# RELATIONSHIPS BETWEEN EASILY AVAILABLE CARBOHYDRATES, NITROGEN RECOVERY, AND GROWTH OF SUGAR BEETS FERTILIZED WITH SEVERAL GREEN MANURES

By

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# INTRODUCTION

One of the chief reasons for green manuring is the improvement of the physical condition of the soil by the increase in bulk of soil organic matter. However, from a soil fertility point of view, green manuring takes on an altogether different aspect from that of improving soil physical condition, base exchange relationships, and water-holding capacity, for organic matter furnishes the food and chemical energy for soil organisms to function. It is then, the dynamic action of soil organisms on mineralization which determines soil fertility, and not the ultimate store of organic matter, except as physical condition might be a factor.

The most abundant chemical elements in the soil organic matter are carbon, oxygen, hydrogen, and nitrogen. However, whether one is concerned with protection against leaching of readily soluble nutrients in an inorganic form, or the contribution of added nitrogen to increased crop yields, the question of relative availability of incorporated organic materials comes into prominence.

The investigation reported herein was set up to determine to what extent the relative accessibility of nitrogen to different plant species might influence the carbohydrate-nitrogen relationships obtained in treated plants. Further, this investigation was designed to ascertain the assimilation of mineralized organic nitrogen by sugar beets, and the influence of the relative abundance of easily available energy sources on the percentage recovery of nitrogen from green manures. The author considered the relationships between the total nitrogen and total sugars and starch content of green manure plants. The investigation consisted of two experimental periods designated as Experimental Period I and Experimental Period II.

## REVIEW OF LITERATURE

Pieters and McKee (1938) stated that the use of green manures can be found in the earliest recordings of agricultural practices. A critical review of literature reported from American experiment stations prior to 1917 was given by A. J. Pieters (1917). As seen from the report of Pieters, prior to 1917, investigations on green manuring conducted at American experiment stations were scant and often very limited in scope and significance. Up to that time, most work had been conducted at experiment stations located in southeastern United States. Even investigations conducted in southeastern United States were limited to only a few summer legumes, principally cowpeas. No consideration was given to the residual effects of green manures, and results indicated only that in more cases than not, the use of legume green manures increased the immediate crop yield.

Jenson (1917) reported that the solubility of lime and phosphorus was raised 30 to 100 percent by the addition of 3 percent organic matter to the soil. This increase of lime and phosphorus in the soil solution did not include the mineral constituents which came directly from the decomposing green manure crop. Potassium, magnesium, and iron were influenced in the same way.

Chang (1939) reported that the decomposition of plant material outside of the soil gave results which indicated that during the earlier stages of decomposition, the amount of organic phosphorus actually increased at the expense of the inorganic fraction. This increase in organic phosphorus occurred regardless of the nature and age of the plant material subjected to decomposition. Chang also found that the ratio of organic nitrogen to organic phosphorus was as significant to the decomposition of plant materials as the ratio of nitrogen to carbon.

Pierre (1948) considered phosphorus in organic compounds to constitute one-half or more of the total amount present in soils. White _et al._ (1949) worked with alfalfa fortified with $P^{32}$ as a green manure. Data obtained from their work pointed out that green manure was as effective a source of phosphorus as potassium di-hydrogen phosphate on deficient soils.

Jenson (1917) and Mumford (1914) indicated that the activities of the soil microbial population were responsible for the mineralization and release of nitrogen and phosphorus from some organic constituents. Mumford (1914) found that the satisfactory completion of the processes of ammonification and nitrification in soils was dependent upon the influence of several factors, among which were the presence of soluble calcium, and a suitable relationship between carbon and nitrogen. Lohnis (1926) did extensive work on nitrogen availability and nitrification of green manures which included both legumes and non-legumes. According to Lohnis, the availability of nitrogen from leguminous green manures varied between 16 and 87 percent, with an average of 50 percent of the total nitrogen content of the manurial crop. Waksman and Hutchins (1935) found that transformations of nitrogen were almost entirely microbial in nature. They reported that the heterotrophic soil organisms act on the soil organic matter and break it down, with the liberation of ammonia, which may be utilized by higher plants, or oxidized by autotrophic organisms to nitrates, also usable by higher plants. However, soil microorganisms sometimes existed in direct competition with higher plants for nutrients, especially nitrogen (Doryland, 1916). The most severe competition was for the nitrogen available to plants and soil microbes, since large amounts were required by both the higher plants and the soil microbes.

Waksman (1938) reported that the existing carbon-nitrogen ratio and the chemical nature of the plant material used as manure regulated the decomposition of plant residues and the subsequent release of available nitrogen. According to Waksman and Tenny (1927), the wider the ratio of carbon to nitrogen of the same plant material, the longer the time required to liberate nitrogen as ammonia. Theoretical calculations revealed that a carbon-nitrogen ratio in plant material of about 30:1 was sufficient to supply the nitrogen needs of microorganisms decomposing plant residues. At a narrower ratio, nitrogen was liberated; but if the ratio were wider than 30:1, additional nitrogen was required for rapid decomposition of residues to take place.

Rege (1927) contended that two factors which controlled biochemical decomposition of natural plant material in the presence of assimilable nitrogen were the presence of pentosans as an energy supplier, and the absence of lignin as an inhibitory substance. Where the ratio of pentosans to lignin was numerically greater than unity, the plant material was easily decomposed. Rege found that increasing the ratio of carbohydrates to lignin in resistant materials by the addition of glucose, xylose, and starch did not increase biochemical decomposition. Rege advanced the thesis that microorganisms attacked nitrogenous or non-nitrogenous plant tissues only after the more easily available foodstuffs had been entirely consumed.

Results of experiments reported by Allison (1927) revealed that the addition to the soil of material with a wide carbon-nitrogen ratio made for increased biological activity and a decrease in soil nitrates, due to assimiliation by soil microorganisms. On the other hand, Collison and Conn (1925) attributed low yields following application of low nitrogen materials to reduction in nitrates, as well as to the toxic effects of some products of decomposition.

Jensen (1929) found the critical carbon-nitrogen ratio varied with the soil reaction. He reported that the critical ratio in alkaline soils was 20 to 25, but in acid soil it was 13 to 18. Jensen attributed this difference to the fact that fungi which predominated in acid soils had a higher nitrogen requirement. Salter (1931) contended that the nitrogen would not be available to growing plants from plant residues until the carbon-nitrogen ratio in plant residues was about 10:1.

Rubins and Bear (1942) showed that a natural material of a given carbon-nitrogen ratio yielded considerably less nitrate than did a synthetic mixture of ammonium sulphate and cellulose having the same carbon-nitrogen ratio. According to Waksman (1942), a definite relationship existed between nitrogen and cellulose decomposition. For every thirty parts of cellulose consumed by fungi and bacteria, one part of nitrogen was changed from an inorganic form into microbial protoplasm. Waksman used rye plants as a green manure and found that when it contained about 1.7 percent nitrogen, there was just sufficient nitrogen to enable the microorganisms to bring about active decomposition without any additional nitrogen required from outside sources, or without any nitrogen being liberated as ammonia until considerable reduction in bulk of the manurial material had taken place.

Pinck, et al. (1948) reported from their work that when fresh plant material was considered, the critical carbon-nitrogen ratio was near 35:1. At wider ratios, crop yields were decreased, at narrower ratios the crops used some of the nitrogen from the green manure. During decomposition by microorganisms, plant materials with a carbon-nitrogen ratio of 30:1 or 20:1 liberated large amounts of nitrogen as ammonia. Pinck et al. (1946) incorporated straw and urea in various weight combinations into the soil to determine the quantity of nitrogen that must be added to a growing crop to counteract the effects of the straw. Results from this investigation indicated that the critical carbon-nitrogen ratio varied with the season of the year. Under winter greenhouse conditions, if the carbon-nitrogen ratio were below 35:1, no injury resulted to plant growth; whereas, in spring and summer, no injury resulted if the carbon-nitrogen ratio were below 27:1.

Bollen (1940) measured the rate of decomposition of added organic matter in artificial cultures by the quantity and rate of carbon dioxide evolution. Bollen pointed to evidence that carbon dioxide evolution was not in proportion to carbon content. Under like conditions of temperature, and under equivalent moisture conditions, the amount of carbon dioxide evolved from native organic matter was determined by the amount of organic matter present, soil texture, and the carbon-nitrogen ratio. Bollen also cited evidence to support the contention that the addition of nitrogen to a soil containing organic matter of a wide carbon-nitrogen ratio, did not necessarily increase decomposition. Upon the addition of ammonium sulphate and nitrates to a soil of a wide carbon-nitrogen ratio, Bollen asserted that a depressive effect may develop. This occurrence was explained by the assumption that nitrogen compounds were absorbed by the humus complex in such a way as to temporarily immobilize previously decomposable carbon compounds. The added nitrogen, being directly assimilable, relieved the microbes of the necessity of decomposing organic compounds for nitrogen requirements.

With the advent of increased interest in principles underlying green manuring, several methods have been devised to measure the rate of decomposition of organic matter in the soil and the subsequent rate of release of nitrogen. The use of radioactive nitrogen and radioactive carbon has come into prominence in recent years (Norman and Werkman, 1943; White et al., 1949). Pinck et al. (1945) used sudan grass as indicator crop. Martin (1927) and Bollen (1940) measured carbon dioxide evolution which served as a criterion of decomposition, while Mumford (1914) and Allison (1927) used a measure of nitrate accumulation as an indicator of decomposition and nitrification.

## EXPERIMENTAL PERIOD I - GROWING THE GREEN MANURES

### Materials and Methods

In Experiment I, selected plant species which included legumes and grasses were grown alone and in association under greenhouse conditions. They received three nutrient treatments. This experiment dealt with the effects of nutrient treatments on yield and carbohydrate-nitrogen relationships of the selected plants.

On October 10, 1950, seeds of alfalfa (*Medicago sativa*), smooth brome grass (*Bromus inermis*), ladino clover (*Trifolium repens*), orchard grass (*Dactylis glomerata*), hairy vetch (*Vicia villosa*), and rye (*Secale cereale*) were planted alone and in mixture in clean, washed, No. 2 plasterers sand contained in each of 162 four-gallon glazed crocks. Each crock was provided with one 3/4-inch drainage hold located to the side and at the bottom. Glass wool was used to cover the drainage hole in each crock so as to provide suitable drainage for the cultures.

All cultures which included alfalfa, ladino clover, and vetch, whether grown in association with selected grass species or in pure cultures, were inoculated at the time of seeding with cultures of suitable Rhizobium in humus. The seeds were planted immediately after inoculation.

After a period of three weeks, when germination appeared complete, each culture was thinned to a uniform stand.

The experiment was arranged so as to provide nine series (see Table 1). Each series contained a specified plant species and consisted of eighteen cultures with three treatments replicated six times.

Throughout the growing period of each culture which received Treatment 1, plants were fed every seven days with one quart of Shive's R5S2 nutrient solution, Miller (1938) which contained the following:

| Reagent | Molarity |
|---|---|
| $KH_2PO_4$ | 0.0180 |
| $Ca(NO_3)_2$ | 0.0052 |
| $MgSO_4$ | 0.0150 |

Plants which received Treatment 2 were fed every seven days with a modified Shive's R5S2 nutrient solution which did not contain nitrogen. This modified nutrient solution contained the following principal salts:

TABLE 1

SERIES DESIGNATIONS, PLANT SPECIES, AND NUTRITIONAL TREATMENTS

| Series Designations | Species | Treatment No. | Nutritional Treatment |
|---|---|---|---|
| 1a | Alfalfa | 1 | Shive's complete solution |
| 2a | | 2 | Shive's solution less nitrogen |
| 3a | | 3 | Tap water |
| 1b | Alfalfa and | 1 | Shive's complete solution |
| 2b | Brome Grass | 2 | Shive's solution less nitrogen |
| 3b | | 3 | Tap water |
| 1c | Brome Grass | 1 | Shive's complete solution |
| 2c | | 2 | Shive's solution less nitrogen |
| 3c | | 3 | Tap water |
| Ia | Ladino Clover | 1 | Shive's complete solution |
| IIa | | 2 | Shive's solution less nitrogen |
| IIIa | | 3 | Tap water |
| Ib | Ladino Clover | 1 | Shive's complete solution |
| IIb | and Orchard | 2 | Shive's solution less nitrogen |
| IIIb | Grass | 3 | Tap water |
| Ic | Orchard Grass | 1 | Shive's complete solution |
| IIc | | 2 | Shive's solution less nitrogen |
| IIIc | | 3 | Tap water |
| $A_1$ | Vetch | 1 | Shive's complete solution |
| $A_2$ | | 2 | Shive's solution less nitrogen |
| $A_3$ | | 3 | Tap water |
| $B_1$ | Vetch and Rye | 1 | Shive's complete solution |
| $B_2$ | | 2 | Shive's solution less nitrogen |
| $B_3$ | | 3 | Tap water |
| $C_1$ | Rye | 1 | Shive's complete solution |
| $C_2$ | | 2 | Shive's solution less nitrogen |
| $C_3$ | | 3 | Tap water |

| Reagent | Molarity |
| --- | --- |
| $KH_2PO_4$ | 0.0180 |
| $CaCl_2$ | 0.0052 |
| $MgSO_4$ | 0.0150 |

All nutrients were made with tap water upon the dilution of each of four stock solutions containing the individual salts. In all cases reagent grade chemicals were used. When not in use, stock solutions were kept in the greenhouse. However, upon the evidence of algal growth, the stock solutions were discarded and resh solutions prepared.

The plants contained in those cultures which received Treatment 3 served as checks, and were fed no nutrient solution; but these cultures were kept watered with tap water throughout the duration of the experiment.

It was not found necessary in any case to add minor elements to the cultures. Cultures of all series which received Treatments 1 and 2 were flooded with tap water every twenty-one days in an effort to eliminate any excess salt accumulation brought about by differential absorption by growing plants.

Daytime temperatures in the greenhouse were maintained at approximately 68 degrees Fahrenheit throughout the experiment.

Plants of all cultures and series were permitted to grow under the specified conditions until flowering was evident in any culture of the several series. The vetch plants of series A and B which received Treatment 2 were the first to give evidence of flowering.

## Harvesting the Plants

Beginning on January 26, 1951, all plants were harvested. Harvesting procedures were conducted as nearly as possible during the morning hours so as to eliminate undue variations in carbohydrate metabolism.

Harvesting operations consisted principally of removing the plants of each culture as nearly quantitatively from the sand medium as conditions would permit. The plants were then fractionated into tops and roots to include the nodules of the legume species. Roots were removed from the cultures with minimum loss by flooding each culture with tap water immediately preceding and during removal. A continuous low pressure stream of water was directed upon the roots as they were removed to avoid loss of nodular tissue from the roots prior to fractionating the plants into designated parts. The entire plants and fractions were weighed immediately after removal from the sand to the nearest one-tenth gram. Green weights of tops and roots were recorded separately for all plants. From each culture which involved associated growth, it was necessary to record root weights as "combined weight" of the two species. Roots of plants of the associated species were entwined and very difficult to separate. Top weights were recorded separately from the plants grown alone and/or in association.

## Preparation of Samples for Biochemical Analysis

After green weight yields were recorded for plants of each culture, the separated plant material was placed in paper bags in the oven and dried. The material was subjected to rapid dessication at a temperature of 70° Centigrade in a forced-air drying oven. The drying period consisted of approximately sixteen hours. Reports of Loomis (1937) and Thomas (1927) indicated that this method does not materially alter the status of the plant metabolites.

After the completion of the period of dessication, the plant material was allowed to attain a state of equilibrium with the moisture of the atmosphere. The dry weights of the plant material were recorded as rough dry weight. The plant material was stored in covered mason jars until analyses were made.

The dry weight determinations were made of the entire plant fractions of all plants obtained from each culture, as was done in making green weight determinations. Dry weight determinations of the roots of the legume and grass species grown in association were made and recorded as dry weight of "combined roots."

Approximately 30 percent of the dry weight yield of six replicated cultures was reserved for chemical analysis. Approximately 70 percent of the dry weight yield of six replicated cultures was reserved as plant material to be used as green manure.

## Methods of Chemical Analysis

Dried plant material was ground in a Wiley mill until all tissue would pass a number 20 sieve. Aliquots of plant tissue which were reserved for chemical analysis were re-dried to a constant weight at a temperature of 80 degrees Centigrade. The re-dried plant material was placed in a dessicator prior to weighing out the aliquots for chemical analysis.

Total nitrogen was determined by the A.O.A.C. (1940) method of Kjeldahl, modified to include nitrates.

Total sugars was determined by the method of A.O.A.C. Munson-Walker tables were used for conversion of sugar values to total invert sugar.

Total starch was determined by a procedure which resulted from a collaborative study by A.O.A.C. and based upon the extraction of starch with dilute calcium chloride solution, precipitation of dissolved starch as a starch-iodide complex, and acid hydrolysis of starch to glucose. Glucose values were converted to starch values by the use of a suitable factor (Hoffpaüir).

## Statistical Analysis

Analysis of variance in accordance with the methods of Snedecor (33) were used to evaluate data concerning dry weight yields, both in Experimental Period I and Experimental Period II. The significance of the derived "F" values, F = (MS treat.)/(MS error) was determined by reference to standard tables (Snedecor, 1946).

## Experimental Results

### Observation of Growth

Treatments 1, 2, and 3 are hereafter referred to as NPK treatment, PK treatment, and tap water treatment, respectively.

Approximately five weeks after germination, all grass species which received PK treatment showed varying degrees of chlorosis diagnosed by visual symptoms as nitrogen deficiency. The deficiency symptoms were quite pronounced, as shown by distinct yellowing and subsequent browning which was evident on approximately one-third of the leaf blades from the tip toward the base. Grasses which received NPK treatments or which were grown in association with selected legumes showed increased growth over the same grass species which received PK treatments, or which received only tap water.

In general, plants of all cultures which received NPK treatment, whether legume species or grass species, grown in pure culture or in association, exhibited a more vigorous growth than their counterparts which received PK treatments or only tap water. Alfalfa and vetch made as much growth when furnished

PK treatment as they did when nitrogen was furnished in the nutrient solution.

The plants of those cultures receiving only tap water (Treatment 3) made very little growth. However, visual symptoms of nutritional deficiencies were not as pronounced as those exhibited by grass species of those cultures which received PK treatment. This was probably due to the fact that plants receiving only tap water were maintained in a state of very low metabolic activity during the course of the experiment.

After approximately eight weeks' growth, rye plants which received NPK treatment showed evidence of mildew on the leaves and stems. This condition was corrected over a period of two weeks by reducing the frequency of watering and by the application of dusting sulphur to the stems and leaves of infected plants.

A comparison of the relative growth attained in representative cultures can be obtained from Figures I, II, III, and IV.

<u>Yield of manures</u>. The average green weight and dry weight per culture of all plant species and associations are presented in Table 2.


Figure I. Growth response of ladino clover and alfalfa to nitrogen.

NPK Culture received Shive's complete nutrient solution.
PK Culture received Shive's solution minus nitrogen.
CK Cultures received tap water.

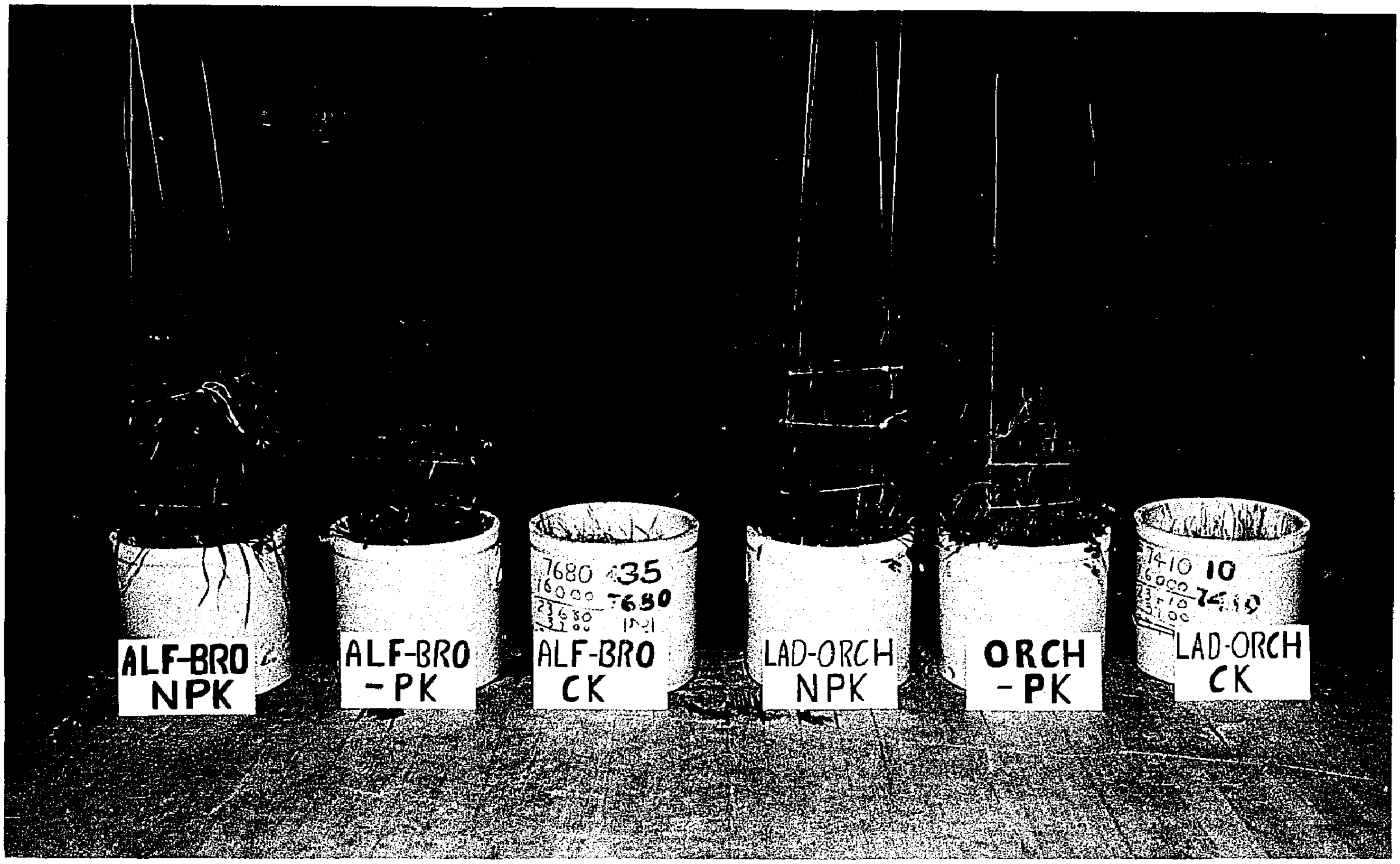


Figure II. Growth response to nitrogen of cultures involving associated growth of alfalfa-brome grass and ladino clover-orchard grass.

NPK Cultures received Shive's complete nutrient solution.
PK Cultures received Shive's solution minus nitrogen.
CK Cultures received tap water.

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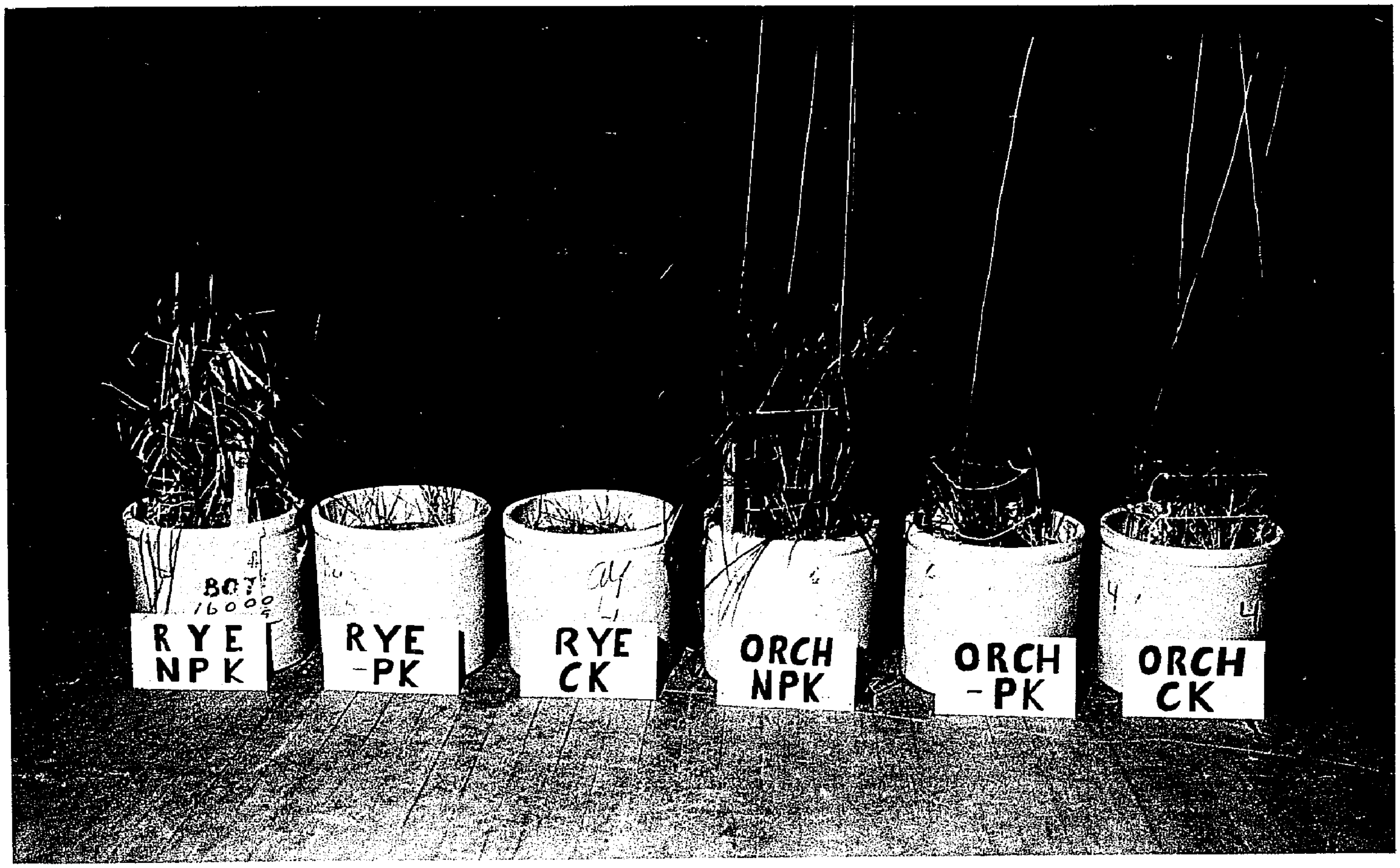


Figure III. Growth response to nitrogen of rye and orchard grass.

NPK Cultures received Shive's complete nutrient solution.
PK Cultures received Shive's solution minus nitrogen.
CK Cultures received tap water.

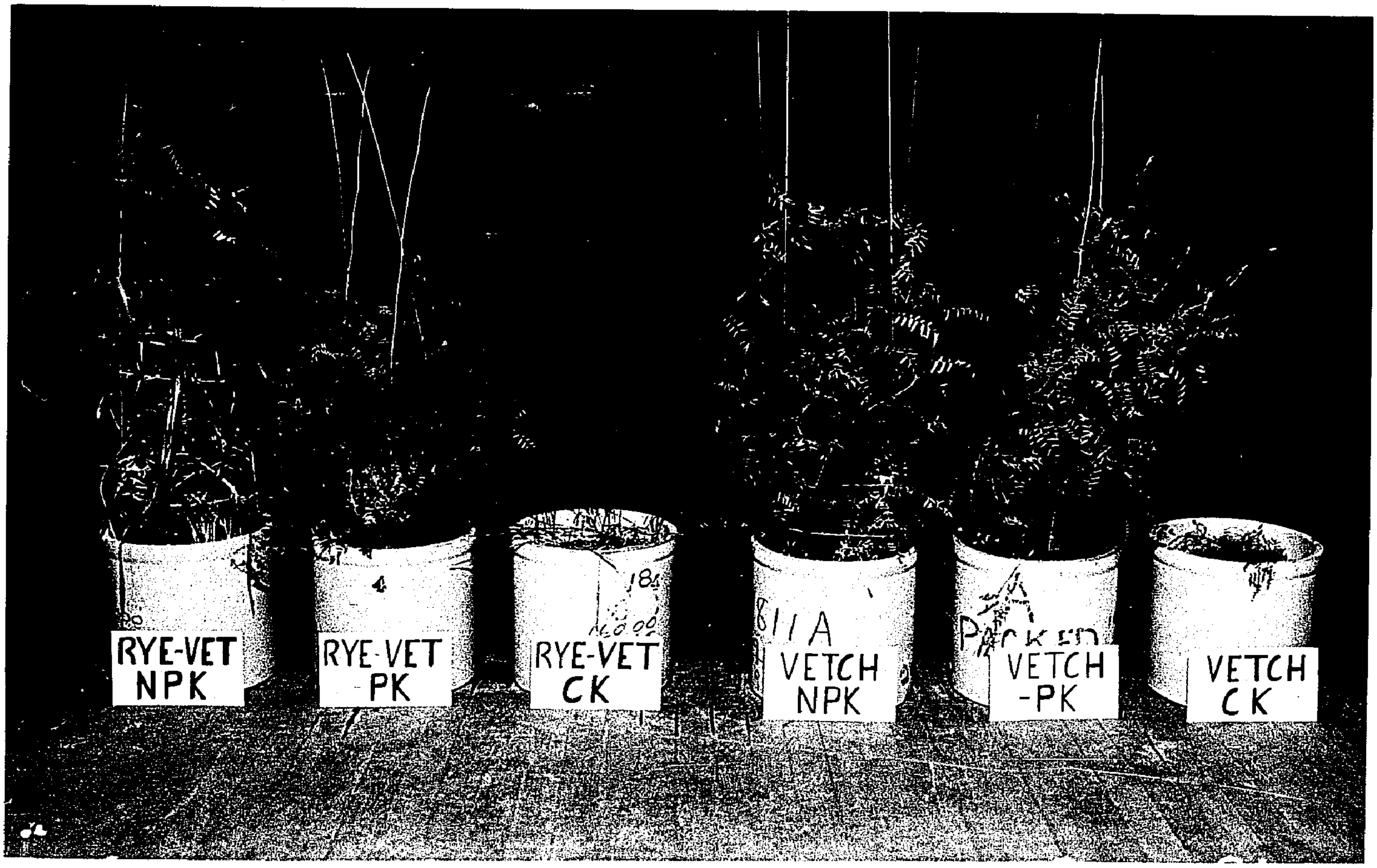


Figure IV. Growth response to nitrogen of rye and vetch.

NPK Cultures received Shive's complete nutrient solution.
PK Cultures received Shive's solution minus nitrogen.
CK Cultures received tap water.

TABLE 2

AVERAGE GREEN WEIGHT AND DRY WEIGHT OF PLANTS PER CULTURE AT TIME OF HARVEST

| Series Designation | Species | Treatment | Average Green Weight | Average Dry Weight |
|---|---|---|---|---|
| | | | gms. | gms. |
| 1a | Alfalfa | NPK | 66.5 | 11.8 |
| 2a | | PK | 69.3 | 12.2 |
| 3a | | $H_2O$ | 10.9 | 1.7 |
| 1b | Alfalfa and | NPK | 157.1 | 23.2 |
| 2b | Brome Grass | PK | 125.9 | 13.6 |
| 3b | | $H_2O$ | 15.8 | 3.3 |
| 1c | Brome Grass | NPK | 135.5 | 22.5 |
| 2c | | PK | 20.3 | 5.1 |
| 3c | | $H_2O$ | 7.1 | 1.7 |
| Ia | Ladino Clover | NPK | 195.7 | 19.1 |
| IIa | | PK | 104.5 | 16.4 |
| IIIa | | $H_2O$ | 12.3 | 1.6 |
| Ib | Ladino Clover | NPK | 204.1 | 29.0 |
| IIb | and Orchard | PK | 112.9 | 17.3 |
| IIIb | Grass | $H_2O$ | 22.8 | 3.5 |
| Ic | Orchard Grass | NPK | 192.0 | 32.1 |
| IIc | | PK | 35.0 | 7.9 |
| IIIc | | $H_2O$ | 12.5 | 2.1 |
| $A_1$ | Vetch | NPK | 275.1 | 34.6 |
| $A_2$ | | PK | 297.8 | 31.4 |
| $A_3$ | | $H_2O$ | 64.0 | 9.8 |
| $B_1$ | Vetch and Rye | NPK | 314.2 | 38.3 |
| $B_2$ | | PK | 310.4 | 39.4 |
| $B_3$ | | $H_2O$ | 36.6 | 6.7 |
| $C_1$ | Rye | NPK | 191.8 | 30.1 |
| $C_2$ | | PK | 36.5 | 7.6 |
| $C_3$ | | $H_2O$ | 22.7 | 5.3 |

Difference required for significance between mean dry weights in grams of plants which received NPK and PK treatments.
P .05 = 4.86.

With the exception of alfalfa cultures, the average dry weight yield per culture which received nitrogen showed an increase over cultures which received PK treatments or which received only tap water and which did not include a source of nitrogen. The increase in dry weight of the legume species which received NPK treatments as compared to those which received PK treatments was of no statistical significance. The difference between the average dry weight yield per culture of legume species used as checks, Treatment 3, and the legume species which received Treatment 1 or 2 was of outstanding significance.

Of the mixed cultures which involved the growth of legumes and nonlegumes in associated growth, the cultures which received NPK treatments showed significantly greater dry weight yields than cultures which received PK treatment. In the series which involved vetch and rye associations, there were no significant differences in dry weight yields between the cultures which received NPK and those which received PK treatment.

In all cases the grass species showed decided response to nitrogen as evidenced by a comparatively large green and dry weight yield difference between the cultures which received NPK treatment and cultures which received PK treatments or only tap water.

In all cases the dry weight yield was significantly less in cultures which received only tap water than in cultures which received NPK or PK treatments.

It is generally observed that with an increase in nitrogen supply to growing plants there is developed a wide shoot/root ratio. The results here as presented in Table 3 confirm this relationship except in the case of vetch plants.

The relationships of shoot to root in mixed cultures which received PK treatment approached that of the plants contained in cultures which received NPK treatment. As the shoot-root relationships are affected, results here support the view that the source of nitrogen is of no particular concern so long as it is available to and assimilable by growing plants. Further, whether combined nitrogen or fixed nitrogen is utilized by legume species, the shoot-root relationships are comparable.

With the exception of vetch plants, the percentage of total nitrogen contained in the plants was higher in those plants which received NPK treatments than in those which received PK treatment. However, the difference between the total nitrogen found

TABLE 3

PERCENTAGE OF TOTAL NITROGEN IN ENTIRE PLANT AND THE SHOOT/ROOT RATIO OF PLANTS AT TIME OF HARVEST

| Series Desig- nation | Species | Treat- ment | Total Nitrogen | Shoot/root Ratio |
|---|---|---|---|---|
| | | | % | |
| 1a | Alfalfa | NPK | 3.34 | 2.90 |
| 2a | | PK | 3.02 | 2.50 |
| 3a | | $H_2O$ | 3.15 | 1.00 |
| 1b | Alfalfa and Brome Grass | NPK | 2.86 | 1.80 |
| 2b | | PK | 2.79 | 1.20 |
| 3b | | $H_2O$ | 1.52 | 0.71 |
| 1c | Brome Grass | NPK | 2.72 | 2.70 |
| 2c | | PK | 0.72 | 0.37 |
| 3c | | $H_2O$ | 1.18 | 0.59 |
| Ia | Ladino Clover | NPK | 3.48 | 7.50 |
| IIa | | PK | 2.96 | 5.30 |
| IIIa | | $H_2O$ | 2.01 | 0.92 |
| Ib | Ladino Clover and Orchard Grass | NPK | 2.69 | 2.30 |
| IIb | | PK | 1.94 | 2.10 |
| IIIb | | $H_2O$ | 1.49 | 1.40 |
| Ic | Orchard Grass | NPK | 2.70 | 2.60 |
| IIc | | PK | 0.58 | 0.71 |
| IIIc | | $H_2O$ | 1.36 | 0.96 |
| $A_1$ | Vetch | NPK | 3.20 | 6.50 |
| $A_2$ | | PK | 3.22 | 9.10 |
| $A_3$ | | $H_2O$ | 2.37 | 0.73 |
| $B_1$ | Vetch and Rye | NPK | 2.56 | 3.30 |
| $B_2$ | | PK | 2.47 | 3.80 |
| $B_3$ | | $H_2O$ | 1.66 | 0.71 |
| $C_1$ | Rye | NPK | 2.42 | 2.90 |
| $C_2$ | | PK | 0.76 | 0.80 |
| $C_3$ | | $H_2O$ | 0.80 | 0.70 |

in the legume species which received NPK treatment and the legume species which received PK treatment was of dubious significance. Likewise, in cultures which involved associated growth of legumes and nonlegumes the difference between the percentage nitrogen in the plants which received NPK treatment and those which received PK treatment was of doubtful significance. These results probably indicate that whether the included legume species were able to utilize combined nitrogen or fixed nitrogen, no material change in the percentage of total nitrogen was evident.

Relationships between total carbohydrates and total nitrogen within the plants are presented in Table 4. With the exception of a very slight deviation in the series which involved vetch, and vetch and rye grown in association, the ratio between total carbohydrates and total nitrogen was generally wider in plants which received PK treatment than in plants which received NPK treatment. As in the case of nitrogen source and its effect on the shoot-root relationships, the source of nitrogen seemed to have had no outstanding effect on the carbohydrate-nitrogen relationships. However, it appears that in cultures which involved growth of legumes and nonlegumes in association there probably

TABLE 4

CARBOHYDRATE-NITROGEN RELATIONSHIPS OF PLANTS AT TIME OF HARVEST

| Series Desig-nation | Species | Treat-ment | Total[1] Carbo-hydrate | Total Carbo-hydrate | Total[1] Nitrogen | Total Nitrogen | C/N* Ratio |
|---|---|---|---|---|---|---|---|
| | | | % | gms. | % | gms. | |
| 1a | Alfalfa | NPK | 10.47 | 1.24 | 3.34 | 0.39 | 3.13 |
| 2a | | PK | 13.14 | 1.60 | 3.02 | 0.37 | 4.35 |
| 3a | | $H_2O$ | 6.91 | 0.12 | 3.15 | 0.05 | 2.19 |
| 1b | Alfalfa | HPK | 4.61 | 1.07 | 2.86 | 0.70 | 1.60 |
| 2b | Brome | PK | 10.67 | 1.45 | 2.79 | 0.38 | 3.81 |
| 3b | Grass | $H_2O$ | 10.06 | 0.33 | 1.52 | 0.05 | 6.60 |
| 1c | Brome Grass | NPK | 3.85 | 0.87 | 2.72 | 0.61 | 1.41 |
| 2c | | PK | 9.35 | 0.48 | 0.72 | 0.04 | 13.05 |
| 3c | | $H_2O$ | 11.99 | 0.20 | 1.18 | 0.02 | 10.17 |
| Ia | Ladino Clover | NPK | 5.07 | 0.97 | 3.48 | 0.66 | 1.45 |
| IIa | | PK | 5.27 | 0.86 | 2.96 | 0.49 | 1.77 |
| IIIa | | $H_2O$ | 5.77 | 0.09 | 2.01 | 0.03 | 2.78 |
| Ib | Ladino and | NPK | 3.04 | 0.88 | 2.69 | 0.78 | 1.12 |
| IIb | Orchard Grass | PK | 5.44 | 0.94 | 1.94 | 0.34 | 2.80 |
| IIIb | | $H_2O$ | 6.42 | 0.51 | 1.49 | 0.05 | 4.30 |

TABLE 4 (Continued)

| Series Designation | Species | Treatment | Total[1] Carbohydrate | Total Carbohydrate | Total[1] Nitrogen | Total Nitrogen | C/N* Ratio |
|---|---|---|---|---|---|---|---|
| | | | % | gms. | % | gms. | |
| Ic | Orchard Grass | NPK | 2.89 | 0.93 | 2.70 | 0.87 | 1.07 |
| IIc | | PK | 5.44 | 0.43 | 0.58 | 0.05 | 9.29 |
| IIIc | | $H_2O$ | 5.29 | 0.11 | 1.36 | 0.03 | 3.86 |
| $A_1$ | Vetch | NPK | 3.18 | 1.10 | 3.20 | 1.10 | 0.98 |
| $A_2$ | | PK | 3.17 | 0.96 | 3.22 | 1.04 | 0.98 |
| $A_3$ | | $H_2O$ | 1.19 | 0.01 | 2.37 | 0.23 | 0.50 |
| $B_1$ | Vetch and Rye | NPK | 4.31 | 1.66 | 2.56 | 0.98 | 1.68 |
| $B_2$ | | PK | 3.67 | 1.45 | 2.47 | 0.97 | 1.51 |
| $B_3$ | | $H_2O$ | 4.56 | 0.31 | 1.66 | 0.11 | 2.74 |
| $C_1$ | Vetch | NPK | 2.99 | 0.90 | 2.42 | 0.73 | 1.24 |
| $C_2$ | | PK | 7.49 | 0.57 | 0.76 | 0.06 | 9.87 |
| $C_3$ | | $H_2O$ | 6.87 | 0.36 | 0.80 | 0.04 | 8.58 |

[1] Percentage of dry weight.

[2] C/N ratio = (Carbohydrate %) / (Nitrogen %).

were significant differences in the ratio of carbohydrates to nitrogen between plants which received NPK treatment and those which received PK treatment. Results suggested that the inability of legumes to supply nitrogen to nonlegumes in amounts commensurate with the ability of the nonlegume to assimilate fixed nitrogen makes for a discrepancy in the carbohydrate-nitrogen relationship differences.

Results which show the relationships between total nitrogen and total sugars, total nitrogen and total starch are presented in Table 5. The same general relationships prevail when one considers relationships between total nitrogen and total sugars, and total nitrogen and starch as when combined values represent the total carbohydrates. It is significant to note that the rye plants which received NPK treatment were shown by chemical analysis to contain no starch. The rye plants which received NPK treatments and PK treatments were shown by chemical analysis to be relatively poor in content of readily available carbohydrates.

Brome grass, orchard grass, and rye which received NPK and PK treatments showed a tendency toward relatively low starch

TABLE 5

RELATIONSHIPS OF TOTAL NITROGEN AND TOTAL SUGARS AND STARCH OF PLANTS AT TIME OF HARVEST

| Series Designation | Species | Treatment | Total Sugar[1] | Starch[1] | Total Nitrogen[1] | Ratios[2] Sugar/N | : Starch/N |
|---|---|---|---|---|---|---|---|
| | | | % | % | | | |
| 1a | Alfalfa | NPK | 2.98 | 7.49 | 3.34 | 0.89 | 2.24 |
| 2a | | PK | 3.17 | 9.97 | 3.02 | 1.05 | 3.30 |
| 3a | | $H_2O$ | 4.82 | 2.09 | 3.15 | 1.53 | 0.66 |
| 1b | Alfalfa Brome | NPK | 2.67 | 1.94 | 2.86 | 0.93 | 0.68 |
| 2b | | PK | 5.08 | 5.59 | 2.79 | 1.82 | 2.00 |
| 3b | | $H_2O$ | 8.98 | 1.08 | 1.52 | 5.91 | 0.71 |
| 1c | Brome | NPK | 3.37 | 0.48 | 2.72 | 1.24 | 0.18 |
| 2c | | PK | 9.01 | 0.34 | 0.72 | 12.51 | 0.47 |
| 3c | | $H_2O$ | 11.59 | 0.40 | 1.18 | 9.82 | 0.38 |
| Ia | Ladino Clover | NPK | 3.74 | 1.33 | 3.48 | 1.07 | 0.38 |
| IIa | | PK | 3.37 | 1.90 | 2.96 | 1.14 | 0.64 |
| IIIa | | $H_2O$ | 3.22 | 2.55 | 2.01 | 1.60 | 1.27 |
| Ib | Ladino Clover | NPK | 2.49 | 0.55 | 2.69 | 0.93 | 0.20 |
| IIb | and Orchard | PK | 4.25 | 1.19 | 1.94 | 2.19 | 0.61 |
| IIIb | Grass | $H_2O$ | 5.23 | 1.19 | 1.49 | 3.51 | 0.80 |

TABLE 5 (Continued)

| Series Designation | Species | Treatment | Total[1] Sugar | Starch[1] | Total[1] Nitrogen | Ratios[2] Sugar/N | : Starch/N |
|---|---|---|---|---|---|---|---|
| | | | % | % | | | |
| Ic | Orchard Grass | NPK | 2.56 | 0.33 | 2.70 | 0.95 | 0.12 |
| IIc | | PK | 5.13 | 0.31 | 0.58 | 8.84 | 0.53 |
| IIIc | | $H_2O$ | 4.98 | 0.31 | 1.36 | 3.66 | 0.23 |
| $A_1$ | Vetch | NPK | 2.72 | 0.46 | 3.20 | 0.85 | 0.14 |
| $A_2$ | | PK | 2.64 | 0.53 | 3.22 | 0.82 | 0.17 |
| $A_3$ | | $H_2O$ | 0.95 | 0.24 | 2.37 | 0.40 | 0.10 |
| $B_1$ | Vetch Rye | NPK | 3.99 | 0.32 | 2.56 | 1.56 | 0.13 |
| $B_2$ | | PK | 2.92 | 0.75 | 2.47 | 1.18 | 0.30 |
| $B_3$ | | $H_2O$ | 4.25 | 0.31 | 1.66 | 2.56 | 0.19 |
| $C_1$ | Rye | NPK | 2.99 | 0.00 | 2.42 | 1.24 | 0.00 |
| $C_2$ | | PK | 7.03 | 0.46 | 0.76 | 9.25 | 0.61 |
| $C_3$ | | $H_2O$ | 6.84 | 0.03 | 0.80 | 8.55 | 0.04 |

[1] Percentage of dry weight.

[2] Sugar/N = (Total Sugar %) / (Total Nitrogen%).
Starch/n = (Total Starch%) / (Total Nitrogen%).

values when compared to legumes or legume-nonlegume associations which received comparable treatments.

## EXPERIMENTAL PERIOD II - UTILIZATION OF GREEN MANURES IN GROWING SUGAR BEETS

### Materials and Methods

Approximately seventy percent of the total dry weight of plants from six replicated cultures of Experiment I were used as green manure in Experiment II. The dried material from the six replicated cultures were composited. However, Potter and Snyder (1917) found that drying legume green manures lowered their manurial efficiency. The composited lot was divided quantitatively into six equal portions and mixed intimately with sand included in each of 6 four-gallon glazed pots provided with a 3/4-inch drainage hole. These six cultures made up a single series.

In each of the series, one-half of the green manure aliquots were incorporated into clean, unused sand and one-half was incorporated into the sand medium in which the corresponding plants were grown for green manure in Experiment I, and which had received corresponding treatments. Cultures to be used as controls in Experiment II received no green manure, but were watered with tap water. Twelve pots were set up as controls.

A schematic representation of treatments is presented in Table 6. Each treatment except controls was replicated three times. Treatments referred to are the methods of incorporating the manures, whether into clean sand or into used sand.

Experiment II was set up as a split plot design in the greenhouse. Green manures were incorporated by two different methods. One-half of the green manure from any one series of Experiment I was incorporated into clean, unused sand, and one-half was incorporated into the sand medium in which the corresponding manure plants originally grew. These methods were treated as sub-plots of the split plot design.

The green manure aliquots were incorporated into approximately fifteen kilos of moist sand. The crocks were approximately twelve inches in height. In the case of green manures incorporated into clean sand, approximately four inches of sand free of organic matter was placed in the bottom of each crock. Green manure aliquots were mixed intimately with a volume of sand necessary to bring the level of the sand in the crocks to eight inches. The sand-green manure mixture was placed on top of the layer of sand to which no organic matter had been added. A two-inch layer of sand was placed on top the sand-green

TABLE 6

SCHEMATIC REPRESENTATION OF TREATMENTS IN EXPERIMENT II

| Green Manure | Treatment in Expt. I | Series Designation | Sand Used | Manure Added |
|---|---|---|---|---|
| | | | | gms./pot |
| Alfalfa | NPK | 1a-1 | clean | 10.70 |
| | NPK | 1a-2 | used | 10.70 |
| Alfalfa | PK | 2a-1 | clean | 8.00 |
| | PK | 2a-2 | used | 8.00 |
| Alfalfa | $H_2O$ | 3a-1 | clean | 0.51 |
| | $H_2O$ | 3a-2 | used | 0.51 |
| Alfalfa and | NPK | 1b-1 | clean | 13.10 |
| Brome Grass | NPK | 1b-2 | used | 13.10 |
| Alfalfa and | PK | 2b-1 | clean | 7.60 |
| Brome Grass | PK | 2b-2 | used | 7.60 |
| Alfalfa and | $H_2O$ | 3b-1 | clean | 2.14 |
| Brome Grass | $H_2O$ | 3b-2 | used | 2.14 |
| Brome Grass | NPK | 1c-1 | clean | 15.10 |
| | NPK | 1c-2 | used | 15.10 |
| Brome Grass | PK | 2c-1 | clean | 3.58 |
| | PK | 2c-2 | used | 3.58 |
| Brome Grass | $H_2O$ | 3c-1 | clean | 1.16 |
| | $H_2O$ | 3c-2 | used | 1.16 |
| Ladino Clover | NPK | Ia-1 | clean | 12.30 |
| | NPK | Ia-2 | used | 12.30 |
| Ladino Clover | PK | IIa-1 | clean | 11.22 |
| | PK | IIa-2 | used | 11.22 |
| Ladino Clover | $H_2O$ | IIIa-1 | clean | 1.10 |
| | $H_2O$ | IIIa-2 | used | 1.10 |
| Ladino Clover and | NPK | Ib-1 | clean | 19.30 |
| Orchard Grass | NPK | Ib-2 | used | 19.30 |

TABLE 6 (Continued)

| Green Manure | Treat- ment in Expt. I | Series Desig- nation | Sand Used | Manure Added |
|---|---|---|---|---|
| | | | | gms./pot |
| Ladino Clover and | PK | IIb-1 | clean | 10.40 |
| Orchard Grass | PK | IIb-2 | used | 10.40 |
| Ladino Clover and | $H_2O$ | IIIb-1 | clean | 2.29 |
| Orchard Grass | $H_2O$ | IIIb-2 | used | 2.29 |
| Orchard Grass | NPK | Ic-1 | clean | 21.98 |
| | NPK | Ic-2 | used | 21.98 |
| Orchard Grass | PK | IIc-1 | clean | 5.20 |
| | PK | IIc-2 | used | 5.20 |
| Orchard Grass | $H_2O$ | IIIc-1 | clean | 1.30 |
| | $H_2O$ | IIIc-2 | used | 1.30 |
| Vetch | NPK | $A_1$-1 | clean | 23.50 |
| | NPK | $A_1$-2 | used | 23.50 |
| Vetch | PK | $A_2$-1 | clean | 22.26 |
| | PK | $A_2$-2 | used | 22.26 |
| Vetch | $H_2O$ | $A_3$-1 | clean | 4.70 |
| | $H_2O$ | $A_3$-2 | used | 4.70 |
| Vetch and Rye | NPK | $B_1$-1 | clean | 22.60 |
| | NPK | $B_1$-2 | used | 22.60 |
| Vetch and Rye | PK | $B_2$-1 | clean | 25.80 |
| | PK | $B_2$-2 | used | 25.80 |
| Vetch and Rye | $H_2O$ | $B_3$-1 | clean | 6.40 |
| | $H_2O$ | $B_3$-2 | used | 6.40 |
| Rye | NPK | $C_1$-1 | clean | 20.70 |
| | NPK | $C_1$-2 | used | 20.70 |
| Rye | PK | $C_2$-1 | clean | 7.80 |
| | PK | $C_2$-2 | used | 7.80 |
| Rye | $H_2O$ | $C_3$-1 | clean | 3.60 |
| | $H_2O$ | $C_3$-2 | used | 3.60 |
| None | | Control | clean | 0.00 |

manure mixture. This arrangement of green manure placement was done in an effort to reduce drying out of that portion of the culture which contained the green manure. The same general procedure was used for those cultures in which previously used sand was included. However, the first layer of sand which covered the bottom of the crocks, and with which the green manure was mixed, included some root fragments and probably some modular tissue from the plants grown in Experiment I.

All green manure mixtures included in the crocks were wetted with tap water and kept moist for a period of ten days, during which time the organic matter additions were permitted to begin decomposition.

Seeds of sugar beets (Beta vulgaris) were germinated in flats containing moist sand. Ten-day-old seedlings were transplanted on March 3, 1951, to the sand-green manure mixtures and to sand alone. Seedlings were transplanted at the rate of three seedlings per pot. No nutrient solution or fertilizer of any kind was applied except the green manures. All cultures were watered with tap water only.

## Harvesting the Plants

Beginning on May 24, 1951, all sugar beet plants were harvested. During the harvesting operations the sugar beet plants were removed as nearly quantitatively as possible from the sand medium in which they grew. Adhering sand was washed from the roots. Tops and roots of the plants from each culture were weighed to the nearest one-tenth gram and the weights were recorded as green weight yields.

## Preparation for Chemical Analysis

After green weight determinations were recorded for plants for each culture, the larger roots were cut into smaller fractions to facilitate better drying. The plant material was dried at a temperature of approximately 70 degrees Centigrade in a forced draft drying oven. The plant material contained in paper bags was weighed immediately after it was taken from the oven. Oven dry weights were recorded for plants of each culture. Immediately after the dry weight for any one culture was recorded, the dried plant material was ground in a Wiley mill. The plant material was then stored in closed Mason jars until chemical analyses were made.

At the time of chemical analysis the stored plant material was redried to a constant weight and determinations for total nitrogen were made by methods of A.O.A.C. (1940).

## Experimental Results

### Growth Observations

Throughout the growing period of the sugar beet plants, varying degrees of leaf chlorosis were noticeable. It was observed that sugar beet plants which showed earliest growth also showed earliest signs of leaf chlorosis. During the latter part of the growth period a large percentage of the older leaves from the more vigorous plants had dried. These dried leaves were collected and labeled, to be added to the dry matter yield of the particular culture from which they were taken. Therefore at the time of harvest most of the older leaves from the most vigorous plants had been removed. In all cultures except controls and those which received comparatively small amounts of green manure, the older leaves appeared to have grown out from the crown in a nearly horizontal position. The younger leaves on the same plants grew out in an almost erect position, thus forming a sharp angle with the crown.

At the time of harvest, those sugar beet plants which received comparatively large quantities of green manure were larger in size than those plants which received comparatively small quantities of green manure.

A comparison of the relative amounts of growth attained in representative cultures presented in Figures V through XII.

Yield of sugar beets. The average dry weight of sugar beets per culture is presented in Table 7. When comparing the data presented in Table 7 it is recognized that the average dry weight of sugar beets was higher in those cultures in which the manures of any one series were turned under into used sand than when the manures were turned under into clean sand. The differences in yield attributable to methods of turning the green manures was probably due to the presence of residual nitrogen and plant fragments contained in the used sand.

In those cultures in which the manures were turned under into clean sand, the average dry weight yields of beets were highest when the manures consisted of orchard grass grown alone and which received nitrogen in Experiment I. However, yield differences were small between beets fertilized with orchard grass or vetch which received nitrogen in Experiment I.

Figure V. Growth response of sugar beets to designated treatments.

Upper photograph shows cultures intact, whereas the lower photograph shows the same plants which have been taken from the cultures.

| | |
|---|---|
| Ia-1 | green manure consisted of ladino clover which received treatment 1 in Experiment I. |
| IIa-1 | green manure consisted of ladino clover which received treatment 2 in Experiment I. |
| IIIa-1 | green manure consisted of ladino clover which received treatment 3 in Experiment I. |
| 1a-1 | green manure consisted of alfalfa which received treatment 1 in Experiment I. |
| 2a-1 | green manure consisted of alfalfa which received treatment 2 in Experiment I. |
| 3a-1 | green manure consisted of alfalfa which received treatment 3 in Experiment I. |

All green manures were turned under into clean sand in Experiment II.

| Ladino Clover | | |
|---|---|---|
| NPK | PK | $H_2O$ |
| Weight of Manure Added | | |
| 12.30 | 11.22 | 1.10 |

| Alfalfa | | |
|---|---|---|
| NPK | PK | $H_2O$ |
| Weight of Manure Added | | |
| 10.70 | 8.00 | 0.51 |

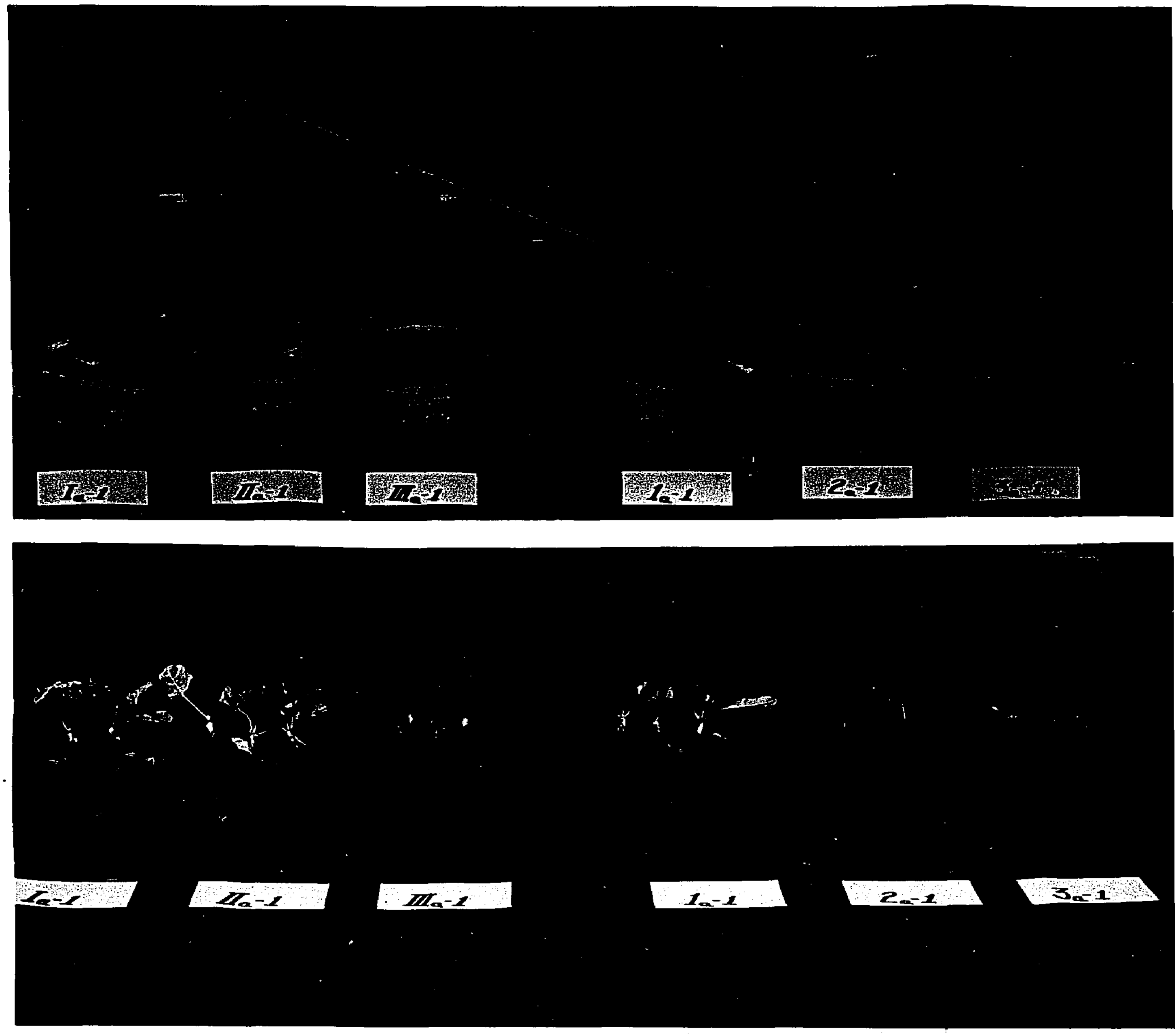


Figure V. Growth comparison of sugar beets from green manures turned into clean sand.

Figure VI. Growth response of sugar beets to designated treatments.

Upper photograph shows cultures intact, whereas the lower photograph shows the same plants which have been taken from the cultures.

| | |
|---|---|
| 1b-1 | green manure consisted of alfalfa-brome grass mixture which received treatment 1 in Experiment I. |
| 2b-1 | green manure consisted of alfalfa-brome grass mixture which received treatment 2 in Experiment I. |
| 3b-1 | green manure consisted of alfalfa-brome grass mixture which received treatment 3 in Experiment I. |
| Ib-1 | green manure consisted of ladino clover-orchard grass mixture which received treatment 1 in Experiment I. |
| IIb-1 | green manure consisted of ladino clover-orchard grass mixture which received treatment 2 in Experiment I. |
| IIIb-1 | green manure consisted of ladino clover-orchard grass mixture which received treatment 3 in Experiment I. |

All green manures were turned under into clean sand in Experiment II.

| Alfalfa and Brome Grass | | | Ladino Clover and Orchard Grass | | |
|---|---|---|---|---|---|
| NPK | PK | $H_2O$ | NPK | PK | $H_2O$ |
| Weight of Manure Added | | | Weight of Manure Added | | |
| 13.10 | 7.60 | 2.14 | 10.30 | 10.40 | 2.29 |

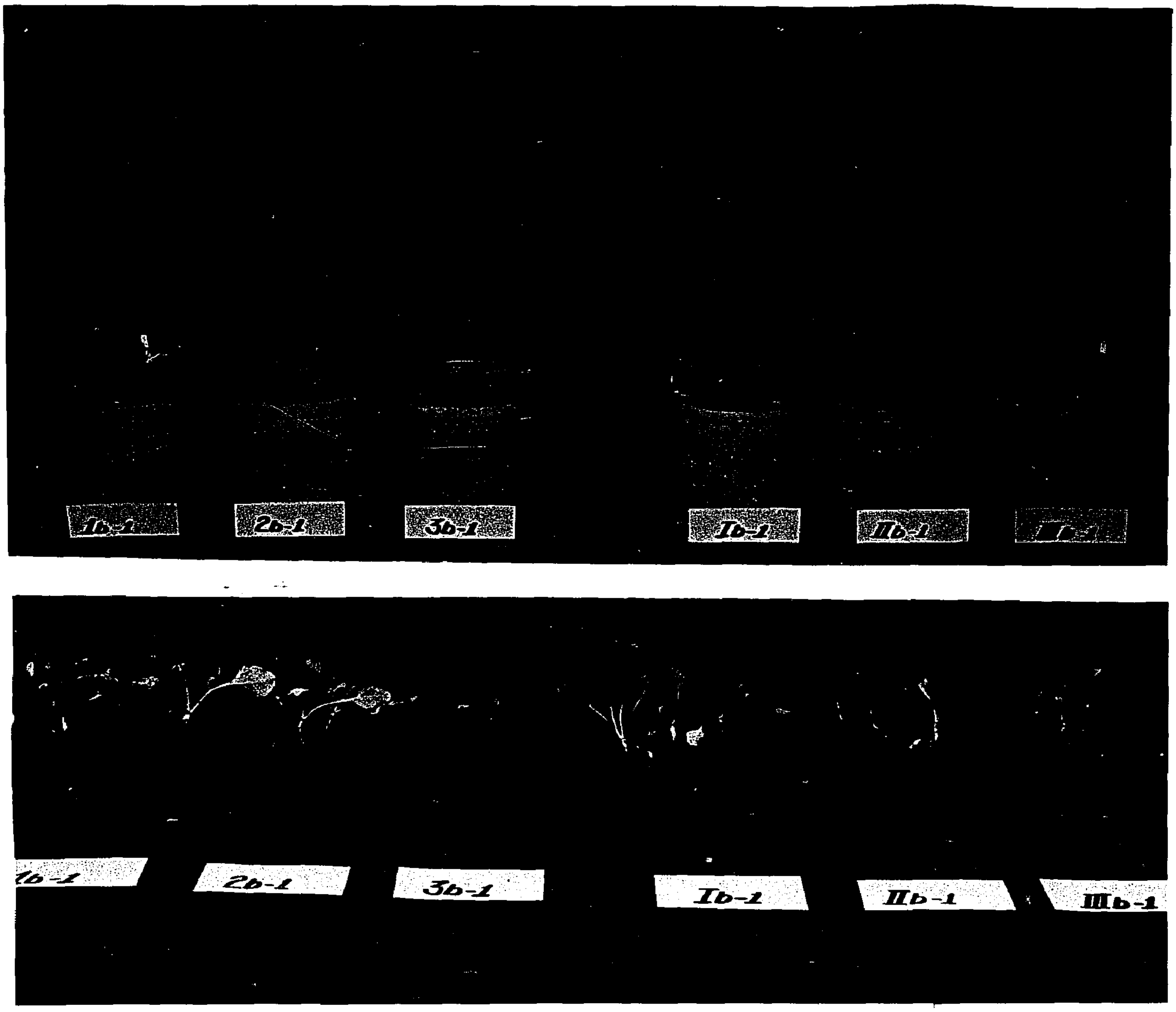


Figure VI. Growth comparison of sugar beets fertilized with green manure turned into clean sand.

Figure VII. Growth response of sugar beets to designated treatments.

Upper photograph shows cultures intact, whereas the lower photograph shows the same plants which have been taken from the cultures.

| | |
|---|---|
| $B_1$-1 | green manure consisted of vetch-rye mixture which received treatment 1 in Experiment I. |
| $B_2$-1 | green manure consisted of vetch-rye mixture which received treatment 2 in Experiment I. |
| $B_3$-1 | green manure consisted of vetch-rye mixture which received treatment 3 in Experiment I. |
| $A_1$-1 | green manure consisted of vetch which received treatment 2 in Experiment I. |
| $A_2$-1 | green manure consisted of vetch which received treatment 2 in Experiment I. |
| $A_3$-1 | green manure consisted of vetch which received treatment 3 in Experiment I. |

All green manures were turned under into clean sand in Experiment II.

Figure VIII. Growth response of sugar beets to designated treatments.

Upper photograph shows cultures intact, whereas the lower photograph shows the same plants which have been taken from the cultures.

$C_1$-1 green manure consisted of rye which received treatment 1 in Experiment I.

$C_2$-1 green manure consisted of rye which received treatment 2 in Experiment I.

$C_3$-1 green manure consisted of rye which received treatment 3 in Experiment I.

Ic-1 green manure consisted of orchard grass which received treatment 1 in Experiment I.

IIc-1 green manure consisted of orchard grass which received treatment 2 in Experiment I.

IIIc-1 green manure consisted of orchard grass which received treatment 3 in Experiment I.

All green manures were turned under into clean sand in Experiment II.

| Rye | | | Orchard Grass | | |
|---|---|---|---|---|---|
| NPK | PK | $H_2O$ | NPK | PK | $H_2O$ |
| Weight of Manure Added | | | Weight of Manure Added | | |
| 20.70 | 7.80 | 3.60 | 21.98 | 5.20 | 1.30 |

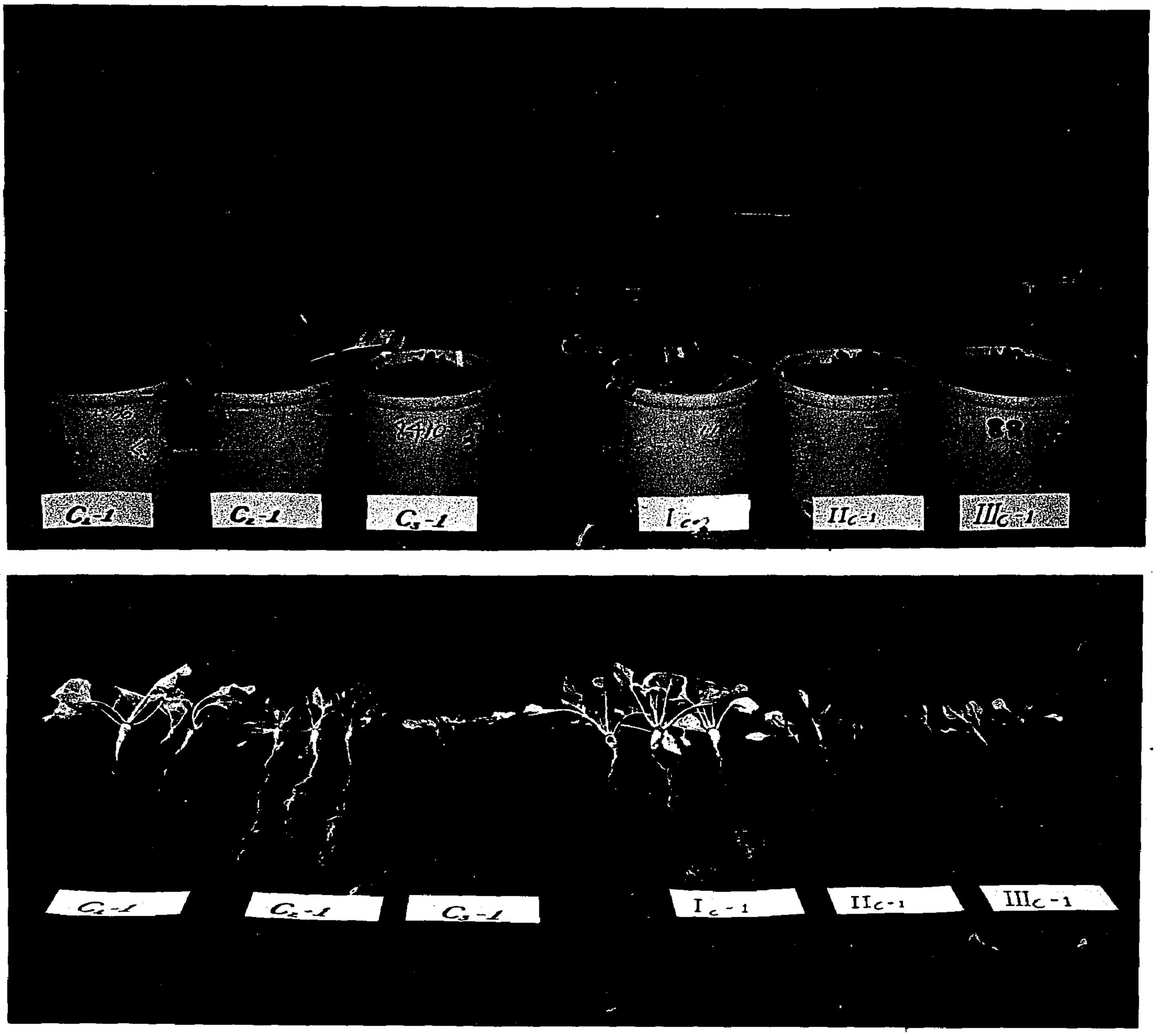

Figure VIII. Growth response of sugar beets fertilized with green manures turned into clean sand.

| Ladino Clover | | | Alfalfa | | |
|---|---|---|---|---|---|
| NPK | PK | $H_2O$ | NPK | PK | $H_2O$ |
| Weight of | Manure | Added | Weight of | Manure | Added |
| 12.30 | 11.22 | 1.10 | 10.70 | 8.00 | 0.51 |

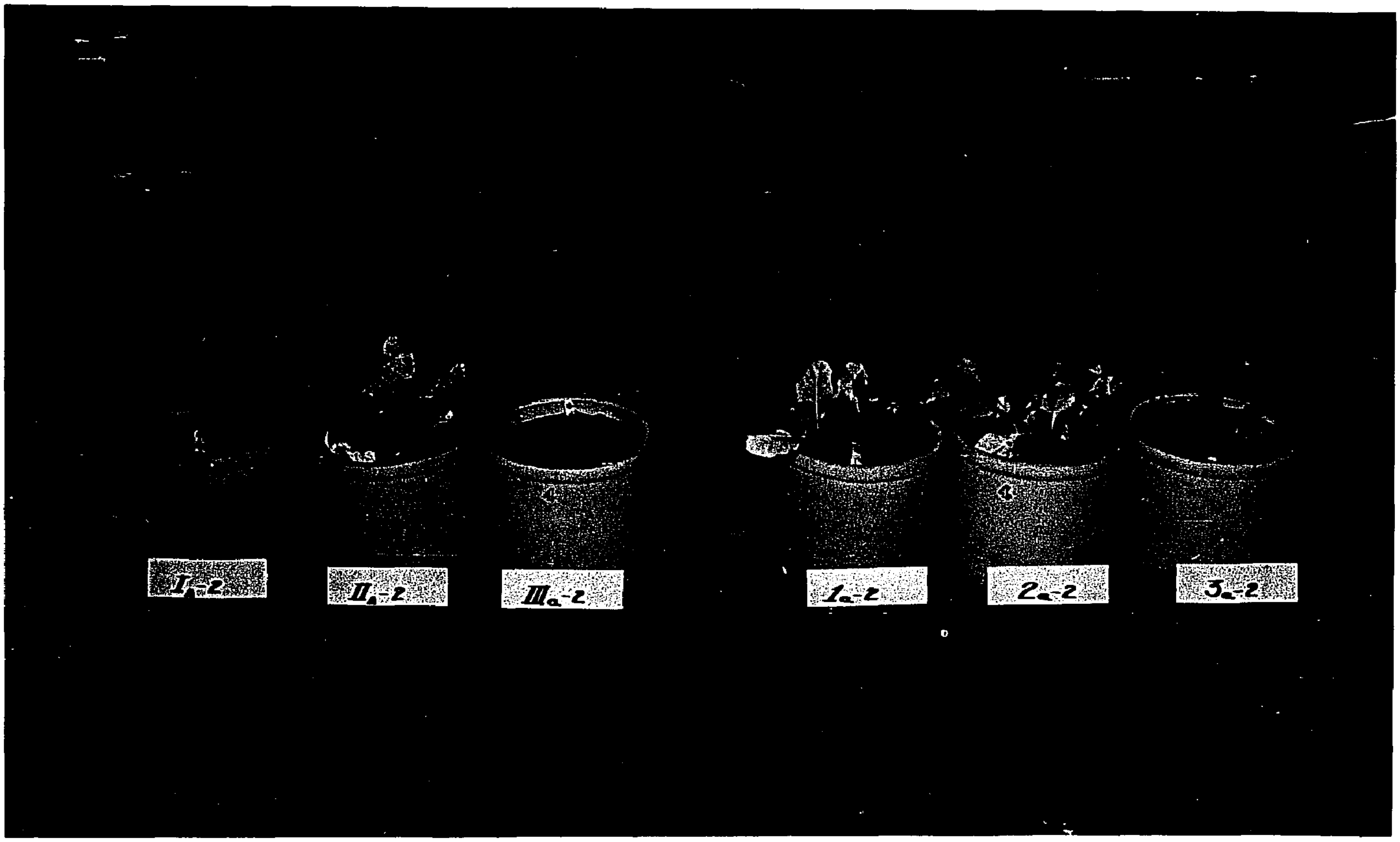


Figure IX. Growth response of sugar beets to green manures turned into clean sand.

| Ladino Clover Orchard Grass | | |
|---|---|---|
| NPK | PK | $H_2O$ |
| Weight of Manure Added | | |
| 19.30 | 10.40 | 2.29 |

| Alfalfa and Brome Grass | | |
|---|---|---|
| NPK | PK | $H_2O$ |
| Weight of Manure Added | | |
| 13.10 | 7.60 | 2.14 |


Figure X. Growth response of sugar beets to green manures turned into used sand.

| Vetch and Rye | | | Vetch | | |
| --- | --- | --- | --- | --- | --- |
| NPK | PK | $H_2O$ | NPK | PK | $H_2O$ |
| Weight of Manure Added | | | Weight of Manure Added | | |
| 22.60 | 25.80 | 6.40 | 23.50 | 22.26 | 4.70 |


Figure XI. Growth response of sugar beets to green manures turned into used sand.

| Rye | | | Orchard Grass | | |
|---|---|---|---|---|---|
| NPK | PK | $H_2O$ | NPK | PK | $H_2O$ |
| Weight of Manure Added | | | Weight of Manure Added | | |
| 20.70 | 7.80 | 3.60 | 21.98 | 5.20 | 1.30 |


Figure XII. Growth response of sugar beets to green manures turned under into used sand.

AVERAGE DRY WEIGHT YIELDS OF SUGAR BEETS PER CULTURE

| Fertilizer Treatment | | Sand Used | Manure Added | Average Dry Matter Yield of Beets | |
|---|---|---|---|---|---|
| Character of Manure | Treatment in Expt. I | | | Total Weight | Increase Over Control |
| | | | gms. | gms. | gms. |
| Alfalfa | NPK | clean | 10.70 | 10.40 | 9.14 |
| | NPK | used | 10.70 | 25.00 | 23.74 |
| | PK | clean | 8.00 | 6.20 | 4.94 |
| | PK | used | 8.00 | 15.30 | 14.04 |
| | $H_2O$ | clean | 0.51 | 0.76 | -0.50 |
| | $H_2O$ | used | 0.51 | 1.00 | -0.20 |
| Alfalfa and Brome Grass | NPK | clean | 13.10 | 12.10 | 10.84 |
| | NPK | used | 13.10 | 24.70 | 23.44 |
| | PK | clean | 7.60 | 4.00 | 2.74 |
| | PK | used | 7.60 | 9.50 | 8.24 |
| | $H_2O$ | clean | 2.14 | 1.60 | 0.35 |
| | $H_2O$ | used | 2.14 | 3.00 | 1.74 |
| Brome Grass | NPK | clean | 15.10 | 16.70 | 15.44 |
| | NPK | used | 15.10 | 25.60 | 24.34 |
| | PK | clean | 3.58 | 0.73 | -0.53 |
| | PK | used | 3.58 | 1.10 | -0.16 |
| | $H_2O$ | clean | 1.16 | 0.63 | -0.63 |
| | $H_2O$ | used | 1.16 | 0.78 | -0.48 |
| Ladino Clover | NPK | clean | 12.30 | 17.10 | 15.84 |
| | NPK | used | 12.30 | 26.50 | 25.24 |
| | PK | clean | 11.22 | 4.90 | 3.64 |
| | PK | used | 11.22 | 17.80 | 16.54 |
| | $H_2O$ | clean | 1.10 | 0.51 | -0.75 |
| | $H_2O$ | used | 1.10 | 0.87 | -0.39 |

TABLE 7 (Continued)

| Fertilizer Treatment | | Sand Used | Manure Added | Average Dry Matter Yield of Beets | |
|---|---|---|---|---|---|
| Character of Manure | Treatment in Expt. I | | | Total Weight | Increase Over Control |
| | | | gms. | gms. | gms. |
| Ladino Clover and Orchard Grass | NPK | clean | 19.30 | 20.10 | 18.84 |
| | NPK | used | 19.30 | 36.80 | 35.54 |
| | PK | clean | 10.40 | 5.10 | 3.84 |
| | PK | used | 10.40 | 9.60 | 8.34 |
| | $H_2O$ | clean | 2.29 | 2.10 | 0.84 |
| | $H_2O$ | used | 2.29 | 2.80 | 1.54 |
| Orchard Grass | NPK | clean | 21.98 | 24.70 | 23.44 |
| | NPK | used | 21.98 | 36.40 | 35.14 |
| | PK | clean | 5.20 | 1.10 | -0.16 |
| | PK | used | 5.20 | 1.90 | 0.64 |
| | $H_2O$ | clean | 1.30 | 0.49 | -0.77 |
| | $H_2O$ | used | 1.30 | 0.73 | -0.53 |
| Vetch | NPK | clean | 23.50 | 24.60 | 23.34 |
| | NPK | used | 23.50 | 53.70 | 52.44 |
| | PK | clean | 22.26 | 24.10 | 22.84 |
| | PK | used | 22.26 | 34.30 | 33.04 |
| | $H_2O$ | clean | 4.70 | 2.10 | 0.84 |
| | $H_2O$ | used | 4.70 | 2.70 | 1.44 |
| Vetch and Rye | NPK | clean | 22.60 | 22.20 | 20.94 |
| | NPK | used | 22.60 | 24.40 | 23.14 |
| | PK | clean | 25.80 | 23.90 | 22.64 |
| | PK | used | 25.80 | 35.60 | 34.34 |
| | $H_2O$ | clean | 6.40 | 3.10 | 1.84 |
| | $H_2O$ | used | 6.40 | 5.20 | 3.94 |

TABLE 7 (Continued)

| Fertilizer Treatment | | | | Average Dry Matter Yield of Beets | |
|---|---|---|---|---|---|
| Character of Manure | Treat- ment in Expt. I | Sand Used | Manure Added | Total Weight | Increase Over Control |
| | | | gms. | gms. | gms. |
| Rye | NPK | clean | 20.70 | 19.10 | 17.84 |
| | NPK | used | 20.70 | 29.50 | 28.24 |
| | PK | clean | 7.80 | 2.60 | 1.34 |
| | PK | used | 7.80 | 4.80 | 3.54 |
| | $H_2O$ | clean | 3.60 | 1.30 | 0.04 |
| | $H_2O$ | used | 3.60 | 2.90 | 1.64 |
| Control | -- | clean | 0.00 | 1.26 | -- |

Difference required[1] for significance.

Comparisons between treatments (NPK and PK) - 3.25.
Comparisons of treatments x methods (Used vs. Clean Sand) - 5.87.

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[1] At 5 percent level.

In every case, the average dry weight yield of beets was higher when manures consisted of plant material which received combined nitrogen or fixed nitrogen than when manures used received no nitrogen.

It is significant to note that in the cases where the manures were turned into clean sand or used sand the average dry weight yields of beets were not always commensurate with the amounts of manure applied. Since the amounts of nitrogen and the amounts of manure added to each series varied greatly, the yields of sugar beets cannot be considered as strictly comparable on the basis of the amount of manure added. Therefore, these yields are merely indicative of the effects of the different manurial materials and the methods of turning, whether into used or unused sand. A positive correlation of 0.988 was obtained between the milligrams of nitrogen recovered in the sugar beets and the milligrams of dry matter produced. Also a positive correlation value of 0.973 was obtained between the milligrams of nitrogen applied as manure and the dry matter yield of beets. These data indicate that the yield of sugar beets was contingent upon both the quantity of nitrogen added as manure and the quantity of nitrogen recovered from the added manures.

Nitrogen recovery of green manures turned into clean sand. Data relating to the percentage recovery of added nitrogen by sugar beets are presented in Table 8. The percentage recovery of added nitrogen by sugar beets was in all cases highest, from any one series, when the largest quantities of nitrogen were applied, in which case the manures used received NPK treatment in Experiment I. The percentage recovery of nitrogen was lowest in the series which involved manures that received only tap water in Experiment I. Whereas, except in the series which involved ladino clover-orchard grass in associated growth as green manure, the percentage recovery of nitrogen by beets was intermediate when manures used received PK treatment. However, the percentage recovery of nitrogen from green manures which were turned into clean sand was not closely associated with the quantity of nitrogen incorporated. A positive correlation value of 0.979, however, was obtained between the milligrams of nitrogen applied as manure and the milligrams of nitrogen recovered by the sugar beets. When large quantities of nitrogen were applied as manure the quantities of nitrogen recovered by the beets was also large. Conversely, when the quantities of nitrogen applied were small the

TABLE 8

RELATIONSHIPS OF THE PERCENTAGE RECOVERY OF ADDED NITROGEN FROM GREEN MANURES TURNED INTO CLEAN SAND

| Fertilizer Treatment: Character of Manure | Fertilizer Treatment: Treatment in Expt. I | Manure Added | Nitrogen in Manure | Nitrogen Added as Manure | Nitrogen in Beets: Total | | Nitrogen Increase Over Control | Recovery of Nitrogen |
|---|---|---|---|---|---|---|---|---|
| | | gms. | %* | mgs. | %* | mgs. | mgs. | %** |
| Alfalfa | NPK | 10.70 | 3.34 | 357.3 | 1.18 | 122.7 | 101.3 | 28.4 |
| | PK | 8.00 | 3.02 | 241.6 | 1.29 | 80.0 | 58.6 | 24.3 |
| | $H_2O$ | 0.51 | 3.15 | 16.1 | 1.38 | 10.5 | -10.9 | -67.7 |
| Alfalfa and Brome Grass | NPK | 13.10 | 2.86 | 374.7 | 1.11 | 134.3 | 112.9 | 30.1 |
| | PK | 7.60 | 2.79 | 212.0 | 1.14 | 45.6 | 24.2 | 11.4 |
| | $H_2O$ | 2.14 | 1.52 | 32.5 | 1.35 | 21.6 | 00.2 | 6.2 |
| Brome Grass | NPK | 15.10 | 2.72 | 410.7 | 1.01 | 168.7 | 147.3 | 35.8 |
| | PK | 3.58 | 0.72 | 25.8 | 1.49 | 10.9 | -10.5 | -40.7 |
| | $H_2O$ | 1.16 | 1.18 | 13.7 | 1.56 | 9.8 | -11.6 | -84.7 |
| Ladino Clover | NPK | 12.30 | 3.48 | 428.0 | 1.24 | 212.0 | 190.6 | 44.5 |
| | PK | 11.22 | 2.96 | 332.1 | 1.33 | 65.2 | 43.8 | 13.2 |
| | $H_2O$ | 1.10 | 2.01 | 22.1 | 1.26 | 6.4 | -15.0 | -67.8 |

TABLE 8 (Continued)

| Fertilizer Treatment | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Character of Manure | Treatment in Expt. I | Manure Added | Nitrogen in Manure | Nitrogen Added As Manure | Nitrogen in Beets Total | | Nitrogen Increase Over Control | Recovery of Nitrogen |
| | | gms. | %* | mgs. | %* | mgs. | mgs. | %** |
| Ladino Clover and Orchard Grass | NPK | 19.30 | 2.69 | 519.2 | 1.11 | 223.1 | 201.7 | 38.8 |
| | PK | 10.40 | 1.94 | 201.8 | 1.10 | 56.1 | 34.7 | 17.2 |
| | $H_2O$ | 2.29 | 1.49 | 34.1 | 1.43 | 30.0 | 8.6 | 25.2 |
| Orchard Grass | NPK | 21.98 | 2.70 | 593.5 | 1.15 | 284.1 | 262.7 | 44.3 |
| | PK | 5.20 | 0.58 | 30.2 | 1.35 | 14.9 | -6.5 | -21.5 |
| | $H_2O$ | 1.30 | 1.36 | 17.7 | 1.42 | 7.0 | -14.0 | -79.1 |
| Vetch | NPK | 23.50 | 3.20 | 752.0 | 0.91 | 223.9 | 202.5 | 26.9 |
| | PK | 22.26 | 3.22 | 716.8 | 1.14 | 274.7 | 253.3 | 35.3 |
| | $H_2O$ | 4.70 | 2.37 | 111.4 | 1.40 | 29.4 | 8.0 | 7.2 |
| Vetch and Rye | NPK | 22.60 | 2.56 | 578.6 | 0.97 | 215.3 | 193.9 | 33.5 |
| | PK | 25.80 | 2.47 | 637.3 | 1.05 | 251.0 | 229.6 | 36.0 |
| | $H_2O$ | 6.40 | 1.66 | 106.2 | 1.66 | 51.4 | 30.0 | 28.2 |

TABLE 8 (Continued)

| Fertilizer Treatment | | Manure Added | Nitrogen in Manure | Nitrogen Added as Manure | Nitrogen in Beets | | Nitrogen Increase Over Control | Recovery of Nitrogen |
|---|---|---|---|---|---|---|---|---|
| Character of Manure | Treatment in Expt. I | | | | Total | | | |
| | | gms. | %* | mgs. | %* | mgs. | mgs. | %** |
| Rye | NPK | 20.70 | 2.42 | 500.9 | 0.94 | 179.5 | 158.1 | 31.6 |
| | PK | 7.80 | 0.76 | 59.3 | 1.39 | 36.1 | 14.7 | 24.8 |
| | $H_2O$ | 3.60 | 0.80 | 28.8 | 1.50 | 19.50 | -1.9 | -66.0 |
| Control | -- | -- | -- | -- | 1.70 | 21.4 | -- | -- |

%* - percentage of dry matter.

%** - percentage recovery = (mgs. of nitrogen over control) / (mgs. of nitrogen added as manure) x 100.

quantities of nitrogen recovered was also small. In fact, when quantities of nitrogen applied were below thirty milligrams per pot the milligrams of nitrogen recovered in the beets was a negative value below that of the controls, indicating an inhibitory influence on the green manure.

Under the conditions of this investigation it was impossible to differentiate between the nitrogen recovered from manures turned into used sand and the nitrogen actually recovered from plant fragments and residual nitrogen in the used sand. It is expected that nitrogen from plant fragments would enhance the total quantity of available nitrogen. Therefore, no consideration was given to the percentage recovery of added nitrogen by beets where the manures were turned into used sand.

Manurial efficiency index of manures turned into clean sand. Regardless of the quantity of green manure added, when the percentage recovery of added nitrogen was high the plants made efficient growth as measured by the dry matter produced per gram of nitrogen in the green manures. Likewise, when the percentage of nitrogen recovered from the green manure was small, the growth of plants per gram of nitrogen applied was also small.

That quantity of nitrogen actually used in the production of a unit dry weight of sugar beets was determined by considering the nitrogen percentage of the sugar beets, such that the higher the percentage of nitrogen in the harvested beets the greater the quantity of nitrogen used in the production of a unit weight of sugar beets. The percentage of nitrogen in the dry matter of the beets in each culture is presented in Tables 8 and 9. However, manurial efficiency indices are indicative of the quantity of dry matter in beets produced per unit weight of nitrogen contained in the green manures, rather than dry matter in beets produced per unit weight of nitrogen contained in the harvested beets.

$$\frac{\text{Dry matter yield of beets over control}}{\text{Nitrogen added as manure}} = \text{Efficiency index}$$

The quantity of dry matter in beets produced per unit weight of nitrogen contained in the green manures showed a positive correlation of 0.957 percentage recovery by beets of the nitrogen contained in the several manures. The percentage of the total nitrogen added as green manure that was recovered by the sugar beets varied with the quantity of nitrogen applied as manure which probably was contingent upon the plant species used as manure as well as the fertilizer treatment

TABLE 9

WEIGHT OF SUGAR BEETS PRODUCED PER UNIT OF NITROGEN ADDED AS GREEN MANURE TURNED UNDER INTO CLEAN SAND (MANURIAL EFFICIENCY INDEX)

| Character of Manure | Nitrogen Added as Manure | Average Dry Weight of Beets | | Efficiency Index* | Nitrogen in Beets | | Recovery of Added Nitrogen %** |
|---|---|---|---|---|---|---|---|
| | | Total | Over Controls | | % | mgs. | |
| | mgs. | gms. | gms. | | | | |
| Alfalfa | 357.3 | 10.40 | 9.14 | 25.6 | 1.18 | 122.7 | 28.4 |
| | 241.6 | 6.20 | 4.94 | 20.4 | 1.29 | 80.0 | 24.3 |
| | 16.1 | 0.76 | -0.50 | -31.1 | 1.38 | 10.5 | -67.7 |
| Alfalfa and | 374.7 | 12.10 | 10.84 | 28.9 | 1.11 | 134.3 | 30.1 |
| Brome Grass | 212.0 | 4.00 | 2.74 | 12.9 | 1.14 | 45.6 | 11.4 |
| | 32.5 | 1.60 | 0.34 | 10.5 | 1.35 | 21.6 | 6.2 |
| Brome Grass | 410.7 | 16.70 | 15.44 | 37.6 | 1.01 | 168.7 | 35.8 |
| | 25.8 | 0.73 | -0.53 | -20.5 | 1.49 | 10.9 | -40.7 |
| | 13.7 | 0.63 | -0.63 | -46.0 | 1.56 | 9.8 | -84.7 |
| Ladino Clover | 428.0 | 17.10 | 15.84 | 37.0 | 1.24 | 212.0 | 44.5 |
| | 332.1 | 4.90 | 3.64 | 11.0 | 1.33 | 65.2 | 13.2 |
| | 22.1 | 0.51 | -0.75 | -33.9 | 1.26 | 6.4 | -67.8 |
| Ladino Clover | 519.2 | 20.10 | 18.84 | 36.3 | 1.11 | 223.1 | 38.8 |
| and Orchard | 201.8 | 5.10 | 3.84 | 19.0 | 1.10 | 56.1 | 17.2 |
| Grass | 34.1 | 2.10 | 0.84 | 24.6 | 1.43 | 30.0 | 25.2 |

TABLE 9 (Continued)

| Character of Manure | Nitrogen Added as Manure | Average Dry Weight of Beets | | Efficiency Index* | Nitrogen in Beets | | Recovery of Added Nitrogen %** |
|---|---|---|---|---|---|---|---|
| | | Total | Over Controls | | % | mgs. | |
| | mgs. | gms. | gms. | | | | |
| Orchard Grass | 593.5 | 24.70 | 23.44 | 39.5 | 1.15 | 284.1 | 44.3 |
| | 30.2 | 1.10 | -0.16 | -4.4 | 1.35 | 14.9 | -21.5 |
| | 17.7 | 0.49 | -0.77 | -43.5 | 1.42 | 7.0 | -79.1 |
| Vetch | 752.0 | 24.60 | 23.34 | 31.0 | 0.91 | 223.9 | 26.9 |
| | 716.8 | 24.10 | 22.84 | 31.9 | 1.14 | 274.7 | 35.3 |
| | 111.4 | 2.10 | 0.84 | 7.5 | 1.40 | 29.4 | 7.2 |
| Vetch and Rye | 578.6 | 22.20 | 20.94 | 36.2 | 0.97 | 215.3 | 33.5 |
| | 637.3 | 23.90 | 22.64 | 35.5 | 1.05 | 251.0 | 36.0 |
| | 106.2 | 3.10 | 1.84 | 17.3 | 1.66 | 51.4 | 28.2 |
| Rye | 500.9 | 19.10 | 17.84 | 35.6 | 0.94 | 179.5 | 31.6 |
| | 59.3 | 2.60 | 1.34 | 22.6 | 1.39 | 36.1 | 24.8 |
| | 28.8 | 1.30 | 0.04 | 1.4 | 1.50 | 19.5 | -66.0 |
| Control | -- | 1.26 | -- | -- | 1.70 | 21.4 | -- |

* Efficiency Index = (mgs. of dry matter in beets over control) / (mgs. of nitrogen added as manure)

** Percentage recovery = (mgs. of nitrogen recovered over control) / (mgs. of nitrogen added as manure) x 100.

to which the manures were exposed during their growth. A positive correlation of 0.979 was obtained between the milligrams of nitrogen applied and the milligrams of nitrogen recovered. A suitable index then to manurial efficiency of the several manures is the unit quantity of dry matter produced per unit of nitrogen contained in the cultures and provided by the green manures. Unit measurements of the dry weight of sugar beets and the unit measurements of nitrogen required were expressed in milligrams.

In all cases the application of manures which received NPK treatments in Experiment I resulted in the highest dry matter yield of beets over controls per unit weight of nitrogen contained in the cultures. The application of manures which received Shive's solution less nitrogen (PK treatment) resulted in intermediate dry matter yields of beets per unit of nitrogen added as manure. Dry matter yields of beets over controls per unit of nitrogen added as manure was lowest when manures used received only tap water in Experiment I. The highest yields of sugar beets over controls were consistently obtained from cultures where the largest quantities of nitrogen were added as green manure. Whether manurial efficiency of the several manures turned into clean sand was measured on the basis of percentage recovery of added nitrogen, or on the basis of dry matter yield of beets per unit of nitrogen added as manure, the value of green manures as a fertilizer for sugar beets was comparable. Data showing the relationships between the dry matter yield of beets per unit of nitrogen added and percentage recovery are presented in Table 9. Data in Table 9 also bring out the relationship between the dry matter yield of beets and the quantity of nitrogen recovered in beets. From these data it appears that the use of green manures of such character that the percentage recovery of nitrogen is high, and the presence of a sufficient quantity of nitrogen provided by the green manures are both necessary in order to obtain a large growth of sugar beets fertilized with green manures.

As seen in Table 9, the increase in dry matter yield of sugar beets over controls was in some cases a negative value. Under such conditions it appears that the green manures were of such character and of such small quantity that a depressive effect on growth resulted.

Differences in the character of the several green manures were measured in terms of an existing ratio of carbohydrates and nitrogen present in the plants used as green manures. Carbohydrates included total sugars and starch. Total nitrogen was considered. The carbohydrate-nitrogen ratios of the several green manures varied with the treatments in Experiment I, and with individual plant species used as green manure. No significant correlation was found between the percentage recovery of added nitrogen and the carbohydrate-nitrogen ratios of the manures. No close association was found between the dry matter yield of sugar beets and the carbohydrate-nitrogen relationships in the green manures. What differences there were in the character of the green manures as measured by the existing ratios of carbohydrates to nitrogen and which might have influenced nitrogen recovery and dry matter yield of sugar beets, seemingly was overshadowed by the effect of some other factor or factors. Those data which show the relationships between the carbohydrate-nitrogen ratios of the green manures and the percentage recovery of added nitrogen are presented in Table 10.

TABLE 10

RELATIONSHIPS OF CARBOHYDRATE-NITROGEN RATIOS OF MANURES TURNED INTO CLEAN SAND AND THE PERCENTAGE RECOVERY OF ADDED NITROGEN

| Series Designation | Species | Analysis of Green Manure: Total Carbohydrates | Nitrogen | Carbohydrate-Nitrogen Ratio | Recovery of Added Nitrogen |
|---|---|---|---|---|---|
| | | %* | %* | | %** |
| 1a-1 | Alfalfa | 10.47 | 3.34 | 3.13 | 28.4 |
| 2a-1 | Alfalfa | 13.40 | 3.02 | 4.35 | 24.3 |
| 3a-1 | Alfalfa | 6.91 | 3.15 | 2.19 | -67.7 |
| 1b-1 | Alfalfa | 4.61 | 2.86 | 1.60 | 30.1 |
| 2b-1 | and Brome | 10.67 | 2.79 | 3.81 | 11.4 |
| 3b-1 | Grass | 10.06 | 1.52 | 6.60 | 6.2 |
| 1c-1 | Brome | 3.85 | 2.72 | 1.41 | 35.8 |
| 2c-1 | Grass | 9.35 | 0.72 | 13.05 | -40.7 |
| 3c-1 | | 11.99 | 1.18 | 10.17 | -84.7 |
| Ia-1 | Ladino | 5.07 | 3.48 | 1.45 | 44.5 |
| IIa-1 | Clover | 5.27 | 2.96 | 1.77 | 13.2 |
| IIIa-1 | | 5.77 | 2.01 | 2.78 | -67.8 |
| Ib-1 | Ladino and | 3.04 | 2.96 | 1.12 | 38.8 |
| IIb-1 | Orchard | 5.44 | 1.94 | 2.80 | 17.2 |
| IIIb-1 | Grass | 6.42 | 1.49 | 4.30 | 25.2 |
| Ic-1 | Orchard | 2.89 | 2.70 | 1.07 | 44.3 |
| IIc-1 | Grass | 5.44 | -.58 | 9.29 | -21.5 |
| IIIc-1 | | 5.29 | 1.36 | 3.86 | -79.1 |
| $A_1$ | Vetch | 3.18 | 3.20 | 0.98 | 26.9 |
| $A_2$ | | 3.17 | 3.22 | 0.98 | 35.3 |
| $A_3$ | | 1.19 | 2.37 | 0.50 | 7.2 |

TABLE 10 (Continued)

| Series Designation | Species | Analysis of Green Manure: Total Carbohydrates | Nitrogen | Carbohydrate-Nitrogen Ratio | Recovery of Added Nitrogen |
|---|---|---|---|---|---|
| | | %* | %* | | %** |
| $B_1$ | Vetch and Rye | 4.31 | 2.56 | 1.68 | 33.5 |
| $B_2$ | | 3.67 | 2.47 | 1.51 | 36.0 |
| $B_3$ | | 4.56 | 1.66 | 2.74 | 28.2 |
| $C_1$ | Rye | 2.99 | 2.42 | 1.24 | 31.6 |
| $C_2$ | | 7.49 | 0.76 | 9.87 | 24.8 |
| $C_3$ | | 6.87 | 0.80 | 8.58 | -66.0 |

* Percentage of dry matter.

** Percentage recovery = (mgs. of nitrogen over control) / (mgs. of nitrogen added as manure) x 100.

# DISCUSSION

It is conceded that photosynthesis is responsible for the production of carbohydrates, a potential source of energy within a green plant; and the processes of respiration result in the release of stored energy. Both of these processes are identified with the growing plant. Synthesis of proteinaceous tissue is supported by chemical energy derived from stored carbohydrates. The formation of amino acids, and in turn, protein tissue, involves the utilization of certain organic acids which themselves are partial oxidation products of sugars. As the reduction of absorbed nitrates to ammonia is supported by energy derived from stored carbohydrates, sugars are concomitantly oxidized to organic acids which may function as the carbonaceous base for amino acid formation (Miller, 1938). As a result of such relationships between energy supply and synthesis, there sometimes arises an inverse relationship between carbohydrate reserves and the nitrogenous constituents and a narrow carbohydrate-nitrogen ratio. It is probable that certain groups of plants utilize a greater proportion of carbohydrates for energy in synthesis of nitrogenous plant constituents per unit of nitrogen absorbed than others. All grass species included in this experiment followed similar trends in carbohydrate-nitrogen relationships. As the nitrogen percentage of the plants increased the carbohydrate-nitrogen ratio became progressively narrow except in the plants which received only tap water.

When one considers the carbohydrate-nitrogen relationships of legumes grown in pure cultures, alfalfa showed the narrowest ratio in those plants which received only tap water, and widest in plants which received Shive's solution minus nitrogen; the percent nitrogen was highest in plants which received Shive's complete nutrient solution. Carbohydrate-nitrogen relationships in ladino clover were widest in those plants which received only tap water and narrowest in cultures which received Shive's complete nutrient solution. These relationships present in vetch were in all cases very narrow whether the plants received combined nitrogen or depended upon fixed nitrogen. The very low carbohydrate content which accompanied the high nitrogen content of vetch conceivably indicates a very low efficiency index for carbohydrate utilization in synthesis of the nitrogenous constituents, yet nitrogen was very high.

Quantities of nitrogen applied to the sugar beet cultures varied with the amounts of green manures. Manurial efficiency was measured in terms of average dry weight yield of beets in milligrams per milligram of nitrogen added as manure. Various weights of nitrogen were required to produce a unit dry weight of sugar beets. The variations in quantity of nitrogen required were peculiar to the kind of manure used and fertilizer treatment received during the production of the manures. By definition, the quantity of nitrogen available to beets in each culture would be equal to the weight of nitrogen applied times the percentage of the total nitrogen recoverable from green manures. Dry matter yield of sugar beets was contingent upon the quantity of nitrogen added as manure and the percentage recovery of the added nitrogen. The percentage of the total nitrogen recovered from green manures, however, would be directly associated with the rate and extent of green manure decomposition. Decomposition of organic matter has been ascribed to microbial activity and the factors which regulate such activity. Waksman and Tenny (1927) contended that when plant residues contain approximately 1.7 percent nitrogen, there was sufficient nitrogen to enable the microorganisms to bring about active decomposition, without any additional nitrogen being supplied from an outside source or without nitrogen being liberated as ammonia until a sizable reduction in bulk of added material had occurred. Rege (1927) contended further than microbes attacked nitrogenous or nonnitrogenous plant tissues only after more easily available foodstuffs had been entirely consumed.

The manures used in this experiment were exposed to ninety-two days of decomposition. In support of active decomposition both sugars and starch are high on the availability scale as proposed by Waksman (1942). It is likely that the sugar beet plants in this experiment were permitted to grow so long that both sugars and starch contents of the original manures were depleted before the end of the experimental period. However, the depletion of the sugars and starch might not have become a factor which limited further decomposition of the green manure since the ratio of carbohydrates and nitrogen in green manure showed little association with dry matter yield of beets. It is proposed that at sometime during the experiment the decomposition of the manures had proceded to the point where hemicelluloses, cellulose, and other carbonaceous constituents of green manure which were more difficult to decompose than sugars and starch were partially hydrolyzed. It is contended that these hydrolytic products of hemicellulose and cellulose decomposition were utilized as a supply of energy to microorganisms for further decomposition of the green manures beyond the point of depletion of the original sugar and starch content. The decomposition of the green manures conceivably proceeded until the percentage increase in the least available and least hydrolyzable carbohydrates became a limiting factor. Following the energy transformations of photosynthesis during the growth of the plants used as green manure, the main channels of carbohydrate change were presumably through condensation of sugars to starch and higher carbonaceous plant constituents. The content of carbohydrates higher than starch were not determined. However, the presence of carbohydrates which are lower on the availability scale than are sugars and starch and the presence of the least hydrolyzable carbonaceous constituents which conceivably increased in percentage as the more easily available sugars and starch and possibly hemicelluloses became depleted in the earlier stages of green manure decomposition. This percentage-wise increase in carbonaceous constituents difficult to hydrolyze possibly limited the extent of green manure decomposition and subsequent nitrogen release during the latter stages of the experimental period. The effect of such carbonaceous constituents on green manure decomposition could possibly have had a greater influence on nitrogen recovery than did the relative abundance of sugars and starch, thus no significant correlation was found between the carbohydrate content, nor the carbohydrate-nitrogen ratios of the manures and the percentage recovery of added nitrogen.

The data included in Table 9 which show the relationships between efficiency indexes of the several manures and the percentage of nitrogen recovered by sugar beets suggests that grasses generally are just as efficient as manurial fertilizers for sugar beets as legume green manures provided the green manure plants are grown under optimum nitrogen nutrition. Although no statistical relationship was established, orchard grass which received NPK treatment in Experiment I gave results which indicated highest manurial efficiency.

## SUMMARY

Alfalfa, brome grass, ladino clover, orchard grass, hairy vetch, and rye were grown in sand cultures under greenhouse conditions. These plant species received three fertilizer treatments: Shive's R5S2 complete nutrient solution, Shive's R5S2 nutrient solution modified to exclude nitrogen, and tap water. These treatments were designated as treatments 1, 2, and 3, respectively. Alfalfa and brome grass were grown alone and in association with each other; ladino clover and orchard grass were grown alone and in association with each other, and vetch and rye were grown alone and in association with each other. All plants were permitted to grow for a period of ninety-eight days. At the end of the growing period all plants were harvested and dried. Composited samples of plants which received the designated treatments were subjected to chemical analysis for total sugars, total starch, and total nitrogen. Approximately seventy percent of the combined weight of six replicated cultures were used as green manures in Experiment II to furnish the sole source of materials for the nutrition of sugar beet plants grown in sand. At the end of the growing period sugar

beets were harvested and analyzed for dry matter and total nitrogen.

1. Legumes as well as nonlegumes grew more rapidly with the application of combined nitrogen than when nitrogen was omitted from the nutrient solutions.

2. Of the several plant species included in this investigation and grown as green manure, hairy vetch produced the greatest average dry weight yield per pot.

3. Differences in average dry weight yield of legume species which received Shive's complete nutrient solution and the same legume species which received Shive's solution minus nitrogen were statistically significant.

4. In all cases the average dry weight yields of plants which received Shive's complete nutrient solution were significantly different from those which received only tap water.

5. Average dry weight yields of grass species which received Shive's solution minus nitrogen were not significantly different from the same species which received only tap water.

6. The carbohydrate-nitrogen relationships within the species used as green manures were altered by the application of combined nitrogen, or by the inoculation of legume species with suitable Rhizobium. The carbohydrate-nitrogen relationships were regulated in part by the physiological specificity of the particular plant species.

7. Carbohydrate content of the plant species used as manures tended to follow an inverse trend with nitrogen nutrition whether plants received combined nitrogen or nitrogen fixed through legume-bacteria symbiosis.

8. Average dry weight yields of sugar beets varied significantly with manurial treatments.

9. Sugar beet plants were able to utilize residual nitrogen from the nutrient solution retained in used sand to the extent that average dry weight yields were significantly higher when beets were grown in the same sand in which the green manures originally grew than when fresh clean sand was used.

10. It was found that various unit weights of nitrogen per pot were required for each unit dry weight of beets produced,

since growth response of sugar beets was contingent upon the quantity of nitrogen contained in the manures and the character of the manures.

11. The percentage of nitrogen recovered from the green manures by sugar beets showed a positive correlation of 0.957 with the milligrams of dry matter in beets per milligram of nitrogen added as manure.

12. The milligrams of nitrogen recovered in beets showed a positive correlation of 0.988 with the milligrams of dry matter in beets.

13. The milligrams of nitrogen recovered in beets showed a positive correlation of 0.979 with the milligrams of nitrogen added as manure.

14. The milligrams of nitrogen added as manure showed a positive correlation of 0.973 with the milligrams of dry matter in beets.

15. Dry matter yield in beets was contingent upon the milligrams of nitrogen applied as manure and the milligrams of nitrogen recovered by the sugar beets. In order to obtain

a large dry matter yield of sugar beets fertilized with green manures, it is necessary to apply large quantities of nitrogen as manure, and the manure must be of such character as to permit a large percentage recovery of the included nitrogen.

16. When the quantities of nitrogen added as manure are too small, and the character of the manure is such as to permit a percentage nitrogen recovery below that of controls, the presence of such green manures exerts an inhibitory influence on the growth of sugar beets.

17. The sugar and starch contents of the various green manures, or the existing ratios of carbohydrates (composed of sugar and starch) and nitrogen did not under the conditions of this investigation determine the manurial efficiency of the several green manures. Manurial efficiency was expressed as the milligrams of dry matter of sugar beets produced per milligram of nitrogen supplied by the green manures.

18. It seems advisable that further work could be done on this problem to determine within a narrow range, parts played by sugars and starch as carbohydrates in the recovery of nitrogen from green manures. In this investigation even when the

largest quantities of nitrogen were applied growth increases of sugar beets were obtained. At some higher point the application of nitrogen as manure might have resulted in no material dry weight increase of beets. If such a point exists it was beyond the scope of this investigation.

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# RELATIONSHIPS BETWEEN EASILY AVAILABLE CARBOHYDRATES, NITROGEN RECOVERY, AND GROWTH OF SUGAR BEETS FERTILIZED WITH SEVERAL GREEN MANURES

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AN ABSTRACT

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BURLEIGH C. WEBB ABSTRACT

This investigation was designed to ascertain the assimilation of mineralized organic nitrogen by sugar beets and the influence of the relative abundance of easily available energy sources on the percentage recovery of nitrogen from green manures. The author considered the relationships between the total nitrogen and total sugars and starch content of the green manure plants.

Experimental Period I consisted of growing alfalfa, brome grass, ladino clover, orchard grass, hairy vetch and rye in sand cultures under greenhouse conditions. These plant species received three fertilizer treatments: Shive's R5S2 complete nutrient solution, Shive's R5S2 nutrient solution modified to exclude nitrogen, and tap water. Alfalfa and brome grass were grown alone and in mixture, ladino clover and orchard grass were likewise grown alone and in association as were vetch and rye. These plants were permitted to grow for a period of ninety-eight days. At the end of the growing period all plants were harvested and dried. Composited samples of the plants which received the designated treatments were subjected to chemical analysis for total sugars, total starch, and total nitrogen.

Results from Experimental Period I showed that the carbohydrate-nitrogen relationships within the species grown for green manures were altered by the application of combined nitrogen, or by inoculation with suitable Rhizobium. The carbohydrate-nitrogen relationships were regulated in part by the physiological specificity of the particular plant species.

These plants were used as green manures and furnished the sole source of materials for the nutrition of sugar beets grown in sand in Experimental Period II. Sugar beets were grown under these conditions for a period of ninety-two days. At the end of the growing period the sugar beets were harvested and analyzed for dry matter and total nitrogen content.

Results from Experiment II showed that various unit weights of nitrogen were required for each unit dry weight of beets produced. Growth response of sugar beets was contingent upon the quantity of nitrogen applied as manure, and the quantity of nitrogen recovered by the sugar beets. In order to obtain a large dry matter yield of sugar beets fertilized with green manures, it was necessary to apply large quantities of nitrogen as manure. A high percentage recovery of the added nitrogen was also necessary. The starch and sugar contents of the various green manures, or the existing ratios of carbohydrate (composed of sugars and starch) and nitrogen did not under the conditions of this investigation determine the manurial efficiency of the several green manures.