# THE EFFECT OF SAWDUST ON THE UP-TAKE OF NITROGEN, PHOSPHORUS, AND POTASSIUM BY STRAWBERRY PLANTS

by

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# THE EFFECT OF SAWDUST ON THE UP-TAKE OF NITROGEN, PHOSPHORUS, AND POTASSIUM BY STRAWBERRY PLANTS

## INTRODUCTION

Organic mulches have never been used extensively as a method of soil management, due to the lack of low cost readily available materials. It must be assumed that any material used as a surface mulch will sooner or later be incorporated into the soil and should have a favorable effect, on the physical, chemical, or biological properties of the soil. Barnyard manure, grain straw, peat moss, and leaves have been demonstrated to have value as mulching materials. However, it is becoming increasingly difficult to find these materials in sufficient quantity, free of weed seeds, to meet the demands for mulching and soil conditioning practices.

The strawberry was used in this experiment as an indicator plant to study the effect of sawdust. The preparatory soil treatment for strawberries usually involves the use of organic matter, which is supplied by applications of manure or crop residues or by plowing under cover crops. These organic materials provide fertility, improve the physical properties of the soil, promote the activity of beneficial soil organisms and increase the water-holding capacity of the soil.

There is ample experimental evidence recorded by this and other experiment stations as to the benefits derived from use of organic mulches in the culture of numerous specialty crops. The small fruit grower is especially interested in the feasibility of mulches for his crops. Orchardists in parts of the state are experimenting with sawdust and other materials to improve the structure of their orchard soils.

Here in the Northwest, where lumbering is a major industry, the question of using by-products of lumbering, of which sawdust is the principal one, for soil treatment is becoming of increasing concern. Products of West Coast mills in the form of alder, hemlock and fir sawdust, shredded fir and redwood bark, cedar and pine shavings, shingle tow, and lignin residues are being offered for sale as mulches and soil conditioners.

A study to determine more accurately the value of such wood wastes, especially when used as mulches and soil amendments, should be conducive to their conservation and more effective utilization, particularly since orcharding, small fruit and nursery stock production in Western Oregon lend themselves to these practices. It is important in using some of these materials to understand their limitations and the methods of using them to best advantage.

Preliminary investigations by the Oregon Agricultural Experiment Station since 1944 with wood waste products have shown that these materials, if properly handled, can be utilized as mulches and soil amendments without the deleterious effects commonly associated with these materials.

These experiments, principally with fir and alder sawdust on such crops as tomatoes, potatoes, strawberries, and blueberries, have shown that the depressive action of the sawdust on plant growth is the result of a deficiency of available nitrogen in the soil. The decrease in available nitrogen is caused by microorganisms that decompose the sawdust, using all available nitrogen in their life processes. When supplemented with some source of readily available nitrogen, the ill effects of nitrogen depression are eliminated. The heavy rates of commercial nitrogen required to overcome this available nitrogen depression (approximately 200 pounds actual nitrogen per acre where 3 inches of sawdust were incorporated) have given best results when balanced with phosphate and potash applications. The nitrogen demands are considerably greater where the sawdust is incorporated with the soil than when used as a surface mulch. The amount of nitrogen needed has been found to decrease from year to year, as the low nitrogen material is gradually decomposed. The growth of the plant and the fertilizer requirements during the period of sawdust decomposition is here under study.

This study was part of the co-operative research project by the Departments of Horticulture, Soils and Bacteriology at the Oregon State College. The objectives of this study were to determine (1) the response of the strawberry plant under different sawdust treatments; (2) the rates of nitrogen fertilizer required for normal plant growth when sawdust was used as mulch and soil amendment; (3) the value of the sawdust in facilitating cultural operations, such as planting, cultivation, weed and pest control and harvesting; and (4) by analysis the nutrients, particularly nitrogen, phosphorus and potassium in the various experimental plots. This thesis deals primarily with point four.

# LITERATURE REVIEW

## Effect of sawdust on plant growth

Physical and chemical effects of mulches such as straw, hay, and manure have been extensively investigated but the effects of sawdust on the soil have come under consideration only in recent years. Experiments at Hawkesburg Agriculture College (59, pp.73-76)[1] over a two-year period indicated that sawdust had little value as a soil improver. Its incorporation into the soil caused serious nitrogen deficiency in succeeding crops for a considerable period. Hardwood sawdust was more injurious than pine sawdust. Ill effects occurred even when such materials were used as a surface mulch on tender plants. There was evidence that sawdust and similar materials further depleted the soil nitrogen supply by the production of a compound injurious to the soil nitrifying bacteria and the possibility that such a compound was poisonous to plant roots could not be overlooked.

Midgely (39, pp.27-36) pointed out that wood materials when added to the soil act like other carbonaceous materials in depressing the nitrogen supply to plants. Anderson and Thom (1, pp.115-126; 52, pp.38-48) reported that the addition of straw and cellulose to the soil depressed the available nitrogen.

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[1] The number in parentheses refers to the literature cited at the end of the thesis.

The experiments carried out by Turk (35, pp.10-22) under greenhouse conditions indicated that the depressive action of sawdust on plant growth was the result of a deficiency of nitrates in the soil. The decrease in nitrates came about through the increase in their assimilation by soil microorganisms supplied with food and energy which increased their demand for available nitrogen. Evidence was presented to show that nitrate formation was not depressed by the sawdust, but that the detriment was a result of the assimilation of nitrates after they were formed. When supplemented with a readily available source of nitrogen, sawdust could be added to soil without fear of harmful effects. In all the greenhouse experiments, nitrogen, whether in the form of dried blood, inorganic nitrogen or in the form of manure, overcame the detrimental influence of sawdust. Other workers (18, pp.303-322; 42, pp.95-100; 56, pp.202-212) have also proved, under greenhouse and field conditions, that sawdust is not harmful to either plant growth or the soil. Midgely (39, pp.27-36) concludes that, while some plant residues contain certain tannins, these are destroyed by the soil organisms before they remain long in the soil.

Analysis has shown that sawdust has virtually no fertilizing value (55, pp.10-22). Its composition with respect to nitrogen, phosphoric acid and potash obviously varies depending upon such factors as the type of the wood from which it came, age of the wood and the degree of rotting. Fresh sawdust contains, on the average, about 4 pounds of nitrogen (N), 2 pounds of phosphoric acid ($P_2O_5$) and 4 pounds of potash ($K_2O$), per ton of air-dry material; this is less than one-third the total plant nutrients usually contained in wheat straw. Not only are nutritive elements low in sawdust, but their availability is also low. Sawdust cannot, therefore, be considered as a fertilizing material.

The benefits derived from mixing sawdust with soil or using it as a mulch are largely of a physical nature (2, pp.46-47). Turk (55, pp.10-22) reports that sawdust, when mixed with heavy soils, tends to loosen them, thereby increasing ease of tillage and ease of water penetration and that when mixed with sandy soils sawdust increases the water-holding capacity. The mulch may reduce cracking of the soil, and in some instances, limits capillary movement of moisture. The mulch may bring about an increased absorption of rainfall by reducing surface runoff. Furthermore, a sawdust mulch may prevent the running together, and the crushing of the surface soil particles under the impact of raindrops.

Savage and Darrow (44, pp.338-340) report that mulching in one form or another is essential to obtain the best growth of highbush blueberries in Northern Georgia under the prevailing conditions of high temperature and oftentimes deficient soil moisture. Sawdust mulch, because of its greater power for retaining soil moisture by reducing surface evaporation and runoff, was by far the best mulch under the conditions of the experiment.

Shutak (47, p.64) found that the sawdust mulch plot significantly outyielded other treatments in an experiment to study the effect of various cultural practices on the growth and yield of highbush blueberries. The soil temperature of plots under sawdust and straw mulch showed little fluctuation, but clean cultivated plots exhibited large temperature fluctuation. Soil moisture was highest under sawdust. Root development was also more extensive under mulches. Both soft and hardwood sawdust were used successfully.

Harris (22, pp.52-60) found that sawdust was not harmful to strawberries; in fact, taking all factors into consideration, the sawdust was beneficial. Besides improving the physical conditions of the soil sawdust prevented heaving of the plants during a severe winter. Yields of fruit were increased markedly after the second year of application of the sawdust mulch.

Griggs and Rollins (21, pp.213-218) found that in comparison with either clean cultivation or hay mulch, sawdust mulch gave greater yields, larger shoot growth of the strawberry, and facilitated such operations as pruning, harvesting and weed control.

The effects of sawdust on crop yields depend upon whether sawdust is applied as a surface mulch or incorporated with the soil, the lapse of time after sawdust application, and the amount of the nitrogen applied to the crop and the kind of crop grown.

Johnson (23, pp.407-412) found that when sawdust was used as a surface mulch, (a) the yields of strawberry increased the first year, (b) the nitrates were slightly depressed the first year and were further depressed the second year, (c) the moisture level in the soil was increased, and (d) a more uniform soil temperature was maintained.

When sawdust was incorporated with the soil, (a) the yields were less for the first crop and higher for the remaining crops than yields for the check, which received an equivalent application of nitrogen; (b) 120 pounds of nitrogen per acre used with sawdust produced greater yields of tomatoes the first year and each year thereafter than was produced by the check plots receiving 60 pounds of nitrogen per acre; (c) the nitrates were greatly depressed by the sawdust the first 18 months, after which time they began to accumulate; and (d) the moisture level in the soil was increased.

Sawdust is an inactive type of organic material from the chemical point of view and its good effects are largely physical after the depressive action is corrected. The review of the literature indicates that sawdust can be satisfactorily applied to soils containing an adequate supply of nitrogen or if supplemented with sufficient nitrogen to overcome the depressive effect of the available nitrate supply in the soil.

Response of strawberries to fertilizers

It has been the general experience of investigators who have carried out experiments on the effects of fertilizer treatment on strawberries that the plant is a difficult one with which to obtain responses giving very clear indications of the effects of the various treatments tested.

The difficulties have been emphasized by Bedford and Pickering (4, pp.98-100) in England and by Chandler (8, pp.332-337) in the United States, in all instances after considerable experience in fertilizer experiments with various kinds of fruit plants.

Pickering published results of experiments with strawberries, using the same treatments that were given to apples, gooseberries and currants in the Ridgmont soil. There was no response to increasing amounts of fertilizers, and in fact in one series where no fertilizer was used the average result was as good as with large quantities of either inorganic fertilizers or manure.

Chandler has summarized some of the earlier experiments in the United States, in Missouri, Hood River Valley Oregon, and New York, and in all cases most emphasis was placed on the effects of nitrogen application. Nitrogen exerted harmful effects in the Missouri experiments, whereas in Oregon nitrogen produced increased yields. In New York the results were rather contradictory, though they suggested favorable effects from phosphorus and potassium in some cases.

In 1919, Brown (6, p.8) published results of a series of fertilizer experiments carried on at the Hood River Experiment Station. The first season's yields from plots fertilized with amounts of nitrate of soda varying from 220 to 440 pounds per 10,000 plants and applied during the spring of the fruiting year were 10 per cent higher than similar unfertilized plots. The following year these same plots treated in the same manner yielded an average increase of 34.8 per cent above the unfertilized plots. The third crop from these plots treated as before, yielded an average increase of 10.5 per cent above the unfertilized plot. There was no conclusive evidence of any benefit from other elements than nitrogen.

More recently, Wentworth (61, pp.358-362) in New Hampshire examined the effect of dressings of nitrate of soda in two plantings and concluded that, although the fertilizer increased the amount of foliage, crop yields were more often reduced than increased.

Taylor (51, pp.313-317) observed the effects of winter application of nitrate of soda under the early conditions obtaining in Alabama. The nitrate dressings resulted in increases in yield. It was also found that superphosphate was beneficial to general vigor but potash dressings produced no visible effect.

Loree (35, p.11) experimented with various fertilizer treatments in potted sand culture. He found nitrogen was the chief limiting element. It was an important factor in promoting vegetative growth and in differentiating fruit buds. Phosphorus alone had little effect, but in combination with nitrogen increased both vegetative growth and fruit production. Ammonium sulfate gave higher yields than sodium nitrate. Loree made chemical analyses of plants from each set of treatments. His results showed that high production was associated with a high nitrogen and high carbohydrate content of the crown at the time of fruit bud differentiation.

Whitehouse (62, pp.201-206) used high, medium and no nitrogen nutrient solutions in sand cultures of strawberries. He concluded that fruitfulness is apparently correlated with a balance between nitrogenous and carbohydrate materials in the plant at time of fruit bud differentiation. He added that a complete nutrient solution with medium nitrogen content gave the highest number of clusters and blossoms per cluster.

Davis and Hill (15, pp.681-692; 16, pp.411-432) in Canada studied the effects of excess and deficient amounts of nutrient elements on both sand and soil cultures of strawberries. They found nitrogen to be most important in stimulating plant growth and yield, but that a proper balance must exist between nitrogen and the mineral elements. They also found that fruit bud differentiation depended to a large extent on a satisfactory balance between phosphorus and potassium.

Darrow and Waldo (14, pp.318-324) working in North Carolina obtained increases in yield of strawberries up to 94 per cent over the checks by the use of inorganic and organic nitrogen fertilizers. Size of berries was materially increased by inorganic nitrogen. Small amounts of phosphorus and potassium had slight beneficial effects on size, quality and yield of fruits.

Whitehouse and Schrader (63, p.178) working in Maryland conducted several tests to determine the value of commercial fertilizers in strawberry production. They found that on fertile soils fertilizers were of little value but that on poorer soils nitrogen applications helped to obtain better stands and a better grade of fruit. They agreed that the response of strawberry plants to fertilizers was often dependent on climatic conditions, particularly the amount of rainfall.

Experimental results on the influence of time of application of fertilizers in the nutrition of strawberry are also contradictory. Brown (6, p.8), in Oregon, conducted one preliminary test in which late summer fertilizer applications to an old bed (after its fifth crop) were compared with spring applications. Yields although quite small, as might be expected from old plants, consistently favored late summer applications.

Chandler (9, p.304), working with rather infertile soils in Southern Missouri, found that spring application of nitrogen either alone or in combination with other elements invariably greatly reduced the size of the following crop though the plants grew much more vigorously.

In Ohio, Shoemaker and Greve (20, p.183) found that applications made in the spring of the bearing year lowered yields, considerably retarded ripening and in addition, caused softer berries. Fall applications, however, gave substantial increases in yields.

Results obtained by Lineberry (29, p.3) indicated that moderate spring applications of nitrogen increased total yields but retarded time of ripening.

During a three year period Waltman (58, p.11) found that the application of nitrogen in the spring of the fruiting year reduced the yield of fruit below that of unfertilized plots. The average reduction for all varieties was 26.76 per cent. He concluded that reduced fruit yields on spring-fertilized plants occurred as a result of more vegetative growth, a greater demand for moisture, more shading of fruits and poor air circulation through the plants.

Although the results of fertilizer experiments are extremely variable, commercial fertilizers have played a part in the production of strawberries in the Pacific Northwest. The use of fertilizer has increased the production an average of 50 per cent

(24, pp.21-24). In 1930, when little fertilizer was used the average production was from 1½ to 2 tons, while in 1940, with fertilizer a general practice, the average was 3 tons. In recent years some strawberry plantings have yielded as high as seven tons per acre.

## Chemical analysis of the strawberry plants

Long (32, pp.386-388; 33, p.15) made chemical analysis of strawberry plants during the growing season showing that the strawberry plant exhibits seasonal fluctuation in nitrogen content which increased rapidly during the spring, when nearly 80 per cent of the total nitrogen was in the leaves. There was a seasonal percentage decrease of nitrogen in the leaves from 2.5 per cent early in the spring to less than one per cent late in the fall. A concommittant increase occurred in roots and stems. Long found that the roots and stems of the strawberry, and especially the former served as reserve organ for the storage of nitrogen; consequently a great demand was made upon the storage reserves in the roots and stems during their growth.

The addition of nitrogen fertilizers did not affect greatly the basic seasonal cycle of variation in nitrogen concentration of the strawberry plant. On a percentage basis there did not appear to be any great seasonal difference, except that in the check plots nitrogen was always lower than in those fertilized.

Little difference could be detected between the dry weight of fertilized strawberry plants at any particular time, but wherever sulfate of ammonia was added, the plants grew more rapidly (32, pp.386-388). Although the control plants weighed only about one-third of the fertilized ones, they exhibited the same tendency to increase in dry weight during the fall and to decrease in winter.

In general, the results of Long indicate that the strawberry plant stores large quantities of nitrogen and carbohydrates in the summer and autumn, making these products available in the spring, using them in the production of fruits and new growth. Treatment that would increase production through modifying fertility, therefore, should be given during the summer and fall months. The earlier work of Gardner (17, p.29) is corroborated in that maximum production of flower clusters, flowers and berries was associated with those summer and fall treatments that led to the greatest accumulation of carbohydrates at the time of fruit bud differentiation.

Loree (35, p.11) made chemical analysis of the strawberry plants in relation to fertilizer treatments. His results showed that the growth of the plants of the various plots which were fertilized during the preceding season was variable. In general, however, the plants which were treated during the summer with fertilizers containing nitrogen grew more vigorously than those which were similarly treated during the spring only. Whenever nitrogen was applied in the spring of the fruiting year there was a quick response in vegetative growth, not only in the development of new foliage but in runner production.

The analytical data show the effect of fertilizer treatments on the nitrogen and mineral content of the strawberry plants. It was observed that in general, the absolute amounts of the nutrient elements in proportion to the amount of dry matter were nearly the same, and that the unfertilized plants and those which were fertilized in the spring showed lower percentage of nitrogen, phosphoric acid and potash than those which were similarly treated during the summer. The greatest differences were in the nitrogen content. When the nutrients were applied in the summer only, the percentage of nitrogen was larger than when corresponding treatments were given during both the spring and summer. In spring-treated plots the nitrogen ranged from 0.66 to 0.79; in the summer-treated plots from 1.59 to 2.02; and in the spring and summer-treated plots from 1.55 to 1.79 per cent (35, p.11).

The data show also that considerable amounts of nitrogen and potash which had been absorbed by the plants during the early stages of growth were lost later in the season (35, p.11). There were probably some losses of these elements from the crowns through runner production and the death of some of the outer leaves during the summer. It is also conceivable that certain amounts of nutrients may have been returned to the soil and that there were losses from the plants by leaching.

## EXPERIMENTAL PROCEDURES

1. Location The experiment was conducted on the Lewis-Brown Horticultural Farm, Corvallis, Oregon.

Soil type The plots were on good quality Chehalis silty clay loam. This soil is a chocolate-brown on lighter brown, friable subsoil. It has a usable water capacity of about 2 inches per foot. Chemically it is well supplied with nutrients with the exception of sulfur and is near neutral in reaction.

Experimental crop Certified plants of the Marshall variety used were grown in the hill system. Marshall is an early mid-season variety most commonly grown in Oregon. It is well adapted to processing and is also popular in the fresh market. Marshall is susceptible to virus diseases but rather resistent to root diseases. Its successful culture depends upon disease-free planting stock.

2. Design of experiment

The experiment was designed to allow statistical analysis of the data. A randomized split plot design was employed. The main plots consisted of (1) no sawdust, (2) sawdust applied as a surface mulch and (3) sawdust incorporated in the surface soil.

The sub-plots compared use of four rates of nitrogen fertilizer, using uniform rate of application of potassium and phosphorus. Check plots were also provided. Four replications were used.

Plot size and shape

Each plot was 15' x 17½' = 1/165.9 acre, containing five 10-plant rows, in addition to border rows, which were not harvested as part of the experiment.

Treatments

(a) Sawdust

In the fall of 1947, the plots were laid out and fresh fir sawdust was applied in weighed amounts to make a layer four inches thick in the sawdust incorporated plots and the sawdust was then roto-tilled in to a depth of six inches. In the spring of 1948 the whole field was roto-tilled twice in order to make a good seed-bed and the strawberry plants were planted. Two months later a weighed amount of sawdust was put on to make a layer 4 inches thick in the sawdust mulch plots. The moisture content of sawdust was determined so that equal weights of dry matter was applied to each plot. The plots were carried through 1949 and 1950 with the fertilizer treatments as indicated. In 1951 due to the attack of the red stele disease all old plants were dug out. The sawdust in the mulch plots was removed and saved. The whole field was roto-tilled twice. The strawberry plants were re-planted in April with healthy plants. All the old sawdust which was removed from mulch plots was put on again in June and fresh sawdust was also added in order to bring up the sawdust to four-inch level.

(b) Fertilizer treatments for the entire period are indicated.

(1) Rates of application

Pounds of $N-P_2O_5-K_2O$ per acre

| Fertilizer plot no. | 1948 | 1949 | 1950 | 1951 |
|---|---|---|---|---|
| | $N\ P_2O_5\ K_2O$ | $N\ P_2O_5\ K_2O$ | $N\ P_2O_5\ K_2O$ | $N\ P_2O_5\ K_2O$ |
| 1 | 0 - 0 - 0 | 0 - 0 - 0 | 0 - 0 - 0 | 0 - 0 - 0 |
| 2 | 0 -150-100 | 0 -150-100 | 0 -150-100 | 0 -150-100 |
| 3 | 200- 0 - 0 | 200- 0 - 0 | 200- 0 - 0 | 200- 0 - 0 |
| 4 | 100-150-100 | 100-150-100 | 100-150-100 | 100-150-100 |
| 5 | 100-150-100 | 50-150-100 | 25-150-100 | 12-150-100 |
| 6 | 200-150-100 | 200-150-100 | 200-150-100 | 200-150-100 |
| 7 | 200-150-100 | 100-150-100 | 50-150-100 | 25-150-100 |
| 8 | 400-150-100 | 400-150-100 | 400-150-100 | 400-150-100 |
| 9 | 400-150-100 | 200-150-100 | 100-150-100 | 50-150-100 |

A uniform rate of phosphate and potash fertilizer was applied to each plot except check and plot no.3. The main object of this plan was to compare the use of four rates of nitrogen fertilizer with the sawdust treatments. No nitrogen was applied in plot no.2. One hundred pounds of nitrogen per acre in plot no.4, 200 pounds in plot no.6 and 400 pounds in plot no.8 were applied each year. In plot no.5, 100 pounds of nitrogen per acre was applied in the first year and the rate of nitrogen application was succeedingly decreased to half in each following year. Plots nos.7 and 9 were treated in the same manner as plot no.5 except that plot no.7 started with 200 pounds of nitrogen per acre and plot no.9 started with 400 pounds of nitrogen per acre.

Ammonium sulfate, superphosphate and muriate of potash were used to supply nitrogen, phosphorus and potassium respectively.

(2) Time and method of application

Potash and phosphate fertilizers were side-dressed on May 20. Nitrogen application was split. One-half was side-dressed with potash and phosphate fertilizer in the spring and one-half was applied on August 1. All fertilizers were surface applied.

(3) Irrigation

Uniform amounts of water were supplied to all plots when needed by means of overhead sprinklers. The amount applied was sufficient to maintain normal growth and development of the plants.

(4) Harvest

The 1952 crop of fruit was harvested and the yields recorded.

3. Foliage analysis

Forty leaves from fifty healthy plants on each plot in 1951 were taken for analysis of dry weight, nitrogen, phosphorus and potassium contents. The analytical data and yield in the fourth year were recorded separately for each plot and analyzed statistically by the method of analysis of variance.

(a) Cleaning-- The most important sources of contamination are soil, atmospheric dust and spray materials. Atmospheric dust is similar in composition to soil; dust may contaminate all the aerial parts of the plant. Spray residues are an important source of contamination for the fruit, stems and leaves of crops to which sprays are normally applied. It was particularly important in this experiment because calcium cyanamide had been used as spray control for red spider.

The removal of surface contamination from plant material is not a simple matter. Many investigators have recommended washing samples with distilled water. This, however, is liable to cause losses of certain nutrients from the plant material by leaching; this may prove particularly serious for potassium. Other workers have wiped the surface of the organs with muslin or other cloth. This avoids the possibility of leaching. The latter was employed in this work.

(b) Drying -- When cleaned, it is generally necessary for the material to be dried. Over-drying at 75°C. was employed throughout this work.

(c) Grinding -- It is usual to grind the dried plant material before analysis -- partly for greater ease in manipulation, partly in order to secure greater uniformity in composition.

A mechanical mill was used for grinding and a vacumn cleaner was used to eliminate the contamination from sample to sample.

(d) Ashing of the plant material -- 0.5 gram samples of oven-dry ground leaves were placed in 200-ml. tall Pyrex beakers, ten ml. of concentrated nitric acid was then added, the beaker covered with a watch glass, and heated gently on a hot plate until no visible signs of solid material remained. At this point the solution was generally straw-colored. The beaker was removed from the hot plate, 5 ml. of 70 per cent perchloric acid were added, the watch glass replaced and the contents gently boiled until clear and there was fuming with copious vapors of perchloric acid. Generally the volume at this point was about 1 to 3 ml. The solution was never allowed to go to dryness. Twenty-five ml. of distilled water was added and brought to a boil, and then filtered through a Whatman no. 40 filter paper into a 100-ml. volumetric flask. The silica was washed with hot water. The filtrate was cooled, diluted to 100 ml. and the solution reserved for the determination of potassium and phosphorus.

(e) Determination of potassium -- Potassium was determined by the use of flame photometer (52, pp.459-466). A Perkin-Elmer flame photometer, model 52A, equipped with the propane burner was used.

(f) Determination of phosphorus -- Phosphorus was determined colorimetrically by the use of a spectrophotometer (52, pp.459-466). A Coleman spectrophotometer, model 11, was used.

(g) Determination of nitrogen -- Nitrogen was determined by Gunning method (42, p.13).

## RESULTS

### The dry weight of the leaves

Seasonal changes in the dry weights of the leaves are shown in Tables I, II and III. According to these data, the dry weight of the leaves increased very rapidly from 7.844 grams per forty leaves in June to a maximum, 23.241 grams, in September.

Dry weights were higher both where sawdust was used as a mulch and where it was mixed with the soil than in the clean cultivated plots. These are shown in Table II and Figure 1. There was no significant difference between sawdust mulch and sawdust incorporated plots.

Table III and Figure 2 indicate that in the check and phosphorus-potassium plots dry weights of the leaves were significantly smaller than those in the plots with nitrogen fertilizer. Twenty-five pounds of nitrogen per acre in the fourth year was sufficient to take care of the depressive effect of sawdust on plant growth. There were no significant differences in dry weights of leaves among the higher rates of nitrogen application.

Table I. Seasonal changes in the dry weight of the leaves during the growing season in 1951. (Dry weights in grams per 40 leaves; an average of four replications).

| Fertilizer treatment | Date | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | June 12 | | | July 12 | | | August 12 | | | September 12 | | | October 12 | | |
| | Sawdust treatment | | | | | | | | | | | | | | |
| | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. |
| Check | 7.43 | 8.72 | 6.52 | 13.83 | 13.25 | 13.10 | 15.75 | 13.73 | 16.44 | 18.85 | 18.90 | 21.65 | 18.93 | 14.45 | 19.80 |
| 0-150-100 | 7.88 | 8.18 | 7.55 | 14.38 | 13.68 | 15.03 | 15.25 | 15.13 | 19.65 | 19.15 | 19.50 | 23.10 | 19.50 | 16.05 | 20.13 |
| 200-0-0 | 7.72 | 8.24 | 7.34 | 15.73 | 14.13 | 16.35 | 21.45 | 15.43 | 22.44 | 24.55 | 21.70 | 28.25 | 21.73 | 14.80 | 20.40 |
| 100-150-100 | 8.47 | 8.93 | 6.18 | 15.78 | 13.63 | 14.18 | 22.85 | 14.45 | 21.70 | 24.70 | 20.40 | 22.80 | 22.45 | 15.58 | 19.80 |
| 12-150-100 | 8.35 | 8.41 | 6.26 | 15.85 | 12.70 | 13.45 | 21.60 | 14.68 | 19.35 | 24.20 | 19.00 | 26.35 | 20.30 | 14.68 | 19.90 |
| 200-150-100 | 7.55 | 9.64 | 6.49 | 15.58 | 14.30 | 16.03 | 22.55 | 15.15 | 22.85 | 24.85 | 22.05 | 27.00 | 21.50 | 14.83 | 20.45 |
| 25-150-100 | 8.03 | 8.37 | 6.88 | 16.60 | 13.70 | 15.88 | 20.65 | 15.45 | 22.05 | 25.00 | 21.05 | 26.25 | 22.00 | 16.48 | 19.63 |
| 400-150-100 | 8.37 | 9.21 | 7.48 | 15.60 | 13.80 | 16.80 | 19.35 | 15.25 | 21.5 | 23.40 | 21.65 | 27.40 | 23.75 | 16.03 | 19.73 |
| 50-150-100 | 8.55 | 8.57 | 6.47 | 16.78 | 14.28 | 16.73 | 23.75 | 16.05 | 22.7 | 25.65 | 22.65 | 27.55 | 21.90 | 15.90 | 21.03 |
| average | 8.04 | 8.70 | 6.70 | 15.57 | 13.72 | 15.28 | 20.33 | 15.03 | 20.97 | 23.37 | 20.77 | 25.58 | 21.34 | 15.42 | 20.09 |

In the above table A, B, and C refer to sawdust mulch, clean cultivated and sawdust incorporated plots respectively.

Table II. The effect of sawdust treatments on the dry weight of the leaves. (Dry weight in grams of 40 leaves per plot; average of all plots)

| Sawdust treatment | Date | | | | | average |
|---|---|---|---|---|---|---|
| | June 12 | July 12 | Aug. 12 | Sept.12 | Oct. 12 | |
| | gram | gram | gram | gram | gram | gram |
| Clean cult. | 8.696 | 13.717 | 15.033 | 20.767 | 15.419 | 14.726 |
| Sawdust mulch | 8.039 | 15.567 | 20.328 | 23.372 | 21.339 | 17.729 |
| Sawdust inc. | 6.797 | 15.281 | 20.967 | 25.583 | 20.094 | 17.744 |
| F value | 2.975 | 2.684 | 19.037** | 14.100** | 14.775** | |
| L. S. D. | - | - | 2.591 | 2.229 | 2.154 | |

Table III. The effect of fertilizer treatments on the dry weight of the leaves. (average of all plots)

| Fertilizer treatment | Date | | | | | average |
|---|---|---|---|---|---|---|
| | June 12 | July 12 | Aug. 12 | Sept. 12 | Oct. 12 | |
| | gram | gram | gram | gram | gram | gram |
| Check | 7.554 | 13.392 | 15.308 | 19.800 | 17.725 | 14.756 |
| 0-150-100 | 7.868 | 14.358 | 16.675 | 20.583 | 18.558 | 15.608 |
| 200-0-0 | 7.766 | 15.400 | 19.775 | 24.833 | 18.975 | 17.350 |
| 12-150-100 | 7.673 | 14.000 | 18.542 | 23.183 | 18.292 | 16.340 |
| 25-150-100 | 7.761 | 15.392 | 19.383 | 24.100 | 19.367 | 17.200 |
| 50-150-100 | 7.866 | 15.925 | 20.833 | 25.283 | 19.608 | 17.905 |
| 100-150-100 | 7.860 | 14.525 | 19.667 | 22.633 | 19.275 | 16.792 |
| 200-150-100 | 7.895 | 15.300 | 20.183 | 24.633 | 18.925 | 17.387 |
| 400-150-100 | 8.352 | 15.400 | 18.700 | 24.150 | 19.833 | 17.287 |
| F value | 0.509 | 3.775** | 11.491** | 8.936** | 2.070 | |
| L. S. D. | - | 1.194 | 1.464 | 1.807 | - | |

** The double star represents the 1 per cent significant level.

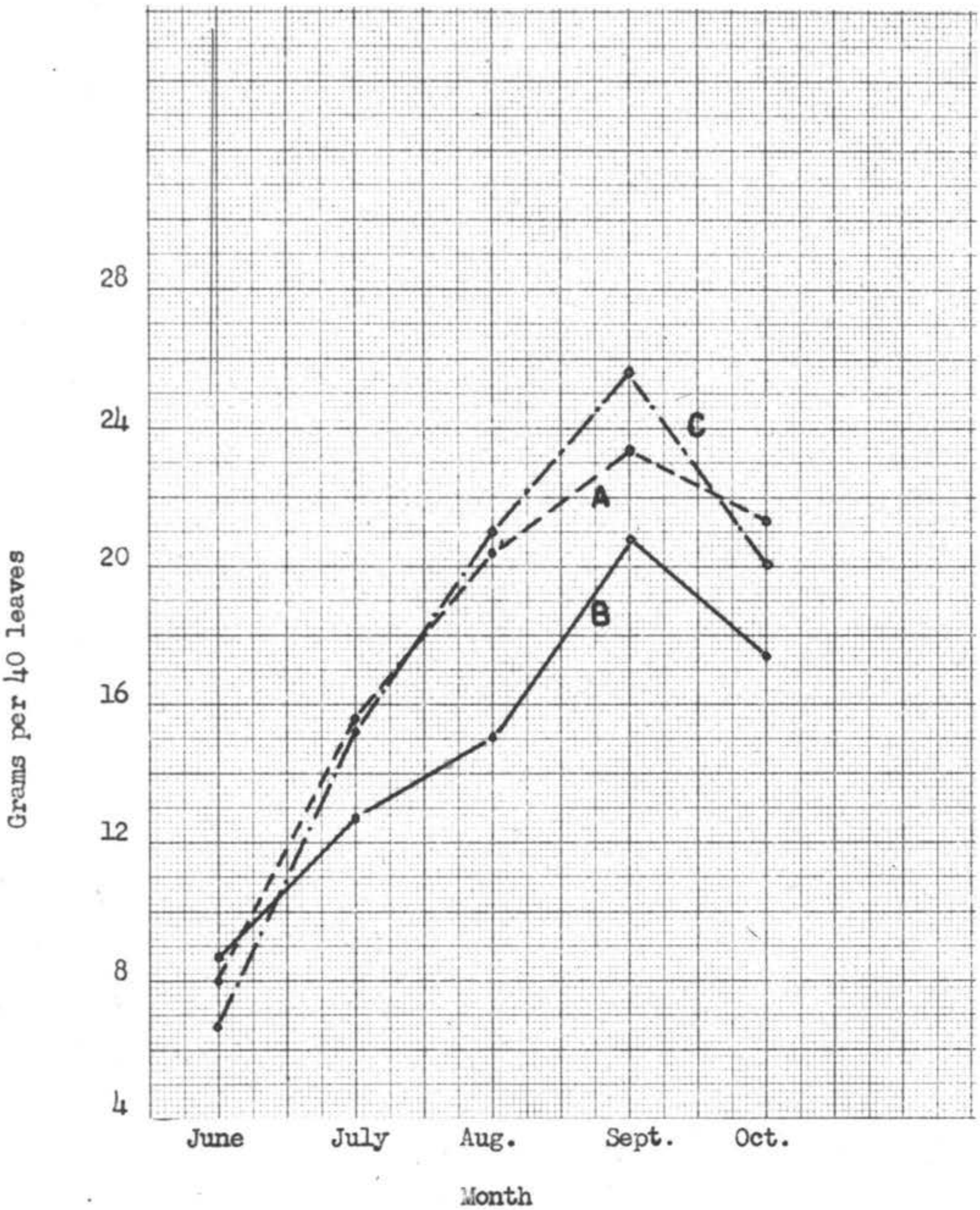


Fig. 1. The effect of sawdust treatment on the dry weight of the leaves. (Summary of all plots)

Legend: A Sawdust mulch
B Clean cultivated
C Sawdust incorporated

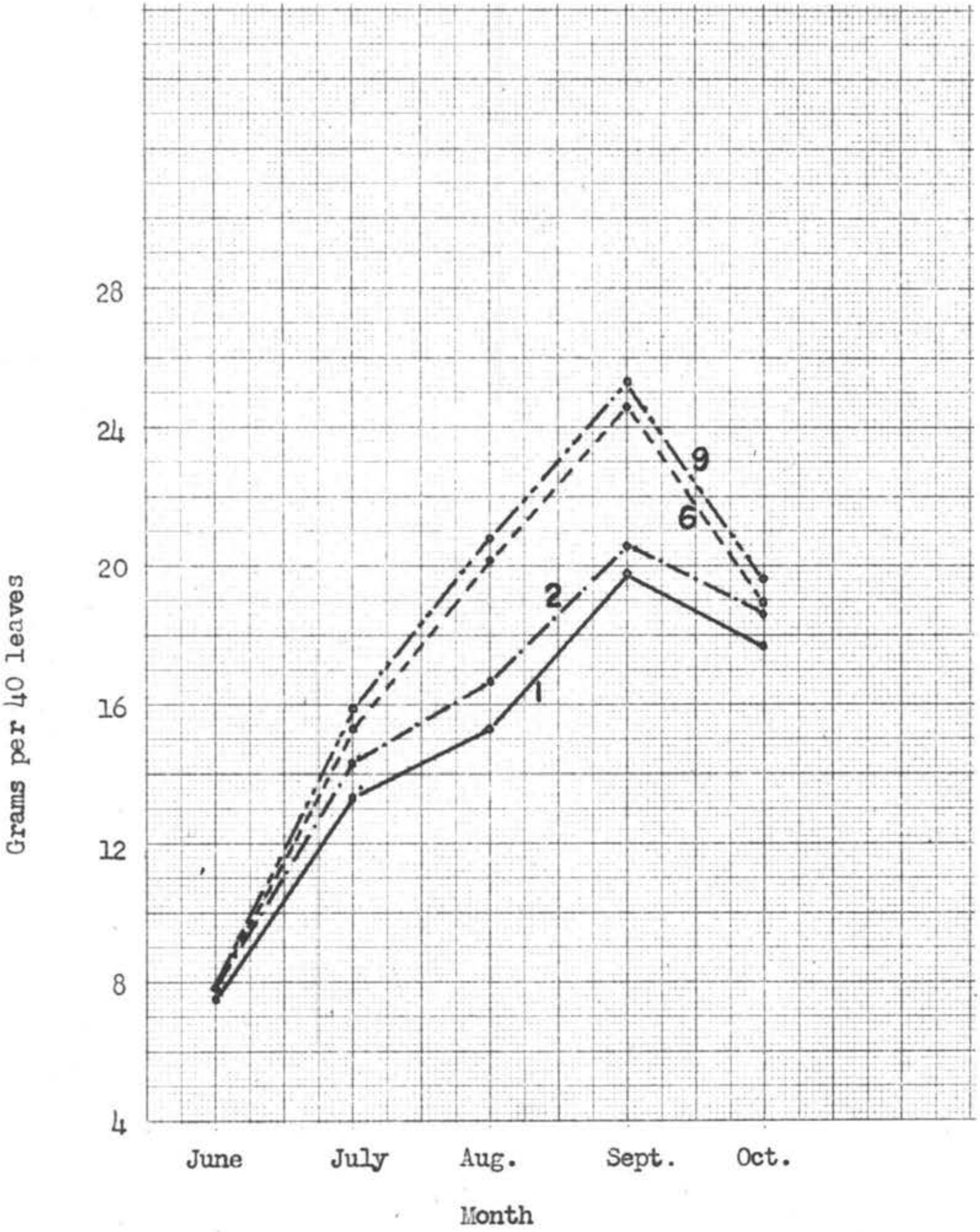


Fig. 2. The effect of fertilizer treatment on the dry weight of the leaves. (Summary of all plots)

Legend: (1) Check (2) 0-150-100
(6) 200-150-100 (9) 50-150-100
The fertilizer plots 3, 4, 5, 7 and 8 are not significantly different from no. 6 and 9.

The nitrogen content of the leaves

The concentration and total amount of nitrogen in the leaves are recorded in Tables IV, V, VI, VII and VIII. The nitrogen content of the leaves was high (2.059 per cent, an average of all plots) in June then declined in August (1.529 per cent) and increased again at the time of fruit bud differentiation (1.703 per cent). The seasonal changes of the nitrogen content in the leaves are also illustrated in Figures 3 and 4.

The results from sawdust treatments shown in Table V and also illustrated in Figure 3 indicate that the leaves taken from the clean cultivated plots had higher nitrogen content than those from either sawdust mulch or sawdust incorporated plots on June 12. However, as the season progressed the leaves from the sawdust mulch had the highest nitrogen content, while the leaves from the sawdust incorporated plots had the lowest nitrogen content. The nitrogen demands were greater when the sawdust was incorporated with the soil than when used as a surface mulch. This agrees with the results of the preliminary investigations by the Oregon Agricultural Experiment Station.

Table VI and Figure 4 show that the leaves from the PK plots always had the lowest nitrogen content. The plants from the plots with higher rates of nitrogen application (more than 25 pounds of nitrogen per acre in the fourth year) had significantly higher nitrogen content than those from plots without nitrogen or with lower rates of nitrogen application.

The curves of Figures 5 and 6 are obtained from the nitrogen content of the leaves from each plot multiplied by the dry weight of the leaves from the corresponding plot. It is obvious that the amount of nitrogen accumulated in the leaves corresponds with the rate of the plant growth.

Table IV. Seasonal changes in the nitrogen content of the leaves during the growing season in 1951. (Per cent of nitrogen on dry weight basis; an average of four replications)

| Fertilizer treatment | Date | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | June 12 | | | July 12 | | | August 12 | | | September 12 | | | October 12 | | |
| | Sawdust treatment | | | | | | | | | | | | | | |
| | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| | % | % | % | % | % | % | % | % | % | % | % | % | % | % | % |
| Check | 2.02 | 2.10 | 2.02 | 2.05 | 1.80 | 2.01 | 1.53 | 1.50 | 1.50 | 1.59 | 1.61 | 1.52 | 1.68 | 1.65 | 1.63 |
| 0-150-100 | 1.98 | 2.10 | 1.95 | 2.06 | 1.83 | 1.94 | 1.44 | 1.46 | 1.47 | 1.49 | 1.57 | 1.50 | 1.63 | 1.64 | 1.61 |
| 200-0-0 | 2.05 | 2.18 | 1.94 | 2.20 | 1.96 | 2.08 | 1.60 | 1.53 | 1.50 | 1.90 | 1.76 | 1.66 | 1.93 | 1.78 | 1.77 |
| 100-150-100 | 2.03 | 2.11 | 1.87 | 2.21 | 1.89 | 2.23 | 1.58 | 1.58 | 1.54 | 1.84 | 1.73 | 1.71 | 1.83 | 1.67 | 1.70 |
| 12-150-100 | 2.10 | 2.08 | 1.91 | 2.06 | 1.86 | 2.05 | 1.43 | 1.47 | 1.49 | 1.59 | 1.63 | 1.61 | 1.77 | 1.69 | 1.63 |
| 200-150-100 | 2.10 | 2.20 | 1.91 | 2.27 | 1.89 | 2.13 | 1.62 | 1.53 | 1.54 | 1.87 | 1.81 | 1.75 | 1.97 | 1.92 | 1.80 |
| 25-150-100 | 2.06 | 2.14 | 1.96 | 2.14 | 1.88 | 2.01 | 1.57 | 1.42 | 1.45 | 1.75 | 1.66 | 1.58 | 1.79 | 1.67 | 1.64 |
| 400-150-100 | 2.08 | 2.36 | 2.04 | 2.28 | 1.91 | 2.05 | 1.75 | 1.62 | 1.59 | 1.98 | 1.83 | 1.76 | 1.92 | 1.85 | 1.86 |
| 50-150-100 | 2.03 | 2.24 | 1.99 | 2.20 | 1.95 | 2.11 | 1.50 | 1.53 | 1.52 | 1.78 | 1.76 | 1.68 | 1.89 | 1.78 | 1.76 |
| average | 2.05 | 2.17 | 1.96 | 2.16 | 1.89 | 2.07 | 1.56 | 1.52 | 1.51 | 1.76 | 1.71 | 1.64 | 1.82 | 1.74 | 1.71 |

In the above table A, B, and C refer to sawdust mulch, clean cultivated and sawdust incorporated plots respectively.

Table V. The effect of sawdust treatments on the nitrogen content of the leaves. (Per cent of N on dry weight basis; average of all plots)

| Sawdust treatment | Date | | | | | average |
|---|---|---|---|---|---|---|
| | June 12 | July 12 | Aug. 12 | Sept. 12 | Oct. 12 | |
| | % | % | % | % | % | % |
| Clean cult. | 2.169 | 1.887 | 1.516 | 1.708 | 1.737 | 1.803 |
| Sawdust mulch | 2.051 | 2.164 | 1.560 | 1.757 | 1.823 | 1.871 |
| Sawdust inc. | 1.957 | 2.069 | 1.512 | 1.644 | 1.713 | 1.779 |
| F value | 7.106* | 8.737* | 2.153 | 39.733** | 9.245* | |
| L. S. D. | 0.138 | 0.165 | - | 0.031 | 0.066 | |

Table VI. The effect of fertilizer treatments on the nitrogen content of the leaves. (Average of all plots)

| Fertilizer treatment | Date | | | | | average |
|---|---|---|---|---|---|---|
| | June 12 | July 12 | Aug. 12 | Sept. 12 | Oct. 12 | |
| | % | % | % | % | % | % |
| Check | 2.045 | 1.952 | 1.513 | 1.577 | 1.653 | 1.748 |
| 0-150-100 | 2.011 | 1.942 | 1.456 | 1.523 | 1.630 | 1.712 |
| 200-0-0 | 2.059 | 2.083 | 1.548 | 1.773 | 1.816 | 1.856 |
| 12-150-100 | 2.031 | 1.993 | 1.464 | 1.614 | 1.698 | 1.760 |
| 25-150-100 | 2.056 | 2.008 | 1.483 | 1.644 | 1.703 | 1.779 |
| 50-150-100 | 2.089 | 2.089 | 1.518 | 1.741 | 1.808 | 1.809 |
| 100-150-100 | 2.007 | 2.109 | 1.569 | 1.761 | 1.736 | 1.836 |
| 200-150-100 | 2.070 | 2.099 | 1.563 | 1.813 | 1.898 | 1.889 |
| 400-150-100 | 2.161 | 2.084 | 1.651 | 1.859 | 1.876 | 1.926 |
| F value | 0.507 | 9.181** | 9.132** | 26.401** | 14.779** | |
| L. S. D. | - | 0.062 | 0.057 | 0.062 | 0.070 | |

* The single star refers to the 5 per cent significant level.
** The double star refers to the 1 per cent significant level.

Table VII. The effect of sawdust treatments on the absolute amount of nitrogen in leaves. (Grams of N in 40 leaves per plot; summary of all plots)

| Sawdust treatment | Date | | | | | average |
|---|---|---|---|---|---|---|
| | June 12 | July 12 | Aug. 12 | Sept. 12 | Oct. 12 | |
| | gm. | gm. | gm. | gm. | gm. | gm. |
| Clean cult. | 0.1886 | 0.2588 | 0.2279 | 0.3547 | 0.2678 | 0.2596 |
| Sawdust mulch | 0.1649 | 0.3369 | 0.3171 | 0.4106 | 0.3890 | 0.3237 |
| Sawdust inc. | 0.1330 | 0.3162 | 0.3170 | 0.4206 | 0.3442 | 0.3062 |

Table VIII. The effect of fertilizer treatments on the absolute amount of nitrogen in leaves. (Summary of all plots)

| Fertilizer treatment | Date | | | | | average |
|---|---|---|---|---|---|---|
| | June 12 | July 12 | Aug. 12 | Sept. 12 | Oct. 12 | |
| | gm. | gm. | gm. | gm. | gm. | gm. |
| Check | 0.1545 | 0.2614 | 0.2316 | 0.3122 | 0.2930 | 0.2505 |
| 0 -150-100 | 0.1582 | 0.2788 | 0.2427 | 0.3135 | 0.3025 | 0.2591 |
| 200- 0 - 0 | 0.1599 | 0.3203 | 0.3061 | 0.4403 | 0.3446 | 0.3142 |
| 12 -150-100 | 0.1558 | 0.2790 | 0.2715 | 0.3742 | 0.3106 | 0.2782 |
| 25 -150-100 | 0.1596 | 0.3091 | 0.2874 | 0.3962 | 0.3298 | 0.2964 |
| 50 -150-100 | 0.1643 | 0.3327 | 0.3162 | 0.4402 | 0.3545 | 0.3216 |
| 100-150-100 | 0.1578 | 0.3063 | 0.3086 | 0.3986 | 0.3346 | 0.3012 |
| 200-150-100 | 0.1634 | 0.3211 | 0.3155 | 0.4466 | 0.3592 | 0.3212 |
| 400-150-100 | 0.1804 | 0.3209 | 0.3087 | 0.4489 | 0.3721 | 0.3262 |

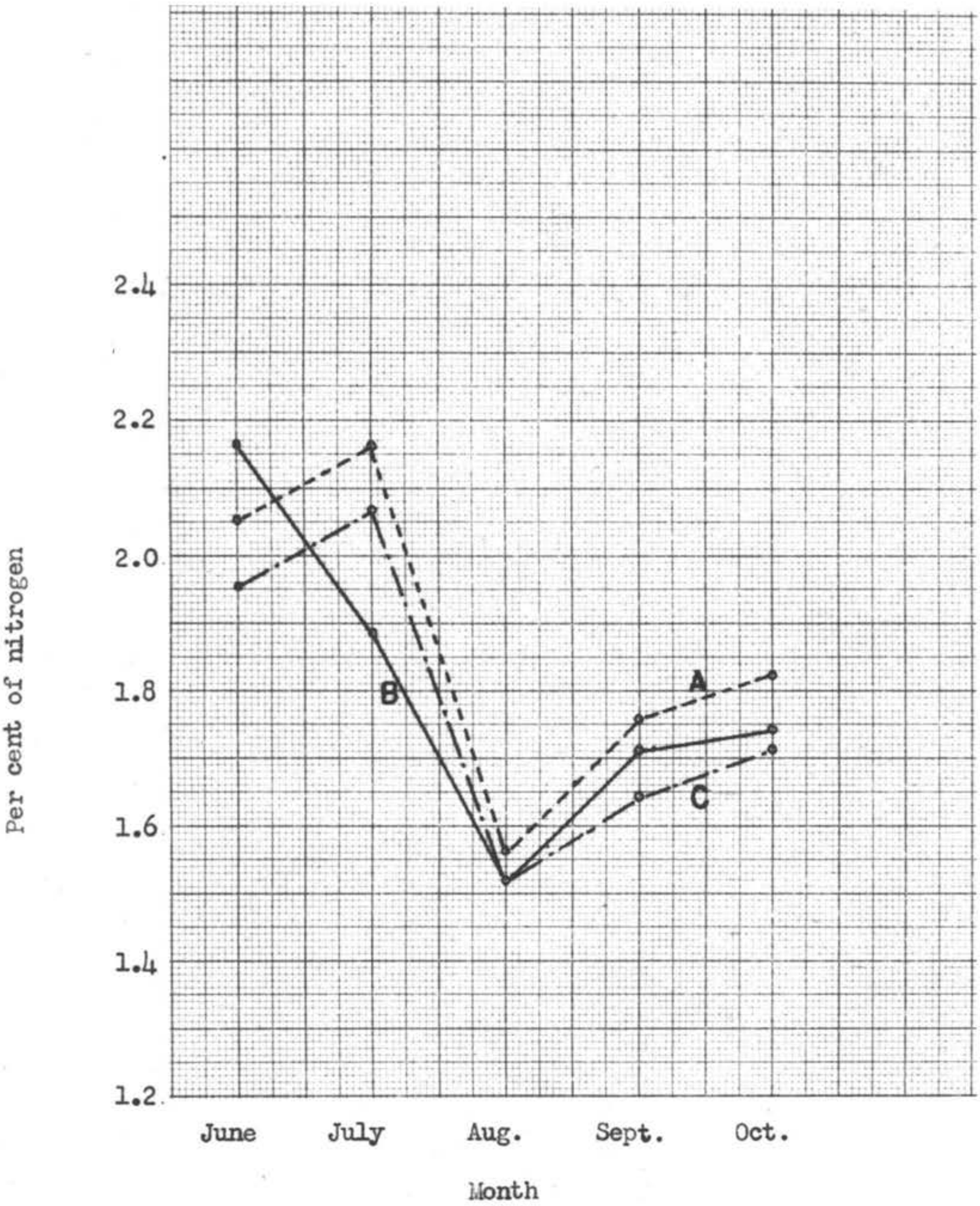


Fig. 3. The effect of sawdust treatment on the nitrogen content of the leaves. (Average of all plots)

Legend: A Sawdust mulch
B Clean cultivated
C Sawdust incorporated

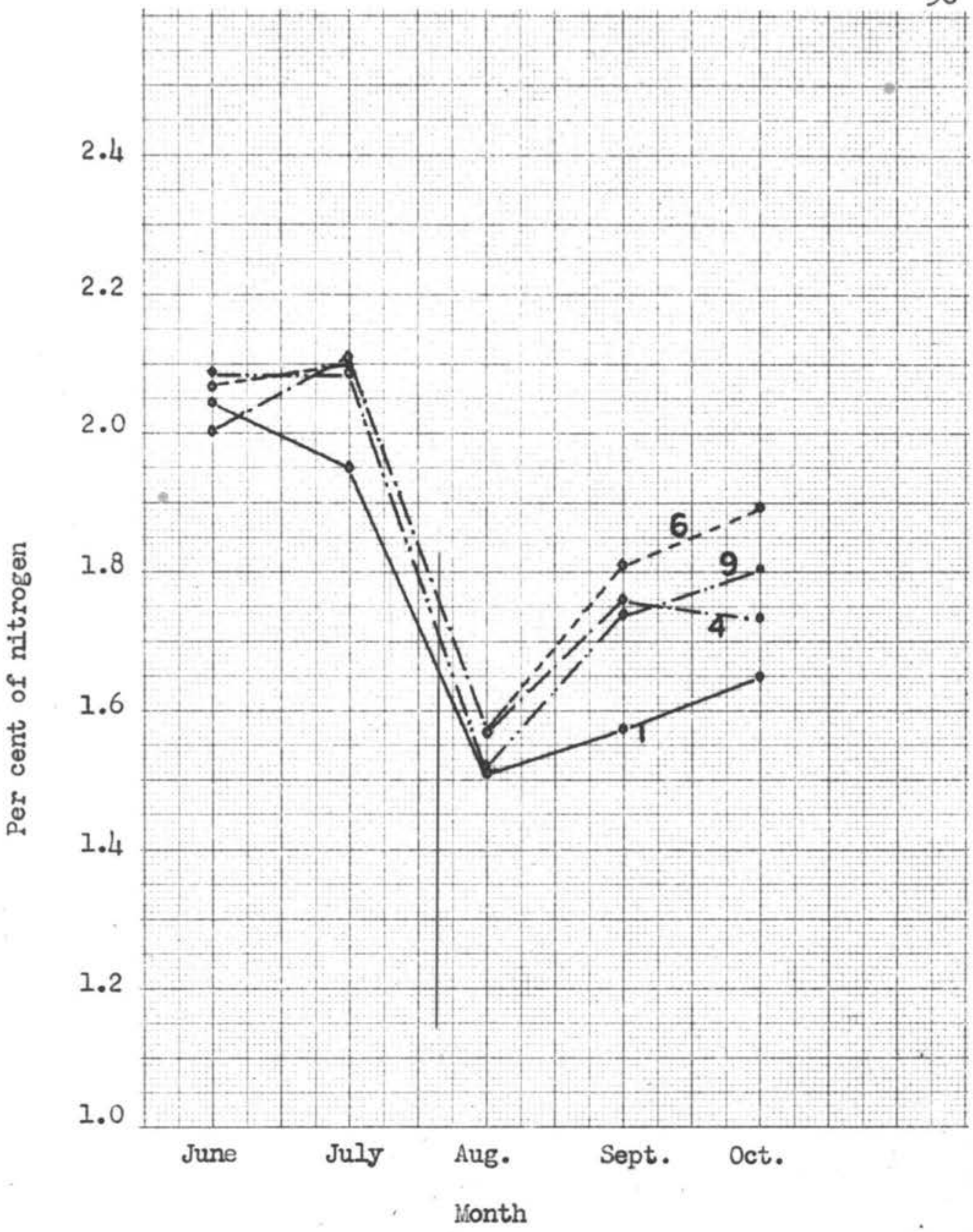


Fig. 4. The effect of fertilizer treatment on the nitrogen content of the leaves. (Average of all plots)

Legend: (1) Check (4) 100-150-100
(6) 200-150-100 (9) 50-150-100

The fertilizer plots 2, 5 and 7 are not significantly different from no. 1; plot 3 is about same as no. 4 and plot 8 about same as no. 6.

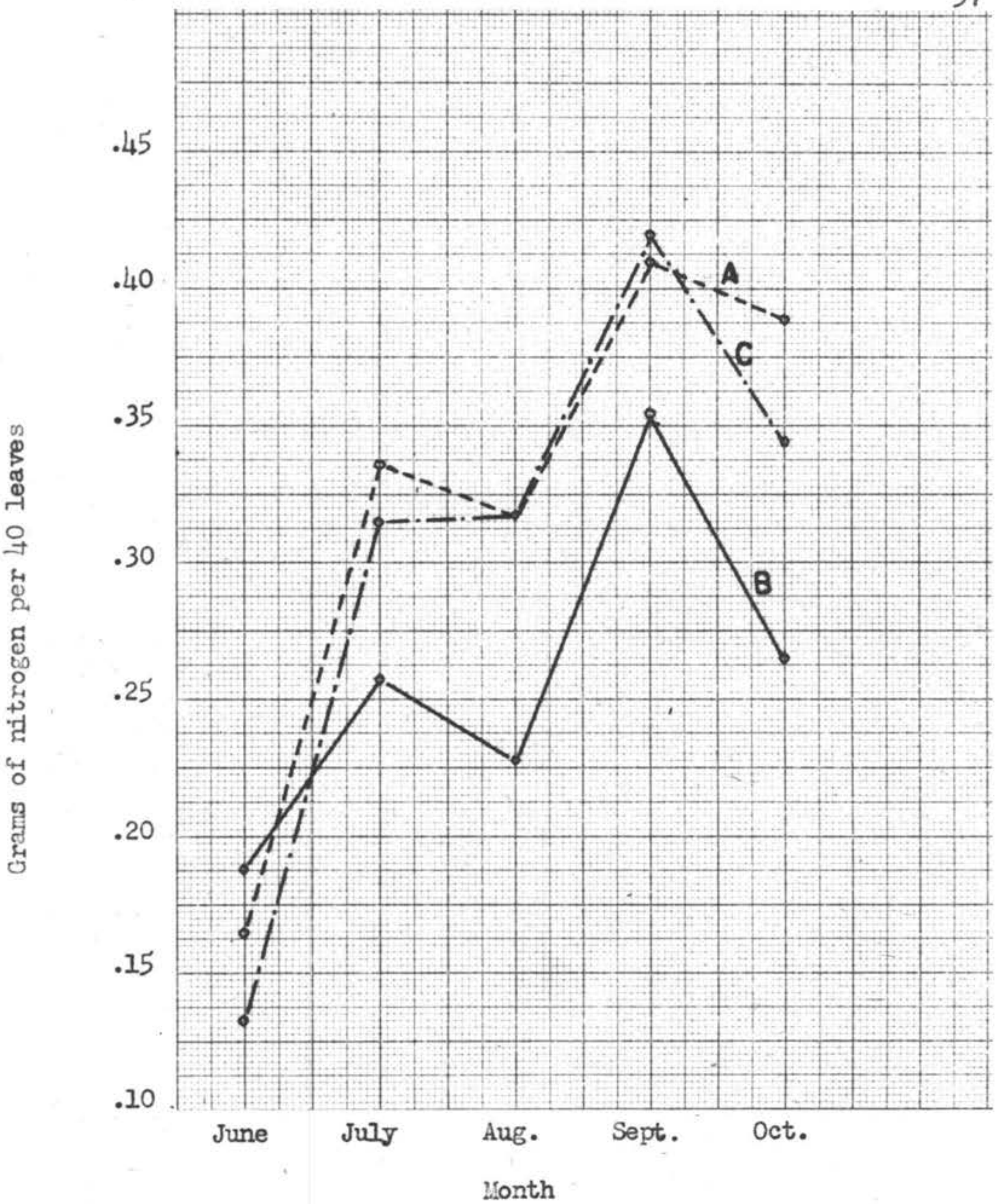


Fig. 5. The effect of sawdust treatment on the total amount of nitrogen in the leaves. (Average of all plots)

Legend: A Sawdust mulch
B Clean cultivated
C Sawdust incorporated

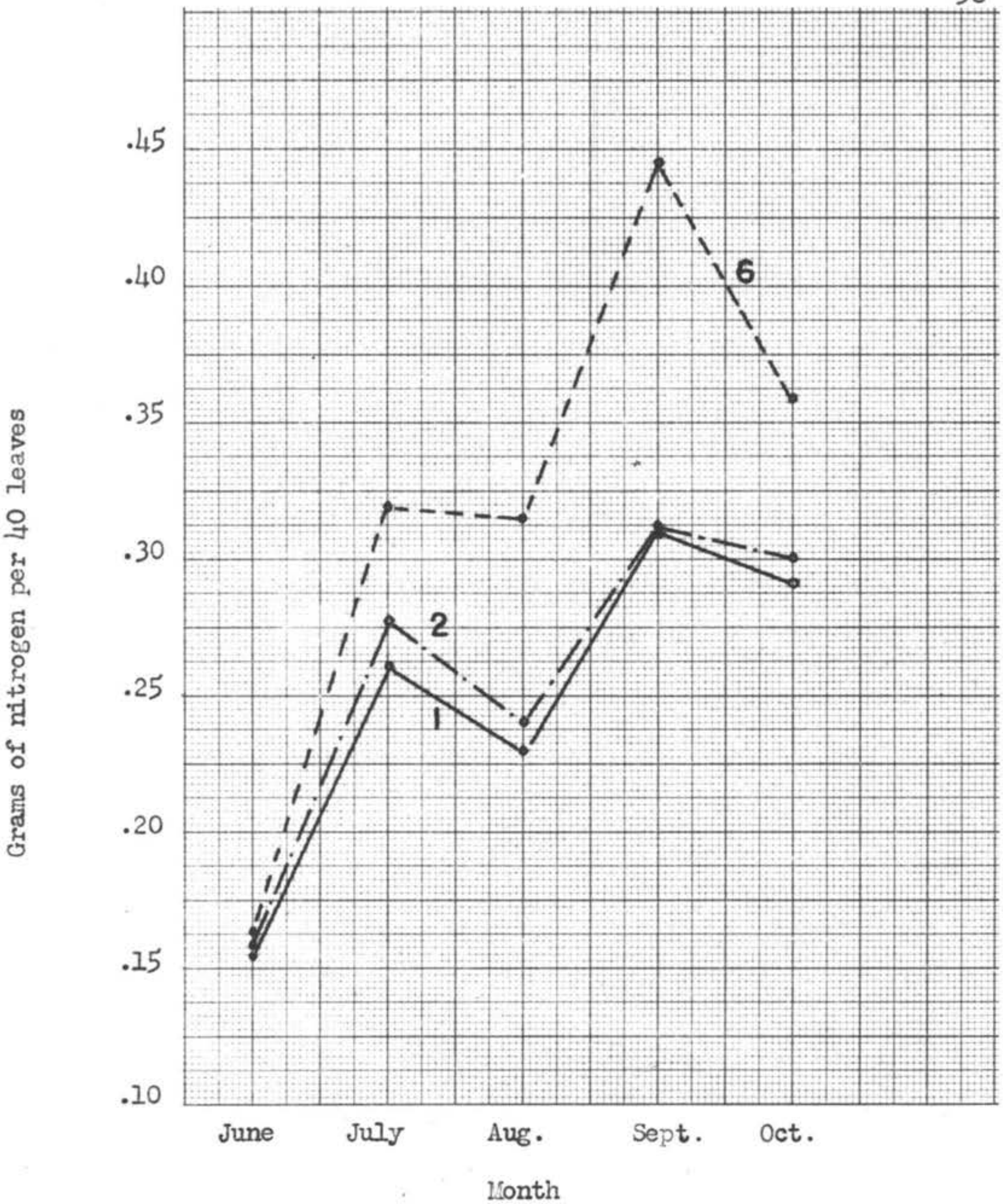


Fig. 6. The effect of fertilizer treatment on the total amount of nitrogen in the leaves. (Average of all plots)

Legend: (1) Check (2) 0-150-100
(6) 200-150-100

The fertilizer plots 3, 4, 5, 7, 8 and 9 are not significantly different from no. 6.

The phosphorus content of the leaves

The concentration and total amount of phosphorus in the leaves are recorded in Tables IX, X, XI, XII and XIII. The phosphorus content of the leaves in the sawdust mulch and sawdust incorporated plots was high in June and became practically constant during the remaining period. This seasonal change of the phosphorus content in the leaves is also illustrated in Figure 7.

Table X and Figure 7 show that the plants in the clean cultivated plots absorbed less phosphorus than those from either the sawdust mulch or sawdust incorporated plots.

Results from the fertilizer treatments shown in Table XI and Figure 8 indicate that in the check and PK plots phosphorus was always higher than in those plots fertilized with higher rates of nitrogen. In fertilizer plot no. 3 which was supplied with 200 pounds of nitrogen per acre and no phosphate fertilizer the phosphorus content of the leaves was significantly lower than that in other treatments.

The seasonal variation of the total phosphorus in the leaves, illustrated in Figures 9 and 10, just as that of the nitrogen had the same trend corresponding to the growth rate of the plant.

Table IX. Seasonal changes in the phosphorus content of the leaves during the growing season in 1951. (Per cent of phosphorus on dry weight basis; an average of four replications)

| Fertilizer treatment | Date: June 12 | | | July 12 | | | August 12 | | | September 12 | | | October 12 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sawdust treatment | | | | | | | | | | | | | | |
| | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| | % | % | % | % | % | % | % | % | % | % | % | % | % | % | % |
| Check | .31 | .21 | .29 | .29 | .18 | .28 | .25 | .21 | .25 | .30 | .21 | .25 | .30 | .25 | .24 |
| 0 -150-100 | .29 | .22 | .32 | .30 | .20 | .27 | .30 | .23 | .27 | .31 | .22 | .25 | .30 | .25 | .28 |
| 200- 0 - 0 | .25 | .20 | .28 | .20 | .17 | .18 | .19 | .19 | .21 | .24 | .18 | .21 | .25 | .22 | .20 |
| 100-150-100 | .30 | .21 | .25 | .23 | .18 | .22 | .20 | .20 | .23 | .26 | .19 | .23 | .27 | .24 | .24 |
| 12-150-100 | .30 | .20 | .28 | .28 | .19 | .25 | .22 | .21 | .25 | .26 | .22 | .26 | .27 | .24 | .26 |
| 200-150-100 | .26 | .20 | .25 | .22 | .18 | .21 | .20 | .20 | .21 | .24 | .18 | .21 | .28 | .26 | .23 |
| 25-150-100 | .28 | .21 | .30 | .24 | .18 | .23 | .23 | .21 | .22 | .28 | .20 | .23 | .28 | .25 | .25 |
| 400-150-100 | .24 | .20 | .28 | .20 | .17 | .17 | .21 | .20 | .20 | .26 | .18 | .19 | .26 | .25 | .23 |
| 50-150-100 | .26 | .20 | .25 | .21 | .19 | .19 | .21 | .20 | .22 | .26 | .18 | .22 | .28 | .26 | .26 |
| average | .28 | .21 | .28 | .24 | .18 | .22 | .23 | .21 | .23 | .23 | .20 | .23 | .24 | .25 | .24 |

In the above table A, B, and C refer to sawdust mulch, clean cultivated and sawdust incorporated plots respectively.

Table X. The effect of sawdust treatments on the phosphorus content of the leaves. (Per cent of P on dry weight basis; average of all plots)

| Sawdust treatment | Date | | | | | average |
|---|---|---|---|---|---|---|
| | June 12 | July 12 | August 12 | Sept. 12 | Oct. 12 | |
| | % | % | % | % | % | % |
| Clean cult. | 0.206 | 0.184 | 0.206 | 0.198 | 0.246 | 0.208 |
| Sawdust mulch | 0.277 | 0.240 | 0.226 | 0.231 | 0.240 | 0.243 |
| Sawdust inc. | 0.280 | 0.224 | 0.231 | 0.231 | 0.240 | 0.241 |
| F value | 15.720** | 9.254** | 17.857** | 22.600** | 6.386* | |
| L. S. D. | 0.0366 | 0.0341 | 0.0035 | 0.0258 | 0.0282 | |

Table XI. The effect of fertilizer treatments on the phosphorus content of the leaves. (Average of all plots)

| Fertilizer treatment | Date | | | | | average |
|---|---|---|---|---|---|---|
| | June 12 | July 12 | Aug. 12 | Sept. 12 | Oct. 12 | |
| | % | % | % | % | % | % |
| Check | 0.272 | 0.253 | 0.241 | 0.256 | 0.266 | 0.258 |
| 0 -150-100 | 0.278 | 0.258 | 0.267 | 0.260 | 0.268 | 0.266 |
| 200- 0 - 0 | 0.243 | 0.188 | 0.198 | 0.212 | 0.225 | 0.209 |
| 12-150-100 | 0.259 | 0.233 | 0.230 | 0.250 | 0.258 | 0.246 |
| 25-150-100 | 0.268 | 0.218 | 0.223 | 0.241 | 0.261 | 0.242 |
| 50-150-100 | 0.237 | 0.196 | 0.211 | 0.221 | 0.257 | 0.224 |
| 100-150-100 | 0.254 | 0.213 | 0.211 | 0.224 | 0.250 | 0.230 |
| 200-150-100 | 0.237 | 0.205 | 0.204 | 0.214 | 0.258 | 0.224 |
| 400-150-100 | 0.242 | 0.182 | 0.205 | 0.214 | 0.248 | 0.218 |
| F value | 3.401** | 5.819** | 8.997** | 9.509** | 8.278** | |
| L. S. D. | 0.0239 | 0.0170 | 0.0205 | 0.0101 | 0.0126 | |

* The single star refers to the 5 per cent significant level.
** The double star refers to the 1 per cent significant level.

Table XII. The effect of sawdust treatments on the absolute amount of phosphorus in the leaves. (Grams of P in 40 leaves per plot; average of all plots)

| Sawdust treatment | Date | | | | | average |
|---|---|---|---|---|---|---|
| | June 12 | July 12 | Aug. 12 | Sept.12 | Oct. 12 | |
| | gm. | gm. | gm. | gm. | gm. | gm. |
| Clean cult. | 0.0179 | 0.0253 | 0.0310 | 0.0411 | 0.0379 | 0.0306 |
| Sawdust mulch | 0.0223 | 0.0373 | 0.0459 | 0.0629 | 0.0591 | 0.0455 |
| Sawdust inc. | 0.0190 | 0.0342 | 0.0484 | 0.0591 | 0.0482 | 0.0418 |

Table XIII. The effect of fertilizer treatments on the absolute amount of phosphorus in the leaves. (Average of all plots)

| Fertilizer treatment | Date | | | | | average |
|---|---|---|---|---|---|---|
| | June 12 | July 12 | Aug. 12 | Sept. 12 | Oct. 12 | |
| | gm. | gm. | gm. | gm. | gm. | gm. |
| Check | 0.0205 | 0.0338 | 0.0369 | 0.0507 | 0.0471 | 0.0378 |
| 0 -150-100 | 0.0218 | 0.0370 | 0.0445 | 0.0535 | 0.0497 | 0.0413 |
| 200- 0 - 0 | 0.0189 | 0.0289 | 0.0390 | 0.0526 | 0.0427 | 0.0364 |
| 12-150-100 | 0.0200 | 0.0327 | 0.0426 | 0.0580 | 0.0472 | 0.0401 |
| 25-150-100 | 0.0208 | 0.0335 | 0.0432 | 0.0580 | 0.0505 | 0.0414 |
| 50-150-100 | 0.0186 | 0.0312 | 0.0440 | 0.0559 | 0.0504 | 0.0400 |
| 100-150-100 | 0.0200 | 0.0309 | 0.0415 | 0.0512 | 0.0482 | 0.0384 |
| 200-150-100 | 0.0187 | 0.0314 | 0.0412 | 0.0527 | 0.0488 | 0.0386 |
| 400-150-100 | 0.0202 | 0.0280 | 0.0383 | 0.0517 | 0.0492 | 0.0375 |

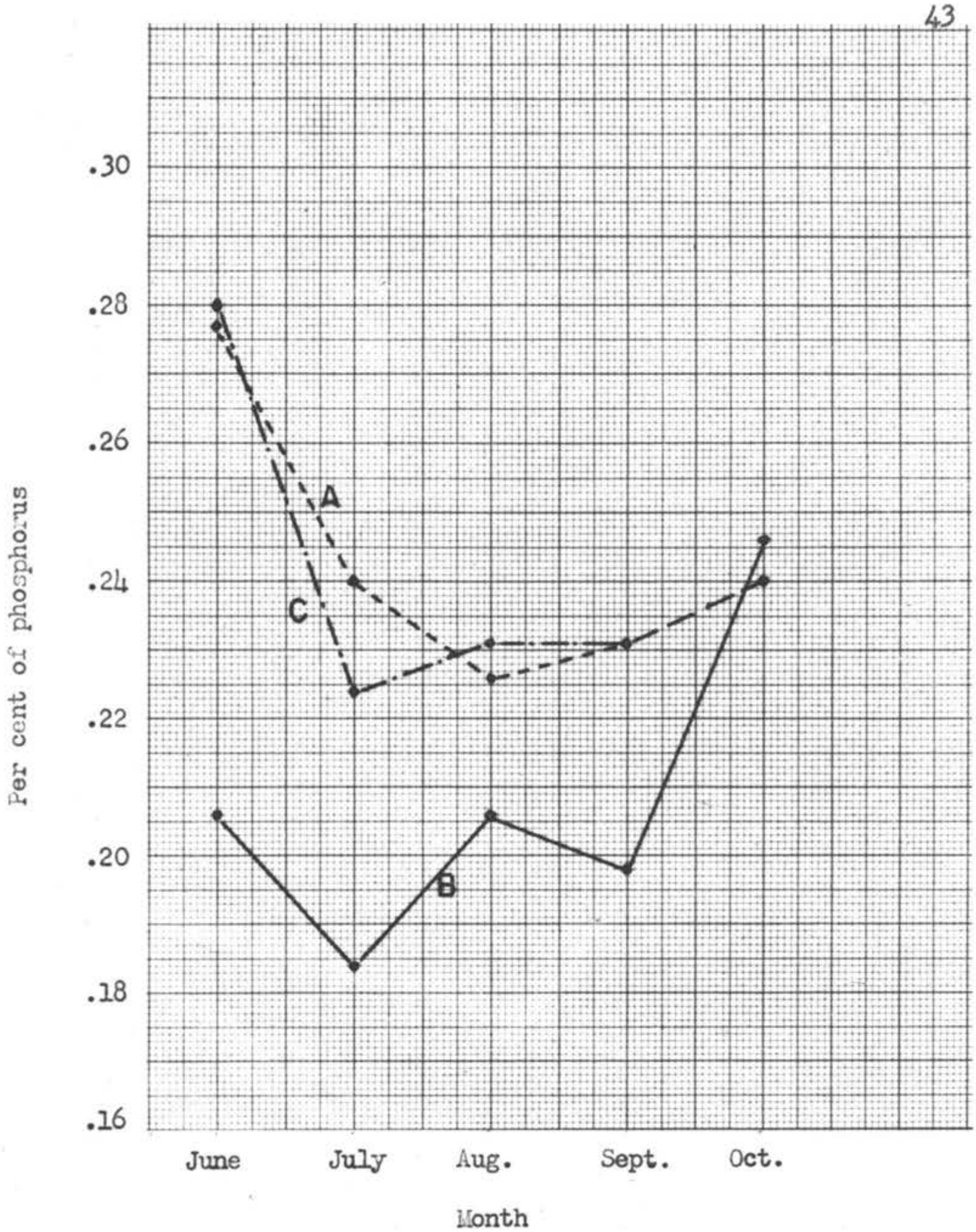


Fig. 7. The effect of sawdust treatment on the phosphorus content of the leaves. (Average of all plots)

Legend: A Sawdust mulch
B Clean cultivated
C Sawdust incorporated

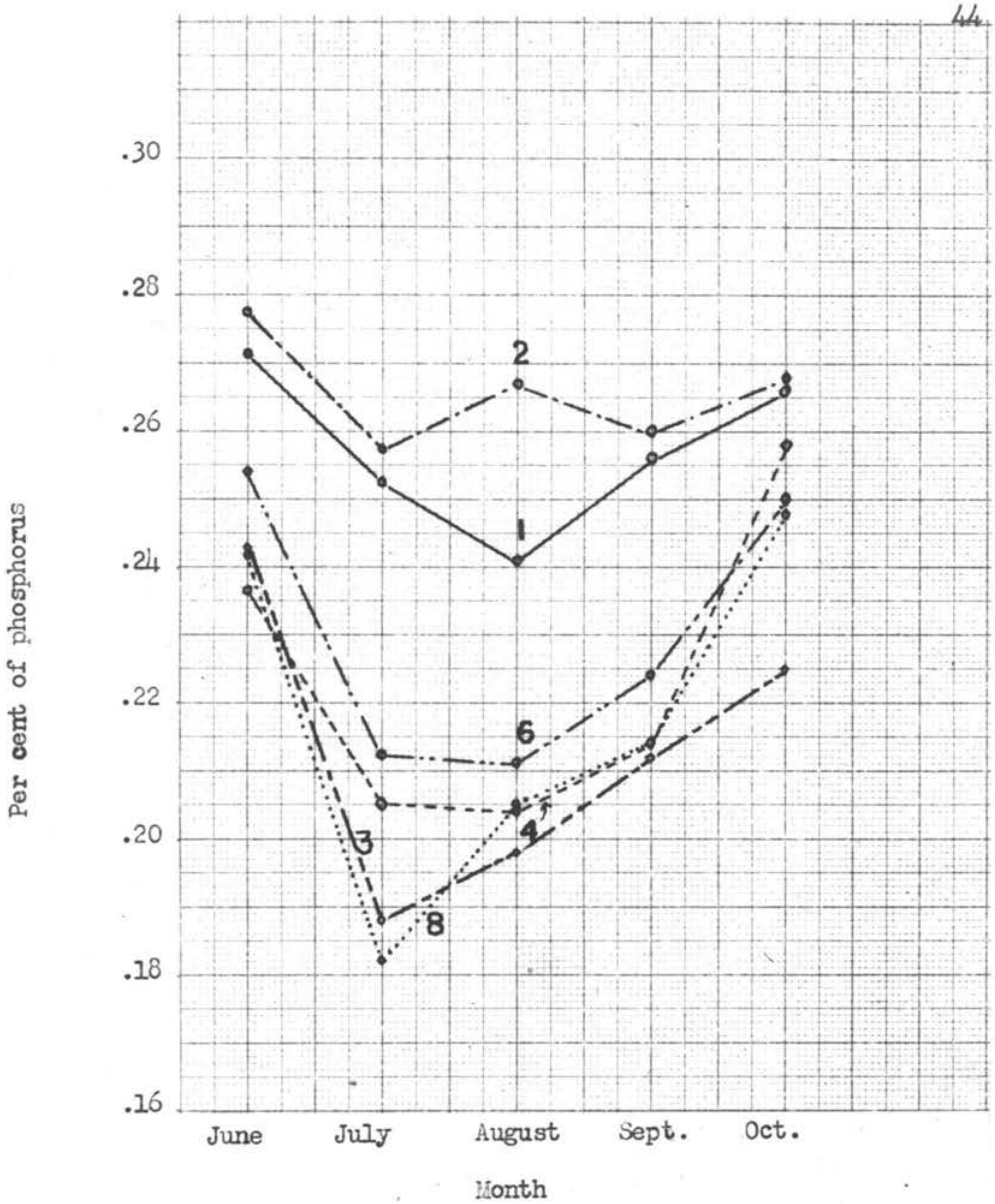


Fig. 8. The effect of fertilizer treatment on the phosphorus content of the leaves. (Average of all plots)

Legend: (1) Check (2) 0-150-100
(3) 200-0-0 (4) 100-150-100
(6) 200-150-100 (8) 400-150-100

The fertilizer plots 5 and 7 are not significantly different from no.4 and plot 9 is about same as no.6.

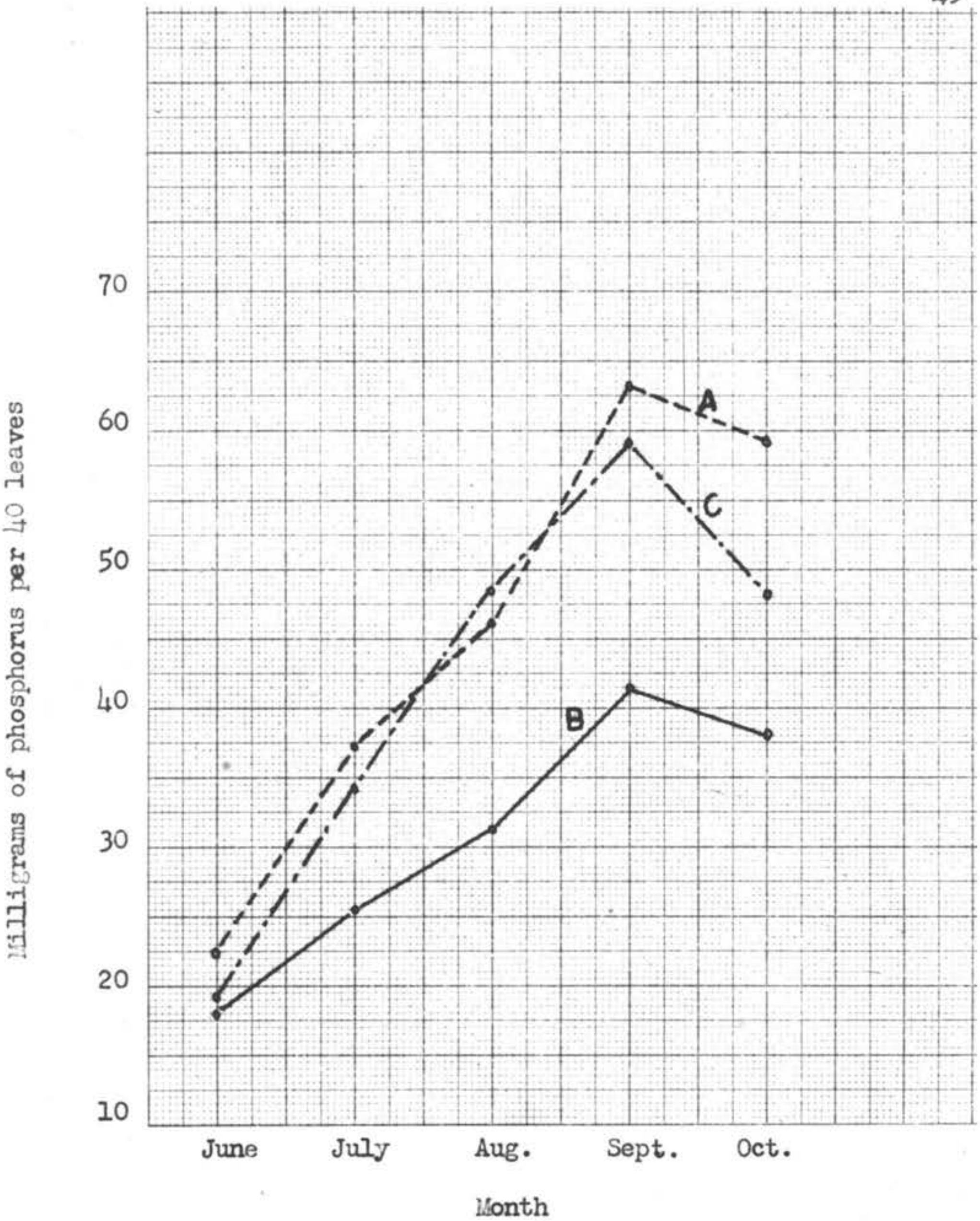


Fig. 9. The effect of sawdust treatment on the total amount of phosphorus in the leaves. (Average of all plots)

Legend: A Sawdust mulch
B Clean cultivated
C Sawdust incorporated

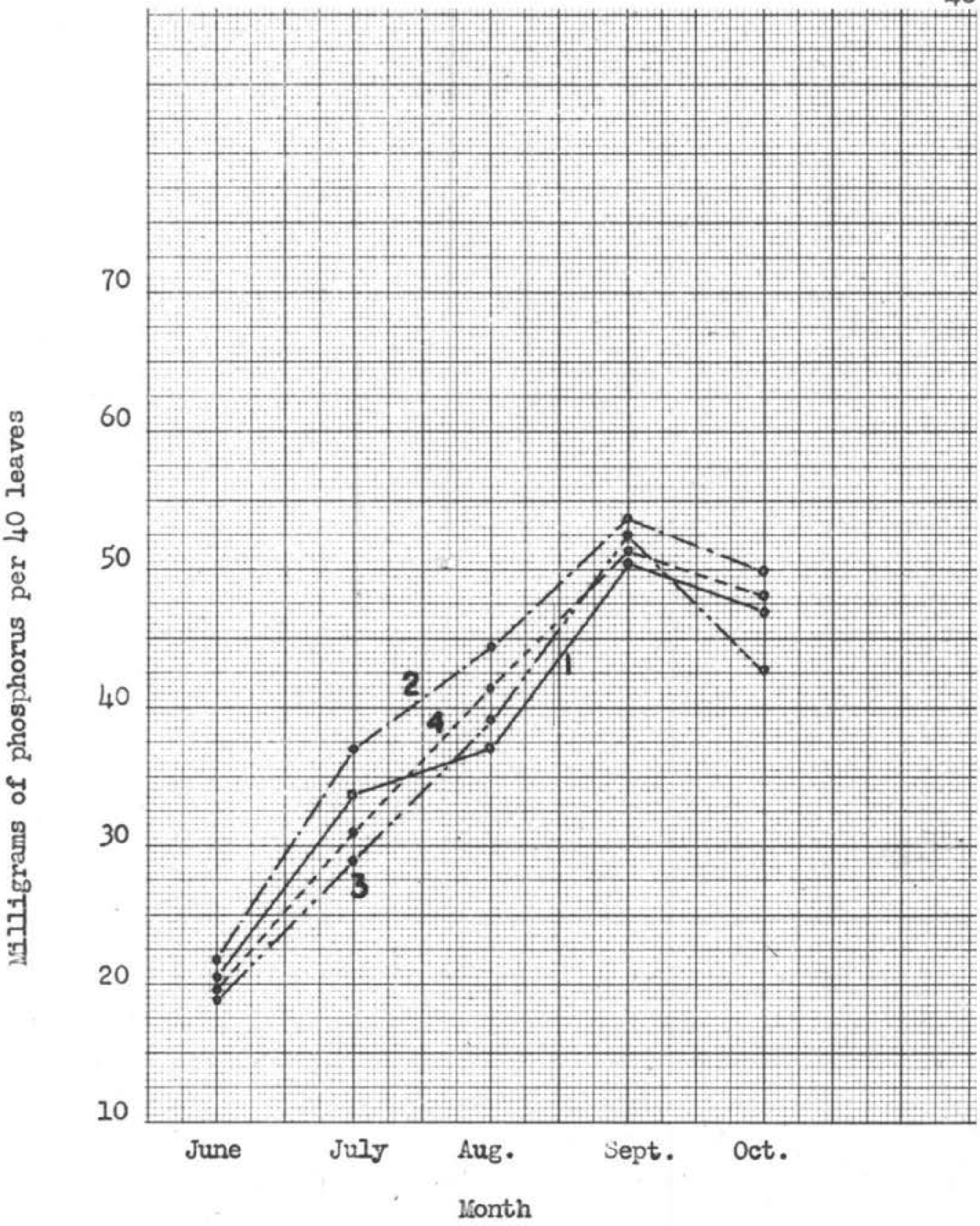


Fig. 10. The effect of fertilizer treatment on the total amount of phosphorus in the leaves. (Average of all plots)

Legend: (1) Check (2) 0-150-100
(3) 200-0-0 (4) 100-150-100

The fertilizer plots 5, 6, 7, 8 and 9 are not significantly different from no. 4.

The potassium content of the leaves

The concentration and total amount of potassium in the leaves are recorded in Tables XIV, XV, XVI, XVII and XVIII. The potassium content of the leaves was high (1.26 per cent, an average of all plots) in June then decreased somewhat in July and increased again in August and finally decreased until leaf senescence in October (0.93 per cent). There was an actual loss of potassium after that time largely from the leaves and stems by the leaching of rain. These seasonal changes of the potassium content in the leaves are also illustrated in Figures 11 and 12.

Table XV and Figure 11 indicate that during the early growing period in the clean cultivated plots the plants absorbed less potassium than those in sawdust mulch and sawdust incorporated plots. However, as the season progressed the differences in the potassium content of the leaves among the three treatments were not significant.

The results from fertilizer treatments shown in Table XVI and Figure 12 indicate that during the early growing period in the check plots the potassium content of the leaves was lower than that in other fertilizer treatments. However, as the season progressed the different fertilizer treatments had no effect on the absorption of potassium by the plant.

The seasonal changes of the total amount of potassium in the leaves, illustrated in Figures 13 and 14, also corresponded with the rate of plant growth.

Table XIV. Seasonal changes in the potassium content of the leaves during the growing season in 1951. (Per cent of potassium on dry weight basis; an average of four replications)

| Fertilizer treatment | Date | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | June 12 | | | July 12 | | | August 12 | | | September 12 | | | October 12 | | |
| | Sawdust treatment | | | | | | | | | | | | | | |
| | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| | % | % | % | % | % | % | % | % | % | % | % | % | % | % | % |
| Check | 1.22 | 1.15 | 1.36 | 1.25 | 1.06 | 1.18 | 1.35 | 1.24 | 1.33 | 1.18 | 1.16 | 1.17 | 0.87 | 0.96 | 0.84 |
| 0 -150-100 | 1.19 | 1.21 | 1.38 | 1.36 | 1.16 | 1.28 | 1.38 | 1.29 | 1.40 | 1.20 | 1.20 | 1.17 | 0.90 | 0.98 | 0.88 |
| 200- 0 - 0 | 1.17 | 1.22 | 1.39 | 1.28 | 1.01 | 1.20 | 1.29 | 1.21 | 1.45 | 1.25 | 1.14 | 1.10 | 0.91 | 1.00 | 0.85 |
| 100-150-100 | 1.36 | 1.16 | 1.26 | 1.36 | 1.13 | 1.25 | 1.37 | 1.31 | 1.39 | 1.20 | 1.17 | 1.12 | 0.94 | 0.95 | 0.92 |
| 12-150-100 | 1.29 | 1.12 | 1.29 | 1.32 | 1.06 | 1.28 | 1.30 | 1.26 | 1.38 | 1.16 | 1.16 | 1.11 | 0.93 | 0.95 | 0.87 |
| 200-150-100 | 1.22 | 1.13 | 1.36 | 1.38 | 1.10 | 1.26 | 1.33 | 1.35 | 1.39 | 1.23 | 1.14 | 1.14 | 0.98 | 0.99 | 0.88 |
| 25-150-100 | 1.35 | 1.21 | 1.43 | 1.34 | 1.08 | 1.21 | 1.44 | 1.31 | 1.39 | 1.22 | 1.22 | 1.13 | 0.95 | 0.98 | 0.92 |
| 400-150-100 | 1.21 | 1.13 | 1.33 | 1.35 | 1.08 | 1.20 | 1.41 | 1.29 | 1.48 | 1.28 | 1.14 | 1.12 | 0.93 | 0.99 | 0.90 |
| 50-150-100 | 1.29 | 1.13 | 1.39 | 1.37 | 1.10 | 1.26 | 1.35 | 1.29 | 1.40 | 1.28 | 1.16 | 1.15 | 1.00 | 1.02 | 0.90 |
| average | 1.26 | 1.16 | 1.36 | 1.31 | 1.09 | 1.24 | 1.36 | 1.28 | 1.40 | 1.23 | 1.17 | 1.14 | 0.94 | 0.98 | 0.88 |

In the above table A, B, and C refer to sawdust mulch, clean cultivated and sawdust incorporated plots respectively.

Table XV. The effect of sawdust treatments on the potassium content of the leaves. (Per cent of K on dry weight basis; average of all plots)

| Sawdust treatment | Date | | | | | average |
|---|---|---|---|---|---|---|
| | June 12 | July 12 | Aug. 12 | Sept. 12 | Oct.12 | |
| | % | % | % | % | % | % |
| Clean cult. | 1.164 | 1.088 | 1.284 | 1.166 | 0.981 | 1.137 |
| Sawdust mulch | 1.259 | 1.307 | 1.359 | 1.233 | 0.935 | 1.219 |
| Sawdust inc. | 1.355 | 1.237 | 1.403 | 1.135 | 0.884 | 1.203 |
| F value | 7.588** | 49.343** | 2.374 | 1.804 | 5.733* | |
| L. S. D. | 0.120 | 0.0613 | - | - | 0.0697 | |

Table XVI. The effect of fertilizer treatments on the potassium content of the leaves. (Average of all plots)

| Fertilizer treatment | Date | | | | | average |
|---|---|---|---|---|---|---|
| | June 12 | July 12 | Aug. 12 | Sept.12 | Oct. 12 | |
| | % | % | % | % | % | % |
| Check | 1.248 | 1.165 | 1.308 | 1.169 | 0.892 | 1.156 |
| 0 -150-100 | 1.263 | 1.268 | 1.358 | 1.192 | 0.921 | 1.200 |
| 200- 0 - 0 | 1.261 | 1.166 | 1.318 | 1.163 | 0.922 | 1.166 |
| 12-150-100 | 1.233 | 1.222 | 1.318 | 1.145 | 0.917 | 1.167 |
| 25-150-100 | 1.332 | 1.213 | 1.381 | 1.190 | 0.951 | 1.213 |
| 50-150-100 | 1.272 | 1.243 | 1.350 | 1.198 | 0.973 | 1.207 |
| 100-150-100 | 1.260 | 1.244 | 1.356 | 1.164 | 0.936 | 1.192 |
| 200-150-100 | 1.240 | 1.246 | 1.361 | 1.168 | 0.951 | 1.193 |
| 400-150-100 | 1.223 | 1.213 | 1.392 | 1.183 | 0.939 | 1.190 |
| F value | 2.009 | 3.865** | 1.802 | 0.677 | 1.954 | |
| L. S. D. | - | 0.051 | - | - | - | |

* The single star refers to the 5 per cent significant level.
** The double star refers to the 1 per cent significant level.

Table XVII. The effect of sawdust treatments on the absolute amount of potassium in the leaves. (Grams of K in 40 leaves per plot; average of all plots)

| Sawdust treatment | Date | | | | | average |
|---|---|---|---|---|---|---|
| | June 12 | July 12 | Aug.12 | Sept.12 | Oct. 12 | |
| | gm. | gm. | gm. | gm. | gm. | gm. |
| Clean cult. | 0.1012 | 0.1492 | 0.1930 | 0.2421 | 0.1513 | 0.1674 |
| Sawdust mulch | 0.1012 | 0.2035 | 0.2763 | 0.2882 | 0.1995 | 0.2137 |
| Sawdust inc. | 0.0921 | 0.1890 | 0.2942 | 0.2903 | 0.1776 | 0.2086 |

Table XVIII. The effect of fertilizer treatments on the absolute amount of potassium in the leaves. (Average of all plots)

| Fertilizer treatment | Date | | | | | average |
|---|---|---|---|---|---|---|
| | June 12 | July 12 | Aug.12 | Sept.12 | Oct. 12 | |
| | gm. | gm. | gm. | gm. | gm. | gm. |
| Check | 0.0943 | 0.1560 | 0.2002 | 0.2315 | 0.1582 | 0.1680 |
| 0 -150-100 | 0.0994 | 0.1821 | 0.2264 | 0.2453 | 0.1709 | 0.1848 |
| 200- 0 - 0 | 0.0979 | 0.1796 | 0.2606 | 0.2888 | 0.1749 | 0.2003 |
| 12-150-100 | 0.0946 | 0.1711 | 0.2444 | 0.2654 | 0.1677 | 0.1886 |
| 25-150-100 | 0.1034 | 0.1867 | 0.2677 | 0.2868 | 0.1842 | 0.2058 |
| 50-150-100 | 0.1002 | 0.1979 | 0.2812 | 0.2029 | 0.1908 | 0.1946 |
| 100-150-100 | 0.0990 | 0.1807 | 0.2667 | 0.2634 | 0.1804 | 0.1980 |
| 200-150-100 | 0.0980 | 0.1908 | 0.2747 | 0.2877 | 0.1800 | 0.2062 |
| 400-150-100 | 0.1021 | 0.1866 | 0.2603 | 0.2857 | 0.1862 | 0.2042 |

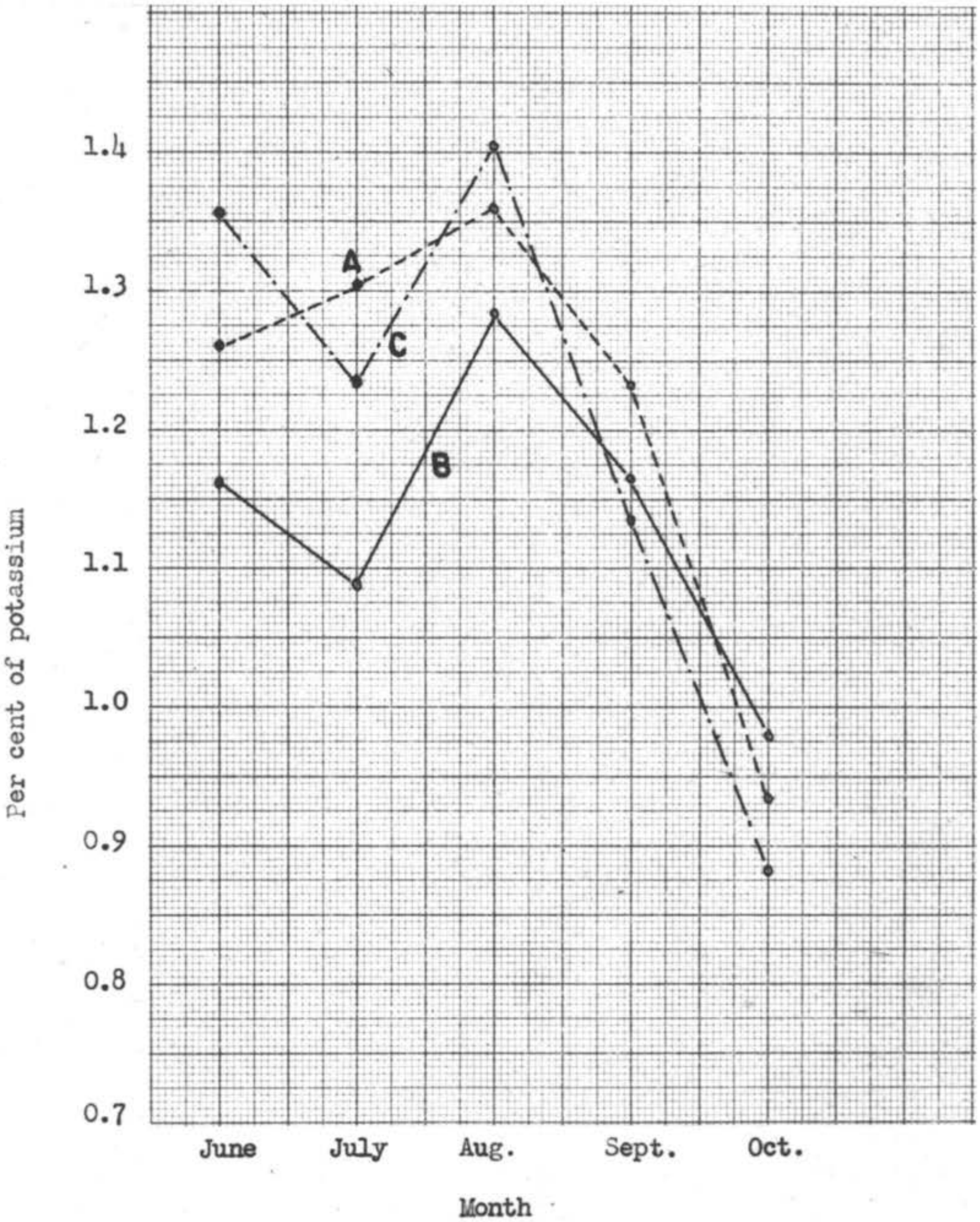


Fig. 11. The effect of sawdust treatment on the potassium content of the leaves. (Average of all plots)

Legend: A Sawdust mulch
B Clean cultivated
C Sawdust incorporated

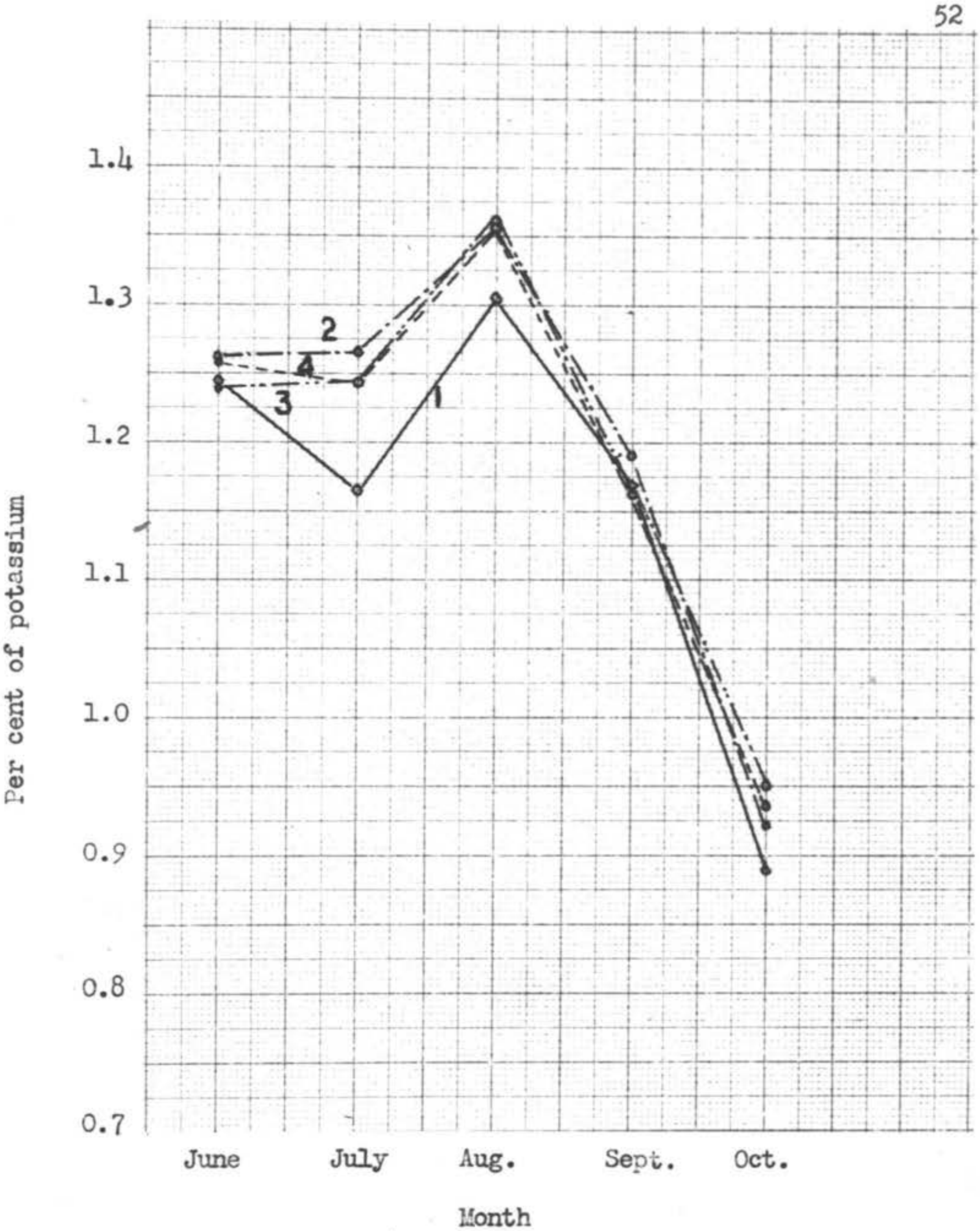


Fig. 12. The effect of fertilizer treatment on the potassium content of the leaves. (Average of all plots)

Legend: (1) Check (2) 0-150-100
(3) 200-0-0 (4) 100-150-100

The fertilizer plots 5, 6, 7, 8 and 9 are not significantly different from no. 4.

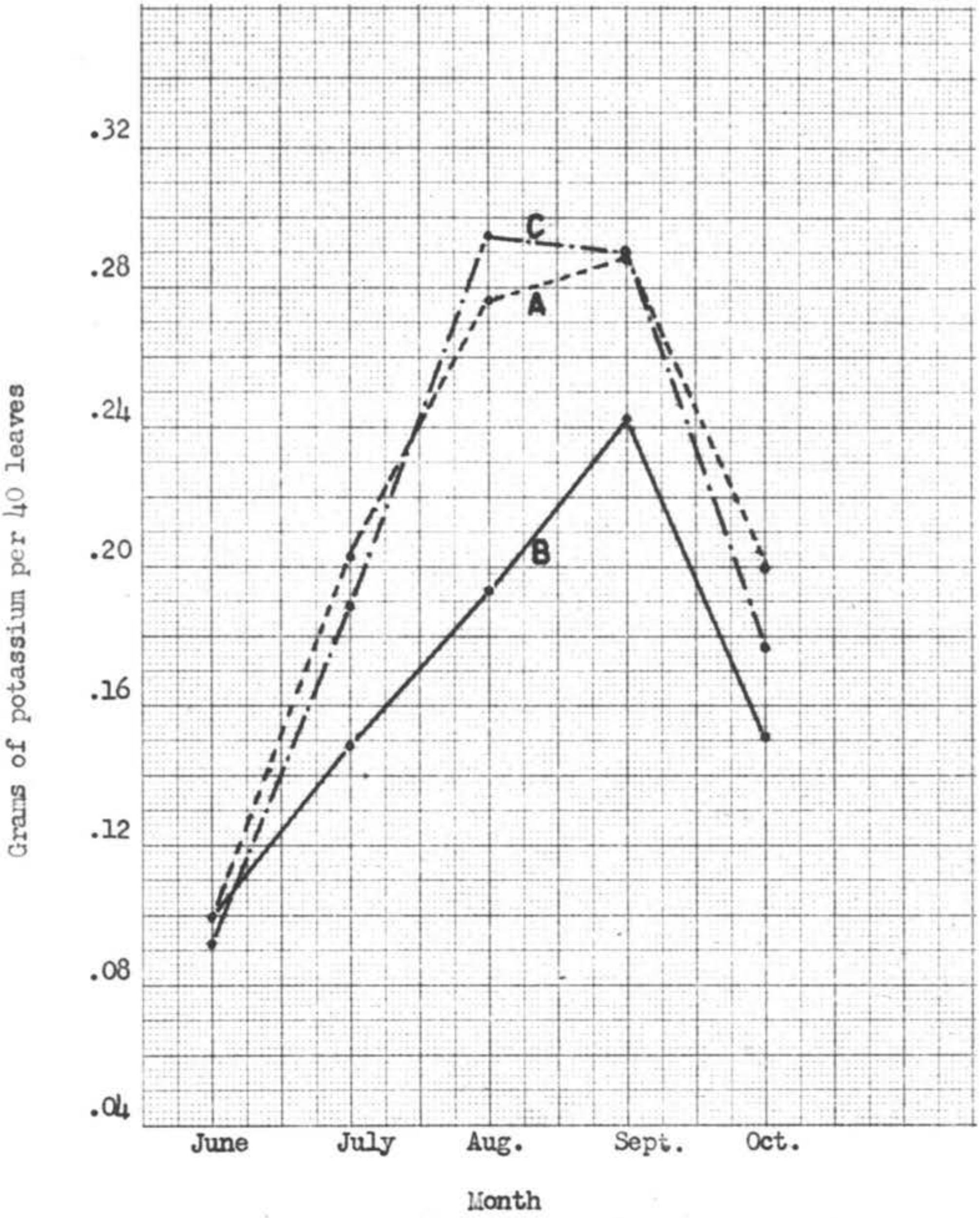


Fig. 13. The effect of sawdust treatment on the total amount of potassium in the leaves. (Average of all plots)

Legend: A Sawdust mulch
B Clean cultivated
C Sawdust incorporated

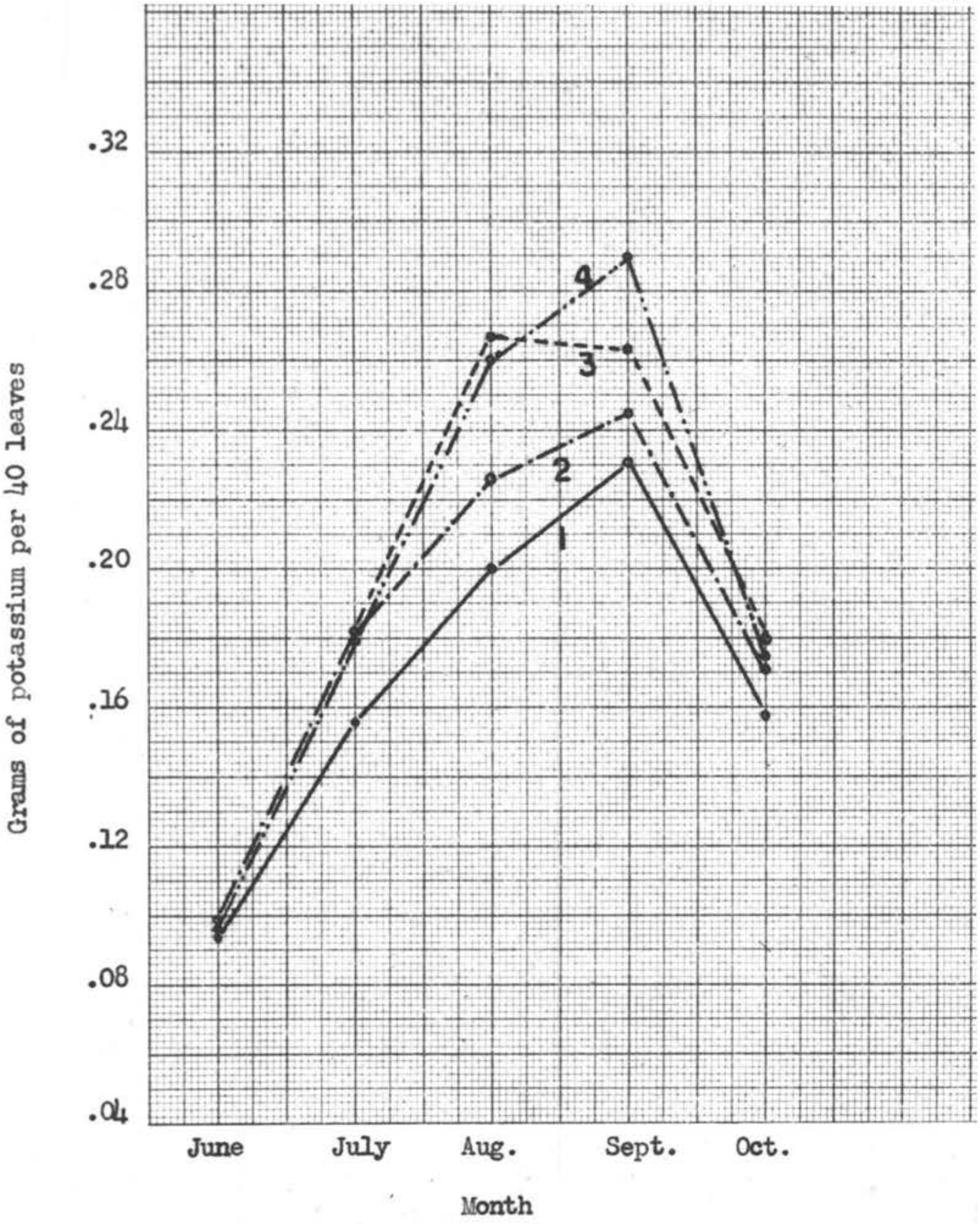


Fig. 14. The effect of fertilizer treatment on the total amount of potassium in the leaves. (Average of all plots)
Legend: (1) Check (2) 0-150-100
(3) 200-0-0 (4) 100-150-100
The fertilizer plots 5, 6, 7, 8 and 9 are not significantly different from no. 4.

Red stele (Phytophthora fragariae) count[1]

"Red stele" is a root disease favored by cold wet soil. The xylem region or stele of the root, as it is known technically, turns red hence the name "red stele". It is a soil-borne disease. After once established in the soil the disease will persist for many years in spite of crop rotation. This disease is widely scattered in strawberry-producing districts of western Oregon.

When growth started in the spring, infested plants grew very little or not at all, depending on the degree of infestation. The leaves usually turned a characteristically red color early in the season. When warm weather appeared, severely infested plants wilted and died. The wilting is the response of the plant to the invasion of the water conducting tissues of the roots by the fungus parasites.

Since the plants in this experimental field were severely infested by the red stele, this disease may be considered as an important factor affecting the yield of the crop. Furthermore, it was interesting to note that both sawdust and fertilizer treatments had significant effect on the infestation of the plants by this disease.

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[1] The data obtained with the help of Dr. E. K. Vaughan, plant pathologist at Oregon State College.

Table XIX shows that in the sawdust mulch plots the plants were most severely infested while in the clean cultivated plots the plants were least infested. The plants in the plots with higher rate of nitrogen application were more severely infested than those in the plots without nitrogen fertilizer or with low rate of nitrogen application.

Table XIX. Red stele (Phytophthora fragariae) counts

| Sawdust treatment | Replication | Fertilizer treatment 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | means |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | 4 | 8 | 37 | 16 | 5 | 34 | 0 | 29 | 27 | |
| | II | 1 | 2 | 18 | 2 | 6 | 41 | 18 | 36 | 20 | |
| A | III | 19 | 2 | 40 | 5 | 3 | 12 | 5 | 48 | 15 | |
| | IV | 8 | 8 | 10 | 9 | 32 | 22 | 24 | 44 | 38 | |
| | av. | 8 | 5 | 26.2 | 8 | 11.5 | 27.2 | 11.8 | 39.2 | 25 | 18.00 |
| | I | 0 | 5 | 3 | 0 | 1 | 10 | 1 | 1 | 3 | |
| | II | 0 | 4 | 20 | 2 | 9 | 9 | 0 | 5 | 0 | |
| B | III | 0 | 0 | 15 | 0 | 0 | 2 | 5 | 17 | 3 | |
| | IV | 0 | 3 | 11 | 2 | 0 | 6 | 0 | 5 | 2 | |
| | av. | 0 | 3 | 12.2 | 1 | 2.5 | 6.8 | 1.5 | 7 | 2 | 4.00 |
| | I | 4 | 0 | 3 | 5 | 16 | 31 | 5 | 8 | 4 | |
| | II | 0 | 1 | 3 | 0 | 6 | 3 | 10 | 8 | 1 | |
| C | III | 4 | 1 | 9 | 6 | 7 | 4 | 1 | 18 | 1 | |
| | IV | 7 | 13 | 1 | 31 | 7 | 7 | 0 | 40 | 34 | |
| | av. | 3.8 | 3.8 | 4 | 10.5 | 9 | 11.2 | 4 | 18.5 | 10 | 8.31 |
| Fertilizer means | | 3.9 | 3.9 | 14.1 | 6.5 | 7.7 | 15.1 | 5.8 | 21.6 | 12.3 | |

Analysis of variance

| Source of variation | degree of freedom | sum of square | mean square | F | significance |
|---|---|---|---|---|---|
| Replication | 3 | 434 | 144.67 | 1.65 | |
| Sawdust | 2 | 3702 | 1851 | 21.11 | ** |
| Error (a) | 6 | 526 | 87.67 | | |
| Fertilizer | 8 | 3510 | 438.75 | 6.01 | ** |
| Sawdust x fertilizer | 16 | 2198 | 137.38 | 1.88 | |
| Error (b) | 72 | 5260 | 73.06 | | |
| Total | 107 | 15630 | | | |

In the above table, A, B and C refer to the sawdust mulch, clean cultivated and sawdust incorporated plots respectively; the arabic numbers are the replications; and the numerical numbers are the fertilizer plot numbers which are listed on page 20.

** The double star refers to the 1 per cent significant level.

Grouping of sawdust treatment means

| Clean cultivated | sawdust inc. | sawdust mulch |
|---|---|---|
| 4.00 | 8.31 | 18.00 |

$$\text{L.S.D.} = 2.45\sqrt{\frac{2 \times 87.67}{36}} = 5.407$$

Grouping of fertilizer treatment means

| Plot no. | 1 | 2 | 7 | 4 | 5 | 9 | 3 | 6 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| | 3.92 | 3.92 | 5.75 | 6.50 | 7.67 | 12.33 | 14.17 | 15.08 | 21.58 |

$$\text{L.S.D.} = 1.99\sqrt{\frac{2 \times 73.06}{12}} = 6.943$$

Yields of the strawberries

The data in Table XX indicate that there was no response in yield from the fertilizer application. In the sawdust mulch plots the yields of the fruit were significantly lower than in either the sawdust incorporated plots or the clean cultivated plots. The lower yields in the sawdust mulch plots were particularly pronounced when higher rates of nitrogen fertilizer were used. In the sawdust incorporated plots the yields were significantly higher than those in the other two treatments but here again nitrogen at higher rates had depressive effect on the yield of the crop.

Table XX. The yields of fruit in grams per plot.

| Sawdust treatment | Replication | Fertilizer treatment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | means |
| | | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | gm. | |
| | I | 3198 | 2112 | 1237 | 1540 | 3412 | 1110 | 1664 | 1072 | 1322 | |
| | II | 2972 | 1132 | 1628 | 1354 | 784 | 194 | 1549 | 262 | 1428 | |
| A | III | 1836 | 3184 | 1214 | 2884 | 3348 | 3577 | 2943 | 380 | 1720 | |
| | IV | 1284 | 1673 | 3246 | 2188 | 648 | 1923 | 3161 | 291 | 1225 | |
| | av. | 2323 | 2025 | 1831 | 1992 | 2048 | 1701 | 2329 | 501 | 1424 | 1797 |
| | I | 1886 | 1550 | 2534 | 1956 | 1150 | 2102 | 3274 | 3240 | 1202 | |
| | II | 2928 | 3516 | 2757 | 2700 | 2040 | 3072 | 3460 | 2926 | 4006 | |
| B | III | 4154 | 4149 | 2464 | 4734 | 1638 | 2670 | 5312 | 1418 | 4378 | |
| | IV | 4208 | 3254 | 2354 | 2380 | 2538 | 1866 | 3339 | 4642 | 2908 | |
| | av. | 3294 | 3117 | 2527 | 2942 | 1842 | 2428 | 3846 | 3057 | 3124 | 2908 |
| | I | 2008 | 4771 | 2810 | 2160 | 2146 | 793 | 2610 | 1525 | 1005 | |
| | II | 3205 | 3902 | 4783 | 4072 | 2862 | 3452 | 3066 | 6038 | 7725 | |
| C | III | 2871 | 3209 | 2472 | 2202 | 1816 | 2156 | 4221 | 2086 | 3168 | |
| | IV | 4376 | 5098 | 5220 | 2022 | 5000 | 3724 | 3964 | 1748 | 1596 | |
| | av. | 3115 | 4245 | 3821 | 2614 | 2956 | 2531 | 3465 | 2849 | 3374 | 3219 |
| Fertilizer means | | 2911 | 3130 | 2726 | 2516 | 2265 | 2220 | 3213 | 2136 | 2473 | |

Analysis of variance

| Source of variation | degree of freedom | sum of square | mean square | F | significance |
|---|---|---|---|---|---|
| Replication | 3 | 12613570 | 4204523 | 0.958 | |
| Sawdust | 2 | 40239210 | 20119605 | 4.585 | * |
| Error (a) | 6 | 26323508 | 4387251 | | |
| Fertilizer | 8 | 14680924 | 1835115 | 1.592 | |
| Sawdust x fertilizer | 16 | 16329901 | 1020619 | 0.885 | |
| Error (b) | 72 | 82946813 | 1152039 | | |
| Total | 107 | 193133926 | | | |

* The single star refers to the 5 per cent significant level.

Grouping of sawdust treatment means

| Sawdust mulch | Clean cultivated | Sawdust inc. |
|---|---|---|
| 1797 | 2908 | 3219 |

$$\text{L.S.D.} = 2.45 \sqrt{\frac{2 \times 4387251}{36}} = 1210$$

# DISCUSSION

As Goodall and Gregory (19, pp.47-58) point out, if the investigator works out a satisfactory technique that takes into account the selection of the samples and the physiological stage of development of the given variety of a crop under the prevailing weather conditions, plant analysis can be of great value in predicting the fertilizer needs of plants, particularly for perennial crops.

Since the plant consists of organs differing greatly in composition, the effect of variation in the proportion of the plant formed by the various organs will be eliminated by confining the analysis to a particular organ, and thus the accuracy of the estimation will be increased.

Since the leaves are the organs of active assimilation, their composition should be the best basis for estimating the nutritional status of the plant. It was believed, therefore, that absorption of plant nutrients from the soil by the crop should be reflected from time to time by changes in the relative or total amounts of absorbed nutrients found in the leaf tissue of the plant.

With a nutrient supply in which all elements except one are maintained at high level, the concentration within the plant of the nutrient in minimum will rise with increasing external supply. In general, the concentration of the element in the plant will depend upon the specific relation of the nutrient to the growth process, the rate of uptake, and the rate of utilization. Thus, with nitrogen deficiency growth remains slow; no auxiliary meristems are laid down, but the uptake of other elements such as phosphorus and potassium does not cease and these are, therefore, present in relatively abundant concentration in the tissues. The same is true to a less extent with phosphorus deficiency, whereas with potassium deficiency growth does not cease and so the nitrogen concentration does not rise to the same degree. The point to be stressed is that the relative concentration of the nutrient elements in the tissues is no measure of the level of supply of any particular element, but depends upon the total supply of all elements -- to a varying degree according to the importance of a particular element in the metabolic processes. It is believed that nitrogen plays the chief part, followed by phosphorus and potassium, to name only the three major nutritive elements. In a balanced system of nutrients, at any particular stage of growth the relative concentrations may remain unchanged although the size of the plant, and hence the yield also, rises with increasing dosage of the nutrients.

The leaf analyses made at different stages of development of the plants showed the seasonal changes of the different nutrient elements. The potassium content was high in June then gradually decreased until leaf senescence in October. The phosphorus content began similarly with high values, and remained practically constant during the remaining period. The nitrogen value was first high then declined somewhat and again increased at the time of fruit bud differentiation.

The initial high nutrient content of the leaves may be due to the slow rate of growth. As the plants rapidly grew the dilution factor due to growth might account for the decreased nutrient content of the leaves although the total amount of nutrients absorbed was considerably increased. This is a fundamentally important fact, because growth involves increase of volume and a continuous dilution of the nutrient substances.

Another factor which should also be considered is the movement of nitrogen from the storage organs such as roots to the assimilating organs such as leaves and vice versa during the growing season. Long (32, pp.386-388) reported from his analysis of the strawberry crown and root that nearly 80 per cent of the total nitrogen was in the leaves in the early spring and that there was a seasonal percentage decrease of nitrogen in the leaves and a concommittant increase in roots.

As the season progressed the leaves from the sawdust mulch had the highest nitrogen content, while the leaves from the sawdust incorporated plots had the lowest nitrogen content. The nitrogen demands were greater when the sawdust was incorporated with the soil than when used as a surface mulch. This agrees with the results of the preliminary investigations by the Oregon

Agricultural Experiment Station. The nitrogen demand for correcting the depressing effect of sawdust on the nitrogen supply in the soil to plant depends not only on the amount of sawdust present but also on the rate of decomposition of the material in question. In the sawdust mulch plots the sawdust decomposed so slowly as to have no depressing effect on the available nitrogen in the soil while in the sawdust incorporated plots the sawdust decomposed more rapidly than in the sawdust mulch plots and hence the demands for nitrogen are greater.

In the check and phosphorus-potassium plots dry weights of the leaves were significantly smaller than those in the plots with nitrogen fertilizer. Nitrogen is the chief nutrient element which promotes the vegetative growth of the plant. Twenty-five pounds of nitrogen per acre in the fourth year was sufficient to take care of the depressive effect of sawdust on plant growth. There were no significant differences among the higher rates of nitrogen application.

The plant from the plots with higher rates of nitrogen application had significantly higher nitrogen content than those from plots without nitrogen or with low rate of nitrogen application. In the Check and PK plots phosphorus was always higher than in the plots fertilized with nitrogen. Nitrogen promoted the vegetative growth of the plant and hence decreased the percentage of other constituents in the leaves. Growth involves increase of volume and a dilution of the nutrient substances.

In comparison with clean cultivation sawdust mulch and sawdust incorporated treatments gave better growth, increased the absorption of nutrients and facilitated such operations as harvesting and weed control. Sawdust mulch and nitrogen fertilizer particularly with high rate of application increased the infestation of the roots by the red stele disease. The succulent vegetative growth of the plant caused by the application of nitrogen fertilizer was conducive to the disease attack on the one hand, while the sawdust mulch favored the activity of the disease organism due to the favorable moisture condition of the soil on the other.

In the sawdust mulch plots the yields of fruit were significantly lower than in either the sawdust incorporated plots or the clean cultivated plots. The lower yields in the sawdust mulch plots were particularly pronounced when higher rates of nitrogen fertilizer were used. In the sawdust incorporated plots the yields were significantly higher than the other two treatments but here again nitrogen at higher rates of application had a depressive effect on the yields of fruit. It is obvious that the lower yields of fruit in the sawdust mulch plots were not due to the depressive effect of sawdust on the nitrogen supply in the soil to plant. In fact, sawdust mulch particularly associated with higher rates of nitrogen fertilizer increased the degree of infestation of the roots by the red stele disease which probably caused the decreased yields of the crop.

There was no response in yield from any fertilizer application. This is in accord with the results shown in the review of literature which indicates that the response of the strawberry to the application of fertilizer is extremely variable. In addition to the causal factors such as insect pests and diseases the plants themselves show the most marked variation as a result of slight difference in the physical condition of the soil such as drainage, and are also sensitive to local climatic conditions. Furthermore, the root system of the strawberry plant is very shallow. Strawberry will markedly respond to the moisture variation in the surface soil as well as to the placement of the fertilizers. Ball and Mann (3, pp.104-112) examined strawberry plants for root distribution and found by sectioning various layers of soil that about 70 per cent of the roots (on dry weight basis) were located in the upper 3 inches and only 10 per cent below the six-inch level. They also expressed the doubt that lateral-feeding roots extend much beyond the spread of the leaves in the young growing strawberry plants.

## SUMMARY

In comparison with clean cultivation sawdust culture both when used as a mulch and when incorporated gave better growth, increased the absorption of nutrients and facilitated such operations as harvesting and weed control. Sawdust culture and nitrogen fertilizer particularly with the higher rates of application increased the infestation of the roots by the red stele disease.

In the sawdust mulch plots the yields of the fruit were significantly lower than those in either the sawdust incorporated plots or the clean cultivated plots. The lower yields in the sawdust mulch plots were particularly pronounced when higher rates of nitrogen fertilizer were used.

The leaf analysis made at different stages of development of the plants showed that the nitrogen content was high in June then declined somewhat in August and increased again at the time of fruit bud differentiation. The potassium content was high in June then gradually decreased until leaf senescence in October. The phosphorus content began similarly with high values, and remained practically constant during the remaining period.

In the check and phosphorus-potassium plots dry weights of the leaves were significantly smaller than those in the plots with nitrogen fertilizer. Twenty-five pounds of nitrogen per acre in the fourth year was sufficient to take care of the depressive effect of sawdust on the plant growth. There were no significant differences among the higher rates of nitrogen application as far as the dry weight of the leaves was concerned.

As the season progressed the leaves from the sawdust mulch plots had the highest nitrogen content, while the leaves from the sawdust incorporated plots had the lowest nitrogen content. The nitrogen demands were greater when the sawdust was incorporated with the soil than when used as a surface mulch.

The plants from the plots with higher rates of nitrogen application had significantly higher nitrogen content than those from plots without nitrogen or with low rate of nitrogen application. In the check and PK plots phosphorus was always higher than that in the plots fertilized with nitrogen. The fertilizer treatments had only slight effect, if any, on the absorption of potassium by the plants.

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