interaction of stages of growth on nitrogen on phosphorus was non-significant (Plate XII).

e. The interaction of stages of growth on nitrogen on potassium gave high significance (Plate XII).

f. The interaction of stages of growth on phosphorus on potassium, Plate XII, reached the P.o5 point but not the P.ol point.

g. The interaction of stages on nitrogen on phosphorus on potassium was also highly significant (Plate XII).

5. The interactions of stages of growth on tissues, tissues on treatments, and stages of growth on tissues on treatments were all of no significance.

Microscopic

No relationship was determinable in collenchyma or in vascular strands between their strength and cross-sectional area. The two factors appeared independent. In some cases large strands were weak and soft and in others the strands were small but tough and strong. A number of nutrient treatments were indicative of small sized strands of both types having unexpected strength and resistance. Hence no correlation was forthcoming.

The cellular wall tissue of the collenchyma showed considerable thickening in the second stage over that appearing in the first stage but in the final stage only a slight additional increase was found. A correspond-ing increase of the thickness of the walls of the vascular

bundle tissue if present was not detected.

In the collenchyma there was a greater variation in the size of individual cells than was found in the vascular tissue although in general large collenchyma strands were inclined to possess large cells and smaller collenchyma strands smaller cells.

DISCUSSION

A study of the foregoing analysis of variance, (Table XI) and the results therein presented, gives some indication of the wide variation in the effects of the three nutrient elements, nitrogen, phosphorus, and potassium. Before an interpretation of the results can be given, mention must be made of the fact that on September 12, 1943 immediately following the completion of stringiness determinations for the second stage, the fifty-four remaining plants to be used for the final stage were moved into the greenhouse to avoid frost injury. While outside, the lower September temperatures had hardened the plants off to some extent, and growth had become slow and inclined to maturity. This can be seen in Plate IV in which the individual petioles used for stage two are thick and sturdy. On transferring the crop to the greenhouse the increased temperatures and relative humidity stimulated new succulent growth. Plate VI indicates clearly that the types of petioles utilized for stage three were elongated and thinner than those at stage two. The habit of growth of the entire plant as in Plate V also suggests considerable elongation over stage two. Stringiness of celery is essentially a differentiation process whereby the cellulose walls become impregnated with lignin, pectin and hemicellulose compounds. Therefore, applications

of nutrients must be considered in relation to their effect upon producing either new growth or differentiation of present growth.

These facts should be borne in mind in interpreting the analysis of variance in Table XI. Here the collenchyma and vascular tissues are shown to be significantly different and Table I (appendix) indicates that the collenchyma has in general twice the strength of vascular tissue. These are essentially the findings of Essau (1936) and Curtis (1938a).

The relationship between nitrogen level and development of stringiness as shown in this experiment coincides in general with plant physiological principles and it may be further explained by the following reasoning. Taking the three stages of growth together, a highly significant effect of nitrogen on decreasing stringiness is shown. When considering the three stages of growth separately the nitrogen treatments did not show a significant effect, although in all cases the lowest nitrogen level indicated a temdency towards higher stringiness. Since restricted nitrogen nutrition of plants depresses growth and promotes differentiation of tissues (in this case hardening of the collenchyma tissue) it is apparent that an adequate nitrogen supply must be maintained for optimum growth of the desired type of

succulent and tender petiole. The higher nitrogen levels used in this experiment probably approached the desired nitrogen requirements. This explanation is in accordance with the concept of growth-differentiation balance as proposed by Loomis (1932). In this regard the maintenance of high applications of nitrogenous fertilizers would appear to be a practical recommendation for commercial celery growers.

In this experiment phosphorus appears to have had no effect upon stringiness whether for the experimental population taken together or considered in separate stages of growth. This indicates that in none of the nutrient treatments did phosphorus become a limiting factor to growth and is in agreement with the findings of Crandall (1937) who showed that celery grew satisfactorily over a wide range of soil phosphorus availability.

Potassium had a significant or highly significant positive effect upon development of stringiness in each of the three stages. The second and third stages and the total show a significant effect of high over low potassium applications, (Tables X, XI). Plates IX and XI showing simple and first order interactions are of particular interest.

The cause of the highly significant interaction between potassium and nitrogen (Plate XI) upon development of stringiness can probably be attributed to the highly significant simple effect of potassium. The simple potassium effect rose to very high significance in the second stage of growth only to drop to the P.05 point again at the third stage. The first order interaction of nitrogen on potassium had a similar climacteric at the second stage, to drop again to zero at the final stage. The fact that the crop was brought into the greenhouse after the second stage may also have some bearing on this remarkable drop in potassium effect and on the drop in the interaction of nitrogen on potassium. The sudden increase of succulent growth following the transfer to the greenhouse has already been mentioned in this connection. The interaction of phosphorus on potassium remaining below significance would suggest a depressive effect of phosphorus when in combination with potassium. The second order interaction of nitrogen on phosphorus on potassium showed significance in the first and second but not in the third stage. Interactions of this type have been found in sand culture experiments in which nutrients are added directly in solution to the sand.

The effects of stages on treatments when separated into their components again indicate the striking potassium effect.

The experiment would suggest that fertilizer combinations are required in which potassium is present in sufficient amounts for optimum growth, but which must be balanced with high nitrogen so that nitrogen does not become a limiting factor to growth. From the findings under the conditions of this experiment it might be suggested that adequate nitrogen and the minimum required amount of potassium would make for the least amount of stringiness. However, reduction in the potassium content of fertilizers must not go below the threshold value required for adequate potassium nutrition of celery on different muck soils. The added applications of nitrogen so often advocated to growers to stimulate growth can be seen to be desirable in producing tender non-stringy petioles.

It is felt that before recommendations could be made on a broader scale further sand culture experiments should be carried on and from the results obtained extensive field tests be made on commercial celery soils.

With regard to the correlations of collenchyma and vascular strand strength and their cross sectional area or size, no relationship was found in this experiment.

The maturity of the tissues especially in the case of collenchyma may have been a factor here rather than their size or cross sectional area. This appears to have been the conclusion of Sayre (1929), the variations in strength, he says, being caused by hardness and age of tissue. He also found stringiness to vary among different varieties.

The thickening of collenchyma wall tissue noted at the second stage of growth may again possibly be associated with maturity. The fact that little if any additional thickening was noted at the final stage may coincide with the burst of soft succulent growth experienced on bringing the plants into the greenhouse at the completion of the second stage of growth.

Reference should be made here to a preliminary experiment of a somewhat similar nature to the one herein described. This was carried on in the greenhouse during the winter 1942-43. In this experiment the same number of collenchyma and vascular strands, approximately one thousand, were used to determine the degree of stringiness. Cuticular moisture loss determinations of celery tissue were also undertaken, by each day weighing detached petioles stored in a humidity chamber. As many of these petioles developed boron deficiency lesions and hence a breakdown of the cuticle, excessive moisture was lost through the

lesions and the experiment was abandoned. This first crop of celery also contracted a physiological type of terminal growth breakdown known as black heart so it too was discarded.

CONCLUSIONS

1. Highly significant differences occurred in the amount of stringiness between different stages of growth.
2. There was a highly significant difference between collenchyma and vascular tissue, the former possessing twice the strength or degree of stringiness of the vascular tissue.
3. The nitrogen effect for the experiment taken as a whole showed a highly significant decreasing effect on stringiness. When separated into stages this decreasing or negative effect continued although it was not significant.
4. Under the conditions of these experiments no combinations of phosphorus proved limiting to growth and thus had no effect in increasing or decreasing stringiness.
5. Potassium had a highly significant effect in increasing stringiness.
6. The strength of collenchyma and vascular strands was independent of their size.
7. The strength of the collenchyma strands varied directly with maturity.
8. Maturity had a lesser effect on the strength of the vascular bundles, in so far as stringiness is concerned, than

it had on the collenchyma strands.

9. A thickening of the walls of the collenchyma cells was noted as maturity progressed.

10. Large collenchyma cells were associated in general with large collenchyma strands and small collenchyma cells with small strands.

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TABLE I *

The Average Breaking Loads in Grams of the Three Collenchyma Strands and Three Vascular Bundles Taken From Each Petiole.

Stage No. 1

Treatment	Plant 1			Plant 2					
N-P-K	Collenchyma	Vasc. Bundles	Total	Collenchyma	Vasc. Bundles	Total	Total Collenchyma	Total Vasc. Bundles	Total Stage 1
4-4-4	606	285	891	643	350	993	1249	635	1884
4-2-4	590	381	871	639	346	985	1229	727	1956
4-1-4	674	347	1021	689	349	1038	1363	696	2059
2-4-4	462	248	710	664	362	1026	1126	610	1736
2-2-4	555	301	856	761	451	1212	1316	752	2068
2-1-4	509	323	832	542	304	846	1051	627	1678
1-4-4	777	401	1178	820	281	1101	1597	682	2279
1-2-4	716	432	1148	500	357	857	1216	789	2005
1-1-4	622	349	971	743	330	1073	1365	679	2044
4-4-2	640	296	936	725	338	1063	1365	634	1999
4-2-2	586	356	942	754	432	1186	1340	788	2128
4-1-2	750	451	1201	799	411	1210	1549	862	2411
2-4-2	651	394	1045	792	485	1277	1443	879	2322
2-2-2	713	314	1027	744	374	1118	1457	688	2145
2-1-2	872	426	1298	762	499	1261	1634	925	2559
1-4-2	885	429	1314	1007	421	1428	1892	850	2742
1-2-2	690	333	1023	660	361	1021	1350	694	2044
1-1-2	712	451	1163	681	304	985	1393	755	2148
4-4-1	688	361	1049	694	344	1038	1382	705	2087
4-2-1	538	347	885	708	366	1074	1246	713	1959
4-1-1	539	389	928	518	279	797	1057	668	1725
2-4-1	759	397	1156	585	385	970	1344	782	2126
2-2-1	595	397	992	605	319	924	1200	716	1916
2-1-1	569	314	883	593	307	900	1162	621	1783
1-4-1	762	434	1196	581	396	977	1343	830	2173
1-2-1	656	343	999	609	248	857	1265	591	1856
1-1-1	767	372	1139	699	384	1083	1466	756	2222
	17883	9871	27754	18517	9783	28300	36400	19654	56054

* Stages 2 and 3 on succeeding pages

Stage No.2

Treatment	Plant 1			Plant 2			Total	Total	
N-P-K	Collenchyma	Vasc. Bundles	Total	Collenchyma	Vasc. Bundles	Total	Collenchyma	Vasc. Bundles	Total Stage 2
4-4-4	600	335	935	625	221	846	1225	556	1781
4-2-4	747	421	1168	809	366	1175	1556	787	2343
4-1-4	841	447	1288	530	354	884	1371	801	2172
2-4-4	799	466	1265	936	357	1293	1735	823	2558
2-2-4	735	384	1119	673	402	1075	1408	786	2194
2-1-4	814	407	1221	770	324	1094	1584	731	2315
1-4-4	839	314	1153	780	412	1192	1619	726	2345
1-2-4	679	412	1091	762	439	1201	1441	851	2292
1-1-4	762	453	1215	810	433	1243	1572	886	2458
4-4-2	678	395	1073	650	378	1028	1328	773	2101
4-2-2	764	418	1182	707	365	1072	1471	783	2254
4-1-2	632	355	987	664	427	1091	1296	782	2078
2-4-2	513	246	759	535	300	835	1048	546	1594
2-2-2	735	306	1041	545	341	886	1280	647	1927
2-1-2	502	282	784	570	350	920	1072	632	1704
1-4-2	502	223	725	592	323	915	1094	546	1640
1-2-2	633	242	875	748	369	1117	1381	611	1992
1-1-2	622	308	930	627	273	900	1249	581	1830
4-4-1	425	249	674	436	210	646	861	459	1320
4-2-1	438	243	681	446	260	706	884	503	1387
4-1-1	484	267	751	526	249	775	1010	516	1526
2-4-1	452	258	710	524	240	764	976	498	1474
2-2-1	589	312	901	503	254	757	1092	566	1658
2-1-1	623	233	856	475	149	624	1098	382	1480
1-4-1	651	300	951	660	256	916	1311	556	1867
1-2-1	539	331	870	604	213	817	1143	544	1687
1-1-1	531	254	785	531	216	747	1062	470	1532
	17129	8861	25990	17038	8481	25519	34167	17342	51509

Stage No.3

Treatment	Plant 1			Plant 2			Total	Total		Grand Total	Grand Total	
N-P-K	Coll-enchyma	Vasc. Bundles	Total	Coll-enchyma	Vasc. Bundles	Total	Coll-enchyma	Vasc. Bundles	Total Stage 3	Coll-enchyma	Vasc. Bundles	Grand Total
4-4-4	597	264	861	660	328	988	1257	592	1849	3731	1783	5514
4-2-4	619	282	901	485	260	745	1104	542	1646	3889	2056	5945
4-1-4	597	247	844	511	255	766	1108	502	1610	3842	1999	5841
2-4-4	551	340	891	551	251	802	1102	591	1693	3963	2024	5987
2-2-4	698	332	1030	592	291	883	1290	623	1913	4014	2161	6175
2-1-4	561	236	797	731	351	1082	1292	587	1879	3927	1945	5872
1-4-4	678	345	1023	606	284	890	1284	629	1913	4500	2037	6537
1-2-4	779	307	1086	657	356	1013	1436	663	2099	4093	2303	6396
1-1-4	705	293	998	571	304	875	1276	597	1873	4213	2162	6375
4-4-2	603	336	939	628	260	888	1231	596	1827	3924	2003	5927
4-2-2	468	309	777	442	245	687	910	554	1464	3721	2125	5846
4-1-2	353	186	539	614	313	927	967	499	1466	3812	2143	5955
2-4-2	531	227	758	598	304	902	1129	531	1660	3620	1956	5576
2-2-2	499	277	776	590	245	835	1089	522	1611	3826	1857	5683
2-1-2	448	163	611	498	281	779	946	444	1390	3652	2001	5652
1-4-2	639	325	964	611	283	894	1250	608	1858	4236	2004	6240
1-2-2	644	283	927	580	283	863	1224	566	1790	3955	1871	5826
1-1-2	577	254	831	703	344	1047	1280	598	1878	3922	1934	5856
4-4-1	426	135	561	418	186	604	844	321	1165	3087	1485	4572
4-2-1	513	163	676	477	214	691	990	377	1367	3120	1593	4713
4-1-1	565	282	847	503	225	728	1068	507	1575	3135	1691	4826
2-4-1	551	309	860	525	185	710	1076	494	1570	3396	1774	5170
2-2-1	630	212	842	548	205	753	1178	417	1595	3470	1699	5169
2-1-1	571	194	765	580	225	805	1151	419	1570	3411	1422	4833
1-4-1	581	274	855	530	324	854	1111	598	1709	3765	1984	5749
1-2-1	650	266	916	530	290	820	1180	556	1736	3588	1691	5279
1-1-1	565	260	825	459	223	682	1024	483	1507	3552	1709	5261
	15599	7101	22700	15198	7315	22513	30797	14416	45213	101364	51412	152776