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SOME INTERRELATIONS OF
FERTILIZERS, CARBOHYDRATE
PRODUCTION AND YIELD OF
FIELD BEANS

THESIS FOR THE DEGREE OF M. S.

C. W. Lauritzen

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THESIS

Soils

Beans

Fertilizers + manures

Soils

SOME INTERRELATIONS OF FERTILIZERS,
CARBOHYDRATE PRODUCTION AND YIELD
OF FIELD BEANS

by
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INTRODUCTION

The yield obtained from any economic plant is dependent upon the many factors which influence the growth of the crop under consideration. Commercial fertilizer applications may be one of these factors, depending on whether there exists a soil deficiency of the elements supplied. If applications of a commercial fertilizer produce a marked effect upon the yield, the other factors remaining unchanged, it is assumed that the plant nutrient elements supplied have or have not been limiting factors in the production of the crop, depending on the yield changes produced by the fertilizer.

Carbohydrate production is undoubtedly a necessary process in the growth of plants. Since fertilizer elements affect plant growth the question is raised as to what part these fertilizer elements play in the synthesis of the various carbohydrates found in plants and what relation exists between carbohydrate production in growing plants and the yields obtained. In order to determine if such relationships exist in the case of bean plants, and also to determine if the rate of production of carbohydrates at different times of the day is influenced by the fertilizer elements supplied, bean plant parts were analyzed for carbohydrates, nitrogen, and dry weight in plant samples taken at four-hour intervals from check plots and from plots receiving applications of various fertilizer elements.

A considerable amount of research on carbohydrate production in plants has been carried out using several kinds of plants.

These researches have been mainly attempts to determine the order of synthesis of the different plant carbohydrates and certain relations they bear to one another; as the variation in the amounts present in the plants with the change of temperature, intensity of sunlight, and consequently the time of day. Other investigations made along this line have had for their purpose the determination of the functions of nutrient elements in the synthesis of carbohydrates in plants.

No one, to our knowledge, has attempted to correlate carbohydrate production during periods of growth with the eventual yield; or has used field beans in researches dealing with carbohydrate production. Beans are a valuable food crop high in carbohydrate content, and they are extremely sensitive to environmental factors which cause uncertainty in their profitable production. Because of the importance of this crop from the standpoint of both production and consumption, studies of this nature are desirable.

HISTORICAL

Noble (9), working with crops that store large amounts of carbohydrates such as sugar beets and mangolds, found that a sufficient supply of potassium was necessary for the normal production of carbohydrates in the plants.

Stocklasa (16) showed that green plants did not have the power of synthesis in the absence of potassium.

Reed (11) found evidence in the plants he studied that potassium was necessary for the formation of starch, but gave no evidence that phosphorus was necessary for starch formation. He showed, however, that a deficiency of phosphorus seriously interfered with the transformation of starch into water-soluble carbohydrates.

Weizsmann (18) made the same observation as Stocklasa.

Smith and Butler (14) could not find evidence to support Stocklasa and Weizsmann.

Schuster (12) pointed out that the results obtained from an application of potassium to a crop depended on the amount of available potassium in the soil as well as other soil properties, and stressed the importance of considering the soil type as a significant factor in planning an investigation of this nature.

Janssen and Bartholomew (4) found that tomato plants grown in mediums low in potassium showed an increase in the per cent of dry matter, nitrogen, and sugars. They also reported (5)

that the percentages of carbohydrates and potassium in the plants fluctuated greatly and concluded that a high per cent of sugars and starch was not necessarily associated with a high per cent of potassium in the plant. They found however a fairly good correlation between the total weight of sugars and starch per plant and the potassium content.

MacGillivray (6) showed that in the case of tomatoes a deficiency of phosphorus resulted in an increase in the per cent of total nitrogen, this increase being mostly water soluble forms of nitrogen, excluding nitrates, but caused a decided increase in the per cent of sugars.

Stark (15) noted that when potassium was applied to soybeans, in addition to limestone and organic matter, a decrease in the per cent of protein resulted; but limestone and organic matter alone gave an increase in the per cent of protein.

Davis, Daish, and Sawyer (2), after making a study of the formation and translocation of sugars in mangolds, reported that the proportion of saccharose in the leaf tissue followed the temperature curve closely during the daytime; and that the proportion of hexoses increased faster than the temperature, and in such a manner that the curve showing the ratio of hexoses to saccharose in practically parallel to the temperature curve.

Davis and Sawyer (3) found in their study of potato plants that saccharose was the principal sugar in the plant when the

tubers were being formed, and that the amount increased from sunrise until 2 P.M. following approximately the rise in temperature. The starch content of the plants reached its maximum point two hours before sunset. From that time on the amount of starch decreased till there was very little present at 2 A.M.

Mason and Maskell (7) studied the transport of carbohydrates in the cotton plant. They found a significant lag in the diurnal variations in the bark over those in the leaves and that the variation of the total sugars was due largely to the variation in the concentration of sucrose.

The rate of transport of carbohydrates from the bark to the boll in cotton plants was found to correlate with the variation in the sucrose gradient from the bark to the boll, the rate being about four times as great in the day as in the night.

Clements (1), working with potato, soybean, and sunflower plants, showed by his graphs that the period of maximum carbohydrate production was from noon until about 9 P.M. The increase in starch content was especially noticeable during this period. A distinct correlation was found between favorable environmental conditions and the formation and translocation of carbohydrates in the plant.

Cole (19) very recently working with the potato plant, found irregular variation in the sugar content of plants grown on plots receiving various fertilizer treatments but no differences were found which could be attributed to fertilizer application. He expresses the opinion that under field conditions other factors such as intensity of light, moisture, and humidity enter in to

cause variations in the sugar content of the potato plant to a greater extent than does the relative supply of nutrient elements present.

FIGURE I

	1 rd.	1 rd.	2 rds.	2 rds.	
Strip from which carbohydrate check was taken	101C	101A	101B		400 lbs. / A
		0 - 16	0 P.U.		
	102C	102A	102B		
		0 - 16	0 B.C.		
	103C	103A	103B		
		0 - 16	8 P.U.		
	104C	104A	104B		
		0 - 16	8 B.C.		200 lbs. / A
	105C	105A	105B		
		0 - 16	8 P.U.		
		4 - 0	0 B.C.		
	106C	106A	106B		
		4 - 16	8 P.U.		
	107C	107A	107B		
		4 - 16	8 B.C.		
	108C	108A	108B		
		4 - 16	8 P.U.		
	109C	109A	109B		
		4 - 16	8 B.C.		

KEY

P.U. Plowed under
B.C. Broadcast

EXPERIMENTAL PROCEDURE

The bean plant samples used in this research and the yield results were obtained from cooperative fertility plots located in the vicinity of Ithaca, Michigan, on the soil type known as Brookston loam. Figure 1 shows the plan of the fertility field, the kinds and amounts of fertilizers applied, the methods of applying the fertilizers, and the location of the check and treated plots from which the plant samples were taken for analysis and from which the yields were obtained.

Judging from the yields of crops produced previously on this land, the field was above the general average in fertility for the locality. The bean yields reported in this thesis, however, are much below the average for the Brookston soil type in this State, due probably to the deficiency of rainfall during the growing season of this year (1930). During the year preceding the establishment of the bean fertility plots this field was cropped to corn and was plowed early in the Spring of 1930 for beans.

The bean fertility plots were laid out and the fertilizers applied in such a way as to make possible comparisons of yields and carbohydrate production of beans on soil receiving no treatment; superphosphate alone; superphosphate and muriate of potash; and nitrate of soda, superphosphate, and muriate of potash. Three methods of fertilizer application were used; namely, (1) broadcast before plowing, (2) broadcast on the plowed and

worked field before seeding, (3) superphosphate and muriate of potash plowed under and nitrate of soda broadcast on the plowed and worked field before seeding. All treatments were applied at the rate of four hundred pounds per acre, except on plots 108 (A and B) and 109 (A and B), which were fertilized at the rate of two hundred pounds per acre. The fertilizers were mixed according to the following formulas: 0-16-0, 0-16-8, and 4-16-8. Then they were carefully broadcast by hand on the plots, having first been diluted by mixing them thoroughly with about twice their volumes of moist soil to prevent any possible blowing and to insure a more uniform distribution over the plots. The beans were planted June 12, 1930, and harvested September 23, 1930.

The plots used to obtain plants for carbohydrate analysis were 102A, 104A, 107A, and the check strip as designated (Figure 1). Plots 102B, 104B, and 107B were harvested and the yields determined for comparison with the carbohydrate production of the plants on the A portion of the corresponding plots. The yields on plots 101C to 107C inclusive, were averaged and this average value taken for comparison with the carbohydrate production on the check strip.

The day preceding sampling was warm and partly cloudy. During the period of sampling the weather was clear and warm, except for the period between four o'clock P.M. and eight o'clock P.M., when it was partly cloudy.

The bean plants at the time of sampling were green having pods somewhat more mature than string beans when taken for table use. Some variation was observed in the maturity of the plants as is always the case; but on the average, it might be said that the plants were of such maturity that the pods contained beans from one-half to full size. The plant samples were taken every four hours during a period of twenty-four hours. The first samples were taken at midnight August 13, 1930, and the last samples at midnight August 14, 1930; thus, the first and last samples were taken at the same time on two different days. The samples were collected by taking plants promiscuously over the plots, the several samples being gathered at one time and taken as quickly as possible to the field laboratory close by where the equipment for preserving the samples was located.

The leaves, stems, and pods of the plant were separated by hand. Fifty grams of each part which previously had been cut into pieces one to two inches in length were placed in pint jars containing approximately one gram of CaCO_3 to neutralize any acids present which would tend to hydrolyze the sugars; the presence of an excess of CaCO_3 being unimportant as its dissociation was such that the pH was not raised enough to cause the breaking down of the sugar molecule which occurs at higher concentrations of hydroxyl ions. The jars were then nearly filled with boiling 95% ethyl alcohol; the caps turned on loosely and the jars set in

a water bath hot enough to keep the alcohol at the boiling point in order to prevent all enzymic action and partially extract the sugars from the plant tissues. At the end of one hour the jars were removed from the water bath and enough more hot alcohol added to cover the plant tissue, in case some had been lost due to evaporation. The jar caps were then tightened down and the jars placed in storage until wanted for analysis.

ANALYTICAL METHODS

Analysis of Bean Tissue

Preliminary treatment of the sample:

The field sample preserved in alcohol was filtered into a 1000 cc. volumetric flask and washed with 80% alcohol until the filtrate was about 950 cc. This volume was made up to 1000 cc. and was called the "extract".

The residue was placed in a 200 cc. weighed beaker and dried in an oven at 65° C. for 48 hours, cooled in a desiccator and weighed. The aliquots for analysis were calculated on the basis of this weight.

Treatment of the Extract

The alcohol from 300 cc. of the alcoholic extract was distilled off under reduced pressure in a clasion flask below 65 C. When about 50 cc. remained the residue was washed from the clasion flask into a 100 cc. volumetric flask, with warm water, cooled, made up to volume and transferred to a 100 cc. centrifuge tube. About 0.2 grams of anhydrous lead subacetate (Horn's dry lead) was added, mixed well, and the samples centrifuged for five minutes. The clear liquid was transferred to another centrifuge tube and de-leading by adding about 0.5 grams of sodium oxalate, mixing and centrifuging five minutes. The clear solution was decanted off into a beaker and 75 cc. of it taken and placed in a 200 cc. volumetric flask. Water was added

to make the contents of the flask up to volume.

The Determination of Dextrose

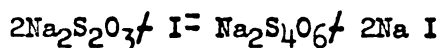
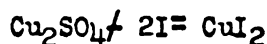
Fifty cc. of the solution were placed in a 300 cc. Erlenmeyer flask and 50 cc. of Fehling's solution were added--25 cc. of "A" (69.28 grams $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ dissolved in water and diluted to 1 liter) and 25 cc. of "B" (346 grams Rochelle salts and 100 grams NaOH dissolved in water and diluted to 1 liter). The flask was placed in a water bath at 80°C . for 30 minutes (10). At the end of this time the flasks were removed and cooled to about 40°C .

The determination was continued using the Schaffer and Hartmann method (13). Twenty-five cc. of an iodide-iodate solution (60 grams KI , 5.2 grams KIO_3 , and a few drops of concentrated NaOH dissolved and diluted to 1 liter with water) was added with shaking. Next, 15 cc. of 8N H_2SO_4 were added and the flask shaken until the Cu_2O was dissolved. Then 20 cc. of a saturated solution of $\text{K}_2\text{C}_2\text{O}_4$ were added and the contents of the flask titrated at once with standard* $\text{Na}_2\text{S}_2\text{O}_3$ solution (24.82 grams $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ dissolved in water, a few drops of concentrated NaOH added and the volume made to 1000 cc. with water).

The burette reading was the number of cc. of $\text{Na}_2\text{S}_2\text{O}_3$ used to oxidize the excess of iodine present which was the amount liber-

* Jour. Assoc. Official Agri. Chem. 12: 169 (1929).

ated by the acid less the amount used in oxidizing the Cu_2O . The amount of iodine which reacted with the Cu_2O was obtained by subtracting the number of cc. $\text{Na}_2\text{S}_2\text{O}_3$ taken to titrate the sample from the number of cc. $\text{Na}_2\text{S}_2\text{O}_3$ taken to titrate the blank determination. The blank consisted of 50 cc. of water run in duplicate, with each set of determinations which received exactly the same treatment as the samples and gave the total amount of iodine liberated.



Since one equivalent of Cu required one equivalent of I for oxidation, the difference in the titration of the blank and the sample in cc. multiplied by the Cu equivalent in milligrams per cc. of the $\text{Na}_2\text{S}_2\text{O}_3$ solution equalled the Cu reduced by sugars and was converted to dextrose by referring to the Munson and Walker tables (8). The dextrose in the determination times 17.777 (dilution factor) equals dextrose in total sample.

When the titration is referred to in cc. of $\text{Na}_2\text{S}_2\text{O}_3$ it should be understood that it is the cc. difference in the titration of the sample and its corresponding blank determination.

The Determination of Total Sugars

Fifty cc. of the same solution used for the determination of dextrose in the extract was placed in a 300 cc. Erlenmeyer flask. Five grams of citric acid crystals were added and the contents of the flask boiled quietly for ten minutes, then cooled and neutralized with NaOH using phenolphthalein as an indicator. The deter-

mination is continued as for dextrose except 20 cc. of 8N H_2SO_4 instead of 15 cc. are used. The cc. $\text{Na}_2\text{S}_2\text{O}_3$ times Cu equivalent of $\text{Na}_2\text{S}_2\text{O}_3$ solution equals Cu reduced in the determination. Dextrose equivalent of the Cu times 17.777 (dilution factor) equals total sugar in sample in terms of dextrose. The total sugar minus the dextrose times 0.95 equals hydrolyzable sugars or sucrose.

The Determination of Dextrine

The dry residue was ground in a Wiley mill and a three-tenths aliquot weighed out in a 150 cc. beaker, 75 cc. of water and a few cc. of toluene were added and the sample allowed to stand over night. The solution was filtered off into a 250 cc. volumetric flask and the residue washed with warm water until the flask contained about 150 cc. of the filtrate. To this filtrate was added sufficient concentrated H_2SO_4 to make it 25% of H_2SO_4 . The mixture was shaken and let stand over night, then made up to volume and a 50 cc. aliquot withdrawn and neutralized with concentrated NaOH using phenolphthalein as an indicator.

The contents were allowed to cool and the determination for dextrose made at once. The number of cc. $\text{Na}_2\text{S}_2\text{O}_3$ times Cu equivalent of $\text{Na}_2\text{S}_2\text{O}_3$ solution equals Cu in determination. The dextrose equivalent times 16.666 (dilution factor) equals dextrine in sample reported as dextrose.

The Determination of Starch

The residue from the dextrine determination was transferred to the original 150 cc. beaker using about 50 cc. of water and

the starch in it determined by the Taka-Diastase Method (17). In this method the beaker containing the residue was heated for 40 minutes on a steam bath with stirring. After cooling, enough Taka-Diastase to digest the starch (0.1 gram Taka-Diastase to 0.3 grams of starch) and 3 cc. of toluene were added. The samples were incubated in a constant temperature oven at 38°C for 24 hours, with stirring at intervals, more toluene being added to replace that lost by evaporation. After digestion was completed the mixture was heated to boiling on a steam bath and boiled for 15 minutes; then the residue was filtered into a 250 cc. volumetric flask and washed until nearly that volume is obtained. Water was added to complete the volume and a 50 cc. aliquot taken for the determination of dextrose.

The total starch in 50 cc. equals $S_1 + S_2$ (17)

$$S_1 = \frac{2R}{2.91} \times 0.900$$

$$S_2 = \frac{R}{2.91} \times 0.947$$

R = Total reducing power of the digested starch.

The starch in 50 cc. is multiplied by 16.666 (dilution factor) to obtain starch in original sample of bean tissue.

Determination of Dry Weight

100 cc. of the extract representing a one-tenth aliquot was placed in a weighed 200 cc. beaker (tall form) and the alcohol evaporated off at a low heat on an electric hot plate. A one-tenth aliquot of the corresponding dry ground tissue was then added to the same beaker and the contents of the beaker

dried at 105°C. for 24 hours, cooled in a desiccator and weighed. From these weighings the per cent dry weights were calculated.

Determination of Nitrogen

The loose, dry residue from the dry weight determination above was transferred from the beaker to an 800 cc. Kjeldahl flask to which was added 15-18 grams of K_2SO_4 and 1 gram of $CuSO_4$. The residue dried on the beaker was washed off by first warming with 15 cc. of concentrated H_2SO_4 and then dislodged by means of a rubber policeman and another 15 cc. of cold concentrated H_2SO_4 and finally washed out with a few cc. of water. From this point the procedure was the same as that employed in the determination of nitrogen by the Kjeldahl method.

DISCUSSION

The results of this research showed some evidence of a relation between the percentages of sugars, starch, and dry weight in the bean plant parts and the time of day. Also, that the average amount of starch found in the plant parts was related to the fertilizer treatment and the yield of beans.

Contrary to the results obtained in 1915 by Davis, Daish, and Sawyer (2), who worked with mangolds, it will be seen by observing graphs 1 and 4 that the per cent of sugars in the bean leaves at different times of the day did not follow the daily temperature changes, but, if anything, tended to be low during periods of high temperature and high during periods of low temperature. If the stems and pods alone were considered, there was a noticeably low content of sugars during the period from 8 A.M. to 8 P.M. (graphs 2, 3, 5, 6, 19, 20). In their work with potatoes, Davis and Sawyer (3) obtained similar results for sugars in the leaves of mangolds and reported in addition a general increase in the per cent of starch from sunrise until two hours before sunset. This work on beans showed some indication of a maximum starch content in the leaves at about 8 P.M. (graphs 10 and 41); but a period of low starch content was shown during the middle of the day.

The stems and pods of the beans did not show a maximum starch content as in the case of leaves at 8 P.M., but rather at some time between 12 M. and 4 A.M., and a minimum point at 12N.

(graphs 10, 11, 12, 22, 41, and 43). The variations in per cent dry weight followed the temperature changes although with some degree of lag; consequently it seemed that a higher per cent of water in the plants was associated with a higher per cent of sugar and starch. During the entire sampling period of 24 hours, the per cent of dextrine and nitrogen was fairly constant in all the plant parts and no variation due to treatments was evident.

It will be noticed that a collective average of the per cent constituents in the leaves, stems, and pods was made. However, it was known that this average did not represent the exact per cent of the constituents in the whole plant, but was taken for the purpose of comparison, as it tended to produce uniformity in the results and conclusions, thus causing the curves of the per cent constituents with the time of day to become smoother and the results of the several treatments to more nearly parallel each other.

Considering the average per cent of the several constituents determined in leaves, stems, and pods separately, some very noticeable relationships become evident, as to the relative amounts of the constituents in the different plant parts. Dextrose was found to be present in the greatest amounts in the stems and the least amounts in the leaves (graphs 1, 2, 3, 25, and 37). Sucrose, on the other hand, although contained to the least amount in the leaves, existed in greater amounts in the pods than in the stems (graphs 4, 5, 6, 26, and 38). The greatest per cent of starch was

in the pods with the least amount in the stems. Carbohydrates, which were the sum of the constituents named above and dextrine, which was present in nearly the same amount in each plant part, increased in amounts from leaves to stems to pods. The per cent dry weight followed the same order in the plant parts as did the per cent carbohydrates. Thus, it will be seen that the bean plant tissue which contained the least water had the largest per cent of carbohydrates, and yet, as was previously shown, the water and carbohydrate content of the plant parts fluctuated together. Nitrogen was present in about the same percentages in the leaves and pods with considerably less in the stems.

The above relationships were discovered from data gathered primarily to determine the effects of fertilizers on the per cent of certain plant constituents at different times of the day, but there seemed to be no apparent relationship shown in this respect, and no attempt will be made here to explain these data on the basis of plant processes.

The fertilizer treatments did not appear to have any distinguishable effect on the per cent sugars in the plant except perhaps the 0-16-3 (graph 25). In this case there was evidence that the per cent dextrose was depressed. When the daily average was considered the per cent starch in the bean plant parts showed a rather definite correlation with the fertilizer application. The bean plants grown on the plot receiving an application of superphosphate and muriate of potash together showed an increase in

the per cent of starch over those grown on the plots receiving superphosphate alone and those grown on the plots receiving no treatment (graphs 29, 35, 44, 45). The addition of nitrate of soda to superphosphate and muriate of potash further increased the per cent of starch in the leaves and stems, but depressed the per cent in the pods. The depressing effect of nitrogen in the fertilizer treatment on the per cent starch in the bean pods might be accounted for in that the plants on this plot may have been a little less mature and starch was not being accumulated there to the extent it would have been if the plants had been more mature. The plants on this plot seemed a little greener at the time the samples were taken than the plants on the other plots.

Considering the fertilizer nutrient elements separately, potassium in the fertilizer apparently increased the per cent of starch in the bean plant parts (11); or at least a combination of phosphorus and potassium increased the per cent starch over no treatment or phosphorus alone. The increase in the yield of beans paralleled the increase in the per cent starch and carbohydrates, as a whole, in the bean plant parts (graphs 44, 45, and 46) (tables 4, 7, and 8). Therefore, the yield seemed to be related to the per cent starch and also to the total carbohydrates in the bean plant parts at this stage of maturity. Both the per cent carbohydrates at this time, and the yield, were related to the fertilizers applied.

SUMMARY

A study was made of carbohydrate production, per cent nitrogen, and the dry weight of the bean plant relative to the time of day and fertilizer application. A relation was found between carbohydrate production and the time of day, but no apparent relation was evident between fertilizer application and percentage constituents at various times of the day. It was found, however, that there was a marked difference in the per cent composition in the leaves, stems, and pods of the plant, and that the relation varies with the constituent under consideration.

It appeared that potassium did increase the percentage of starch and total carbohydrates in the bean plant parts and that this increase was reinforced by the addition of nitrogen or perhaps it should be said that phosphorus and potassium together gave an increase in carbohydrates which was further increased by the addition of nitrogen. This increase in carbohydrate production at this period of growth was paralleled by a corresponding increase in yield.

TABLE I Per cent dextrose in bean plant parts from check and fertilized field plots calculated on the dry weight basis.

Time	Check	0-16-0	0-16-8	4-16-8	Average of Treatments
Leaves					
12 M.	1.00	1.04	0.67	0.78	0.87
4 A.M.	0.68	0.95	0.83	0.75	0.80
8 A.M.	0.55	0.69	0.68	1.35	0.82
12 N.	0.52	0.87	0.60	0.70	0.67
4 P.M.	0.95	0.81	0.58	0.93	0.82
8 P.M.	0.62	0.66	0.71	0.69	0.67
12 M.	1.51	1.41	1.12	1.21	1.31
Average	0.83	0.92	0.74	0.91	0.85
Stems					
12 M.	3.12	3.40	3.47	3.60	3.40
4 A.M.	3.51	3.14	2.80	3.37	3.21
8 A.M.	2.56	3.59	2.45	2.83	2.86
12 N.	2.40	1.18	1.77	3.30	2.16
4 P.M.	2.25	2.95	2.48	2.83	2.63
8 P.M.	2.14	2.96	2.09	2.86	2.51
12 M.	3.28	3.65	3.02	3.08	3.26
Average	2.75	2.98	2.58	3.14	2.86
Pods					
12 M.	2.24	2.41	1.33	0.96	1.74
4 A.M.	2.80	1.78	1.97	2.04	2.15
8 A.M.	1.50	1.33	1.16	1.46	1.36
12 N.	0.89	0.81	1.35	1.41	1.12
4 P.M.	1.43	1.20	0.78	1.36	1.19
8 P.M.	1.36	0.99	0.87	0.46	0.92
12 M.	1.25	2.73	1.35	1.42	1.45
Average	1.64	1.61	1.26	1.30	1.45

TABLE 2 Per cent sucrose in bean plant parts from check and fertilized field plots calculated on the dry weight basis.

Time	Check	0-16-0	0-16-8	4-16-8	Average of Treatments
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Leaves

12M.	1.33	2.07	1.71	1.78	1.72
4 A.M.	1.31	1.59	1.86	1.57	1.58
8 A.M.	1.72	1.78	1.72	1.84	1.77
12 N.	1.90	1.80	1.54	1.72	1.74
4 P.M.	1.68	1.52	1.23	1.25	1.42
8 P.M.	1.30	1.12	1.97	1.79	1.55
12 M.	1.96	2.12	1.81	1.87	1.94
Average	1.60	1.90	1.69	1.69	1.72

Stems

12 M.	2.27	2.80	3.21	2.46	2.69
4 A.M.	2.79	2.72	2.66	2.62	2.70
8 A.M.	2.40	1.44	2.31	2.49	2.16
12 N.	1.66	2.49	1.75	2.38	2.07
4 P.M.	2.81	2.80	1.58	1.29	2.12
8 P.M.	2.49	1.99	2.61	3.17	2.57
12 M.	2.41	2.85	2.87	3.15	2.82
Average	2.40	2.44	2.43	2.51	2.45

Pods

12 M.	2.74	4.56	3.31	2.84	3.36
4 A.M.	3.99	3.82	3.71	3.02	3.64
8 A.M.	3.05	3.53	3.53	3.40	3.38
12 N.	2.80	1.90	2.65	2.78	2.53
4 P.M.	3.15	2.74	1.85	1.35	2.27
8 P.M.	2.45	1.71	2.96	2.90	2.51
12 M.	3.90	3.06	3.27	3.23	3.37
Average	3.15	3.04	3.04	2.79	3.01

TABLE 3 Per cent dextrine in bean plant parts from check and fertilized field plots calculated on the dry weight basis.

Time	Check	0-16-0	0-16-8	4-16-8	Average of Treatments
Leaves					
12 M.	0.61	0.64	0.60	0.69	0.64
4 A.M.	0.97	0.79	0.98	0.62	0.84
8 A.M.	0.63	0.68	0.81	1.00	0.78
12 N.	0.85	0.89	0.62	0.79	0.79
4 P.M.	0.71	0.76	0.68	0.76	0.73
8 P.M.	0.86	0.84	0.80	0.86	0.84
12 M.	0.65	0.75	0.60	0.83	0.71
Average	0.76	0.76	0.73	0.79	0.76
Stems					
12 M.	0.47	0.48	0.48	0.51	0.49
4 A.M.	1.36	1.31	1.21	0.77	1.16
8 A.M.	0.78	1.01	0.81	0.92	0.88
12 N.	0.94	1.21	0.95	1.03	1.03
4 P.M.	0.86	1.09	0.97	1.10	1.01
8 P.M.	1.16	1.15	0.90	1.08	1.07
12 M.	1.43	0.88	0.93	1.00	1.06
Average	1.00	1.02	0.89	0.92	0.96
Pods					
12 M.	0.65	0.52	0.53	0.46	0.54
4 A.M.	1.66	1.06	1.04	1.01	1.19
8 A.M.	0.78	1.18	1.07	0.76	0.95
12 N.	1.11	1.08	1.10	1.00	1.07
4 P.M.	1.40	1.02	1.00	1.10	1.13
8 P.M.	1.25	1.06	1.15	1.08	1.14
12 M.	0.98	1.05	0.94	0.94	0.98
Average	1.12	1.00	0.98	0.91	1.00

TABLE 4 Per cent starch in bean plant parts from check and fertilized field plots calculated on the dry weight basis.

Time	Check	0-16-0	0-16-8	4-16-8	Average of Treatments
Leaves					
12M.	0.80	0.97	4.42	4.61	2.70
4 A.M.	3.99	4.80	5.36	4.90	4.76
8 A.M.	4.78	4.61	6.08	5.42	5.22
12 N.	4.61	5.02	3.37	3.33	4.08
4 P.M.	5.39	3.79	2.47	3.87	3.88
8 P.M.	7.84	3.69	5.30	11.80	7.16
12 M.	1.15	1.05	6.59	7.48	4.07
Average	4.08	3.42	4.80	5.92	4.56
Stems					
12 M.	0.79	1.63	4.34	4.10	2.72
4 A.M.	4.56	5.34	2.27	5.16	4.33
8 A.M.	4.76	3.02	4.32	3.55	3.91
12 N.	2.70	3.22	2.96	2.42	2.82
4 P.M.	3.84	3.60	2.10	3.93	3.37
8 P.M.	4.10	3.42	4.26	4.78	4.14
12 M.	3.22	1.56	6.02	7.97	4.69
Average	3.42	3.11	3.75	4.56	3.71
Pods					
12M.	4.95	9.84	9.78	8.73	8.32
4 A.M.	9.52	9.95	9.01	8.69	9.29
8 A.M.	5.99	7.77	7.49	6.86	7.03
12 N.	5.60	4.97	6.87	4.47	5.48
4 P.M.	5.61	4.87	6.90	6.12	5.88
8 P.M.	7.10	5.24	9.62	8.79	7.69
12 M.	10.09	11.03	12.16	12.70	11.49
Average	6.98	7.67	8.83	8.05	7.88

TABLE 5 Per cent dry matter in bean plant parts from check and fertilized field plots.

Time	Check	0-16-0	0-16-8	4-16-8	Average of Treatments
Leaves					
12 M.	19.80	20.23	19.94	19.90	19.47
4 A.M.	19.64	19.99	18.61	20.50	19.69
8 A.M.	20.86	19.59	18.44	18.78	19.42
12 N.	21.07	20.97	21.34	20.78	21.04
4 P.M.	20.25	19.94	21.16	20.60	20.49
8 P.M.	20.10	19.13	20.99	21.71	20.48
12 M.	19.50	19.06	21.38	21.02	20.24
Average	20.18	19.84	20.27	20.47	20.19
Stems					
12 M.	22.28	21.55	22.37	22.05	22.06
4 A.M.	21.41	21.62	20.96	22.14	21.53
8 A.M.	23.51	20.91	22.31	20.74	21.87
12 N.	23.29	22.96	23.16	23.06	23.12
4 P.M.	24.09	23.64	23.26	23.67	23.67
8 P.M.	21.21	21.97	24.91	22.41	23.38
12 M.	21.55	19.60	22.08	22.60	21.46
Average	22.48	21.75	22.72	22.38	22.33
Pods					
12 M.	26.15	25.98	27.08	28.57	26.95
4 A.M.	21.93	25.21	25.76	24.25	24.31
8 A.M.	25.17	26.93	24.43	25.03	25.39
12 N.	25.79	29.09	28.36	27.43	27.67
4 P.M.	25.45	28.40	28.50	26.88	27.31
8 P.M.	23.15	29.94	27.59	30.42	27.77
12 M.	27.74	25.55	28.16	27.53	27.25
Average	25.05	27.31	27.12	27.16	26.66

TABLE 6 Per cent nitrogen in bean plant parts from check and fertilized field plots calculated on the dry weight basis.

Time	Check	0-16-0	0-16-8	4-16-8	Average of Treatments
------	-------	--------	--------	--------	--------------------------

Leaves

12 M.	3.46	3.46	3.43	3.40	3.44
4 A.M.	3.88	3.66	3.57	3.22	3.58
8 A.M.	3.64	3.36	3.80	3.15	3.49
12 N.	3.38	3.27	3.98	3.33	3.49
4 P.M.	3.69	3.36	3.53	2.97	3.39
8 P.M.	3.19	3.57	3.43	3.03	3.31
12 M.	3.17	3.18	2.98	2.73	3.02
Average	3.49	3.41	3.53	3.12	3.39

Stems

12 M.	1.80	2.54	2.22	1.94	2.13
4 A.M.	2.12	2.35	1.97	1.79	2.06
8 A.M.	2.06	2.25	1.91	2.04	2.07
12 N.	1.87	2.25	2.27	1.99	2.10
4 P.M.	1.87	2.07	1.95	1.75	1.91
8 P.M.	2.30	2.30	2.07	2.11	2.20
12 M.	1.37	1.56	1.36	1.41	1.43
Average	1.91	2.19	1.96	1.86	1.98

Pods

12 M.	3.37	3.17	3.29	3.36	3.30
4 A.M.	3.81	3.69	4.48	4.36	4.09
8 A.M.	3.76	3.89	3.43	3.63	3.68
12 N.	3.33	2.41	3.41	3.65	3.20
4 P.M.	3.33	3.18	3.67	3.10	3.32
8 P.M.	3.45	3.36	3.50	3.45	3.44
12 M.	2.92	3.74	2.80	2.81	3.07
Average	3.42	3.35	3.51	3.48	3.44

TABLE 7 Average per cent constituents in bean leaves, stems and pods from check and fertilized field plots calculated on the dry weight basis.

Time	Check	0-16-0	0-16-8	4-16-8	Average of Treatments
------	-------	--------	--------	--------	-----------------------

Dextrose

12 M.	2.12	2.28	1.82	1.78	2.00
4 A.M.	2.23	1.96	1.87	2.05	2.05
8 A.M.	1.54	1.87	1.43	1.88	1.68
12 N.	1.27	0.95	1.24	1.80	1.32
4 P.M.	1.54	1.65	1.28	1.71	1.55
8 P.M.	1.37	1.54	1.22	1.34	1.37
12 M.	2.01	2.60	1.83	1.90	2.12
Average	1.73	1.84	1.53	1.78	1.72

Sucrose

12 M.	2.11	3.14	2.74	2.36	2.59
4 A.M.	2.36	2.71	2.74	2.40	2.64
8 A.M.	2.39	2.25	2.52	2.24	2.44
12 N.	2.12	2.06	1.98	2.29	2.11
4 P.M.	2.21	2.35	1.55	1.30	1.94
8 P.M.	2.08	1.61	2.51	2.61	2.21
12 M.	2.42	2.68	2.65	2.75	2.54
Average	2.24	2.40	2.38	2.28	2.33

Dextrine

12 M.	0.58	0.55	0.54	0.55	0.56
4 A.M.	1.33	1.05	1.08	0.80	1.06
8 A.M.	0.73	0.96	0.90	0.89	0.87
12 N.	0.97	1.06	0.89	0.94	0.96
4 P.M.	1.02	0.96	0.88	0.99	0.96
8 P.M.	1.09	1.02	0.95	1.01	1.02
12 M.	1.02	0.89	0.82	0.92	0.92
Average	0.96	0.93	0.87	0.87	0.91

Year	1990	1991	1992	1993	1994	1995
1	10	10	10	10	10	10
2	10	10	10	10	10	10
3	10	10	10	10	10	10
4	10	10	10	10	10	10
5	10	10	10	10	10	10
6	10	10	10	10	10	10
7	10	10	10	10	10	10
8	10	10	10	10	10	10
9	10	10	10	10	10	10
10	10	10	10	10	10	10

[illegible]

Year	1990	1991	1992	1993	1994	1995
1	1	1	1	1	1	1
2	2	2	2	2	2	2
3	3	3	3	3	3	3
4	4	4	4	4	4	4
5	5	5	5	5	5	5
6	6	6	6	6	6	6
7	7	7	7	7	7	7
8	8	8	8	8	8	8
9	9	9	9	9	9	9
10	10	10	10	10	10	10

CONTINUATION OF TABLE 7

Time	Check	0-16-0	0-16-8	4-16-8	Average of Treatments
------	-------	--------	--------	--------	--------------------------

Starch

12 M.	2.18	4.15	6.18	5.81	4.58
4 A.M.	6.01	6.70	5.55	6.25	6.13
8 A.M.	5.18	5.13	5.96	5.28	5.39
12 N.	4.30	4.40	4.40	3.41	4.13
4 P.M.	4.95	4.09	3.82	4.64	4.38
8 P.M.	6.35	4.12	6.39	8.46	6.33
12 M.	4.82	4.55	8.26	9.38	6.75
Average	4.83	4.73	5.79	6.18	5.31

Nitrogen

12 M.	2.88	3.06	3.31	2.90	2.96
4 A.M.	3.27	3.23	3.34	3.12	3.24
8 A.M.	3.15	3.17	3.05	3.27	3.08
12 N.	2.86	2.64	3.22	2.99	2.93
4 P.M.	2.96	2.87	3.05	2.61	2.87
8 P.M.	2.98	3.08	3.00	2.86	2.98
12 M.	2.49	2.49	2.38	2.65	2.51
Average	2.94	2.93	3.05	2.91	2.96

Per cent dry matter on green weight

12 M.	22.74	22.59	23.13	23.51	22.83
4 A.M.	20.66	22.31	21.78	22.30	21.84
8 A.M.	23.18	22.48	21.73	21.52	22.23
12 N.	23.38	24.34	24.29	23.76	23.94
4 P.M.	23.26	23.99	24.31	23.72	23.82
8 P.M.	21.49	23.68	24.50	24.85	23.88
12 M.	22.93	21.40	23.87	23.72	22.98
Average	22.52	22.97	23.37	23.34	23.05

TABLE 8 Average per cent carbohydrates in bean plant parts from check and fertilized field plots during a 24-hour sampling period calculated on the dry weight basis.

	Check	0-16-0	0-16-8	4-16-8
Leaves	7.27	7.00	7.96	8.81
Stems	9.57	9.55	9.65	11.13
Pods	12.89	13.32	14.11	13.05
Average	9.76	9.90	10.57	11.15

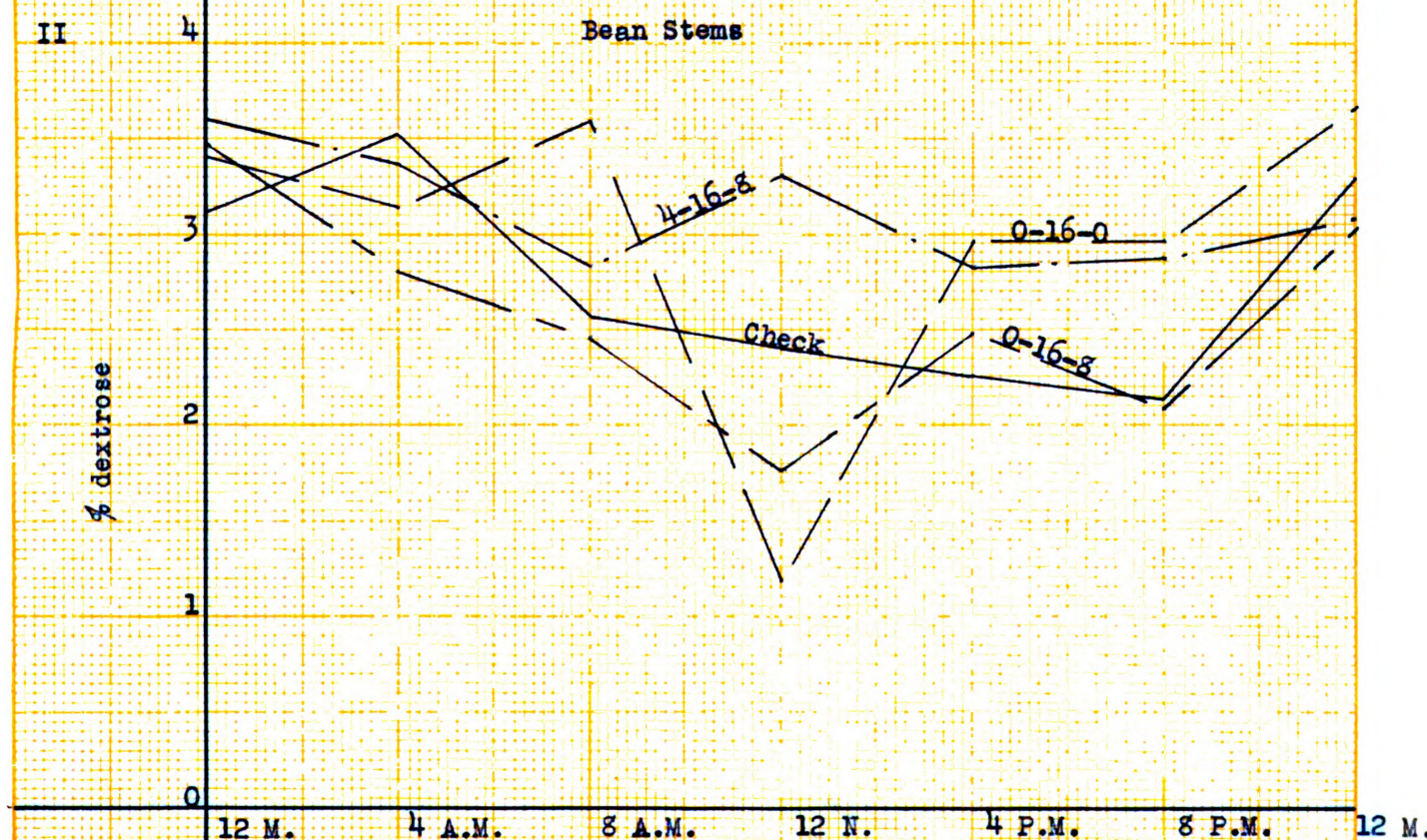
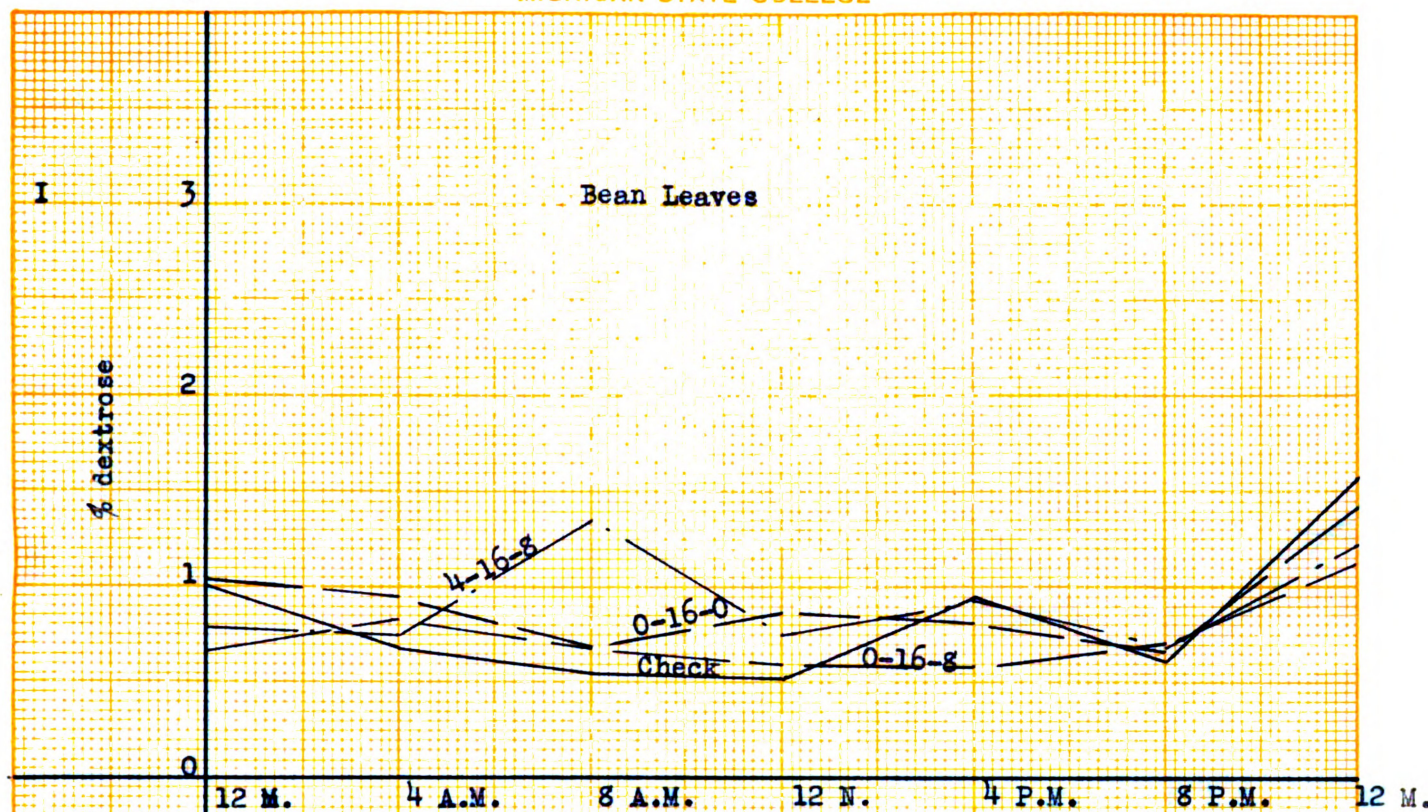
TABLE 9 Yield in bushels per acre of clean dry beans.

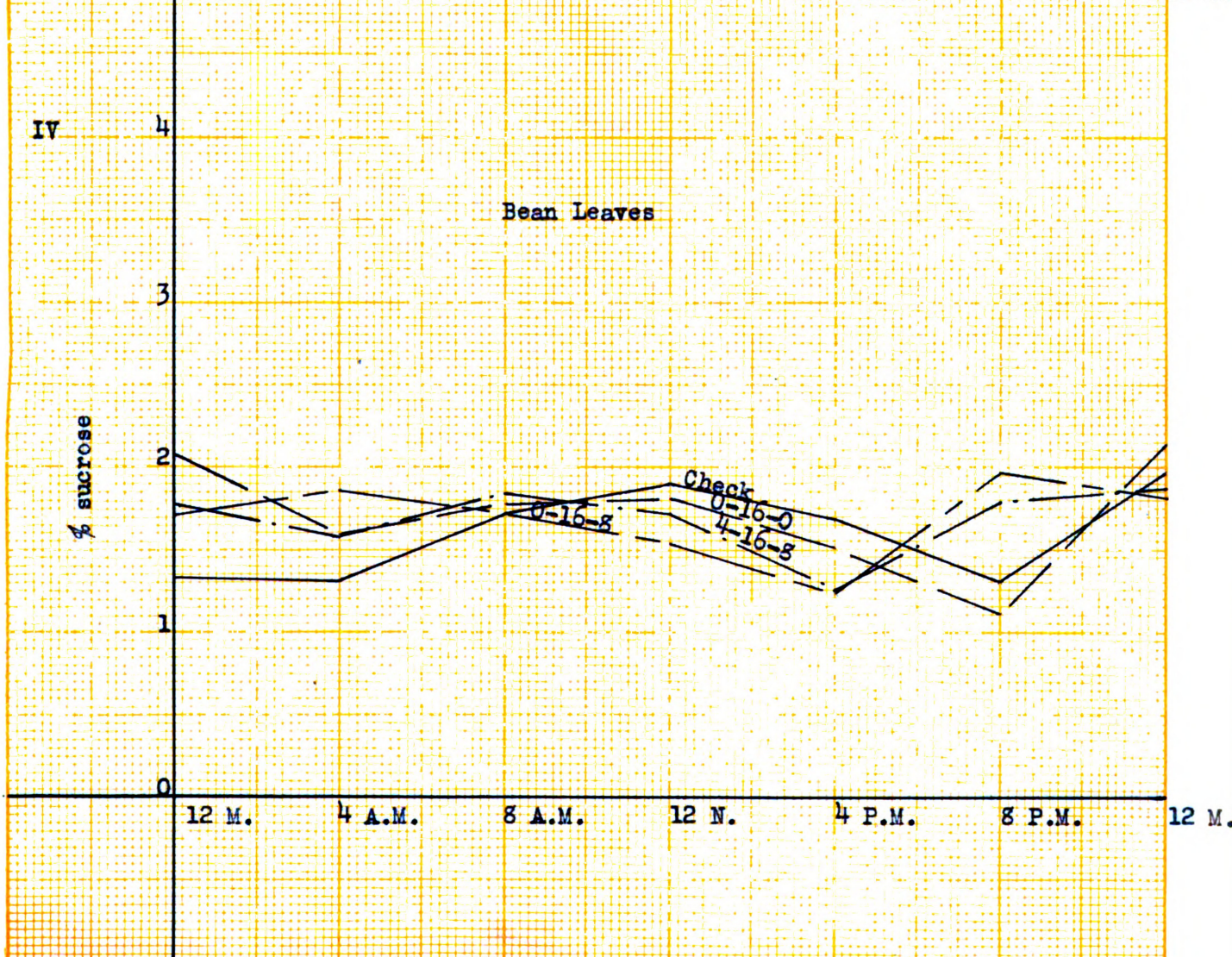
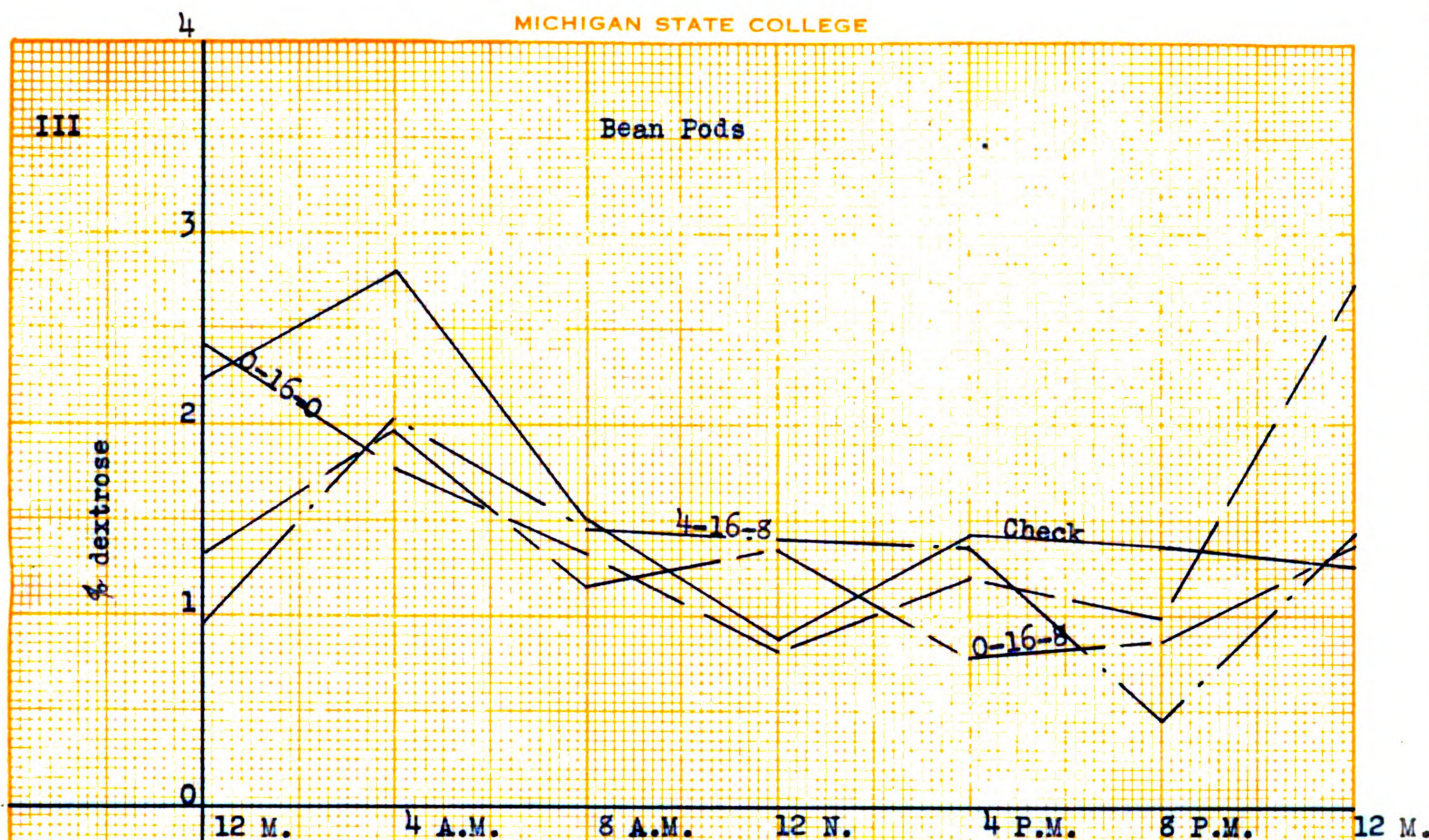
	Check	0-16-0	0-16-8	4-16-8
Bushels per acre	9.68	9.95	12.60	13.31

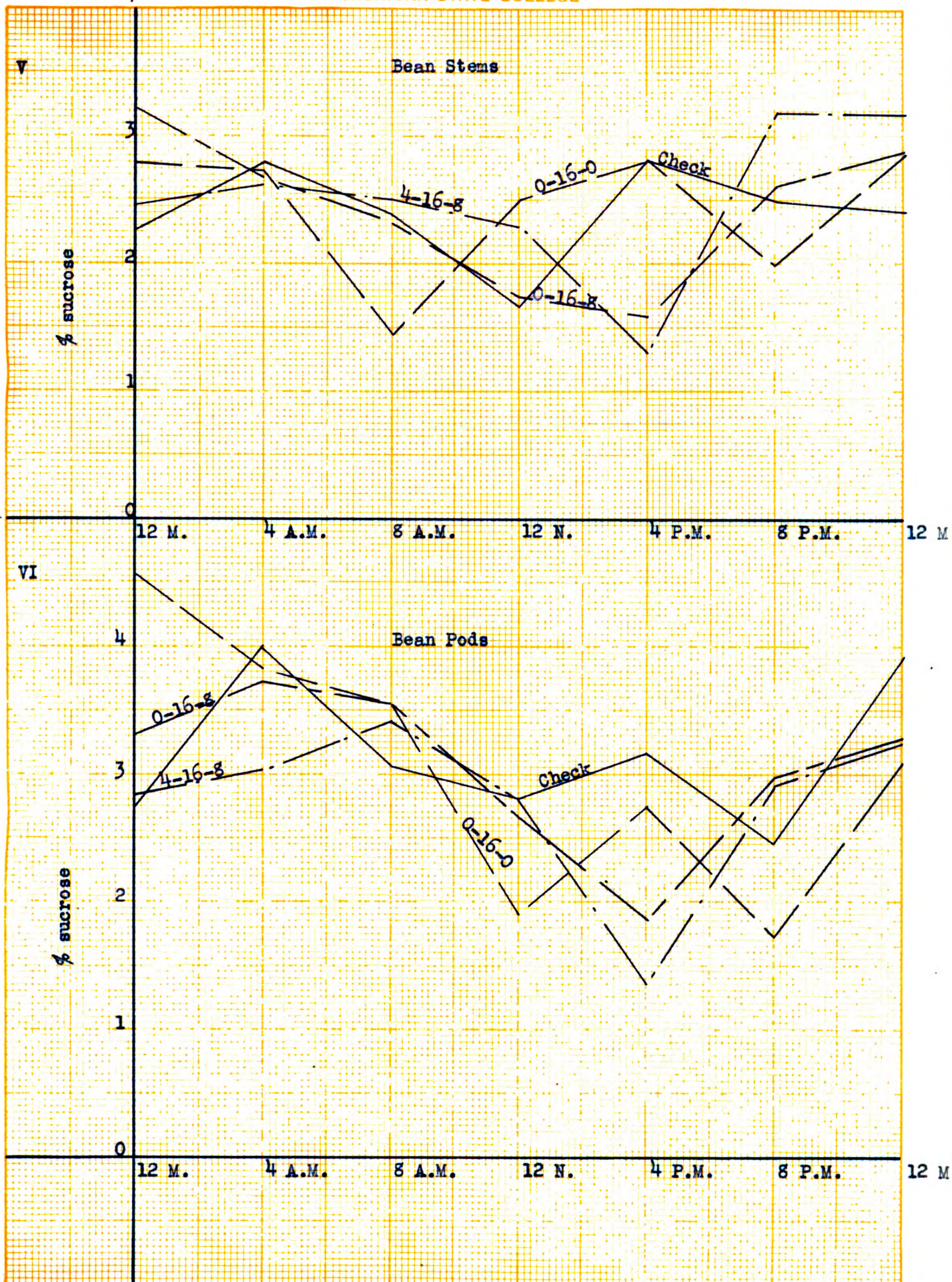
LITERATURE CITED

1. Clements, H. P. Hourly variations in carbohydrate content of leaves and petioles. Bot. Gaz. 89: 241-272, 1930.
2. Davis, W. A., Daish, A. J., and Sawyer, G. C. Studies of the formation and translocation in plants. I. The carbohydrates of the mangold leaf. Jour. Agr. Sci. 7: 255-286, 1916.
3. Davis, W. A., and Sawyer, G. C. Studies of the formation and translocation of carbohydrates in plants. III. The carbohydrates of the degradation of starch in the leaf. Jour. Agr. Sci. 7: 352-384, 1916.
4. Janssen, G., and Bartholomew, R. P. The translocation of potassium in tomato plants and its relation to their carbohydrate and nitrogen distribution. Jour. Agr. Res. 38: 447-465, 1929.
5. Janssen, G., and Bartholomew, R. P. Influence of potassium concentration in the culture medium on the production of carbohydrates in plants. Jour. Agr. Res. 40: 243-261, 1930.
6. MacGillivray, J. H. Effect of phosphorus on the composition of the tomato plant. Jour. Agr. Res. 34: 97-129, 1927.
7. Mason, T. G., and Maskell, E. J., Studies on the transport of carbohydrates in the cotton plant. I. A study of the diurnal variations in the carbohydrates of leaf bark and wood and of the effect of ringing. Ann. of Bot. 42: 190-253.
8. Munson, L. S., and Walker, P. H. The unification of reducing sugar methods. Jour. Amer. Chem. Soc. 28: 663-686, 1906.
9. Noble, Über die organische Leistung des Kalium in der Pflanze. Landw. Versuchs Stat. 13: 321-423
10. Quesumbing, F. A., and Thomas, A. W. Conditions affecting the quantitative determination of reducing sugars by Fehling's solutions. Jour. Amer. Chem. Soc. 43: 1503-1526, 1921.
11. Reed, H. S. The value of certain nutrient elements to the plant cell. Ann. of Bot. 21: 501-543, 1907.

12. Schuster, G. L. Potash in relation to quality of crop.
Jour. Amer. Soc. Agron. 19: 506-517, 1927.
13. Shaffer, E. A., and Hartman, A. F. The codometric
determination of copper and its uses in sugar analysis.
Jour. Biol. Chem. 45: 365-390, 1920.
14. Smith, T. O., and Butler, O. Relation of potassium in
plants. Ann. of Bot. 35: 189-227, 1921.
15. Stark, R. W. Environmental factors affecting the protein
and oil content of soybeans and the iodine number of
soybean oil. Jour. Amer. Soc. Agron. 16: 636-646,
1924.
16. Stocklase, J., and Pitra, J. Uber die Einwirkung der
Kalisalze auf die Entwicklung der Gerste. Ziet. f.
Landw. Versuch im Oesterr. P. 567.
17. Thomas, Walter. The colorimetric determination of carbo-
hydrates in plants by the picric acid reduction method.
II. The determination of starch and other "reserve"
polysaccharides. Jour. Amer. Chem. Soc. 46: Part 2,
1670, 1924.
18. Weiszmann, H. Uber den Einfluss des Kaliums auf die Entwicklung
der Pflanzen und ihren morphologischen und anatomischen Bau,
bei besonderer Berucksichtigung der landwirtschaftlichen
Kulturpflanzen. Ziets. f. Pflanzendungung 2: 1-79, 1923.
19. Cole, Ralph C. The diurnal and seasonal changes in the sugar
content of the sap and tissue of potato plants as affected
by soil fertilization. Soil Science 33: 347-362. 1932.







VII

Bean Leaves

% dextrine

4

3

2

1

0

12 M.

4 A.M.

8 A.M.

12 N.

4 P.M.

8 P.M.

12 M.

0-16-8

0-16-0

4-16-8

Check

VIII

Bean Stems

% dextrine

4

3

2

1

0

12 M.

4 A.M.

8 A.M.

12 N.

4 P.M.

8 P.M.

12 M.

0-16-0

4-16-8

0-16-8

Check

IX

Bean Pods

% dextrine

4

3

2

1

0

12 M.

4 A. M.

8 A. M.

12 N.

4 P. M.

8 P. M.

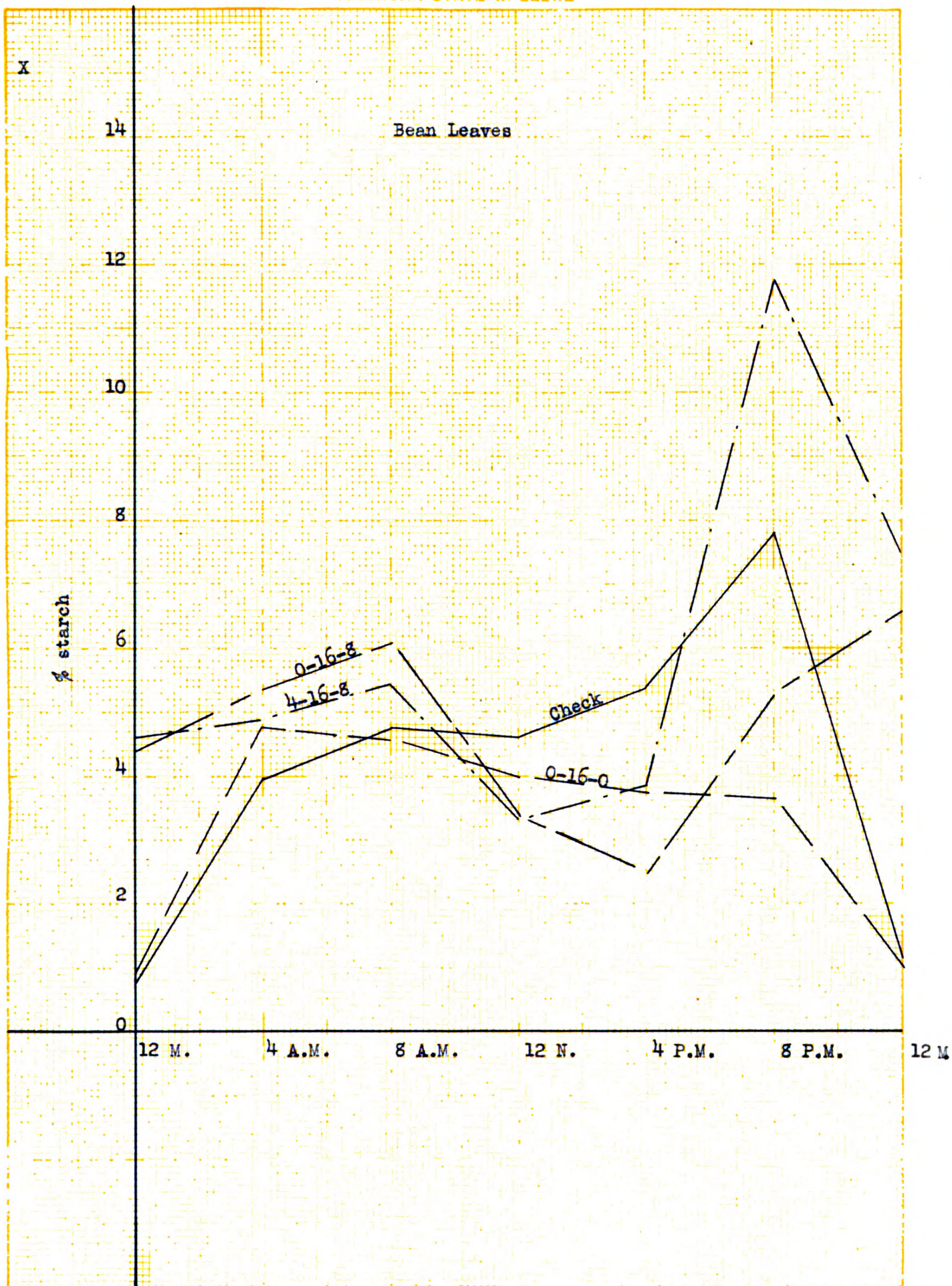
12 P.

0-16-0

0-16-8

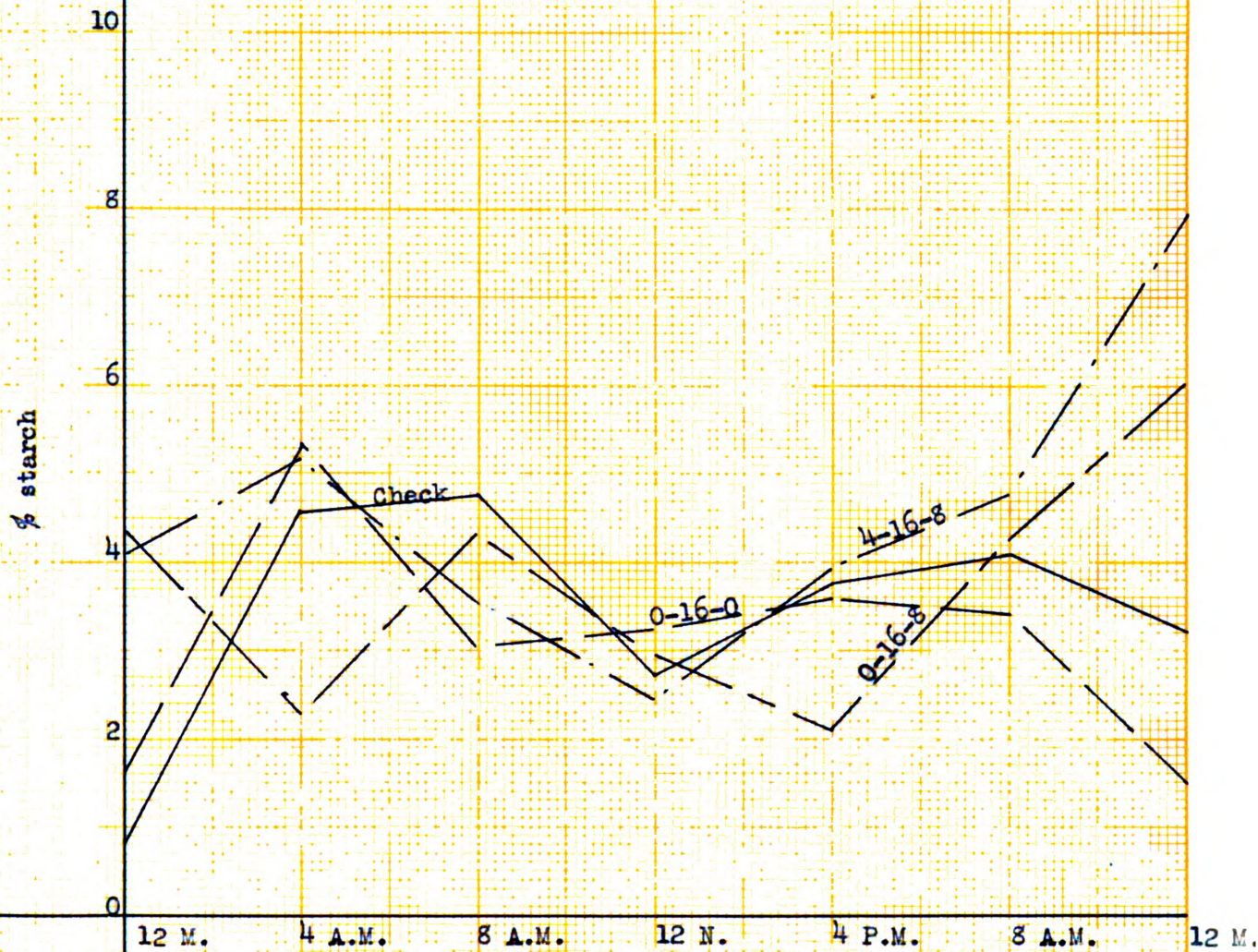
4-16-8

check



XI

Bean Stems



XII

Bean Pods

% starch

14

12

10

8

6

4

2

0

12 M.

4 A.M.

8 A.M.

12 N.

4 P.M.

8 P.M.

12 M.

0-16-8

Check

4-16-8

0-16-0

XIII

Bean Leaves

% dry matter

23

22

21

20

19

18

12 M.

4 A.M.

8 A.M.

12 N.

4 P.M.

8 P.M.

12 M.

Check

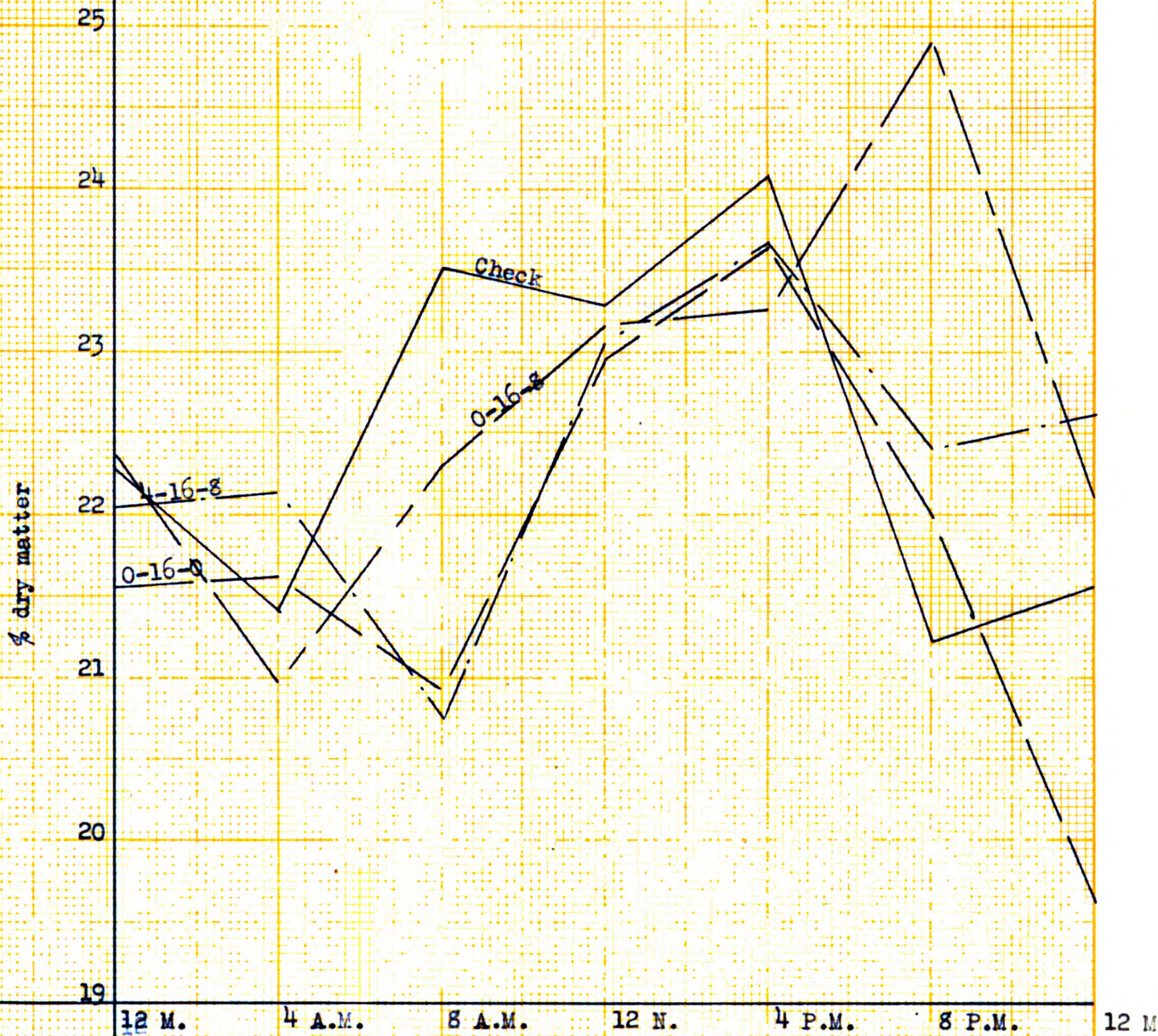
0-16-8

4-16-8

0-16-0

XIV

Bean Stems



xv

% dry matter

Bean Pods

29

28

27

26

25

24

23

22

0-16-8

4-16-8

Check

12 M.

4 A.M.

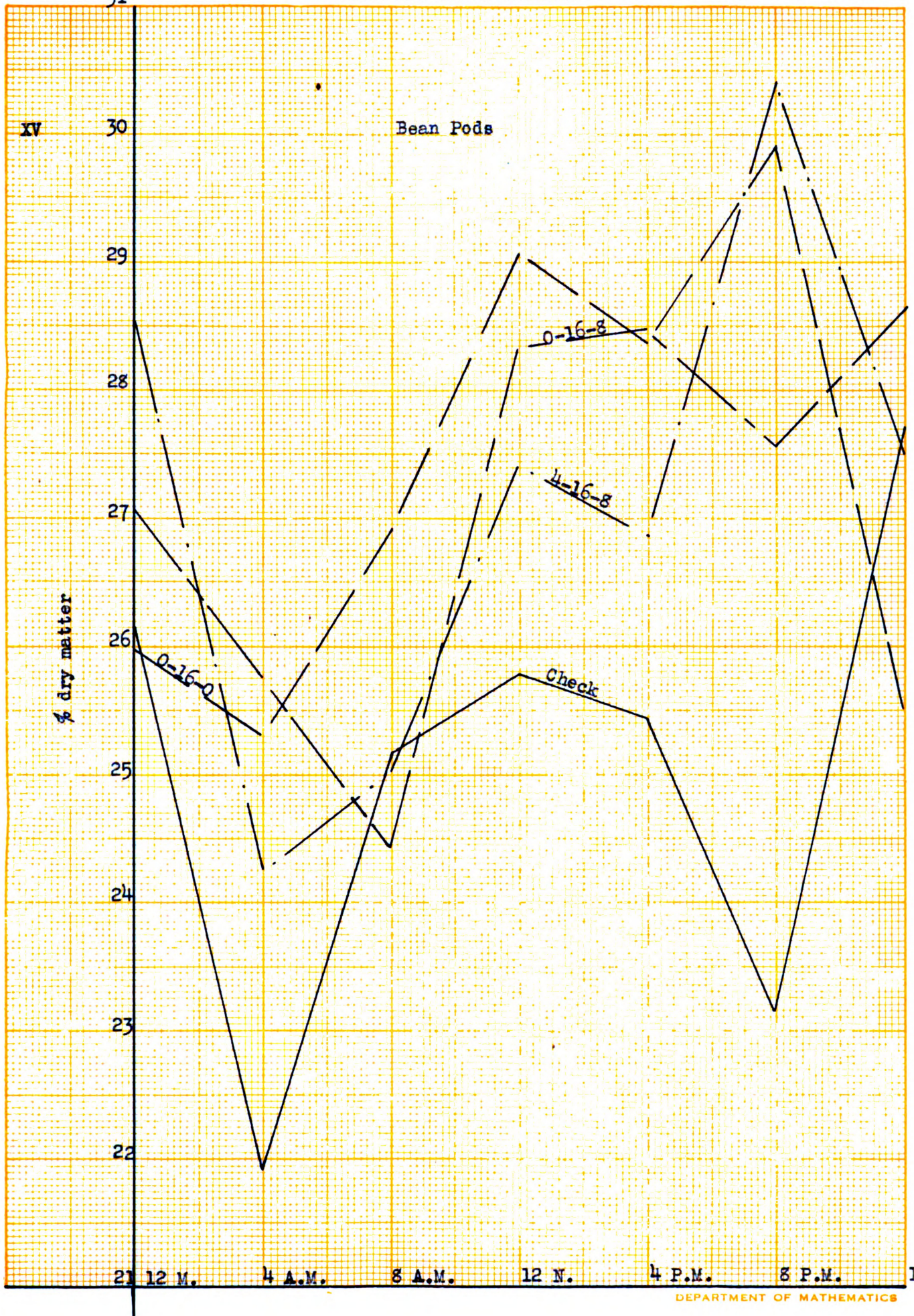
8 A.M.

12 N.

4 P.M.

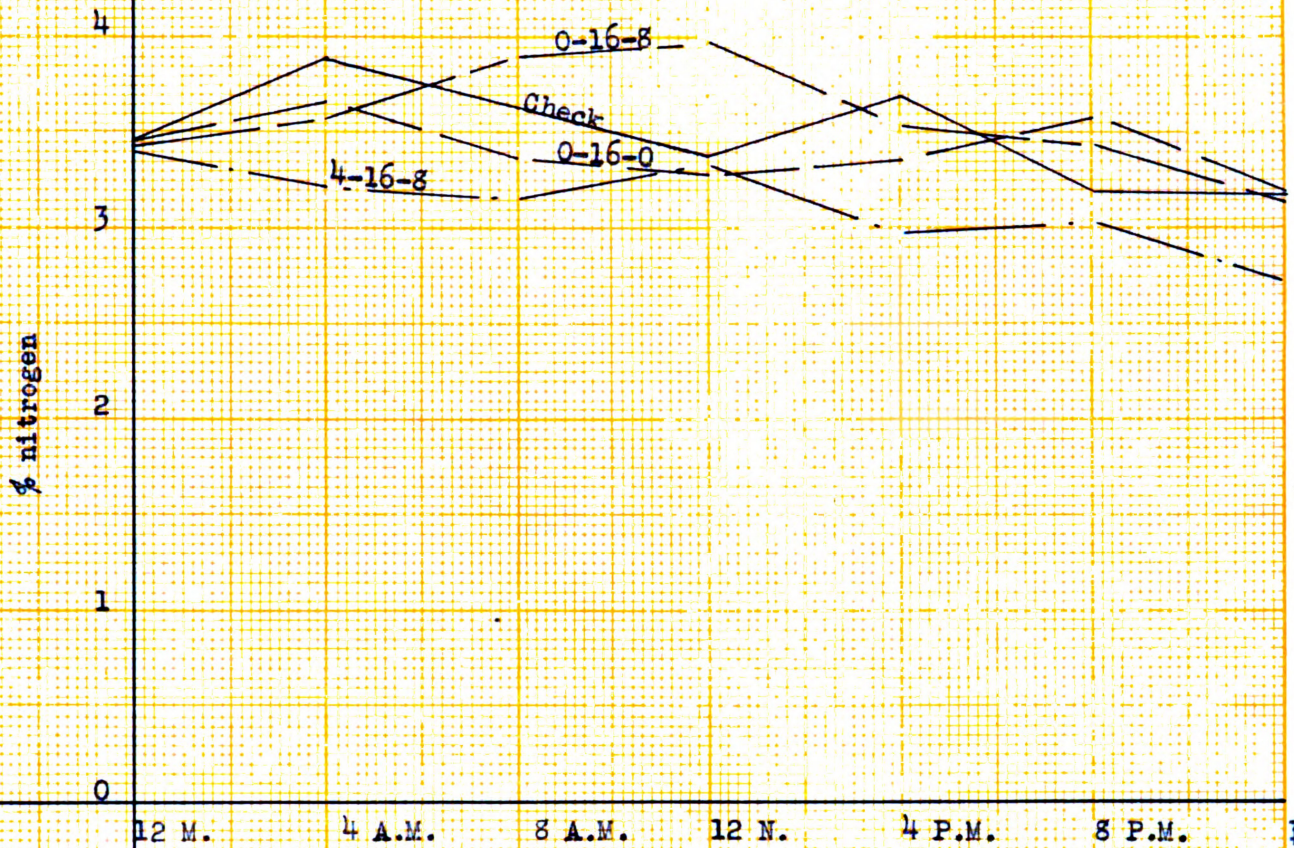
8 P.M.

12 M.



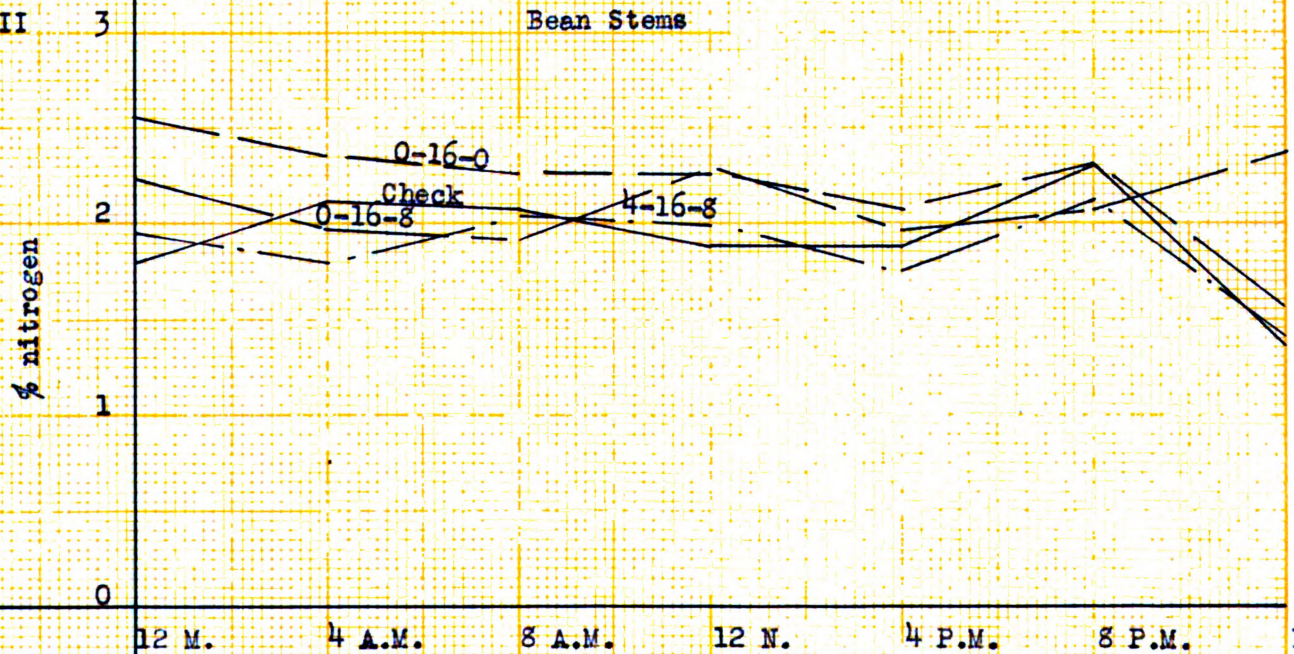
XVI

Bean Leaves



XVII

Bean Stems



XVIII

Bean Pods

% nitrogen

5

4

3

2

1

0

12 M.

4 A.M.

8 A.M.

12 N.

4 P.M.

8 P.M.

12 M.

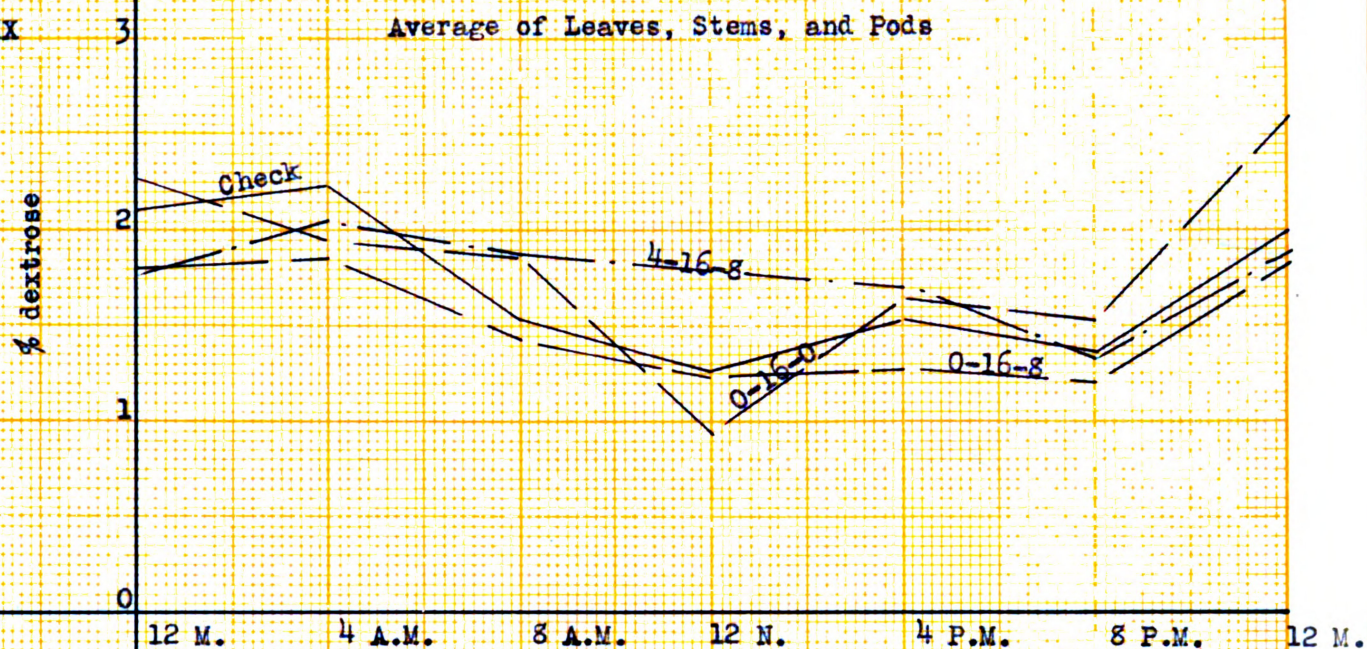
4-16-8

0-16-8

Check

0-16-0

XIX



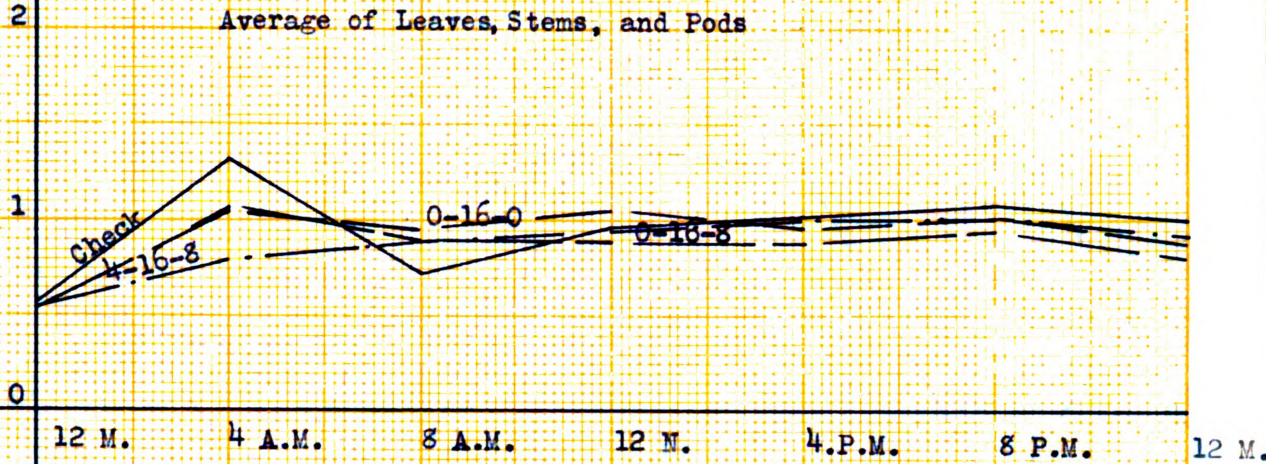
XX



XXI

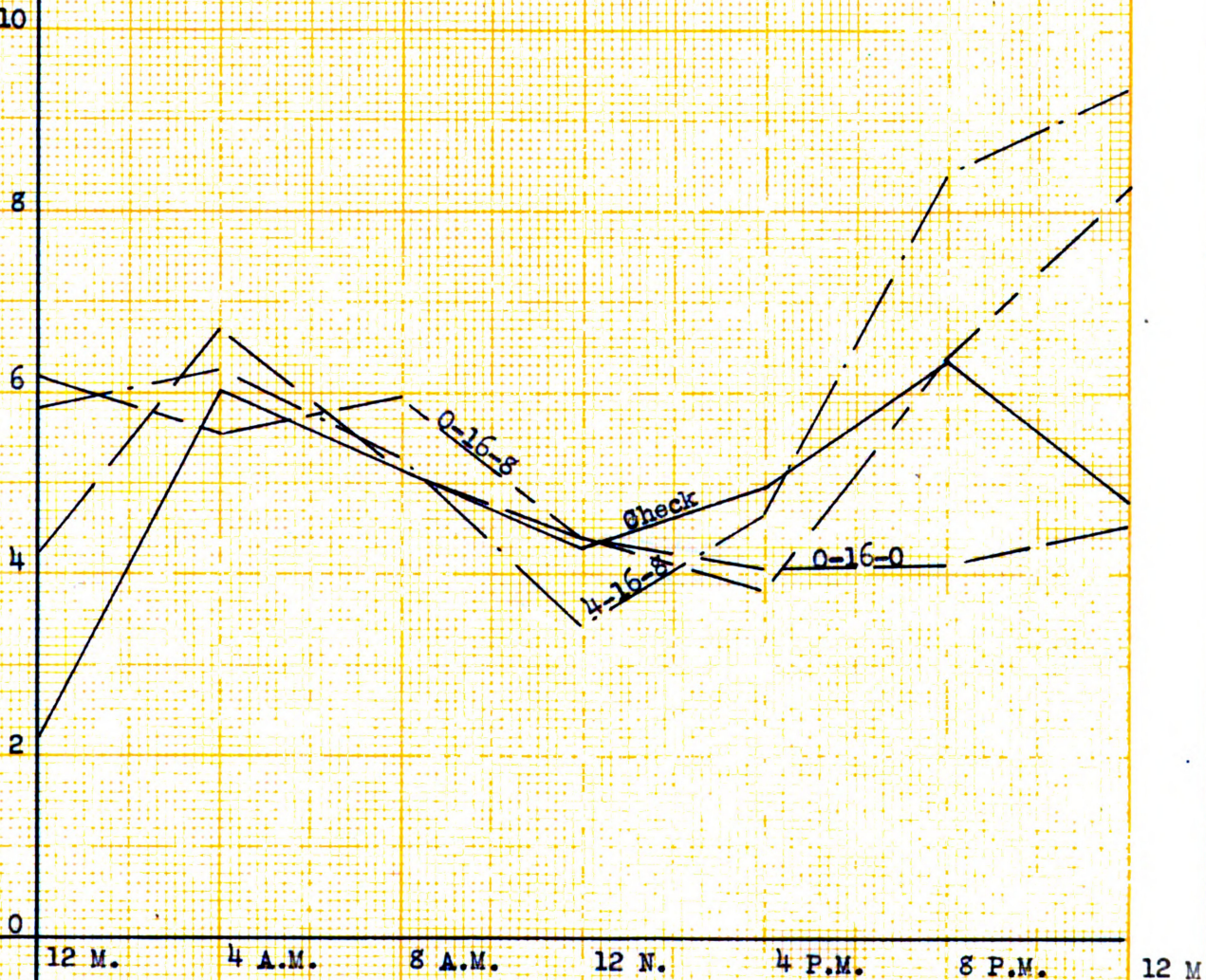
% dextrine

Average of Leaves, Stems, and Pods



XXII

% starch



XXIII

% dry matter

Average of Leaves, Stems, and Pods

0-16-8

4-16-8

24

23

22

21

20

12 M.

4 A.M.

8 A.M.

12 N.

4 P.M.

8 P.M.

12 M.

XXIV

% nitrogen

4

3

2

1

12 M.

4 A.M.

8 A.M.

12 N.

4 P.M.

8 P.M.

12 M.

4-16-8

0-16-8

Check

0-16-0

XXV

4

Daily Average

Stems

Leaves

Pods

3

2

1

0

Check

0-16-0

0-16-8

4-16-8

Check

0-16-0

0-16-8

4-16-8

Check

0-16-0

0-16-8

4-16-8

XXVI

4

3

2

1

0

Check

0-16-0

0-16-8

4-16-8

Check

0-16-0

0-16-8

4-16-8

Check

0-16-0

0-16-8

4-16-8

XXVII

Daily Average

% dextrine

2

1

0

Leaves

Stems

Pods

Check

0-16-0

0-16-8

4-16-8

Check

0-16-0

0-16-8

4-16-8

Check

0-16-0

0-16-8

4-16-8

XXVIII

% nitrogen

4

3

2

1

0

Check

0-16-0

0-16-8

4-16-8

Check

0-16-0

0-16-8

4-16-8

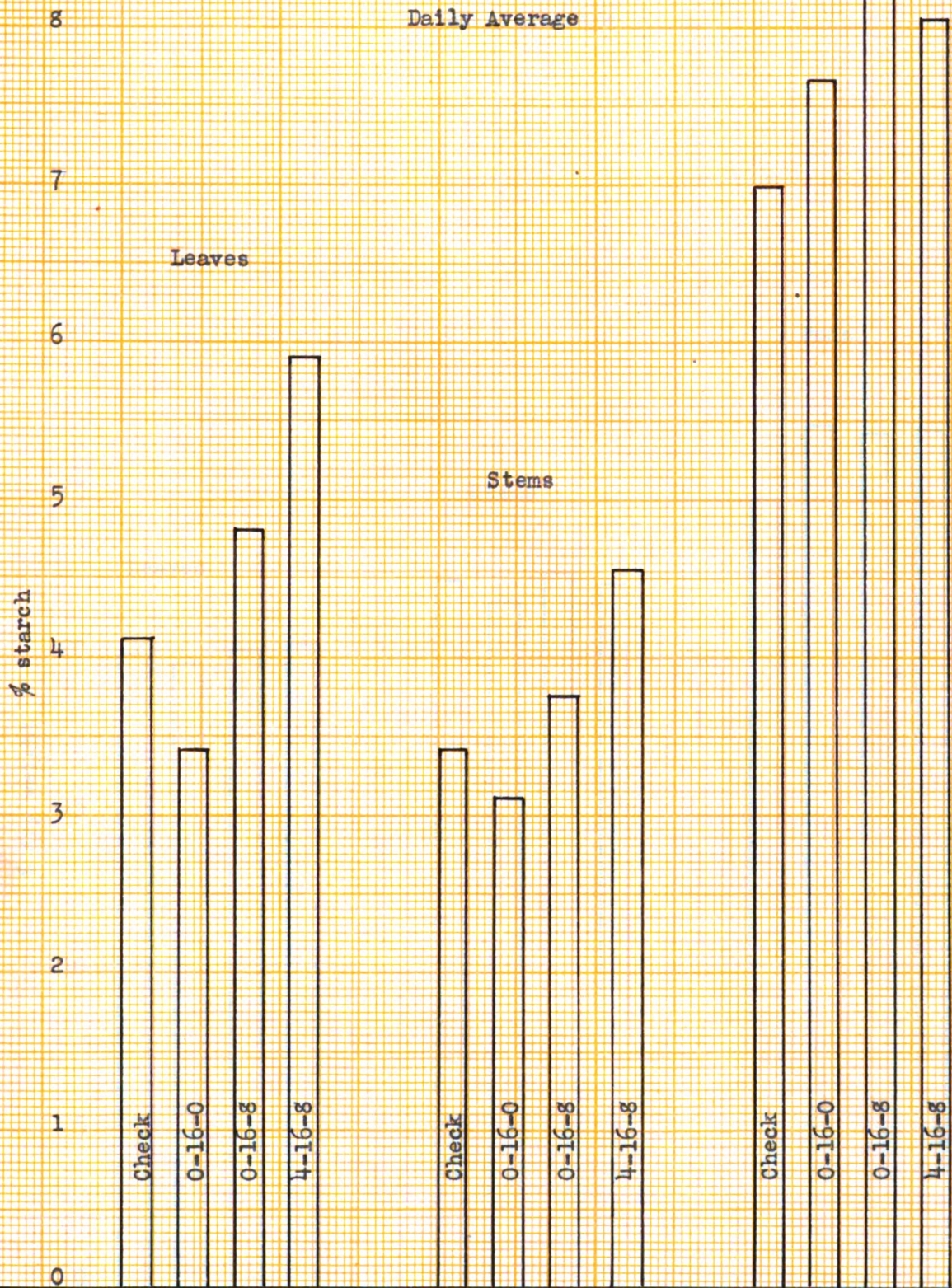
Check

0-16-0

0-16-8

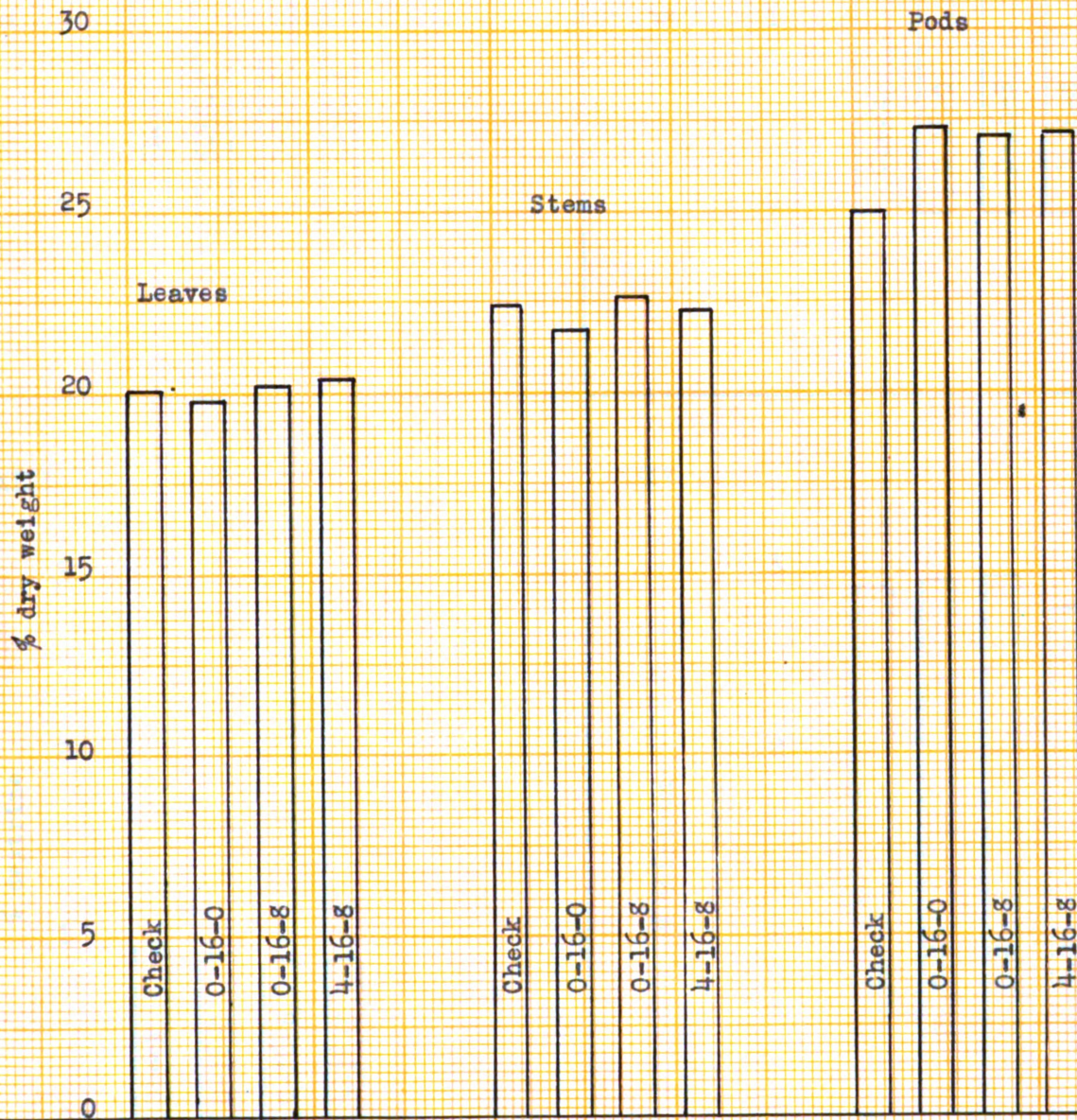
4-16-8

XXIX



XXX

Daily Average



XXXX

3

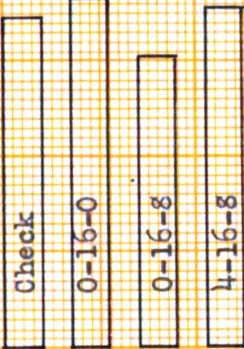
Mean of the Daily Averages for Leaves, Stems, and Pods

% dextrose

2

1

0



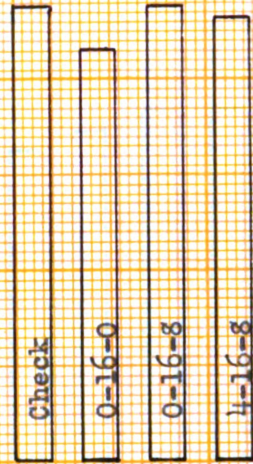
XXXII

% sucrose

2

1

0



XXXIII

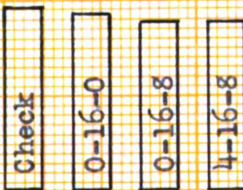
% dextrine

3

2

1

0



XXXIV

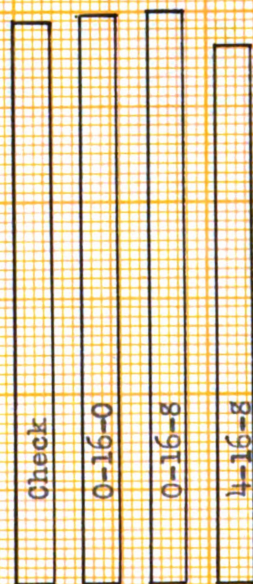
% nitrogen

3

2

1

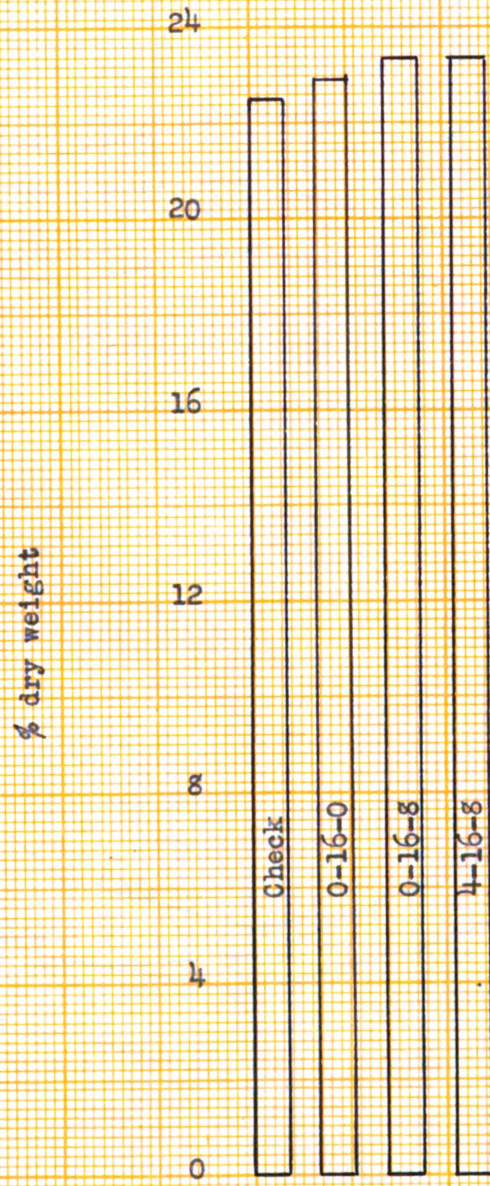
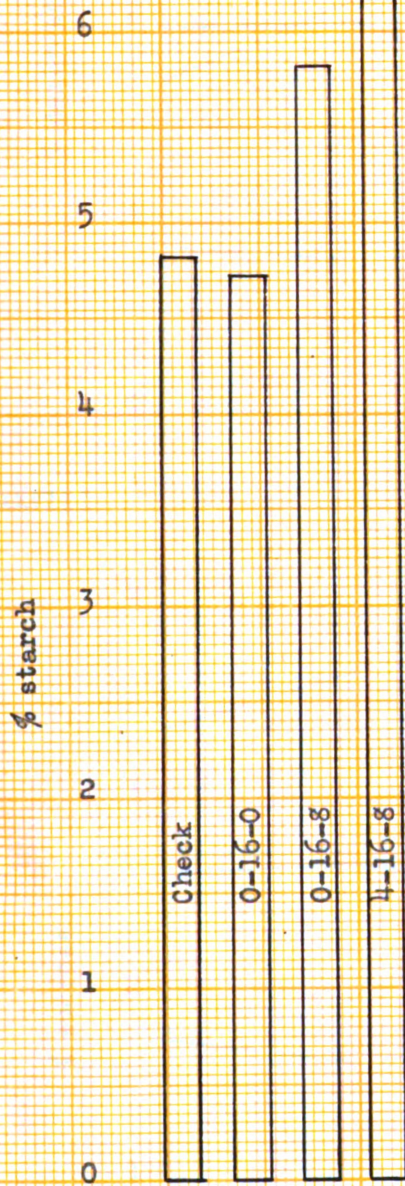
0

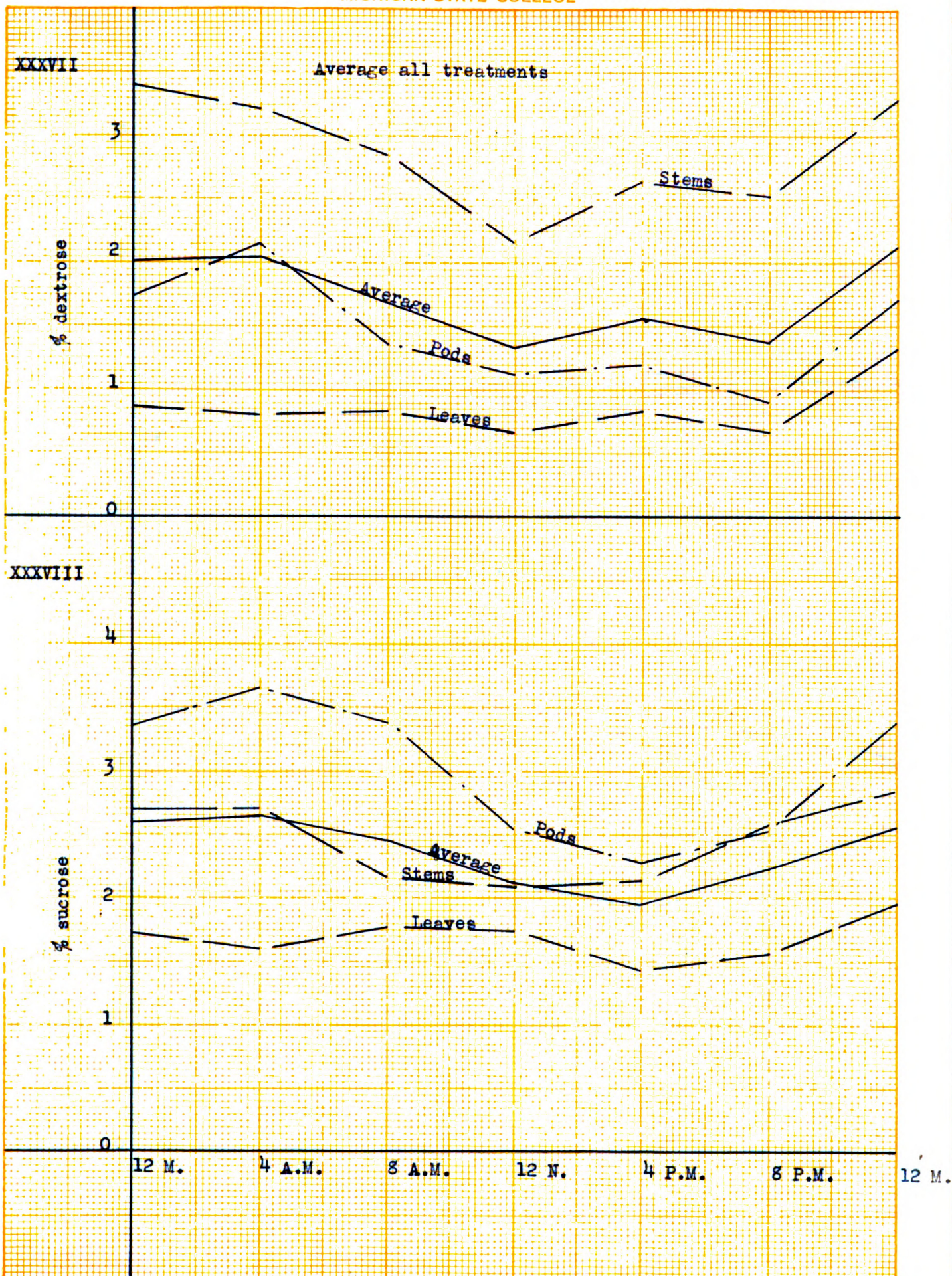


XXXV

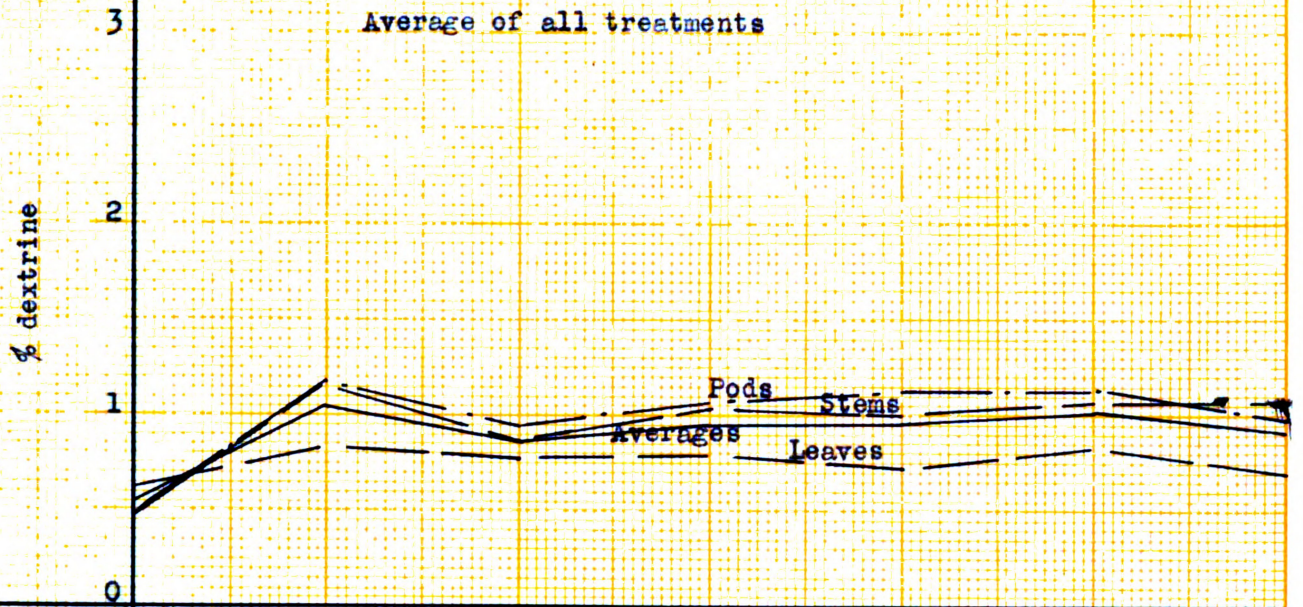
XXXVI

Mean of the Daily Averages for Leaves, Stems, and Pods

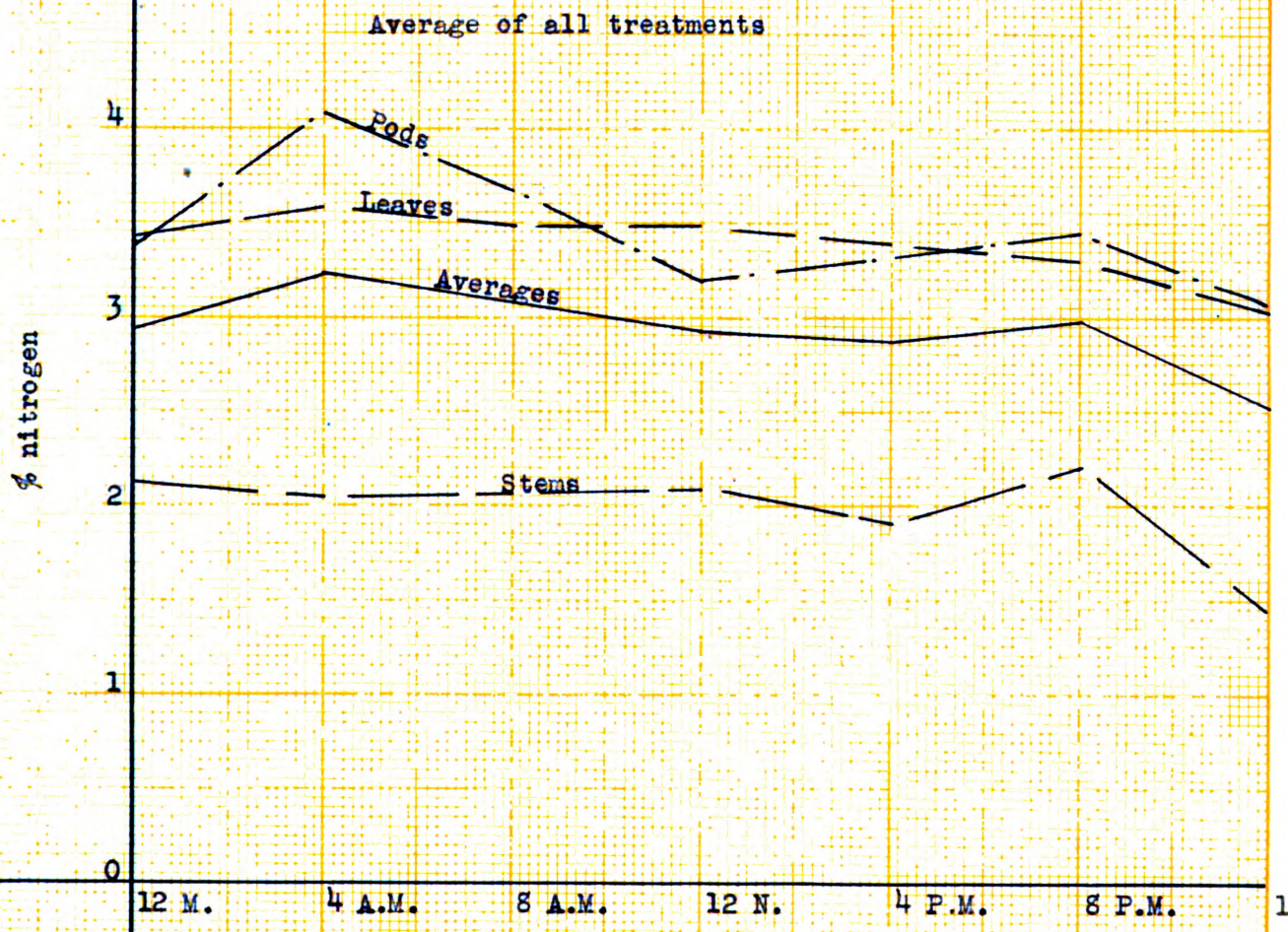




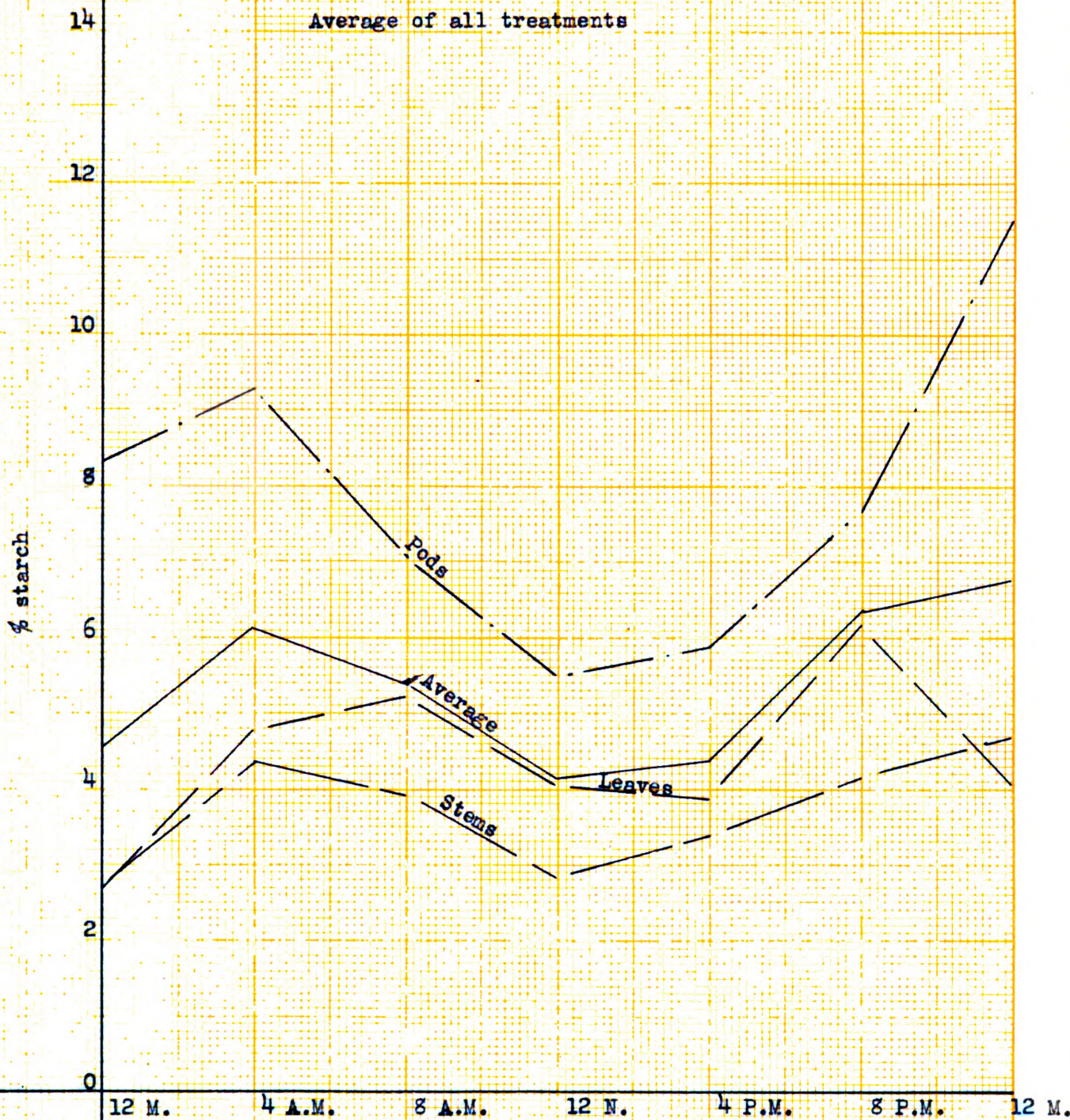
XXXIX



XL

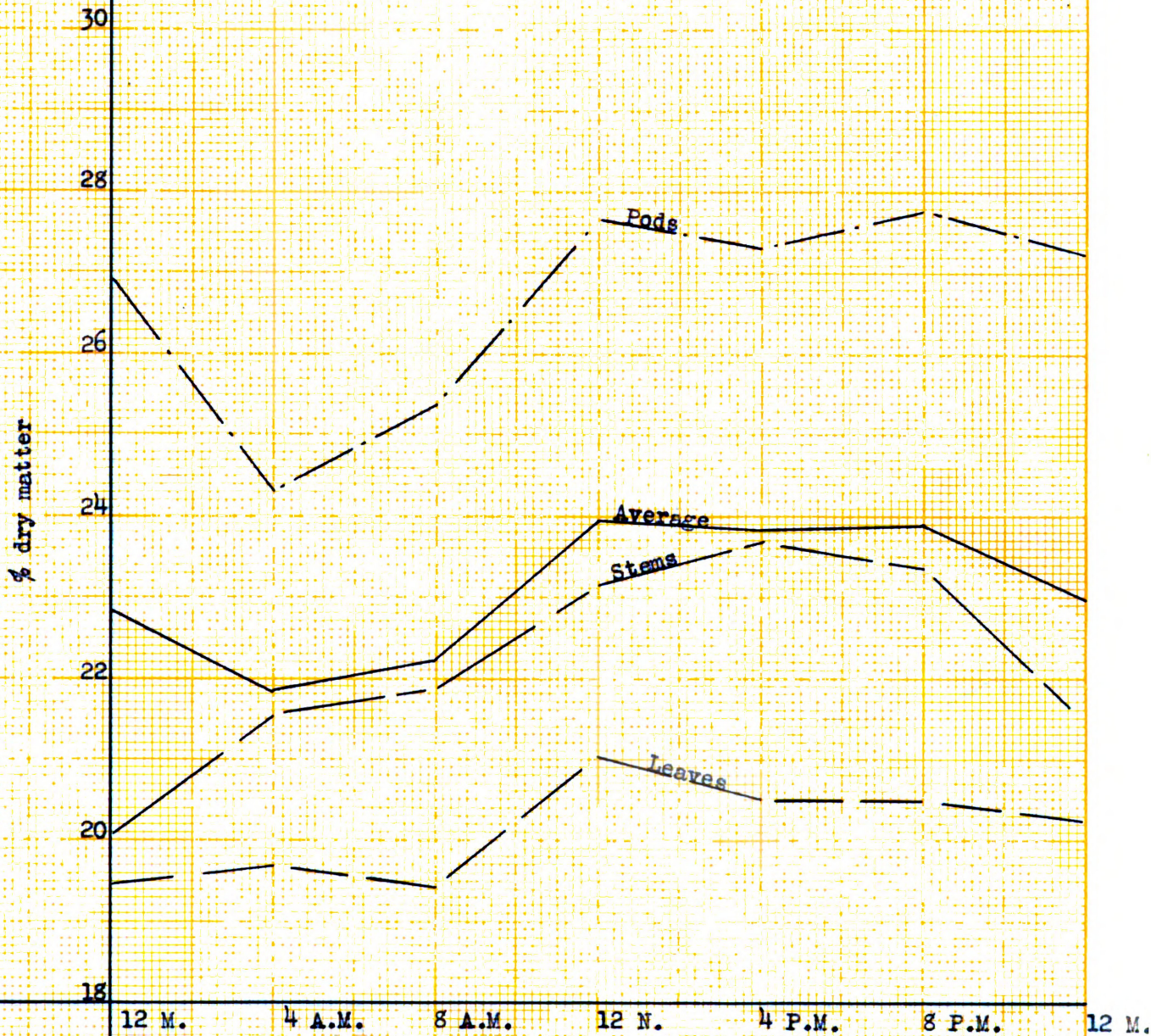


XLI

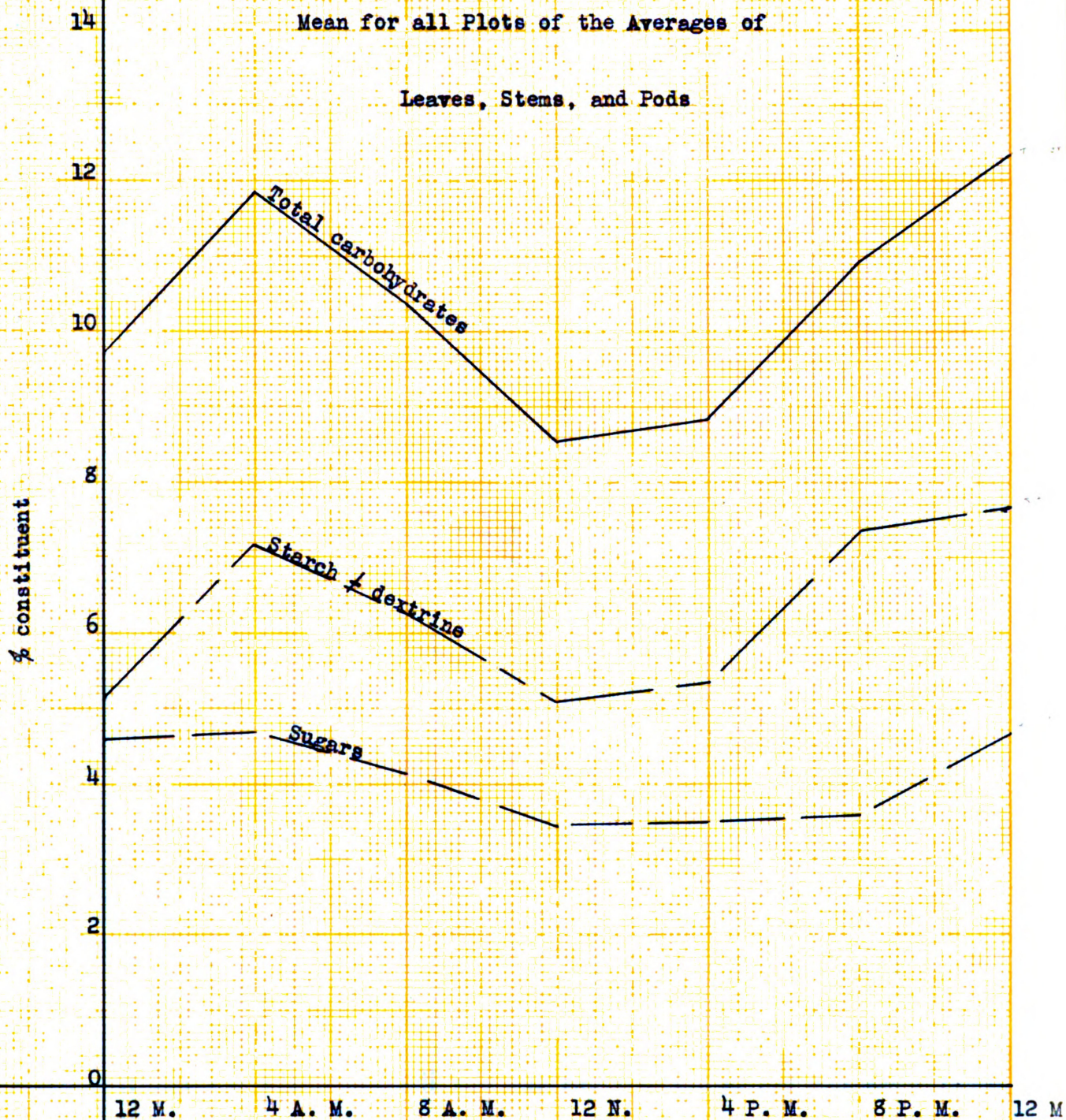


XLIII

Average of all treatments



XLIII



XLIV

16

Daily Averages

Pods

14

12

Stems

Leaves

10

% carbohydrates

8

6

4

2

0

Check

0-16-0

0-16-8

4-16-8

Check

0-16-0

0-16-8

4-16-8

Check

0-16-0

0-16-8

4-16-8

XLV

Average of the Daily

Averages of

16

Leaves, Stems, and Pods

% carbohydrates

14

12

10

8

6

4

2

0

Check

0-16-0

0-16-8

4-16-8

XLVI

Yield

bushels per acre

Check

0-16-0

0-16-8

4-16-8

ROOM USE ONLY

Aug 16 '56

ROOM USE ONLY

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