PLANT RESPONSES TO VARIOUS FERTILIZER TREATMENTS IN SIX SOILS OF LEBANON

by

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RESPONSE OF LEBANESE SOILS TO FERTILIZERS

Khan

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ABSTRACT

Six Lebanese soils were analyzed for textural composition, carbonate content as well as for the status of available phosphorus, nitrogen and potassium. Phosphorus was estimated by Olsen et al, Bray and Kurtz No. 1 and Miller and Axley methods. Nitrogen was determined by the Kjeldahl method and the Stanford and Hanway technique. Potassium was extracted with both the 1N ammonium acetate and with the Sutton and Seay solution. Barley or lettuce were raised as indicator crops on these soils in the green-house with varying levels of P_2O_5, nitrogen and potassium.

The performance of the test crops indicated that all of the six soils were deficient in nitrogen. Three of the soils were found to be low in phosphorus. On two other soils the yields were increased with the addition of phosphatic salt, however, the differences were not statistically significant at the five per cent level. The sandy soil appeared to be well supplied with phosphorus probably due to previous phosphorus fertilization made by the farmer. With the exception of the sandy soil the available potassium appeared to be adequate in the soils tested.

Dry weight of plants was correlated with the soil chemical tests for the various nutrients. A high correlation was found between the dry weight of barley on the phosphorus treatments and the analyses of the results obtained with the three methods used. No correlation was found between the nitrogen results obtained by a Stanford and Hanway method and the dry weight of lettuce. The weight of lettuce and organic nitrogen content of the soil were found to be highly correlated. The potassium extracted with 1N ammonium acetate and the Sutton and Seay solution (0.15N sulfuric acid) was significantly correlated with dry weight of the lettuce.

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INTRODUCTION

Lebanon is a small country on the eastern coast of the Mediterranean with Syria on the north and east and Palestine on the south. The topography of the country is characterized by a variety of contrasting physical features with attendant differences in weather, soils and agriculture of different regions.

Two chains of mountains, the Lebanon and the Anti-Lebanon, are separated by a level and fertile Beka'a plain. The Lebanon mountains generally run parallel to the coast but turn eastward in the north of Tripoli. These are part of the range extending from Syria to Palestine. The coastal area on the west is rather narrow with the widest segments near Saidon, Tyre, north of Beirut, Tripoli and Akkar. The two main rivers, Litani and Orantes, flow in the Beka'a. Litani runs southwards while Orantes flows towards north.

The climate of Lebanon is generally of the Mediterranean type with marked local variations resulting from topographical relief. The Lebanon range acts as a barrier to moisture laden winds causing greater rainfall on the western coastal region while the eastern slopes, Beka'a plain and Anti-Lebanon range receive less rain. In the summer season the coastal part is warm and humid but on the mountains it is cool and dry. During winter, the weather is cold and moist near the seaside, while the mountains are covered with snow.

The total area of Lebanon is about 10300 sq. kms., of which about sixty percent or 6500 sq. kms., are unculturable, being rocky, waste or in forests. The balance, 3800 sq. kms., constitutes the cultivable land.

Of this amount, 2730 sq. kms. is actually cultivated and about 1150 sq. kms. is mostly of poor quality or of rough terrain and considered very costly to cultivate (65).

The limited area under plough and the high pressure of population (around 1.5 million) necessitate the importation of a substantial quantity of cereals and large number of livestock to meet the demand for food stuffs and meat. This results in great strain on the country's economy, and suggests a strong need for the efficient development of the agricultural resources of the country.

Lebanon grows many crops, vegetables and fruits that are adapted to the Mediterranean climate. The yields however, are low compared to countries where advanced agriculture is practiced. This is partly due to varietal and climatic differences and partly because of the soil, its inherent fertility and management. Improvement in all of these phases is necessary to increase the yields. Discussion here, however, will be confined, only to some aspects of the soil fertility problem.

Some important prerequisites on which to build modern agriculture involve a knowledge of the soils and their fertility or productive capacity. The program of scientific land utilization always envisages growing crops best suited to the area. The importance of soil survey has been recognized by the Lebanon Government and as a result a reconnaissance soil survey of the soils in Lebanon was prepared by B. Geze and published in 1956 (20).

Another phase of good land use includes the determination of the nutrient status of soils of the various regions through field trials and green-house experiments. The present study describes the results obtained in the green-house on six different soils fertilized with nitrogenous, phosphatic and potash salts, when lettuce and barley were used as yield indicators.

The study was conducted during the winter of 1958-59 and summer of 1959. The soil samples were collected from the following locations in Lebanon:

(a) Three samples were taken from the coastal area, on the road from Beirut to Saidon. One from an olive garden in the south of Beirut, the second from a field about 20 kms. further south and the third from a loquat garden in Saidon. The main plantation in this region is bananas, olives, citrus and figs.

(b) Sala'k, central Beka'a, on a road off-shooting towards the east from Zahleh. Irrigation is more common here than in other regions. This area is the wheat granary of Lebanon, though other crops like barley, corn, chickpeas, and vetch are also cultivated. Under more secure water supply conditions vegetables and fruits are grown.

(c) Nabel-Safa, located in Mount Lebanon at the terminus of road starting from Aindara on Beirut-Damascus highway. This is region of fruit crops. Apples, vine, peaches, pears, figs, and olive are raised at heights suitable for the respective trees. Pine trees are also common in this area.

(d) American University Farm:- This soil is representative of the northern part of the central region of the Beka'a valley. The common crop rotation is cereal - fallow but where more water is available fruits like figs, appricots, grapes are grown.

REVIEW OF THE LITERATURE

The growth of a plant is conditioned by its genetic constitution and environments. The former being a fixed identity which determines the potential for the maximum growth of a plant under a given set of environmental conditions. The level of soil nutrients is one of the environmental factors affecting plant growth. The several techniques employed to assess the nutrient status of soil are: (a) Chemical soil tests, (b) Biological methods, using higher or lower plants, (c) Chemical analysis of plant tissues, and (d) Study of nutrient deficiency symptoms.

The different chemical soil tests indicate the total and "available" nutrients present in the soil. Much reliance, however, cannot be placed on these tests owing to variable results obtained with different extractants. Growing of indicator crops is one other good way of soil fertility assessment. However, factors such as, plant species, degree of ramification of roots, rate of growth, nutrient requirements, metabolically produced carbon dioxide and H-ion on plant roots, place limitations on general applicability of results of biological methods. Gray et al (22), Mehlich (39) and Maclean and Adam (37) have stressed the importance of root absorption of nutrients from the soil. The data obtained by biological methods, studied in conjunction with results of soil chemical tests, provide a more accurate picture of soil fertility than when either test is used alone.

Biological Methods

(a) Higher Plants

Biological methods employing higher plants consist of field trials and green-house experiments. Field trials also serve the useful purpose of determining the optimum amounts and kind of fertilizer to be used under practical conditions. These have, however, the draw back of being a slow method and more suceptible to factors like changes in temperature, moisture, rainfall, and insect and disease influences. The national Soil Test Work Group 1956 (46) reports lower correlations between soil tests and percentage yields obtained in field trials than in greenhouse studies.

Field trials have been in progress in Lebanon for nearly 10 years. Money Kyrle (44) has reviewed the results of the trials conducted by five agencies, namely; Ministry of Agriculture, U.S. Overseas Mission, American University of Beirut, Lebanese-French Technical Mission and Comptoire Agricole du Levant.

Early investigations on the relation between growth and nutrient supply were made by Hellriegel and Wilfarth (25). Barley was grown in sand in pots where all necessary nutrients were applied except nitrogen salt, which was added in varying quantity in the different pots. Yields obtained followed a sigmoid curve. Subsequent investigations got similar responses with other nutrients. The smoothness of curves suggested that these could be expressed mathematically. E.A. Mitscherlich (42,43) was the first to do this. He developed the following equation:-

$$\text{Log } (A-y) = \text{Log } A - c(b+x)$$

When x = Plant nutrient added to the soil.

b = Plant nutrient present in the soil, calculated in in terms of 'x'

y = Yield produced by $x + b$

A = Maximum yield possible

c = Proportionality constant.

On the basis of this equation Mitscherlich constructed yield tables from which one could determine the percentage increase in yield, due to each addition of fertilizer in relation to maximum increase (A). His pot culture method consists of growing oats to maturity in 10 pots each having 6 pounds of soil. The yields are expressed as percentage of the yield obtained in pot receiving complete fertilizer treatment.

The controversial part of Mitscherlich equation is the constancy of 'c' factor. Mitscherlich and his colleages (43) consider that the factor 'c' for each nutrient is constant irrespective of the nature of the plant, soil type, or other factors. Wilcox (68,69) applied the Mitscherlich constant to many investigations and showed that the calculated yields are close to determined yields indicating constancy of 'c' factor. On the other hand, workers like Bray (9) and Borda (6) have criticized the constancy concept. Bray (11) showed that 'c' factor should vary with (i) kind of plant, (ii) form of nutrient, (iii) fertility pattern and (iv) planting rate and pattern. He postulated that relatively mobile form of nutrients, like nitrates, tend to follow Leibig's "Law of Limiting Nutrients" and only relatively immobile form of a nutrient like sorbed phosphorus tends to obey Mitscherlich-Baule percentage sufficiency concept. Previously, Bray (9) had modified the Mitscherlich equation to $\text{Log}\ (A-y) = \text{Log}\ A - c_1 b - cx$. When '$c_1$' and 'c' are efficiency factors for the nutrient present in the soil and that added as fertilizer, respectively.

Balba and Bray (3) utilized the above equation for calculation of plant nutrient due to fertilizer increments using wheat plants. They found that the modified equation expresses successfully the soil-plant relationship. It might also serve as a means to differentiate between the amount of nutrient taken up by the plant from the soil and that from the added fertilizer. The relative magnitude of the efficiency factors was considered as quantitative measure of the net relative availability of the nutrient forms involved.

Jenny et al (28) used a modified Mitscherlich technique for green-house assay of fertility on California soils. They grew romain lettuce for 6-8 weeks in pots containing soils collected from different locations and fertilized with varying rates of nitrogen, phosphorus and potassium salts. The dry weight of plants were expressed relative to the full treatment yields. The percentage yield was taken as measure of nutrient supply of the soil. An advantage claimed for taking relative yield is that it is less susceptible to seasonal changes than the absolute yield. The same procedure was also employed by Benigham (4) to collaborate a chemical phosphate test. Jenny et al found that these soils responded to fertilizer addition in the field which gave in the green-house 20 percent or 50 percent yield without phosphorus or nitrogen compared to full respective treatments.

Adams and Sayegh (1) collected a large number of Lebanese soils and observed their response to nitrogen, potassium and phosphorus fertilizers in the green-house. From the growth of barley and lettuce sown in these soils, they concluded that there is deficiency of nitrogen and phosphorus but not of potassium.

A disadvantage of the conventional pot methods is the time (1-3 months) required before significant differences are discernable in relative growth and yield. Precise measurements are not possible in early stages due to slow rate of plant growth. Analysis of plants is, therefore, resorted to for study of the extent of nutrient absorbed from the substratum. The tests are conducted on (i) plants after growing them in different mediums (ii) by removing a particular portion of the crop and analyzing it and or (iii) on some specific part of the standing crop. These methods have also some drawbacks as pointed out by Lynd et al (33), but when used judiciously they can be a useful tool to determine the nutrient level of the soil.

Stanford and DeMent (60) developed a method to measure short-term nutrient uptake. Plants were grown in bottom-less carton for about 2 weeks. The carton, with a mat of roots developed at the base, was nested in another carton having 200 gms of soil or soil plus fertilizer (superphosphate). After one to seven days the plant tops and roots were analyzed for total phosphorus. Results showed a linear relation between phosphate rate and recovery of phosphorus by the plants, indicating that the method holds considerable promise.

DeMent et al (15) applied the above method for the potassium uptake using oats and corn plants. The study was done with three potassium salts using different moisture levels on six soil types to test the usefulness of the technique. It was reported that after one week the potassium content of plant tops is a suitable critarian for assessing relative effect of treatments on potassium nutrition of the plants as well as for potassium status of the soil.

Another method which gives quick results and requires only 100 grams of soil is by growing rye seedlings as proposed by Neubauer and Schneider (48). The method is generally used to study the relative effectiveness of different phosphate fertilizer. Mooers (45) found a reasonable agreement between Neubauer test and rapid chemical methods for determining the phosphorus availability. McGeorge (36) found that with some modifications the results of Neubauer's test with rye are applicable to many field crops.

Radio isotopes of phosphorus were used by Fried and Dean (19) for calculating the availability of the nutrient in the soil. They conceived that absorption of a nutrient by a plant is directly proportional to the amount taken from the soil and the fertilizer sources. This was measured by using fertilizer (standard) tagged with P_{32}. The mathematical expression of the relation is:-

$$A = \frac{B(1-Y)}{Y}$$

When A = Amount of nutrient in soil (lbs/acre of P_2O_5)

B = Amount of nutrient in fertilizer (lbs/acre of P_2O_5)

Y = Proportion of nutrient in the plant derived from the fertilizer, determined by radio chemical analysis of plants.

A soil high in an available nutrient, contributes more of it to the plant and its "A value" is accordingly higher. The opposite will be true for a deficient soil. As the tagged fertilizer reacts differently with different soils the method is not suitable for inter-comparison of soils. However it is good for comparing the effects of different operations on the availability of a nutrient on the same soil (67).

(b) Microbiological methods.

Inhibition in the growth of microorganisms in the absence of mineral elements holds a promise to their use as a measure of available nutrients in the soil. Butkewisch (13) was the first to suggest the use of *Aspergillus niger* as an indicator of available phosphorus and potassium. The method was extensively developed by Niclas *et al* (49) and was further improved by Sekera and Schober (57).

The soil-plague method suggested by Winogradsky and Ziemiecka (71) employs Azotobactor. Hockensmith et al (26) used it extensively for calcareous soils. The method is not applicable when soil pH is below 5.8 due to sensitivity of the organism to low pH. Halversen and Hoge (23) found for Idaho soils that the Azotobector growth gives a greater response to phosphorus than that obtained with field crops.

For use over wide range of reaction (pH 4-9) Mehlich et al (39) proposed the use of Cunninghamella blakesleena. It has the additional advantage of utilizing the various organic forms of phosphorus found in the soil.

(c) Salt - Soil - Plant Interrelationship.

Nutrient grade, salt solubility, physical and chemical characteristics of soil have much to do with the nutrition of the plants. If the phosphorus level of soil has been determined in green-house by using superphosphate, a different value may be expected than when a more soluble salt is used. The results of the same salt would vary when used on acid and calcareous soils or with a grass and a legume crop.

In the case of superphosphate the question often arises as to the influence of calcium and sulphate ions on the phosphorus uptake and how far this source of phosphorus compares with ammonium phosphate. On calcareous soils the common ion effect of calcium ion in superphosphate will alter the availability of phosphorus.

A comparison of two ammonium forms (ammonium metaphosphate and ammonium orthophosphate) with superphosphate was made on an acid sandy loam and calcareous clay soil by Godfrey et al (21). They added calcium sulfate to the ammonium salts equivalent to calcium and sulfate ions in superphosphate in order to eliminate differences due to these ions. Crops raised were sweet-sudan (grass) and cowpeas (legume). It was observed that all sources of phosphorus were about equal in their effect on crop yield and the two crops responded to phosphorus treatment at both locations. Yield of sweet-sudan increased about 90 percent over check while in cowpeas the increase was 10 to 15 percent. Phosphorus content was higher in crops grown on acid sandy loam soil. The phosphorus content of cowpeas on calcareous clay soil was not effected by the addition of phosphate showing strong specie-soil-fertilizer inter-action on yields.

Availability of potassium in potassium calcium pyrophosphate, potassium metaphosphate and potassium chloride for corn at various moisture levels was compared in sand and various soils by DeMent et al (15). They reported that potassium uptake from potassium chloride occurred more readily than from potassium metaphosphate, which was in turn better than potassium calcium pyrophosphate. Sandy soil supplied potassium faster than clay soil. Perhaps the easily water soluble fraction of the fertilizer equilibrated rather quickly with the exchange complex of the soils with resultant decrease of potassium in solution. Little exchange reaction is expected in sands and very light textured soils thus accounting for more initial potassium uptake from these soils. Higher potassium activity was noticed near the moisture equivalent than that found at lower moisture levels.

Zimmerman et al (72) studied in the green-house the effect on wheat of differently soluble high nitrogen compounds having cations like sodium and ammonium and anions like bromide, iodide, or thiocyanate. These were compared with ammonium nitrate and urea. The system of $NaSCN-NH_3$, $NH_4SCN-NH_3$, NH_4I-NH_3 and $NaINH_3$ were found very toxic to wheat. Lethal effects of $NaSCN-NH_3$ and $NH_4SCN-NH_3$ lasted for 5 months but NH_4I-NH_3 and $NaI-NH_3$ were toxic for longer period. Application of NH_4BR-NH_3 caused considerable wilting at first but no lethal effect were observed. Ammonium nitrate and urea applied at the rate of 200 lbs. nitrogen per acre gave the best yield. Slightly less yield was obtained with 100 pounds of nitrogen per acre applied in the form of $NH_4NO_3-NH_3$.

Chemical Soil Tests

A number of extractants are employed to approximate the root influence in the soil on different nutrient elements present therein. Those used for phosphorus, potassium and nitrogen are discussed below:-

(a) Phosphorus

Nelson et al (47) have reviewed the literature on soil tests for phosphorus. Kurtz (30) reviewed the results on inorganic phosphorus in acid and neutral soils while Olsen (50) for alkaline and calcareous soils. Black and Goring (8) have discussed the status of organic phosphorus in soils.

Extractants commonly used for phosphorus are of three types; (a) water, (b) carbon dioxide saturated water, (c) acids, bases, salts and buffered solutions. Since there are many forms of phosphorus in the soil the results of these tests are emperical.

In Florida Forsee(18) has reported the use of water for the extraction of phosphorus in sandy soils. Low extraction and unclear solution obtained with water has made this reagent unpopular. Also, solubility of phosphorus is influenced by the presence of electrolytes, such as potassium chloride, which make alkaline earth phosphorus more soluble but reduces the solubility of iron and aluminum phosphates (Mattson et al (34).

Carbon dioxide saturated water gained importance in phosphate studies because the roots of plants produce carbon dioxide (Mitscherlich (43). McGeorge (36) observed increasing phosphorus solubility by increase in carbon dioxide concentration and obtained variable results with change in soil-water ratio. Olsen et al (51,52) showed that available phosphorus content determined with carbon dioxide extract varied with the amount of calcium carbonate in the soil.

Acids, bases, salts and buffered solutions have been used extensively and a summary of the extractants used by the various workers is reported below:-

Extractant Used	Worker
Citric Acid	Lemmerman and Fresenius (1943)
Lactic Acid	Reihm (1940)
Acetic Acid	Hibbard (1931)
0.2N H_2SO_4	Olsen (1946)
0.314 N HCL	Baver and Bruner (1939)
0.01N HNO_3	Vonsigmond (1929)
0.025N HCL + 0.03N NH_4F	Bray and Kurtz (1945)
0.1N HCL + 0.03N NH_4F	Bray and Kurtz (1945)
0.002 H_2SO_4 + $(NH_4)_2SO_4$	Truog (1930)
Acetic acid + Sod. acetate	Lunt et al (1950)
N/21 H_2SO_4 + Sod. Borate	Beater (1949)

Extractant Used	Worker
0.5N NaOH	Jone (1949)
1% K_2CO_3	Das (1930)
0.5M $NaHCO_3$	Olsen (1954)

Brind (12) has dealt with the papers of the above named workers, therefore, the attached literature cited does not include references pertaining to them, except only those which have been discussed below.

Bray and Kurtz (10) suggested the use of 0.025 N HCL + 0.03N NH_4F and 0.1N HCL + 0.03N NH_4F for adsorbed and adsorbed + acid soluble phosphorus, respectively. The tests are also known as P_1 and P_2. National Test Group 1956 (46), Thompson and Pratt (63) and Smith et al (58) found P_1 test of Bray well correlated with available phosphorus in soils and useful for predicting yield responses due to fertilizer additions.

Olsen et al (51) proposed to employ 0.5M $NaHCO_3$ adjusted to pH 8.5. It lowers the activity of calcium and the same time releases phosphorus from iron and aluminum complexes. Results of studies on cotton in California reported by Mikkelsen (40) showed that the sodium bicarbonate method gave a better correlation with response from phosphate fertilization in both green-house and field tests than other methods. In Nebraska soils having pH between 5.5 to 8.2, sodium bicarbonate method and P_1 test of Bray and Kurtz proved the best methods for evaluating available phosphorus (53).

A complication is introduced during extraction of phosphorus with acids due to "refixation", (Wild) (68). The readsorption is caused by a reduction in H-ion concentration of the acid extractant and/or fixation by metallic ions like iron and aluminum. To overcome the former the acids are buffered and for the latter complexing agents are used e.g. citric acid, oxalic acid, potassium ferrocyanide, 8-hydroxyquinoline. Cooke (14) compared a number of complexing reagents for their effect on "refixation" by oxides of titanium (TiO_2), iron (Fe_2O_3) and aluminium (Al_2O_3). He observed selenious acid, citric acid, oxalic acid and ammonium floride to be very effective, potassium ferrocyanide to be moderately effective and 8-hydroxyquinoline to be least effective.

The nature of anion in the extractant also exerts an influence on the solution of phosphorus from exchangeable forms and iron and aluminium phosphates. Kurtz et al (31) reported replacing ability of ahions for sorbed phosphorus in increasing order, chloride, sulfate, thiocyanate, acetate, bicarbonate, citrate, oxalate and floride. Bray and Kurtz method (10) uses ammonium floride to take advantage of the high efficiency of floride.

(b) Potassium

Although as much as 40000 pounds of potassium per acre are present in the surface six inches of soil, not more than 100 to 400 pounds of this are in the available form at any one time. Most of soil potassium occurs as part of the silicate minerals or is "entrapped" between crystal units of clays. Conversion from non-exchangeable to exchangeable form is caused by weathering processes and changes in the temperature and the moisture content of the soil. The equilibrium between non-exchangeable and exchangeable or available forms is influenced by freezing and thawing, wetting and drying and plant withdrawals. Methods for the release of non-exchangeable potassium have been suggested by Reitemeier et al (56), Reitemeier (55) Kolterman and Truog (29).

Pratt (54) suggested the use of nitric acid for potassium extraction. Hunter and Pratt (27) have developed a more rapid method using sulfuric acid which gives results comparable to nitric acid. Harrison and Weeks' (24) method utilizes 0.1N sulfuric acid.

Ammonium acetate is a standard extracting agent. Some laboratories in the United States use dilute sodium acetate or 25 percent sodium nitrate (Fitts and Nelson)(16). National Soil Test Group (46) reported the efficiency order of replacing potassium as NH_4^+, Na^+, H^+, $Na^+ + H^+$.

Pratt (54) stated that the best single criterion for predicting potassium removed by alfalfa was the determination of exchangeable potassium before cropping. Working on Ohio soils Pratt found the release of non-exchangeable potassium related more to soil type and locality than exchangeable potassium values.

Six Kentucky soils were cropped in the green-house by Sutton and Seay (62) with millet and red clover to determine the degree of correlation between potassium removed by the crops and that extracted with sulfuric acid 0.15N and 1.38N, 1N ammonium acetate and 1N nitric acid. The most satisfactory indexes of the potassium supplying power of soils were obtained from air-dried soils using 0.15N sulfuric acid and 1N ammonium acetate and from moist soils extracted with 1.38N sulfuric acid. (Earlier Attoe (2) reported that larger amount of potassium was removed when the soils were air-dried than if kept moist before cropping in the green-house.

(c) Nitrogen

Nitrogen is present in soils in all grades from the immobile form of organic matter to the mineralized form of nitrates or as elemental nitrogen, which is innert. Organic matter is comprised of living and dead microbial and plant tissues varying in their capacity to decay and yield nitrates. The conversion to nitrate form is effected by microorganisms whose activity is determined by nature and the amount of organic residue, temperature, moisture, aeration, soil reaction and nutrient status of the soil.

The soil organic matter contains nitrogen in amino form. This nitrogen is determined by the conventional Kjeldahl method using concentrated sulfuric acid to convert amino nitrogen to stable ammonium sulfate which is further reacted with sodium hydroxide. The liberated ammonia is received in excess of standard boric acid solution. From back titration with standard hydrochloric acid the amount of ammonia evolved and the nitrogen contained in it are calculated.

Truog <u>et al</u> (64) proposed nitrogen estimation by boiling the soil with potassium permanganate and anhydrous sodium carbonate for 5 minutes in a Kjeldahl flask under carefully controlled conditions. The distilled ammonia is determined with Nesseler's solution. This is quick test but fails to give the nitrogen present in fresh organic matter.

The method proposed by Fitts <u>et al</u> (16) and Stanford and Hanway (60) has received great popularity. It measures the amount of biologically mineralizable nitrogen in the soil. The method involves incubating soil for 2 weeks under ideal conditions of temperature (30°-35°C) and moisture for microbial activity. Soil is leached with water and the nitrate content of leachate is measured on a colorimeter using phenoldisulphonic acid. It is claimed that this method gives reliable information on the nitrogen supplying power of the soils.

EXPERIMENTAL PROCEDURE

The objective of the study was to determine the nitrogen, phosphorus, and potassium fertility status of Lebanese soils in a green-house experiment using lettuce and barley as test plants.

Soil samples were collected in October 1958 from nine sites representing varying conditions in Lebanon. Preliminary analyses showed that the phosphorus content of three samples was very similar to the others, so these were discarded. The details of the sites from which the soil samples were obtained are given below.

Site No. 1. Olive garden in Mafreh El Kaubbeh, located on the southern side of Beirut at turning point of Beirut - Saidon highway. The land is owned by Michel Mattar. It is a terraced area. Sample was taken from the fourth terrace at a distance of 59.2 meters from the road and 11.6 meters from the edge of the third terrace. No fertilizer was reported to have been applied on this land during the past few years.

Site No. 2. A fallow field in the village Niamih, on the Beirut - Saidon highway, further to the south of site No. 1. The area is situated on the western side of the road opposite to an electrical station and a church. It was being prepared for growing squash in the ensuing season. The owner's name is Najib Mattar. The sample was taken from the second terrace at a distance of 5.0 meters from the edge of first terrace and 32.3 meters from the bank of a small road towards north of the field. Some organic manure and phosphatic fertilizer had been applied to the soil.

Site No. 3. Loquat garden in Saidon owned by Mr. Mohammad Kalash. The site sampled is 10 meters south-west of a walnut tree. No fertilizer had been added for the last 10-15 years. Sand was mixed with the original soil to reduce its heaviness.

Site No. 6. A fallow field in Sala'ak. It is seven kms. from the starting point of a road opposite Maalaka, on Zahleh-Baalbeck highway. The sampling site is 400 meters on the right side of this road and 28 meters from a water channel which is on the south of the site. The land is owned by Mr. Freiji who uses a wheat-onion rotation. Last winter it was under wheat. The field receives farm yard manure and commercial nitrogenous fertilizers.

Site No. 7. A pear orchard owned by Salim Zaidan in Nabel-Safa, at the terminus of road starting from Aindara, on Beirut-Damascus highway. The sampling place was on the first terrace, 10 meters from a drain and 2.1 meters from a pear tree. In the summer season nitrogen fertilizer was applied. One week before sampling goat manure was added. Superphosphate and potash fertilizers were applied in the winter of 1957-58. All manure were added very close to the trees.

Site No. 8. The sample was taken from an alley in a field under rotational experiments being conducted by Agronomy Section at the American University Farm. The place sampled is 36.5 meters from the fence and 21.6 meters on the right side of the road opposite to the gate. The layer of soil immediately below the plow layer was very hard and compact.

Soils

The soil samples from six sites, (No. 1, 2, 3, 6, 7 and 8), on which experimental work was carried out pertained to the Coastal Zone, Mount Lebanon and Central Beka'a. A brief description of the soils of these regions, based on the report of Lignon (32) is given below, to give an idea of the general features of the profiles represented by these samples.

a) Coastal Zone:- The strip along the coast on the western side of Mount Lebanon has a variety of soils. Generally these are light and permeable. Sites No. 1, 2 and 3 fall in this zone.

b) Mount Lebanon. These soils are shallow with parent rock exposed wherever erosion has occurred. However the original soil characteristics have changed due to terracing, which is common in this area. Site No. 7 is in Mount Lebanon.

c) Central Beka'a:- In the northern side the profile is shallow and pebbley with parent rock out-cropping at many places. In the middle and southern parts, the soil is deep and fine textured. Water logging persists during the rainy season due to impeded drainage and flatness of land. Sites No. 6 and 8 were to the north and south of this zone, respectively.

Preparation of samples and sowing of crops

The samples were air-dried and crushed with a wooden mallet. The soil was then passed through a 0.5 cm. sieve to ensure mixing and removal of stones. The three macro nutrients, nitrogen, phosphorus and potassium, were applied in the form of ammonium nitrate, calcium dihydrogen phosphate and potassium chloride, respectively. The salts were thoroughly mixed with the soil and then placed into earthern pots coated on the inside with asphalt. A similarly coated earthen dish was also placed under each pot to receive the water that might drain through. The leachate was returned to the respective container next day.

In each pot only the nutrient under study was changed keeping the other two constant in sufficient quantities to prevent limitation of plant growth. For example, nitrogen and potash were applied at the rate of 11.2 kgms. (70 kgm of 16% sodium nitrate) and 8 kgms. per dunum to pots which had received 0, 6, 12 and 18 kgms.of P_2O_5 per dunum. Each treatment was replicated three times. Eight seeds of Atlas barley were planted on February 16, 1959 in each pot and were subsequently thinned down to six. The crop was grown in the green-house.

The experiment on nitrogen consisted of 0, 6, 12 and 18 kgms. per dunum of the nutrient added to each pot in addition to 12 kgms. per dunum of P_2O_5 and 4 kgms. per dunum of K_2O. The treatments were replicated three times.

In the third set of pots, K_2O was added at the rate of 0, 4, 8 and 12 kgms. per dunum together with nitrogen and P_2O_5 given at the rate of 11.2 and 12 kgms. per dunum, respectively.

Each treatment received three replications. Nitrogen and phosphorus experiments were carried out during summer 1959. Temperature at that time was high, barley could not be grown. Lettuce was therefore raised as the indicator crop. Lettuce seedlings (raised for 2 weeks in sand with Hoagland nutrient solution) were transplanted to the pots on May 30 and 31, 1959. Three seedlings were allowed to grow in each pot. Those which failed to establish in the early stages were replaced by healthy ones. Due to excessive heat in the green-house (118°F) the pots were moved outside under the shade of trees.

In the case of both barley and lettuce, pots were randomized and the rows were interchanged every week.

Crop Growth

Growth of barley was generally good except in pots of soil No. 2, where it was affected by *Helminthosporium sativum*. In some other pots also stray plants showed the symptoms of Spot Blotch attack. In all cases, new seeds were immediately planted in the same pots and when these germinated satisfactorily, the affected ones were removed. The crop was irrigated with distilled water once or twice a day depending upon the weather conditions. Water applied was approximately equal to field capacity of the different soils.

Barley was harvested before the onset of heading, though in a few plants which had made rapid growth heads did appear before the plants were cut. Figure 1 shows the stand of the crop in soil No. 6 before it was harvested.

The lettuce seedlings started well. The crop was protected from the casual attacks of birds by placing wire gauze frames on two sides and dry twigs on the other two.

The lettuce was irrigated with distilled water. The crop was harvested after 6 weeks. The stand of lettuce in soil No. 2 and 8 under the nitrogen and potash experiments is shown in Figures 2 and 3.

<u>Harvesting, drying and weighing of plants</u>

Plants were cut very close to the soil and put in serially numbered paper bags. The material was dried at 70°C until the weight became constant. After that the bags were weighed on a torsion balance with and without plants. The weight of plants was calculated by difference.

<u>Soil Analysis</u>

One hundred gms. of soil was dried at 105°F. to a constant weight. From the loss of weight the moisture percentage was calculated.

The percentage of sand, silt and clay was determined by the Bouyoucos method (7). The textural class was determined with the help of

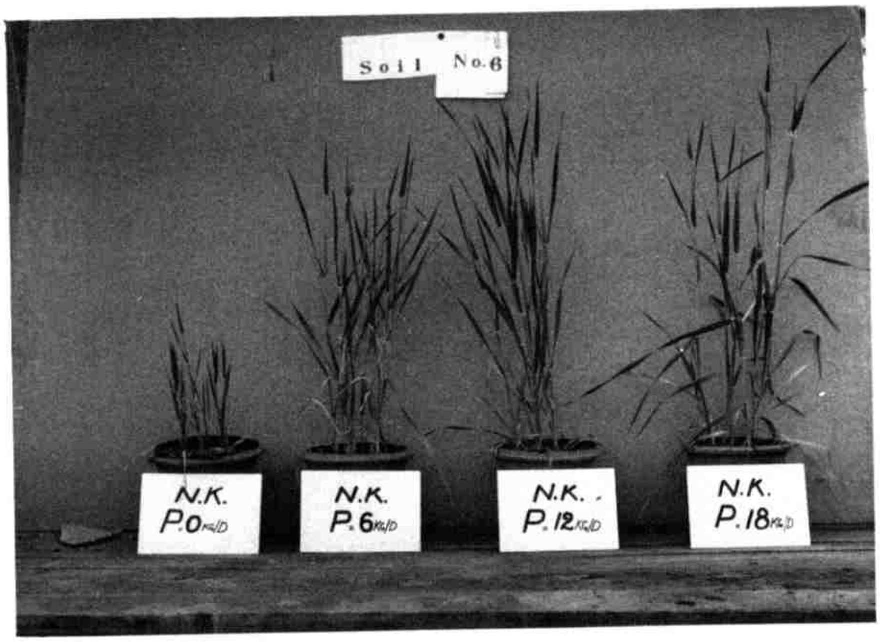

Fig. 1. Barley growing in soil of Site No. 6 (Sala'k) with varying amounts of P_2O_5

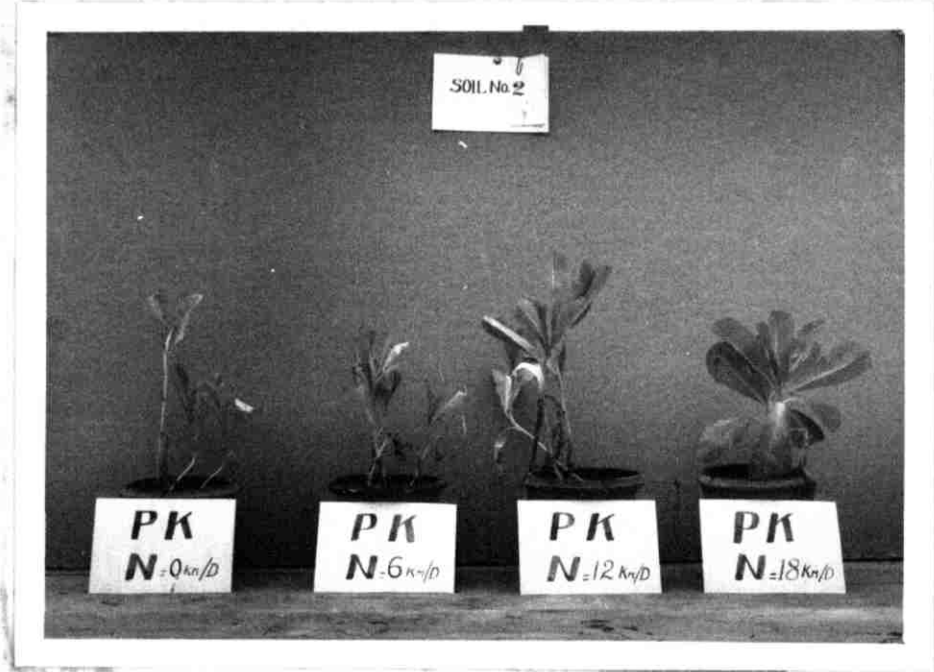

Figure 2. Lettuce growing in soil of Site No. 2 (Niameh) with varying amounts of nitrogen.

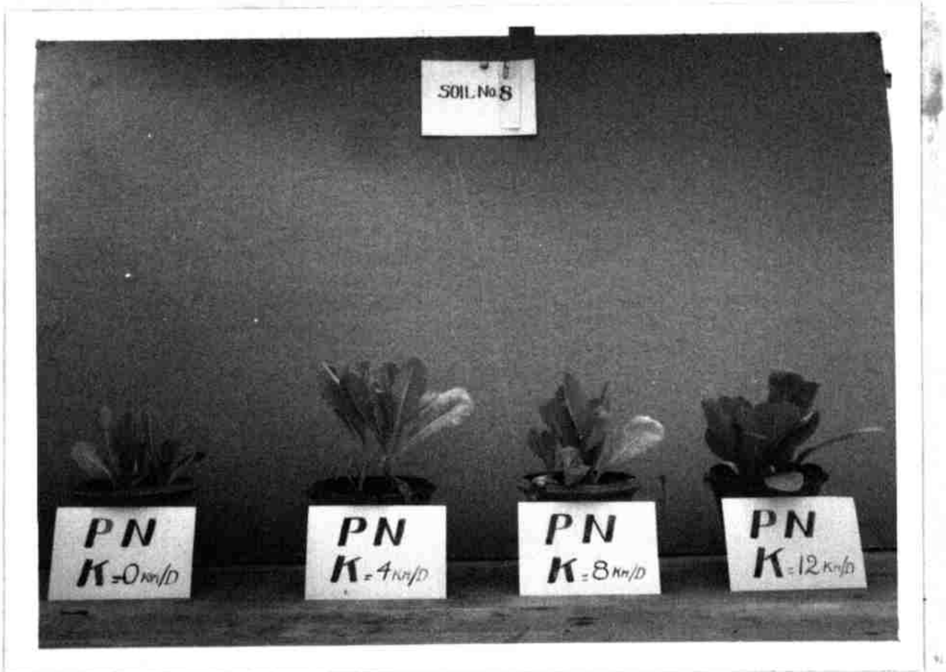

Figure 3. Lettuce growing in soil of Site No. 8 (American University Farm) with varying amounts of potassium

the triangular diagram given in Agriculture Handbook No. 18 U.S.D.A. (59).

The determination of alkaline earth carbonates was carried out by gravimetric method as outlined in method No. 23(a) in Agriculture Handbook No. 60. U.S.D.A. (66).

Organic nitrogen was determined by the conventional Kjeldahl method and the organic matter was calculated by multiplying the nitrogen results by 17.24, a factor usually employed for Lebanese soils.

Nitrate producing capacity of soil was estimated by the method proposed by Stanford and Hanway (60).

Analysis for available phosphate was done by methods suggested by (a) Olsen et al (51) (b) Bray and Kurtz No. 1 (10) and (c) Miller and Axley (41).

A flame photometric technique was employed for available potassium determination as proposed in method No. 11(a) in Agriculture Handbook No. 60, U.S.D.A. Available potassium was also determined by using 0.15 N sulfuric acid as employed by Sutton and Seay (62).

The physical and chemical tests were carried out on the untreated soils.

Statistical Work

The differences in the dry weight of plants due to increments in fertilizers were tested by analysis of variance. Correlation coefficients between the results of soil chemical tests and the yields of dry weight of plants were determined by the conventional statistical methods.

RESULTS AND DISCUSSIONS

Results of the physical and chemical analysis of the soils are presented in tables 1 to 4. Table 2 embodies the results of the mechanical analysis results of the six soil, screened through 2 m.m. mesh and the percentage of water in air dried soils.

Table 2 gives the percentage of calcium carbonate estimated gravimetrically and the phosphorus content determined by the use of reagents proposed by Olsen _et_ **_al_**, Bray and Kürtz No. 1 and Miller and Axley. From the average weight of plants in three replications, the percentage of the weights under different treatments, relative to no-treatment weights, were computed and are incorporated in table 2 to enable easy comparison with the soil analysis results.

Table 3 reports the organic nitrogen results determined by Kjeldahl method, the amount of nitrate produced during two weeks incubation at 95°F in moisture saturated atmosphere and the relative yields of lettuce on different soils with varying treatments.

The amounts of potassium in kgms. per dunum extracted with 1N ammonium acetate and 0.15N sulfuric acid are given in table 4, along with percentage yield of lettuce obtained with 4, 8, and 12 kgms. per dunum of potash.

Actual yields+ of barley and lettuce plants obtained with different levels of phosphatic, nitrogenous and potashic salts are shown in tables 5, 6 and 7.

1. Soil Characterization On The Basis Of Physico-Chemical Analyses And The Crop Yield Data.

Site No. 1, Mufreh El Kaubbeh, Coastal Area. It is a coarse-textured

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+ The term "yield" in this chapter is used for dry weight of the parts of the plants above the ground.

Table 1. Percentage of Sand, Silt, Clay, Textural Class and the Water in Six Soils.

Soil No.	Name of Site	Sand	Silt	Clay	Textural Class	Water++
		%	%	%		%
1	Mafreh El Kaubbeh	24.0 #16.8+	24.5 17.1+	51.5 36.8+	Clay	6.5
2	Niameh	91.2	1.1	7.7	Sand	1.0
3	Saidon	69.3	11.3	19.3	Sandy Loam	2.4
6	Sala'ak	9.7	26.8	63.5	Clay	7.3
7	Nabel Safa	60.5	11.6	27.9	Sandy Clay Loam	2.5
8	A.U.B. Farm	23.1	30.0	46.9	Clay	4.6

\+ Percentages calculated on the basis of unsieved soil, the rest of the figure in the table are percentages of the soil that passed through a 2 mm. mesh screen.

\# In addition to 16.8 percent sand gravels and stones were 30 percent.

++ Water is calculated in air dried soil.

Table 2. Percentage Calcium Carbonate, Phosphorus in Kgms per Dunum+ Determined by Three Methods and Relative Barley Yields With Different P_2O_5 Applications.

Soil No.	Name of Site	Calcium Carbonate	Olsen	Bray and Kurtz P_1 Test	Miller and Axley	Relative Yield			
						T_0	T_1	T_2	T_3
		%	kgm/Du.	kgm/Du.	kgm/Du.				
1	Mafreh El Kaubbeh	11.8	3.20	4.22	4.51	100	108	117	122
2	Niameh	0.5	4.50	6.00	6.20	100	92	103	107
3	Saidon	8.1	3.90	5.06	5.17	100	113	124	132
6	Sala'ak	27.2	0.40	0.93	1.10	100	318	431	626
7	Nabel-Sáfa	2.2	1.58	2.61	2.54	100	230	281	333
8	A.U.B. Farm	24.7	2.42	3.00	3.69	100	249	249	237
	Correlation Coefficient (r)		-0.86++	-0.94++	-0.91++				

++Significant at 0.05 level.

T_0 = 0 kgm/Dunum P_2O_5

T_1 = 4 kgm/Dunum P_2O_5

T_2 = 8 kgm/Dunum P_2O_5

T_3 = 12 kgm/Dunum P_2O_5

+ Dunum = 1000 sq. meters, 6" depth, (225000 kgms.)

Table 3. Organic Nitrogen, Organic Matter, Nitrate Produced During 2 Weeks Incubation and Relative Lettuce Yield with Different Nitrogen Applications.

Soil No.	Name of Site	Organic Nitrogen	Organic Matter	Nitrate after two weeks	Relative Yield			
					T_0	T_1	T_2	T_3
		%	%	kgm/Dunum+				
1	Mafreh El Kaubbeh	0.08	1.38	9.95	100	393	408	483
2	Niameh	0.04	0.69	5.40	100	97	272	389
3	Saidon	0.08	1.38	9.70	100	171	183	209
6	Sala'ak	0.07	1.20	4.46	100	106	155	186
7	Nabel-Safa	0.05	0.86	6.55	100	116	159	173
8	A.U.B. Farm	0.08	1.38	3.85	100	152	167	168
	Correlation Coefficient (r)	-0.83++		+0.44				

++Significant at 0.05 level.

T_0 = 0 kgm/Dunum N

T_1 = 4 kgm/Dunum N

T_2 = 8 kgm/Dunum N

T_3 = 12 kgm/Dunum N

+ Dunum = 1000 sq. meters, 6" depth (225000 kgms.)

Table 4. Potassium in Kgms per Dunum[+] Extracted with 1N Ammonium Acetate and 0.15 N Sulfuric Acid and Relative Lettuce Yields with Different Potash Applications.

Soil No.	Name of Site	1N Ammonium Acetate	0.15N Sulfuric Acid	Relative Yields			
				T_0	T_1	T_2	T_3
1	Mafreh El Kaubbeh	50.12	12.40	100	83	82	74
2	Niameh	10.15	5.91	100	127	143	147
3	Saidon	44.71	12.68	100	103	95	114
6	Sala'ak	45.40	10.53	100	93	125	116
7	Nabel-Safa	48.87	12.62	100	72	75	96
8	A.U.B. Farm	54.39	13.00	100	96	80	89
	Correlation Coefficient (r)	-0.86++	-0.90++				

++Significant at 0.05 level

T_0 = 0 kgm/Dunum Potash

T_1 = 4 kgm/Dunum Potash

T_2 = 8 kgm/Dunum Potash

T_3 = 12 kgm/Dunum Potash

+ Dunum = 1000 sq. meters, 6" depth (225000 kgms.)

Table 5. Dry Weight in Grams of 6 Barley Plants with Varying Amounts of P_2O_5 Added to 700 Gms. Soil

Treatment	Soil No. 1				Soil No. 2				Soil No. 3			
	R++I	R II	R III	Av. wt.	R I	R II	R III	Av. wt.	R I	R II	R III	Av wt
0 kgm P_2O_5/Dunum	2.76	4.30	3.36	3.47	2.50+	2.83	2.70+	2.67	3.08	2.25	2.84	2.74
6 kgms P_2O_5/Dunum	3.34	4.24	4.04	3.70	2.50+	2.71	2.22+	2.47	3.56	2.40	3.37	3.11
12 kgms P_2O_5/Dunum	4.00	4.00	4.06	4.05	2.46+	2.32	3.45	2.74	3.27	3.87	3.06	3.40
18 kgms P_2O_5/Dunum	4.55	4.01	4.10	4.22	3.25	2.38	3.08	2.87	3.95	3.07	3.84	3.61
Calculated F		= 1.06					= 0.47				= 2.09	

Treatment	Soil No. 6				Soil No. 7				Soil No. 8			
	R++I	R II	R III	Av. wt.	R I	R II	R III	Av. wt.	R I	R II	R III	Av. wt.
0 kgm P_2O_5/Dunum	0.73	0.75	0.83	0.77	1.08	0.96	1.16	1.06	1.34	1.32	1.27	1.31
6 kgms P_2O_5/Dunum	3.41	1.66	2.28	2.45	2.13	3.04	2.17	2.44	2.82	3.14	3.82	3.26
12 kgms P_2O_5/Dunum	3.06	4.09	2.81	3.32	2.41	2.26	2.93	2.93	3.23	3.53	3.11	3.29
18 kgms P_2O_5/Dunum	3.95	3.85	4.35	4.05	3.13	3.06	2.47	3.53	3.50	3.02	3.00	3.10
Calculated F		= 13.0					= 14.4				= 25.94	

++ R = replication

+ = Plants in these pots were more diseased than in other pots of soil No. 2.

Tabulated F at 5% level = 4.76
Tabulated F at 1% level = 9.78

Table 6. Dry Weight in Grams of Three Lettuce Plants with Varying Amounts of Nitrogen Added to 600 grams Soil.

Treatment	Soil No. 1				Soil No. 2				Soil No. 3			
	R I	R II	R III	Av. wt.	R I	R II	R III	Av. wt.	R I	R II	R III	Av. wt.
0 Kgm N/Dunum	0.42	0.41	0.43	0.42	0.63	0.46	0.85	0.64	1.55	1.26	1.50	1.43
6 kgms N/Dunum	1.32	2.36	1.29	1.65	1.07	0.69	1.10	0.62	2.20	2.58	2.55	2.44
12 kgms N/Dunum	1.55	1.97	1.59	1.70	2.57	1.81	1.86	1.74	2.59	2.50	2.78	2.62
18 kgms N/Dunum	1.59	2.28	2.23	2.03	2.87	2.02	2.60	2.49	2.99	2.65	3.34	2.99
Calculated F		16.14				46.07				33.00		

Treatment	Soil No.6				Soil No. 7				Soil No. 8			
	R I	R II	R III	Av. wt.	R I	R II	R III	Av. wt.	R I	R II	R III	Av. wt.
0 kgm N/Dunum	0.62	0.67	0.47	0.58	1.08	0.66	0.39	0.71	0.95	0.80	1.15	0.96
6 kgms N/Dunum	0.47	0.80	0.59	0.62	0.93	0.68	0.90	0.83	1.50	1.52	1.38	1.46
12 kgms N/Dunum	0.61	0.69	1.40	0.90	1.45	1.15	0.80	1.13	1.51	1.60	1.70	1.60
18 kgms N/Dunum	0.77	1.30	1.19	1.08	1.77	0.87	1.06	1.23	1.76	1.89	1.20	1.61
Calculated F		1.70				3.60				4.69		

R = Replications

Tabulated F at 5% level = 4.76
Tabulated F at 1% level = 9.78

Table 7. Dry Weight of Three Lettuce Plants in Grams with Varying Amounts of Potash Added to 600 gms Soil.

Treatment	Soil No. 1 R I	R II	R III	Av. wt.	Soil No. 2 R I	R II	R III	Av. wt.	Soil No. 3 R I	R II	R III	Av. wt.
0 kgm K_2O/Dunum	1.97	1.57	2.28	1.94	1.89	0.81	1.63	1.44	2.31	1.90	1.83	2.01
4 kgms K_2O/Dunum	1.66	1.61	1.57	1.61	2.00	1.74	1.75	1.83	2.83	1.85	1.53	2.07
8 kgms K_2O/Dunum	1.22	2.00	1.33	1.60	2.40	1.96	2.48	2.28	2.54	1.73	1.50	1.92
12 kgms K_2O/Dunum	1.47	1.62	1.21	1.43	2.55	1.92	2.50	2.32	2.51	1.85	2.80	2.39
Calculated F	= 1.82				= 11.5				= 0.86			

Treatment	Soil No. 6 R I	R II	R III	Av. wt.	Soil No. 7 R I	R II	R III	Av. wt.	Soil No. 8 R I	R II	R III	Av. wt.
0 kgm K_2O/Dunum	0.54+	0.89	1.26	0;89	0.75	1.65	1.16	1.10	1.46	1.59	1.04+	1.36
4 kgms K_2O/Dunum	0.70+	0.65+	1.14	0.83	0.63	1.27	2.31	1.40	1.00	1.65	1.24	1.29
8 kgms K_2O/Dunum	1.35	1.71	0.22	1.11	0.60+	1.02	0.83	0.82	1.01	1.20	1.07+	1.09
12 kgms K_2O/Dunum	1.51	1.30	0.28	1.03	1.46	1.17	0.54+	1.06	-++	1.78	1.43	1.07
Calculated F	= 0.126				= 0.5							

R = replication

Tabulated F at 5% level = 4.76
Tabulated F at 1% level = 9.78

+ One plant stolen from each pot

++ All plants damaged.

soil with sand, gravel and stone totalling 47.8 per cent. Silt and Clay are 17.1 and 36.1 per cent, respectively. The soil contains 11.8 per cent calcium carbonate. The available phosphorus was determined according to the methods of Olsen et al, Bray and Kurtz (P_1) and Miller and Axley. Values obtained were 3.20, 4.22 and 4.51 kgms. of the nutrient per dunum, respectively. Addition of 6, 12 and 18 kgms. per dunum of P_2O_5 produced a respective increase of 7, 8 and 22 per cent in the dry weight of barley plants over plants in check pots. The differences were not significant at the five per cent level, but the upward trend in the yield with increasing levels of phosphorus points out the inadequacy of the nutrient in the soil.

Organic nitrogen in the soil was 0.08 per cent. Following the Stanford and Hanway technique, 9.45 kgms. per dunum of nitrate was found in the untreated soil. Compared to no-treatment, the 6, 12 and 18 kgms. of nitrogen per dunum gave an increase of 293, 305 and 384 per cent in the plant weight, which shows the soil was deficient in nitrogen.

Total potassium extracted with 1N ammonium acetate and 0.15N sulfuric acid was 50.12 and 12.48 kgms. per dunum. The yield of lettuce declined with addition of potassium salts indicating an adequate supply of potassium in the soil.

Site No. 2, Niameh Coastal Zone. It is a sandy soil (91.2% sand). The soil moisture content under air-dried condition was low as one per cent against 6.5 per cent of site No. 1. The calcium carbonate in the soil was almost negligible (0.5 percent).

Although the soil is predominently sand, the highest results were obtained for phosphorus content by all of the three methods. This is due to phosphate fertilization of land some time before sampling. The owner has to add sufficient quantity of fertilizer or natural manure for successful crop production on such a poor land. Seven per cent increase in the weight of plant with 18 kgms. of P_2O_5 per dunum is not significant. Tables 2 and 5 show that despite the highest amount of phosphorus in the soil the plant weights were lowest in this soil which is perhaps due to fungus attack on plants in some pots. The pots receiving 18 kgms. P_2O_5 showed the most healthy plants. Better condition in these pots might be partly ascribed to greater resistance induced by the high amount of the fertilizer.

As expected from the poor textural composition, the soil organic nitrogen was very low, (0.04 per cent). After two weeks incubation 5.40 kgms. per dunum of nitrate was produced. Average plant weight increased from 0.64 grms. with no nitrogen to 1.74 grms.and 2.47 grms.with 12 kgms.and 18 kgms. nitrogen added per dunum; the increase is 172 and 290 per cent. A slight depression in weight (3 per cent) was recorded with 6 kgms. nitrogen per dunum. The reason for this is not understood.

Unlike soil No. 1, the soil of Site No. 2 gave 47 per cent higher yield with the application of 18 kgms. potash per dunum, which may be attributed to lack of potassium in the original sandy soil. 10.15 kgms. per dunum of potassium was extracted with 1N ammonium acetate and 5.91 kgms. per dunum with 0.15N sulfuric acid. These values were the lowest of all of the six soils tested.

Site No. 3, Saidon. The upper six inch layer from which the sample was taken contained 69.3 per cent sand, 11.3 per cent silt and 19.3 per cent clay. The soil is sandy loam in texture. Originally the soil was fine-textured but the owner mixed sand with the surface layers to facilitate agricultural operations and enable the crops to establish well. The underlying strata, however, remained clayey.

The soil contained 8.1 per cent calcium carbonate. Phosphorus ranged from 3.9 kgms. per dunum by the Olsen method to 5.17 by Miller and Axley method. The quantity seemed inadequate as the dry weight of barley rose with higher additions of phosphorus, though the differences were not significant at the five per cent level.

During two weeks' incubation, 9.70 kgms. per dunum of nitrate nitrogen was produced. Organic nitrogen was estimated to be 0.08 per cent. Response to applied nitrogen was observed at all the three levels tried. Twelve kgms. per dunum of nitrogen gave the highest value of 209 per cent increase in plant weight over the control.

Extraction with 1N ammonium acetate and 0.15N sulfuric acid yielded 44.7 1 and 12.68 kgms per dunum of potassium, respectively. A three per cent increase with 4 kgms. potash per dunum and 114 per cent increase with 12 kgms. per dunum potash, was recorded. The intermediate dose of 8 kgms. produced five per cent decrease which cannot be accounted for. However, statistical analysis showed the difference due to treatments to be non-significant at the five per cent level.

Site No. 6, Village Sala'k, Beka'a Valley. The soil of this site is very fine-textured with clay 63.5 per cent and sand less than ten per cent. Owing to its fine texture, 7.3 per cent water, which is maximum of all soils under study, was held by the soil under air-dry conditions. The soil also had the highest carbonate content (27.2 per cent) but had the least phosphorus content. The values by Olsen <u>et al</u>, Bray and Kurtz P_1 and Miller and Axley methods were 0.4, 0.93 and 1.10 kgms. per dunum, respectively. It is apparent from Figure 1 that barley plants were very pale and stunted in check pots even though the two nutrients, nitrogen and potassium, were added at the same rate as in other pots. With 18 kgms. per dunum of P_2O_5 the plant weight rose by 6.25 times. The addition of 6 kgms. per dunum of P_2O_5 more than tripled the yield. Twelve kgms. per dunum increased it by 4.3 times. It can be safely inferred from the yield data that phosphorus is the limiting factor for crop growth on this soil.

Following the Kjeldahl procedure, 0.07 per cent organic nitrogen was found. The nitrate producing capacity was low. Addition of 6, 12 and 18 kgms. per dunum of nitrogen as ammonium nitrate gave respectively 6, 59 and 86 per cent enhanced yield of lettuce, compared to the control. Though the variation due to treatments is not significant at the five per cent level, the trend for increased yield with applied nitrogen indicates possible nitrogen deficiency in the soil.

Potassium level was adequate in the soil as shown by the non-significant differences in the weight of lettuce. It is difficult to explain the rise and fall in the weights by the applications of successive increment of potassium salt. To some extent it is due to pilferage of one plant, out of the three, from some pots, during the early stage of experiment. 45.40 kgms. per dunum of potassium was extracted by using 1N ammonium acetate while 0.15N sulfuric acid gave the value of 10.53 kgms. per dunum.

Site No. 7, Nabel-Safa, Mount Lebanon. The soil of this site is sandy clay loam. Very little (2.5 per cent) water was held by it when dried under air conditions. Calcium carbonate as well as phosphorus content of the soil were found to be low. The former being 2.2 per cent and the latter ranged from 1.58 to 2.6 kgms. per dunum. The low supply of phosphorus was confirmed by response to the phosphorus treatment. Six, 12 and 18 kgms.

per dunum of P_2O_5 produced 130, 191 and 235 per cent more dry weight than that of the barley grown in non-treatment pots.

The contents of organic nitrogen and that of the nitrogen readily convertible to nitrate were low. The respective amounts were 0.05 per cent and 6.55 kgms. per dunum. Application of 18 kgms. per dunum of nitrogen resulted in an increase of 73 per cent in average dry weight of the lettuce. The lesser rates of 6 and 12 kgms. per dunum produced 17 and 59 per cent increase.

1N ammonium acetate and 0.15N sulfuric acid removed 48.87 and 12.62 kgms. per dunum of potassium. The quantity appeared sufficient for the normal requirement of lettuce as application of additional amounts of potassium made no significant improvement in dry weight of the lettuce.

Site No. 8, Agronomy Section Plot, American University Farm. It is a clayey soil. The percentage of sand, silt and clay is 23.1, 30.0 and 46.9, respectively. When the land was dry, the high clay content made the working of the spade very difficult during sampling. This soils contained 24.7 per cent calcium carbonate. The phosphorus status was low. Treatment of soil with the reagents proposed by Olsen _et al_ Bray and Kurtz P_1 test, and Miller and Axley, removed 2.42, 3.00 and 3.69 kgms. per dunum of phosphorus. In consequence of low initial phosphorus the plant yield increased 1.5 times with six kgms. per dunum of P_2O_5. No further increase was observed by higher treatments.

Nitrogen in the soil as determined by the Kjeldahl method and Stanford and Hanway incubation technique was 0.08 per cent and 3.85 kgms. per dunum, respectively. A substantial increase (67 per cent) was affected in the dry weight of plants by addition of 12 kgms. per dunum of the nutrient. Higher treatment rates produced no further change in weight.

The results of the two chemical tests as well as the yield data showed that the potassium status of the soil was adequate. Four to 20 per cent depression in yield was caused by different potash additions.

2. Correlation Of Results Of Soil Chemical Tests With Yield Data Of Barley And Lettuce

(a) Phosphorus Tests. Average correlation coefficient between Olsen et al test and percentage yield of barley was 0.86 under the three levels of P_2O_5 added on the six soils. For Bray and Kurtz P_1 test and Miller and Axley method the "r" value came to 0.94 and 0.91, respectively. Under the condition of the experiment Bray and Kurtz No. 1 test was slightly more efficient than the other two methods though all were significant at the one per cent level. For 17 Maryland soil types the averages of "r" values for the three soil tests found 0.310, 0.344 and 0.359 when the analysis results and logarithm of alfalfa yield were correlated (41). However "r" values ranged in the various soils between 0.108 to 0.876 for Olsen method, 0.191 to 0.885 for Bray and Kurtz and 0.104 to 0.884 for Miller and Axley methods. The large difference between the values obtained for the various soils and the averages for each soil type suggest that effectiveness of individual tests should be ascertained by taking large number of samples within that soil type.

Though the three methods gave high correlation with the yield, yet the amount of phosphorus removed was not the same. 1N sodium bicarbonate solution (Olsen et al reagent) gave the lowest value. 0.03N ammonium floride + 0.03N sulfuric acid (Miller and Axley reagent) extracted the most, while 0.3N ammonium floride + 0.025N hydrochloric acid (Bray and Kurtz reagent) was intermediate.

Soils No. 1, 2 and 3 gave no significant response to the addition of phosphorus. The average phosphorus content above which the three soils ceased to give significant increase in weight of barley plant was 34.06 pounds per acre by Olsen et al method, 44.75 pounds per acre by Bray and Kurtz No. 1 test and 46.64 pounds per acre by Miller and Axley method. For alfalfa and wheat on Maryland soils the respective figures obtained were 35 pounds, 55 pounds and 70 pounds (4). In Colorado the zero response level for alfalfa and oats was determined to be 48 pounds per acre by Olsen et al solution and 110 pounds per acre for potatoes by the same method (52). The sufficiency limit mainly varies with the plant specie, soil type and the reagent employed.

(b) Nitrogen Tests. The results of Stanford and Hanway method failed to give any correlation with dry weight of lettuce. The reason is not well understood. However significant correlation (r=0.83) was obtained between organic nitrogen determined by Kjeldahl method and the dry weight of lettuce.

The soils No. 1, 2 and 3 were found deficient in nitrogen as various applications of this nutrient in the form of ammonium nitrate resulted in 71 to 383 per cent increase in the weight of lettuce. Deficiency of nitrogen in the other three soils, viz. Nos. 6, 7, 8, was also indicated by an appreciable enhancement (6 to 86 per cent) in the yield of lettuce with fertilization. However, at five per cent level the differences did not appear significant. A green-house study by Adams and Sayegh (1) had also shown that nitrogen was deficient in the Lebanese soils.

(c) Potassium Tests. Potassium extracted with both 1N ammonium acetate and 0.15N sulfuric acid gave significant correlation with lettuce yields. The quantity of the nutrient extracted by 0.15N sulfuric acid was nearly one fourth of that removed by 1N ammonium acetate but "r" value of the former was higher (0.90) than the latter (0.86). Sulton and Seay have reported "r" values of 0.859 and 0.861 for the two reagents by correlating the results with uptake of potassium by Millet from five Kentucky soils (62).

It is evident from the yield data that fertilization with potassium salt did not make significant improvement in the yield of lettuce on five out of six soils. The sandy soil of village Miameh was deficient in potassium and hence gave favorable response to the addition of this nutrient. Other soils were well supplied in available potassium. These results are in agreement with the findings of Adams and Sayegh (1).

SUMMARY

Two soil samples were collected from coastal area, (Mufreh El Kubleh and Niameh), one from south (Saidon), one from Mount Lebanon (Nabel Safa), one from Central Beka'a (Sala'k) and one from northern Beka'a (American University Farm). Physico-chemical analyses of the soils were done for texture, carbonates, phosphorus, nitrogen and potassium. The three methods suggested by Olsen _et al_, Bray and Kurtz P_1 test and Miller and Axley were employed for phosphorus determination. Nitrogen was estimated by the Kjeldahl method and the Stanford and Hanway technique. Potassium was measured by using 1N ammonium acetate and Sutton and Seay solution, 0.15N sulfuric acid.

To evaluate the usefulness of these methods for the Lebanese soils the results of chemical tests were correlated with dry weights of barley or lettuce plants when grown at different levels of phosphorus, nitrogen and potassium.

Phosphorus was applied as calcium dihydrogen phosphate, nitrogen as ammonium nitrate and potassium as potassium chloride. The nutrient under study was applied at varying rates while the other two were supplied in amounts that did not limit normal growth. The rates in kgms per dunum at which the nutrient were applied are as follows:-

Phosphorus experiment	P_2O_5 = 0, 6, 12, 18; N = 11.2; K_2O = 8
Nitrogen Experiment	N = 0, 6, 12, 18; P_2O_5 = 12; K_2O = 4
Potash Experiment	K_2O = 0, 4, 8, 12; P_2O_5 = 12; N = 11.2

The experiment on phosphorus was conducted in the winter of 1958-59 with barley as the indicator crop. Nitrogen and potash experiments were carried out during the summer of 1959 using lettuce as the tester crop since

barley could not be grown during that period of high temperature.

The soil analyses and yield data showed that:-

1. Soil of village Mufreh El Kubbeh was sandy clay loam. It was well supplied with potassium but was deficient in nitrogen. There was increase in the yield of the crops with additions of phosphorus showing an inadequacy of this nutrient in the soil. However, the differences in yield were not significant at the five per cent level.

2. Soil from the village Niameh was sandy in texture (90% sand). Its levels of nitrogen and potassium were low but the phosphorus was high since some phosphatic fertilizer had been applied to the land prior to sampling.

In the Saidon soil the potassium was found to be adequate but the amount of nitrogen was low. This soil was not well supplied with phosphorus. The clay content of the lower layers was high while the texture of upper six inches was a sandy loam.

Soil of village Sala'k was clayey in nature, the clay fraction being 63.5 per cent. Calcium carbonate content of this soil was 27.2 per cent, the highest of all the soils tested. This soil was highly deficient in phosphorus. Its nitrogen content was low but the potassium was adequate.

Soil of Nabel Safa was classified as sandy clay loam. It was low in calcium carbonate, nitrogen and phosphorus but was well supplied with potassium.

The soil at the American University Farm was clay in texture. Calcium carbonate was high (23.1 per cent). It was low in nitrogen and phosphorus but adequate in potassium.

From the comparison of chemical analyses and yield data it was found that the three methods of estimating available phosphorus viz. Olsen et al, Bray and Kurtz No. 1, Miller and Axley, were well correlated with dry weight of barley. Bray and Kurtz No. 1 test gave the highest correlation. The Miller and Axley method extracted comparatively higher phosphorus than the Bray and Kurtz test, which in turn removed more phosphorus than the Olsen et al method.

Nitrates,as determined by the Stanford and Henway technique, gave no correlation with the yield of lettuce. However, there was significant correlation between organic nitrogen content and dry weight of the plants.

The amount of potassium extracted with 1N ammonium acetate and Miller and Axley reagent was highly correlated with the yield of lettuce in the potassium experiment.

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