STUDIES ON THE EFFECT OF FERTILIZERS ON THE GROWTH, YIELD AND QUALITY OF OIL OF CITRONELLA

BY

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THESIS

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CERTIFICATE

This is to certify that the thesis herewith submitted contains the results of bona fide research work carried out by Shri C. Ravindranathan Pillay under my supervision. No part of the work embodied in this thesis has been submitted earlier for the award of any degree.

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(G. Ravindranathan Pillay)

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INTRODUCTION

INTRODUCTION

Cymbopogon nardus Rendle, Ceylon type, an aromatic grass, is the main source of valuable citronella oil. The oil occupies an important position among essential oils, owing to its high percentage of alcohols mainly geraniol and terpenes. The oil is much sought after for its rounded lemony balsomic rosaceous odour.

The oil has wide applications in cosmetics, soap perfumes and pharmaceutical products. It is also used as a soothing smear for mosquito and leach bites. Mixed with other ingredients it is a good repellent against insects. It is a source of perfumery-isolates like geraniol and citronellal which can be converted into some widely used aromatics like hydroxy citronellal, synthetic menthol esters of geraniol, citronellol etc.

Present demand of citronella oil in India is about 140 to 150 tonnes. If self sufficiency in citronella oil is achieved the country can save twenty lakhs rupees worth of foreign exchange. The demand of this oil is increasing and it is expected to be about 500 tonnes per year. (Dutta and Virmoni, 1961).

Citronella oil is not produced in this country on a large scale. The internal requirements are at present being met by imports, chiefly from Formosa, Ceylon, France, Netherlan and to a small extent from West Germeny, U.K., and Singapore.

The Ceylon type of citronella grass has now been successfully cultivated on an experimental scale at Southern Zonal Centre, Bangalore by the Central Indian Medicinal Plants Organisation. Its cultivation has also been taken up on an experimental scale from 1960 by the Lemongrass Research Station, Odakali, Kerala. Cultivation at Lemongrass Research Station, Odakali showed that the climatic and soil conditions are quite suitable for the profitable production of this valuable oil under Kerala conditions (Pillay, 1960). It is well known that Kerala occupies a large area under lemongrass (cymbopogon flexuosus) and produces nearly 75% of the total world productio of lemongrass oil. Both lemongrass, and citronella grass are closely related species with more or less similar habits and requirements. The cultivation of citronella grass has the following advantages under Kerala conditions:-

1. Citronella grass will be a better substitute for those areas where lemongrass has been abandoned due to uneconomic returns.

2. Just like lemongrass it can be cultivated in places and soils where other crops do not come up well.
3. Cultivators will get a steady income from the 4th month onwards, at regular intervals of 45 days.
4. The crop does not require much care or attention and is free from any serious pests or diseases.
5. It is a soil binding crop suitable for soil conservation on hill slopes.
6. The spent-grass obtained after the extraction of oil can be used as a good organic manure.

Before popularising any crop it is highly essential to obtain adequate information on the agrondmic practices to be adopted under the prevailing soil and climatic conditions. Among the proved techniques in increasing crop production the use of fertilizers is one of the most important. Being a newly introduced crop no systematic attempts have been made in this country to investigate the nutritional requirements or the effects of nutrients on its yield and quality. Only a very limited number of experiments have been reported so far on this crop. The most important among them are the works conducted by Dejoie (1949), Brown and Matthews (1951), Joachim and Panditt sekera (1953) and Lin and Lian (1962). These

authors have reported that citronella grass is a heavy feeder and rapidly exhausts the soil. Periodical harvest of the crop removes 10-12 tonnes of cut grass from a hectare per year. Varying amounts of nitrogen, phosphorus and potash have been recommended under different soil and climatic conditions.

The work conducted at Mayaguez Experimental Station in 1923 and by other workers namely, Davis et al (1957), Korezava (1961) and Cutting (1961), in other places on other essential oil crops show a uniform positive response to calcium in the matter of yield and quality of essential oil.

Since citronella grass is very important in industry and economy of the country, investigation on its cultivation practices becomes necessary. Its possibilities for substituting lemongrass in uneconomic plantations are marked. Therefore an attempt has been made in this investigation to determine the manurial requirements of this important crop.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Effect of soil and climate

Soil, climate and altitude profoundly affect the vitality and life-span of the crop as well as yield and quality of oil mainly citronellal.

George (1924) discussed the soil conditions, yield of oil and methods of cultivation of lemongrass and citronella grass. He has stated that citronella grass grows wild in the Nilgiris and Salem districts of South India, and thrives well under sandy loam soils also.

According to Hischmann (1938) calcarious soils with only a thin layer of sand yielded good grass and oil but are exhausted later. As soon as the roots reach subsoil the citronellal content decreases. He believes that the sandy soils on which the grass does not grow very high offer a natural protection for a good oil yield.

Guenther (1949) stated that Ceylon citronella flourishes in a less fertile soil and require only less cultural care and moisture, than the Java type. The localities

where Ceylon citronella is grown, usually are hilly and less fertile. Most favourable soil is a 'rich alluvial one'.

Brown and Matthews (1951) reported that citronella needs abundant well distributed rain fall, and sunshine throughout, particularly during harvest time. Most soils sufficiently fertile are suitable. Very rich or vergin soils give a greater yield of grass, but its oil content is abnormally low. Deep sandy soils sufficiently fertile are better than loamy or fertile ones. They are less affected by weeds, the yield of leaf is lower but the percentage of oil in the leaf is higher.

Joachim and Panditteekera (1953) reported that citronella grass grows well in typical latiritic, gravelly-loams of Ceylon.

Desilva (1957) reported that citronella grows in ordinary soils and comes up well upto an altitude of 2000 ft. Alternate rainy and sunny weather is favourable for the crop.

According to Sadgopal (1960) Ceylon citronella is hardier and has longer lifespan, than Java type. It flourishes in soils of even poor fertility and requires only very limited cultural and manurial care.

Dutta and Virmani (1964) reported that Ceylon citronella, grass can be grown upto an altitude of 600 metres. The annual rainfall where the grass is grown in Ceylon is 152 to 178 cms. The grass grows well on poor type of soils particularly on the slopes of hills. It grows in the sun as well as in the shade. But shade is detrimental to the yield of oil, and its total geraniol content.

Influence of Nitrogen, Phosphorus, Potash and Calcium on growth, grass yield, oil yield and quality of oil

Only very few investigations on the effect of fertilisers on Cymbopogon nardus have been reported, but there is considerable published work on other essential oil yielding crops. A review of the literature pertaining to the effect of manures and fertilisers on Cymbopogon nardus and other essential oil yielding plants is given below.

Organic manures

Organic manures are reported to be used in replenishing plantations of citronella and other essential oil yielding crops.

Beckley (1931) recommended the use of at least 15

tonnes of compost along with 200 lbs of potassium sulphate per acre for lemon grass before planting.

Hischmann (1936) stated that citronella is a soil exhausting crop, and suggested using Tephrosia candida, Tephrosia vogilii, crotalaria species and various mimosa varieties for regenerating the soil and renewing the plantations.

Powers and Jones (1942) in green house trials obtained maximum yield of peppermint, which received farm yard manure and Muriate of potash. But in field trials this result was not obtained.

According to Powers (1948) mint soils require a good supply of organic matter and nutrients for satisfactory growth.

Ahammed and Tihud (1949) recommended the application of farm-yard manure in poor soils for rosha grass along with fertilisers.

As reported by Guenther (1949) the best method of fertilizer application to citronella grass is mulching the crop with chopped exhausted grass received from the same area, along with superphosphate. Guenther also suggested the application of spent grass ash.

Moorthi and Moosad (1949) reported that Brinemanure and ground nut cake increased the oil content of vetiver roots.

Brown and Matthews (1951) reported that Java citronella is green manured after five years with tephrosia, crotalaria and mimosa species.

Khotin (1951) showed significant differencein the yield of essence in rose geranium by the application of farmyard manure and recommended the application of 30 metric tonnes per ha of farm yard manure along with complete fertiliser at the time of planting.

Fernando (1953) got significant difference in yield of citronella by the application of 4 tonnes of compost and 240 lb of citronella ash per acre. Manuring with compost and citronella ash in the third year produced 12% increase in yield of oil. Regular and frequent dressing of manure commencing earlier than the third year is likely to be more effective.

According to Menon (1954) cowdung manure and fish guano increases the yield of Patchouli.

Chamura (1955) reported that the application of

rape seed oil cake gave best oil yield from mint plants.

Chopra (1962) reported that trials on Mentha arvensis at Jammu and Kashmir showed a good response to organic manures and recommended 12 tonnes of farm-yard manure before planting. He also found that green manuring was suitable for satisfactory growth.

Pillay (1962) reported that 5 years trial with 10 tonnes of well rotted leaf, farm yard manure or compost gave increased yields of Mentha arvensis.

Trials conducted at Lemongrass Research Station, Odakali on lemongrass, from 1959 to 1963, have revealed that mulching lemongrass with 30,000 lb of spent lemongrass per acre per year gives significantly increased grass and oil yields. Another trial at the same station with spent lemongrass compost and wood ash during the same period applied at the rate of 5000 lb and 2000 lb respectively per acre per year has given significantly superior results (Ann. Progress Report - L.G.R.S., Odakali, 1963-64).

Gulati (1963) stated that either organic or inorganic manures can be applied to Pogostemon patchouli.

At the Indian Institute of Science, Bangalore it was found that farm yard manure at 1125 kg./ha. along with 2275 kgms. of Ammonium sulphate has given better growth of patchouli than farm yard manure, oil cake, or ammonium sulphate alone.

Dutta and Virmani (1964) stated that fertilizer application increases the growth and yield of citronella. But the usual practice of Ceylon is to replenish the fields bienially with ashes of citronella which has been obtained from the spent lemongrass burnt as fuel. Green manuring is considered beneficial to java type of citronella.

Effect of nitrogen

Burns (1923) estimated that one hundred weight of lemongrass removed 167 gms. of nitrogen from the soil.

Barner (1938) reported that nitrogen increased the oil content of Salvia officiaalis and Artimesia absinthium. He did not get any response to nitrogen in other plants. He concluded that no general rule can be laid down, but the manurial requirements of each specie and variety must be tested separately.

Kwinichidze (1939) reported that ammoniacal fertilizers increased the oil percentage in Mentha pipereta. The

moisture content of the soil was also found to affect the percentage of oil.

Masselennikov (1939) showed that on podsol soils of humid tropics geranium responded extremely well to nitrogenous fertilizers.

It is stated in the report of the Agricultural Experiment Station, Puertorico (1939), that nitrogen gives significant increase in grass, oil and citral in lemongrass. The same station report (1940) states that levels of nitrogen upto 240 lb./ acre have given significant increase in grass, oil and citral yields.

Ilin (1940) while studying the effect of mineral nutrition on the formation of essential oil in peppermint, found that moderate nitrogen nutrition during the initial periods of growth and supplementary nitrogen during budding and flowering periods increased the contents of carbohydrates and essential oil.

As stated by Guenther (1949) Dejoe found that citronella grass is very sensitive to nitrogenous fertilizers. It reduces the yield of oil per ton of grass and increases the green matter abnormally. This seems to be a result of

imbalance between nitrogen and phosphoric acid.

Autran and Foundard as quoted by Guenther (1949) reported that most prolefic growth of lavender is obtained by the application of nitrogen in the form of sodium nitrate or ammonium sulphate.

Murthi and Moosad (1949) reported, increase in essential oil content in vetiver by the application of ammonium sulphate.

Schartz and Wiemann (1949) found that in labiatae adequate nitrogen supply is essential for high oil yields.

Khotin (1950) reported that application of sodium nitrate and ammonium sulphate to cherenozem soils nearly doubled the oil yield of Mentha pipereta especially when applied early in the growth period of the plant.

Brown and Matthews (1951) found that citronella requires ammonium sulphate along with other fertilizers.

Joachim and Panditttsekera (1953) while investigating the effect of organic and artificial fertilizers on grass and oil yield in citronella, found that nitrogen alone did not increase the oil yield.

Chamura (1955) observed that, ammonium sulphate application increased the oil yield of peppermint.

Baird (1956) from his experiments on Mentha piperata from 1951 to 1956 concluded that nitrogenous fertilizers markedly increased the hay and oil yield.

Davis et al (1957) reported that nitrogen applied at the rate of 25 and 50 lb. per acre has given large response in peppermint.

Hotin (1957) reported that nitrogen applied during bud formation in mint increased the menthol content.

Steigerwald (1958) from his long term fertilizer experiments with peppermint on mineral soil reported that green matter and dryleaves were more affected by nitrogen than phosphorus and potash. Fertilizer except nitrogen tended to decrease the oil content which again was more affected by weather than fertilizers.

Schroeder (1959) recommended 80 to 100 lb. of nitrogen per acre for marjoram (Origum vulgari) to produce maximum yield of herbage.

Latypov (1960) reported that ammoniacal form of nitrogen stimulated the production of essential oil to a

greater extent than nitrate form. Ammonium sulphate was more effective than chlorides in oil production. The fertilizers not only increased the essential oil content but also improved the composition.

Cutting (1961) reported that nitrogenous fertilizers may increase the yield of geranium oil but the quality of oil is reduced.

Lin and Lian (1962) showed that nitrogen significantly increased the yield of citronella oil. An optimum dose of 30 kg./ha. in the first year of planting and 60 kg./ha. in the following years have been recommended.

Singh and Guptha (1962) concluded in their manurial experiments on Rosa damascena Mill., that a mixture of 20 gm. of ammonium sulphate and 20 gm. of potassium nitrate per square metre gives significant results.

Gulati (1963) reported that nitrogenous fertilizers increases the yield of patchouli. The application of fertilizers increases the yield of patchouli. The application of fertilizers did not make any difference in the oil content and quality of oil in leaves.

Shii, Young and Hu (1964) in their fertilizer

experiment on citronella on lateritic red soil containing 2.21% organic matter; and 0.1% nitrogen, found that ammonium sulphate increased total yield by 51 to 61%. The quality of oil was reduced.

Choudhary and Biswas (1964) reported that application of 20 lb. nitrogen per acre in the form of ammonium sulphate, significantly increased the yield of leaves and oil in Ocimum kilimandscharicum. There was hardly any difference in physical properties of oil or camphor under the influence of treatments.

Skrubis (1964) reported that nitrogen at the rate of 14.3 gm. per sq. m. had significantly increased the herbage and essential oil yield of peppermint. The composition of oil was not affected.

Effect of phosphorus

Burno and Sorger (1923) in Sicily found 14.75% phosphoric acid in lemongrass ash and it was calculated that each cwt. of grass removed 345 gm. of phosphorus from the soil.

Barner (1938) got response to phosphatic fertilizers, in plants of the labiatae and compositae families

other than Salvia officinalis and Artimisia absinthium. He concluded that manurial requirements of each specie and variety must be tested separately.

Kwinichidze (1939) reported that superphosphate increased the percentage oil content in Mentha pipereta.

Maslennikov (1939) did not get any response in geranium to phosphorus.

Mazzaron (1940) showed that both mentha and thyme responded well to phosphatic fertilizers.

Report of the investigations on essential oils in Puertorico (1941) shows that phosphorus gives singnificantly superior yields of grass, oil and citral than control plots in lemongrass.

Lutzenberger (1942) reported that phosphorus has a particularly beneficial effect on the pepper mint plant.

Powers (1943) found that phosphorus tends to promote blooming and early maturity of mint plants.

Scharatz and Wiemann (1949) showed that addition of phosphorus did not increase the essential oil content of labiatae.

As reported by Guenther (1949) Dejoie recommends 300 lb. of superphosphate per acre along with spent grass mulch for best results in citronella grass.

Brown and Matthews (1951) reported that addition of phosphorus to lemongrass is essential.

Joachim and Panditttsekera (1953) reported that phosphorus was important in manuring citronella.

Baird (1957) reported that phosphorus caused only small increases in herb and oil yield of peppermint on a fine sandy loam soil in Washington.

Davis et al (1957) has indicated the response of mint to phosphorus.

Steigerwald (1958) in his long term fertilizer experiments with peppermint in mineral soils showed, that fertilizers, other than nitrogen tended to decrease the oil content which again was more affected by weather than by fertilizers.

Schroeder (1959) from his experiments on the influence of nitrogen, phosphorus and potassium on yield and volatile oil content of marjoram (origam vulgari) could not

demonstrate any definite effect of phosphorus on volatile content but the yield of herbage was increased.

Singh et al (1962) suggests from their manurial experiments on Rosa damascena. Mill. that phosphorus should be applied in addition to nitrogen in the rose fields for getting higher yields.

Annual progress report of L.G.R.S., Odakali (1963-64) in the results of the combined analysis of the yield data on fertilizer trial with lemongrass, stated that the effect of phosphorus is highly significant in grass yield, oil yield and citral yield. The same station progress report for (1964-65) stated that there is a significant difference in weight of Vetiver roots due to phosphorus application, but not on oil yield.

Skrubis (1964) reported that phosphorus had no effect on green matter and oil yield of peppermint.

Shii et al (1964) reported that fertilizer experiments with citronella on lateritic red soils, showed that the response of double super was significant. After two years with the annual application of 120 kg./ha. of phosphorus there was no response in the third year.

Effect of potash

Hood (1917) showed that lemongrass required more potash than other grasses in Florida sandy soils. On analysis it was found that 1000 lb. of grass contain 33.2 lb. of potash. Better growth was obtained when potash was applied as sulphate.

Bruno et al (1923) estimated 6.24% potash in lemongrass. They estimated a removal of 153 gm. of potash from soil by each cwt. of grass.

Beckley (1921) recommended 200 lb. of potassium sulphate per acre per year for lemongrass along with compost, for superior yields.

Barner (1938) reported increased oil yield for salvia officinalis and artemesia absinthium due to potash application.

Bourne (1941) reported that a very marked response was obtained for lemongrass due to potash application on sandy soils.

Powers and Jones (1942) in their trials on mint obtained maximum yield of hay with potassium sulphate.

Scharatz et al (1949) reported that potash did not increase the essential oil content of labiatae.

Guenther (1949) recommended well rotted stable manure or commercial fertilizers containing high percentage of potash for getting a good peppermint crop.

Brown et al (1951) stated that beneficial effects will be obtained if lemongrass is manured with potash when the plant is well established.

Joachim and Panditttsekera (1953) reported that potash is also important in manuring citronella.

Baird (1955) in his experiments on peppermint at Central Washington showed that potash had little effect on yields.

Experiments conducted by Gonzalex and Alonso (1955) on mint, balm and fennel showed increased essential oil content with potash deficiency.

Davis, Lucas and Shepherd (1956) reported improved vigour of mint especially in spring of the first year due to potash application. Hay yields were well correlated with potash application.

Baird (1957) reported that potash had negligible effects on yield and oil of pepper mint.

Long term fertilizer experiments of Steiger-wald (1958) on peppermint revealed that there was no significant effect on yield and oil content by the application of potash.

Latypov (1960) stated that potassium sulphate was effective in increasing the oil production and also improving the composition of oil in mint. The increase in oil production was upto 80%.

Four years results of the fertilizer experiment at L.G.R.S., Odakali, Kerala has revealed that the effect of potash is highly significant with regard to grass and oil yield in lemongrass. There was no significant difference in citral percentage due to potash application.

Another experiment conducted at the same station on lemongrass has shown significant increase in oil yield upto 125 lb. of potash per acre (Ann. Progress Report of L.G.R.S., Odakali 1963-64).

A manurial trial on vetiver at the same station showed that potash had significantly increased the root

yields of vetiver but not the oil yield. (Ann. Progress Report of L.G.R.S., Odakali 1965-66).

Skrubis (1964) reported that potash had no effect on green matter yield in the first harvest. But the essential oil yield was increased.

Shii et al (1964) reported from the fertilizer experiments on citronella in lateritic red soils, that average response to potash was 5 to 19%.

Effect of calcium

Burno et al (1923) estimated that each cwt. of lemongrass removed from the soil 389 gm. of lime. It is more than any other major nutrients removed from the soil.

Report of Puertorico (Mayagaez) Agrl. Experiment Station (1939) stated that increased yield of grass and oil was obtained by the application of lime to lemongrass.

Davis et al (1957) recommended calcium and magnesium along with other nutrients to mentha.

Atanarev (1961) while studying the effect of liming on yield and quality of lavender oil reported that in two years test in brown meadow soils of pH 5.8 calcium carbide

at the rate of 1500 kg./ha. gave the highest favourable yield i.e., 23% abpve control. The same treatment also increased lenanyl acetate content to 10%. Under commercial condition the use of slaked lime also has given the same results.

Cutting (1961) in his note on the production of geranium stated that liming acid soils to raise the pH from 6.5 to 8 is desirable.

Korezawa (1961) from his studies on the development of essential oil content and environmental conditions in pelargonium species reported that the essential oil content parrelled with the calcium content.

Effect of nitrogen phosphorus, potash and calcium in combinations

Nitrogen and phosphorus

Savitsky (1938) showed that good yields of thyme could be obtained by the use of at least NP fertilizers.

Kwinichidze and Rozanski (1939) found an increase in percentage of oil by the application of ammoniacal fertilizers with superphosphate, for Mentha pipereta.

Maslennikov (1939) found that in podsol soils of humid subtropics geranium responded to phosphatic fertilizers

only in the presence of nitrogen.

Autran and Foundard as quoted by Guenther (1949) recommended application of nitrogen along with phosphoric acid for higher oil yields in lavender.

Hotin (1957) reported that nitrogen and phosphoric acid applied during bud formation increased the menthol content in mint oil.

Cutting (1961) reported that NP fertilizers may increase yield and oil content of geranium. But often the oil quality is reduced.

Singh et al (1962) from his manurial experiments on Rosa damascena recommended nitrogenous and phosphatic fertilizers for higher yields.

Fertilizer trial on lemongrass, for four years at L.G.R.S., Odakali, Kerala, showed that interaction of N x P is highly significant for grass yield, but not for oil yield, or citral percentage (Ann. Progress Report of L.G.R.S., Odakali 1963-64).

Skrubis (1964) reported that in peppermint the essential oil of the 2nd harvest was increased by 'NP'

fertilizers. The composition of the oil was not affected.

Nitrogen and potash

Maslennikov (1939) found that in podsol soils of humid subtropics geranium responded to potash fertilizers only in the presence of nitrogen.

Bourne (1941) reported that application of 200 lb. of potassium chloride with 200 lb. of ammonium sulphate per acre gave the best yields of lemongrass oil in Florida willon elder peat soils.

Report of the Puertorico station (1941) stated that combination of 100 lb. of nitrogen and 100 lb. of potash per acre has given significantly superior grass, oil and citral yields in lemongrass.

Fertilizer trials on lemongrass at Lemongrass Research Station, Odakali for four years showed that the interaction 'NK' was highly significant for grass yield and oil yield, but not for citral percentage in the oil. (Ann. Progress Report of L.G.R.S., Odakali 1963-64).

Skrubis (1964) reported that in peppermint essential oil of the first harvest was increased by NK fertilizers.

Phosphorus and potash

Ellis et al (1941) reported that yield of peppermint oil is directly affected by fertilizers. A fertilizer mixture having either one part of phosphorus to two parts of potash or equal parts of phosphorus and potash are most effective.

Scharatz and Weimann (1949) reported that the addition of phosphorus and potash in combination did not increase the essential oil content of Mentha piperata.

Skrubis (1964) showed that in peppermint 'PK' interaction had no significant effect on yield.

Manurial trials on vetiver at Lemongrass Research Station, Odakali from 1963-1965, indicated that 'PK' fertilizers 20 lb. each per acre has given the higheryield of vetiver roots. There was no significant difference in oil yield due to 'PK' treatment.

Another experiment conducted at the same station on spacing cum manurial trial on lemongrass showed that the interaction P x K had significant effect on oil yield. (Ann. Progress Report of L.G.R.S., Odakali 1965-66).

Effect of nitrogen and calcium

Report of the Puertorico Experiment Station (1941)

shows that application of a mixture of 100 lb. each of nitrogen and calcium per acre has given significantly superior yield of grass, oil and citral in lemongrass.

Effect of potassium and calcium

Powers and Jones (1962) in their trials on mint obtained maximum yield of hay with potassium sulphate and magnesium limestone.

Effect of nitrogen phosphorus and potash

Hood (1917) reported that in Florida sandy soils a 4-5-8 NPK mixture applied at the rate of 600 lb./acre for lemongrass gave the optimum results.

Russel (1919) approximately doubled the yield of lemongrass oil by using 300 lb. of fertilizer mixture containing 15 parts of acid phosphate, 4 parts of dry tobacco stem and 5 parts of sodium nitrate.

Mazzaron (1937) found that Potash and phosphorus with just enough of nitrogen should be used to ensure initial growth in thyme oil plants.

Boshart (1938) reported that essential oils respond little or unfavourably to fertilizers as regards quality, but

this effect is offset by an increased crop yield.

Javillier and Gaude (1938) observed a general increase in yield of plants producing alkaloids, glucosides, essential oils and vitamins by the application of complete fertilizer. The results showed that fertilizers generally increased the yield of green matter than the proportion of active principle.

Savitsky (1938) showed good response in thyme to NPK fertilizers.

Mazzaron (1940) reported that optimum yield and quality of oil in mint can be obtained with the application of a nitrate superphosphate mixture, with small proportions of potash.

Report of the Puertorico Experiment Station (1941) stated that a combination of 100 lb. each of nitrogen, phosphorus and potash has given significantly superior results with regard to grass, oil and citral in lemongrass.

Ahamad et al (1948) reported that manuring on rich soils produce thick stems in Rosha grass and reduce oil yield.

Weichmann (1948) reported that fertilizers increase

yield of marjoram and lemon oil, while only minor changes were obtained with oils of thyme basil, terrigon, dill, fennel, etc.

Brown and Matthews (1951) recommended nitrogen, phosphorus and potash for lemongrass. An economic fertilizer suggested was a 4-5-8 NPK mixture at the rate of 600 lb. per acre.

Joachim and Panditttsekera (1953) from their experiments to see the effect of organic and artificial fertilizers on yield of citronella, found that manuring with a complete fertilizer was most effective in increasing grass and oil yields. The increase in grass yield was two to three times, and oil yield was nearly four times to that of unmanured plots. Manuring had a beneficial effect on oil content, optimum results being obtained with a complete fertilizer.

According to Burger (1957) higher yields in mint could be obtained only with a generous application of manure mixed with 100 kg. of potash, 50 kg. of phosphorus and 100 kg. of nitrogen per hectare.

Davis, Lucas and Shepherd (1957) reported good

response in mint to fertilizers. 100 lb. each of phosphoric acid and potash plus 25 to 50 lb. of nitrogen per acre was recommended for mint grown in organic soils.

Steigerwald (1958) observed that fertilizing mint, with 60 to 90 kg. of nitrogen, 80 to 120 kg. of phosphorus and 120-180 kg. of potash per hectare increased the green matter yields by 58-80% and dry matter yields by 51 to 58%.

Bujko (1959) obtained higher root yields in Inula helenium when NPK mixture was applied. The percentage of oil was also more when compared to unmanured plots.

Schroeder (1959) could not find any definite effect of fertilizers on valatile oil content in marjorum. In practical cultivation it was therefore best fertilized to produce the maximum yield of herbage. The fertilizers normally recommended are nitrogen 80 to 100 kg. phosphorus 36 to 45 kg. and potash 60 to 80 kg. per hectare.

Steward (1960) concluded that no one element is extremely specific in increasing the production of oil. Complete fertilizers generally increase yield of green matter. Within limits there is no relation between total Growth of hay and oil yield. The role of fertilizers in

the production of oil is more inexplicable than in the production of green or total dry matter.

Korezava (1961) reported that fertilizers had little effect on oil yield in Pelargonium. The yield depends largely on temperature, humidity and insolution.

Lin and Lian (1962) recommended an optimum rate of 30 kg. of nitrogen 15 kg. of phosphoric acid and 15 kg. of potash per hectare in the first year of planting and 60-20-20 kg. per hectare each of NPK mixture in the following years, for citronella grass.

Gulati (1963) stated, the application of complete fertilizer to patchouli increased the yield of leaves, but did not make any difference in oil content or quality of oil.

Skrubis (1964) reported an increased essential oil yield in peppermint during the 2nd harvest, by the application of NPK mixture. The composition of oil was not affected.

Nitrogen phosphorus and calcium

Report of Puertorico Experiment Station (1941)

stated that a combination of 100 lb. each per acre of nitrogen phosphorus and calcium significantly increased the grass, oil and citral yields in lemongrass.

Nitrogen, potash and calcium

Report of puertorico Experiment Station (1941) stated that a combination of 100 lb. each per acre of nitrogen, potash and calcium significantly increased the grass, oil and citral yields in lemongrass.

Nitrogen, phosphorus, potash and calcium

Report of Puertorico Experiment Station (1941) stated that a combination of 100 lb. each per acre of nitrogen, phosphorus, potash and calcium significantly increased the grass, oil and citral yields in lemongrass.

MATERIALS AND METHODS

MATERIALS AND METHODS

Experiment

The present investigation to determine the effect of nitrogen, phosphorus, potassium and calcium on yield and quality of citronella oil, was undertaken during 1965-66 as a statistically laid out field experiment.

Experimental site

The investigations were carried out in the dry land area of the farm attached to the Agricultural College and Research Institute, Vellayani. The soil is red loam. The mechanical and chemical characteristics of the soil are furnished in Appendix XI.

Treatments and layout

There were 36 treatments in the trial comprising of all possible combinations of 3 levels each of Nitrogen and Potash and 2 levels each of phosphorus and calcium.

Levels of fertilizers

Nitrogen	N_0:	No nitrogen
	N_1	100 kg. of nitrogen/hectare
	N_2	200 kg. " "

Potash	K_0	No potash
	K_1	100 kg. of potash/hectare
	K_2	200 kg. " "
Calcium	C_0	No calcium
	C_1	1000 kg. of Ca (OH) 2 per hectare

Phosphorus P_0 : No phosphorus P_1: 100 kg P_2O_5/ha.

Treatment combinations are given along with the plan of experimental layout.

Layout

The experiment was laid out as a $3^2 \times 2^2$ confounded factorial Randomised Block Design with two replications confounding NK in replication I and NK^2 in replication II. Plan of the experimental layout is given in Fig. I

Details of plot

Plot size	Gross	: 4.4 m. x 4.05 m.
	Net	: 4.0 m. x 3.15 m.
Spacing	Between plants:	40 cm.
	Between rows:	45 cm.
Number of plants per plot	Gross	: 99
	Net	: 80

PLAN OF THE EXPERIMENTAL LAYOUT.

DESIGN:- MIXED CONFOUNDED FACTORIAL IN RANDAMISED BLOCK DESIGN.

REP: I. (CONF: NK)

$N_0K_2C_{a0}P_0$	$N_0K_0C_{a0}P_1$	$N_0K_0C_{a1}P_0$	$N_2K_2C_{a1}P_0$	$N_2K_2C_{a0}P_0$	$N_2K_2C_{a0}P_1$	$N_0K_2C_{a1}P_1$	$N_0K_2C_{a0}P_0$	$N_2K_0C_{a1}P_1$
$N_2K_1C_{a0}P_0$	$N_2K_1C_{a1}P_1$	$N_2K_1C_{a0}P_1$	$N_0K_1C_{a0}P_0$	$N_1K_0C_{a0}P_1$	$N_1K_0C_{a1}P_0$	$N_1K_1C_{a1}P_0$	$N_0K_2C_{a1}P_0$	$N_1K_1C_{a0}P_0$
$N_1K_2C_{a0}P_1$	$N_1K_2C_{a1}P_0$	$N_0K_0C_{a0}P_0$	$N_1K_0C_{a0}P_0$	$N_0K_1C_{a0}P_1$	$N_1K_0C_{a1}P_0$	$N_1K_1C_{a0}P_1$	$N_1K_1C_{a1}P_1$	$N_2K_0C_{a1}P_0$
$N_1K_2C_{a1}P_1$	$N_2K_1C_{a1}P_0$	$N_0K_0C_{a1}P_1$	$N_0K_1C_{a1}P_1$	$N_0K_1C_{a1}P_0$	$N_2K_2C_{a1}P_1$	$N_2K_0C_{a0}P_1$	$N_2K_0C_{a0}P_1$	$N_0K_2C_{a0}P_1$

REP: II (CONF: NK^2)

$N_1K_1C_{a0}P_0$	$N_2K_2C_{a1}P_1$	$N_0K_0C_{a1}P_0$	$N_2K_1C_{a1}P_0$	$N_0K_2C_{a0}P_0$	$N_1K_0C_{a1}P_1$	$N_2K_0C_{a0}P_1$	$N_1K_2C_{a0}P_0$	$N_2K_2C_{a0}P_1$
$N_1K_1C_{a0}P_1$	$N_0K_2C_{a0}P_0$	$N_0K_0C_{a0}P_1$	$N_0K_2C_{a1}P_0$	$N_2K_1C_{a0}P_0$	$N_2K_1C_{a1}P_1$	$N_1K_2C_{a1}P_1$	$N_0K_1C_{a1}P_1$	$N_2K_0C_{a1}P_0$
$N_2K_2C_{a1}P_0$	$N_1K_1C_{a1}P_0$	$N_0K_2C_{a1}P_1$	$N_0K_2C_{a0}P_1$	$N_1K_0C_{a0}P_0$	$N_0K_2C_{a1}P_1$	$N_2K_0C_{a0}P_0$	$N_0K_1C_{a1}P_0$	$N_0K_1C_{a0}P_1$
$N_2K_2C_{a0}P_1$	$N_2K_2C_{a0}P_0$	$N_1K_1C_{a1}P_1$	$N_1K_0C_{a1}P_0$	$N_2K_1C_{a0}P_1$	$N_1K_0C_{a0}P_1$	$N_2K_0C_{a1}P_1$	$N_0K_1C_{a0}P_0$	$N_1K_2C_{a1}P_0$

PLOT SIZE.

GROSS: 4.4 × 4.05 SQ. METRES.

NET: 4.0 × 3.15 " "

TREATMENTS: 36.

FIG: I

Seed materials and sowing

Crop: Cymbopogon - nardus - Randle. lanalutu pengiri (Andropogon nardus Ceylon de Jong)

Order: Glumiforae

Family: Gramminae

A stoloniferous grass 1.5 m. to 2.1 m. high - and copiously tillering. Leaves are narrow with conspicuous mid-rib and, filiform apex and aromatic. Panicle is effuse with zigzag branches, divaricate bracts small spikelets and less developed awns. Plant is robust and grown in ordinary soils. Bulk of the Ceylon citronella oil and a portion of the Java citronella oil is derived from this.

Seed materials

Uniform stools, of fully grown healthy plants, obtained from lemongrass Research Station, Odakali, were used for planting.

Manures and fertilizers

Cattle manure: The analysis of cattle manure used for basel dressing is given below:-

Nitrogen (total) .. 0.64%

Phosphoric acid	..	0.32%
Potash	..	0.47%
Calcium	..	0.53%

Fertilizers

1. Nitrogen was applied in the form of ammonium sulphate, analysing 20.2% N.

2. Phosphoric acid was applied in the form of superphosphate analysing 16.31% P_2O_5.

3. Potash was applied in the form of muriate of potash analysing 58.24% K_2O.

4. Calcium was applied in the form of slaked lime ($Ca(OH)_2$) analysing 54.8% CaO.

Cultivation

Nursery

Stools were planted in well prepared nursery beds and the young sprouted plants thus obtained were used for the experiment. Raised nursery beds 1½ m. x 4 m. size were prepared without manuring. Slips were planted on 4.6.1965 at a distance of 8 to 10 cm. both ways. Shade was provided over the nursery and beds were regularly irrigated.

Experimental plots

(a) Preparation of land

The land was ploughed twice and weeds removed. Then dug to a depth of 10" and levelled. Main bunds to separate blocks and secondary bunds to demarkate plots were made, according to the layout plan.

(b) Application of manures and fertilizers

Cattle manure was applied prior to digging of plots at the rate of 5,000 kg. per hectare, and incorporated with the soil, by digging.

Lime was applied 15 days before the application of cattle manure and incorporated with the soil.

Full dose of superphosphate and half dose each of ammonium sulphate and muriate of potash was applied as basel dressing prior to planting. The balance of ammonium sulphate and muriate of potash were applied after first weeding given forty days after planting. The plots were raked after fertilizer application.

(c) Planting

Young sprouted stools with uniform growth and vigour were selected from the nursery, for transplanting

to the main plots. Young plants were planted at a distance of 45 cm. x 40 cm. with only a single plant in a hole 10 to 12 cm. deep. Dutta and Virmani (1964) recommended 40 to 45 cm. spacing for Ceylon citronella grass. The planting was carried out on 2-7-1965.

(d) Irrigation

During the first 3 weeks after planting the plots were uniformly irrigated during dry weather.

(e) After cultivation

1. Gapfilling: Two weeks after planting gaps were filled and the number of plants in all the plots were made equal.

2. Weeding: Two hand weedings were carried out during the course of investigations, one forty days after planting and the other ninety days after planting.

3. Harvesting: The crop was harvested twice during the course of investigation. The first harvest was done 90 days after planting that is on 2-10-1965 and the second on 20-11-1965 (45 days after the first harvest). Harvesting citronella grass at the above intervals was found to be optimum under Kerala conditions (Pillay 1960). The grass was cut 8 to 10 cm. above ground level and fresh

weight of grass recorded separately from each plot. The border was cut and removed separately.

Observations made and characters studied

1. Height of plants

Height of plants from ground level to top most open leaf was recorded in cm. prior to 1st harvest.

2. Number of functioning leaves

Number of leaves on the main tiller from 10 plants selected at random from each plot were recorded prior to harvest.

3. Number of tillers

Number of tillers have been recorded from 10 clumps selected at random from each plot, prior to harvest.

4. Fresh weight of grass

Green weight of grass soon after harvest was recorded, from all the plots separately.

5. Oil yield

During the first harvest the oil yield was estimated in the laboratory by steam distillation. 1 kg. sample of grass from each experimental plot was distilled, 24 hours

after harvest. Meantime better facilities for distillation was acquired. Hence during second harvest samples weighing 3 kg. each were distilled in bigger water and steam distillation units. The grass was cut into small bits before distillation for easy, and quick recovery of oil. Each charge was distilled for a period of 2½ hours after the first distillate came out through the condenser.

6. Percentage recovery of oil

The volume of oil in Ml. recovered from a certain weight of grass used in distillation was reduced to volume/weight ratio and was later expressed in percentage, for tabulation of data.

7. Quality of oil

Composite samples of oils were analysed to determine the total alcohols, by acetylation. The oil is acetylised with acetic-anhydride and the ester content of the resulting oil was determined. From this the percentage of alcohol in the original oil was calculated.

RESULTS

Results of field experiments conducted to study the effects of different doses of fertilizers on yield and quality of citronella oil are presented in the following pages.

Height of plants

Observations on the height of plants were recorded 90 days after planting and the data have been statistically analysed. The analysis of variance table is given in Appendix I It is seen that only the effects of nitrogen and calcium are significant in increasing the height of plants.

The mean height of plants corresponding to the levels of nutrients N, P, K and Ca are presented in Table No.I(a Table No. I(b) gives the mean heights of plants corresponding to the treatment combinations.

TABLE NO. I(a)

Mean height of plants in cm. corresponding to different levels of nitrogen, phosphorus, potash and calcium

Levels	Nitrogen	Phosphorus	Potash	Calcium
0	79.33	80.82	80.25	80.29
1	83.94	83.75	83.84	84.24
2	83.56	—	82.69	—
C.D.(0.05)	3.95	3.26	3.95	3.26

Nitrogen showed a significant increase in the height of plants upto N_1 level (100 kg. per hectare) and afterwards there is a slight reduction in height indicating that the optimum level is around N_1 level. Effect of calcium was also found to be significant in increasing the height of plants.

In the case of phosphorus a positive response is noticed even though it is not statistically significant. In the case of potash also a positive response is noticed upto K_1 level (100 kg./ha.) and afterwards a slight reduction in height. The increase recorded has failed to show significance.

TABLE I(b)

Mean height of plants in cm. corresponding to different treatment combination

		N_0		N_1		N_2	
		P_0	P_1	P_0	P_1	P_0	P_1
	K_0	65.75	78.35	80.25	75.20	79.70	88.10
CaO	K_1	78.15	82.55	83.85	85.20	75.15	86.65
	K_2	73.40	80.20	82.65	86.45	77.95	85.35
	K_0	79.50	80.50	86.05	79.30	87.40	82.85
Ca_1	K_1	77.00	89.35	80.65	88.90	91.75	86.85
	K_2	87.10	80.45	88.25	90.45	79.25	80.55

C.D. (0.05) 13.729

It is seen that the minimum height is recorded by

the control plot and maximum by the treatment N_2, K_2, Ca_1, P_0 i.e. 65.75 cm. and 91.75 cm. respectively.

Number of leaves per main tiller

Data on the number of leaves per main tiller recorded 90 days after planting have been statistically analysed. The analysis of variance table is given in Appendix II. It is seen that none of the main effects or interactions are statistically significant in increasing the number of leaves per plant.

The mean number of leaves corresponding to the levels of nutrients N, P, K and Ca are presented in Table II(a) and mean number of leaves corresponding to the treatment combinations are presented in Table II (b).

TABLE II(a)

Mean number of leaves per plant corresponding to different levels of nitrogen, phosphorus, potash and calcium

Levels	Nitrogen	Phosphorus	Potash	Calcium
0	5.05	5.07	5.00	5.05
1	5.11	5.09	5.11	5.13
2	5.09	--	5.14	--

TABLE II(b)

Mean number of leaves per plant corresponding to different treatment combinations

		N_0		N_1		N_2	
		P_0	P_1	P_0	P_1	P_0	P_1
	K_0	4.80	5.15	4.80	4.65	5.05	4.85
Ca_0	K_1	5.05	5.35	5.15	5.10	4.85	5.00
	K_2	4.80	5.20	5.20	5.25	5.05	5.55
	K_0	5.05	5.00	5.35	4.80	5.60	4.95
Ca_1	K_1	4.81	4.45	5.20	5.15	5.05	5.20
	K_2	5.05	4.90	5.40	5.20	5.00	5.00

Even though none of the effects of nutrients and their interactions are statistically significant in increasing the number of leaves per tiller it is observed that the interactions N x P, P x K and P x Ca tend to increase the number of leaves per plant.

Number of tillers

The data on the number of tillers, recorded 90 days after planting was statistically analysed. The analysis of variance table is given in Appendix III. It is seen that nitrogen, phosphorus and potash significantly increase the

number of tillers. The effect of calcium is also positive even though it is not found to be statistically significant. Interactions P x K and P x K x Ca were found to be significant.

The mean number of tillers corresponding to the levels of nutrients N, P, K and Ca are given in Table III (a). Table III(b) gives the mean number of tillers corresponding to the treatment combinations.

TABLE III(a)

Mean number of tillers per plant corresponding to different levels of nitrogen, phosphorus, potash and calcium

Levels	Nitrogen	Phosphorus	Potash	Calcium
0	44.20	50.96	49.60	52.15
1	55.89	56.19	55.75	55.00
2	60.64	--	55.39	--
C.D. (0.05)	4.42	3.61	4.42	3.61

Number of tillers increases steadily with levels of N and P. For the factor K there is increase upto K_1 level beyond which there is a slight reduction, indicating that the optimum level is around K_1. The effect of calcium is to increase the number of tillers even though the increase recorded has failed to show significance.

TABLE III (b)

Mean number of tillers per plant as affected by different treatment combinations

		N_0		N_1		N_2	
		P_0	P_1	P_0	P_1	P_0	P_1
	K_0	31.60	44.30	44.50	54.70	57.00	62.40
Ca_0	K_1	39.45	40.55	58.95	58.15	54.25	68.05
	K_2	50.50	43.80	52.75	52.30	67.50	58.00
	K_0	51.10	37.50	48.60	53.45	55.75	54.30
Ca_1	K_1	36.95	47.05	55.70	55.55	51.95	72.05
	K_2	52.00	55.55	45.90	59.85	62.85	63.65

C.D. (0.05) = 15.300

It can be seen that the interaction P x K is negative in the absence of calcium and positive in the presence of calcium. The maximum number of tillers have been recorded by the treatment N_2 K_1 Ca_1 P_1 followed by N_2 K_1 Ca_0 P_1 (72.05 and 68.05 respectively). The control plot has recorded the minimum number of 31.6 tillers per clump.

Grass yield

The data on the fresh weight of grass recorded at the time of harvests have been statistically analysed. The analysis of variance table is given in Appendix IV and V. It is seen that N, K, Ca, and interactions N x K and K x Ca are statistically significant in increasing grass yield, during the first harvest. During second harvest the effect of N and interaction; N x K are found to be significant. Calcium has also shown a positive response even though it is not statistically significant.

The mean yield of grass per plot corresponding to the levels of nutrients N, P, K and Ca are given in Table IV(a), and V(a) and those corresponding to the treatment combinations are given in tables IV (b) and V (b).

TABLE IV (A)

Mean yield of grass per plot in kg. corresponding to different levels of nitrogen, phosphorus, potash and calcium

(First Harvest)

Levels	Nitrogen	Phosphorus	Potash	Calcium
0	5.26	5.93	5.74	5.85
1	6.18	6.14	6.06	6.23
2	6.67	—	6.32	—
C.D. (0.05)	0.36	0.31	0.36	0.31

The mean yield of grass increases steadily with increase in level of nitrogen and calcium. In the case of potash there is a tendency to increase grass yield due to the increase in levels of potash but a significant differences in mean yield is noticed only between 0 level and 2 level. The effect of calcium is also to increase the mean yield of grass even though the difference is not significant.

TABLE IV (b)

Mean yield of grass in kg. per plot corresponding to different treatment combinations

(First harvest)

		N_0		N_1		N_2	
		P_0	P_1	P_0	P_1	P_0	P_1
	K_0	3.84	4.65	4.92	5.98	6.02	6.52
Ca_0	K_1	4.90	5.27	5.70	6.65	6.00	5.90
	K_2	6.20	6.12	5.95	5.92	8.05	6.62
	K_0	5.35	4.91	6.12	6.36	6.95	7.14
Ca_1	K_1	5.00	5.00	7.15	7.67	6.22	7.25
	K_2	6.02	5.95	5.87	5.80	6.50	6.91

C.D. (0.05) = 1.264

The treatment N_2 K_2 Ca_0 P_0 has recorded the maximum grass yield of 8.05 kg. as against 3.84 in the control plot.

TABLE V (b)

Mean yield of grass per plot in kg. corresponding to different levels of Nitrogen, phosphorus, potasium and calcium

(Second harvest)

Levels	Nitrogen	Phosphorus	Potash	Calcium
0	9.18	12.54	12.25	12.57
1	13.98	13.76	13.59	13.74
2	16.29	--	13.60	--
C.D. (0.05)	1.71	1.40	1.71	1.40

It is seen that the mean yield of grass increases significantly with levels of nitrogen. In the case of phosphorus and calcium there is a tendency to increase the grass yields, but the increase is not significant. In the case of potash also there is a tendency to increase grass yield upto N_1 level but the difference between N_1 and N_2 levels is neglegible.

TABLE V (b)

Mean yield of grass per plot in kg. corresponding to different treatment combinations

(Second harvest)

		N_0		N_1		N_2	
		P_0	P_1	P_0	P_1	P_0	P_1
	K_0	5.55	6.80	13.15	14.00	15.45	16.80
Ca_0	K_1	9.45	8.90	14.50	12.85	12.35	14.75
	K_2	10.35	8.25	9.55	11.65	18.85	11.95
	K_0	10.80	7.35	11.15	17.20	11.85	17.00
Ca_1	K_1	8.90	10.25	17.45	21.10	13.00	18.55
	K_2	10.85	12.70	12.30	12.00	18.25	15.65

C.D. (0.05) = 5.90

During second harvest also the treatment N_2 K_2 Ca_0 P_0 has given the maximum average yield of 18.85 kg. as against 5.55 kg. in the control pot.

Oil yield

Data on yield of oil per plot recorded after each harvest and distillation have been statistically analysed.

The analysis of variance table is given in Appendix VI and VII.

The analysis of variance table shows that N, K and interaction N x K significantly increases the oil yield during first harvest, and during 2nd harvest N, K, N x K and K x C were found to be significant. The effect of Ca is also found to be positive during both the harvests even though it failed to show significance.

The mean yield of oil per plot corresponding to the levels of nutrients N, P, K and Ca are given in tables VI (a) and VII (a) and those corresponding to treatments combinations are given in tables VI (b) and VII(b).

TABLE VI (a)

Mean yield of oil in ml. per plot corresponding to different levels of nitrogen, phosphorus, potash and calcium

(First harvest)

Levels	Nitrogen	Phosphorus	Potash	Calcium
0	44.06	49.57	47.70	48.99
1	51.75	51.53	50.93	52.11
2	55.83	--	53.02	--
C.D. (0.05)	4.52	3.71	4.52	3.71

It is seen that mean yield of oil increases steadily with levels of nitrogen and potash. Between levels of nitrogen significant difference is noticed between 0 and 1 levels and 0 and 2 levels. Even though the difference is positive between 1 and 2 levels it failed to show significance. In the case of potassium the oil yield increases steadily with the levels of fertilisers, but a significant difference is obtained only between 0 and 2 levels. Application of phosphorus and calcium has shown a tendency to increase the oil yield.

TABLE VI (b)

Mean yield of oil in ml. per plot corresponding to different treatment combinations

(first harvest)

		N_0		N_1		N_2	
		P_0	P_1	P_0	P_1	P_0	P_1
	K_0	38.50	38.50	43.00	48.25	50.75	55.75
Ca_0	K_1	48.25	46.50	47.75	56.00	49.00	47.25
	K_2	48.00	50.25	49.25	51.00	60.35	57.00
	K_0	44.50	41.25	49.25	52.00	57.25	58.25
Ca_1	K_1	41.75	41.75	61.00	65.00	50.75	62.25
	K_2	49.75	50.75	49.25	49.25	56.50	57.50

C.D. (0.05) = 15.078

The tables show that the maximum average yield of oil is recorded by the treatment N_1 K_1 Ca_1 P_1 and minimum by the treatment N_0 K_0 Ca_0 P_0 (control) i.e. 65.0 ml and 38.5 ml respectively per plot.

TABLE VII(a)

Mean yield of oil in ml. per plot corresponding to different levels of nitrogen, phosphorus, potash and calcium

(Second harvest)

Levels	Nitrogen	Phosphorus	Potash	Calcium
0	29.39	38.70	34.45	38.17
1	45.70	42.03	43.80	42.28
2	45.99	--	42.37	--
C.D. (0.05)	6.01	4.93	6.01	4.93

In the case of nitrogen the yield of oil increases only upto N_1 level and the difference between N_1 and N_2 levels is negligible. In the case of potash a steady increase is noticed upto K_1 level and then a slight reduction. In the case of N and K the difference between 0 and 1, and 0 and 2 levels are significant.

Phosphorus and calcium have also given increased mean yield of oil but the increases are not statistically significant.

TABLE VII (b)

Mean yield of oil in ml./plot corresponding to different treatment combinations

(Second harvest)

		N_0		N_1		N_2	
		P_0	P_1	P_0	P_1	P_0	P_1
	K_0	14.40	21.00	41.00	49.75	47.25	42.00
Ca_0	K_1	32.90	28.90	55.40	41.00	34.00	32.00
	K_2	31.75	37.20	32.95	32.40	56.25	64.75
	K_0	18.50	26.35	32.55	39.50	36.50	51.15
Ca_1	K_1	32.00	41.10	63.45	77.40	31.75	55.25
	K_2	40.20	30.25	46.25	35.40	53.75	46.75

C.D. (0.05) 20.972

During second harvest also the maximum average yield of oil was recorded by the treatment N_1 K_1 Ca_1 P_1 and minimum by N_0 K_0 Ca_0 P_0, i.e. 77.4 ml. and 14.4 ml. respectively per plot.

Percentage recovery of oil

The data on percentage recovery of oil recorded after each harvest and distillation has been statistically analysed. The analysis of variance tables are given in Appendix VIII and IX.

The analysis of variance tables show that only the effects of interactions N x K, K x Ca, N x K x Ca, P x K x Ca, have significantly influenced the percentage recovery of oil during first harvest. During second harvest the main effects N, K and interactions N x K and N x P have significantly affected the percentage recovery of oil.

The mean percentage recovery of oil per plot corresponding to levels of nutrients N, P, K and Ca are given in tables VIII (a) and IX (a) and those corresponding to the treatment combinations are given in tables VIII (b) and IX (b).

TABLE VIII (a)

Mean percentage recovery of oil per plot corresponding to different levels of nitrogen, phosphorus, potash and calcium

(first harvest)

Levels	Nitrogen	Phosphorus	Potash	Calcium
0	0.840	0.838	0.835	0.839
1	0.836	0.839	0.844	0.838
2	0.834	--	0.838	--
C.D. (0.05)	0.093	0.075	0.093	0.075

It is seen that none of the effects are significant.

TABLE VIII (b)

Mean percentage recovery of oil per plot corresponding to different treatment combinations

(first harvest)

		N_0		N_1		N_2	
		P_0	P_1	P_0	P_1	P_0	P_1
	K_0	0.875	0.830	0.860	0.810	0.845	0.855
Ca_0	K_1	0.880	0.860	0.850	0.845	0.720	0.805
	K_2	0.790	0.825	0.820	0.830	0.845	0.865
	K_0	0.830	0.835	0.805	0.830	0.825	0.815
Ca_1	K_1	0.840	0.850	0.850	0.840	0.815	0.860
	K_2	0.830	0.860	0.840	0.850	0.865	0.835

C.D. (0.05) = 0.032

TABLE IX (a)

Mean percentage recovery of oil per plot corresponding to different levels of nitrogen, phosphorus, potash and calcium

(Second harvest)

Levels	Nitrogen	Phosphorus	Potash	Calcium
0	0.322	0.310	0.288	0.313
1	0.327	0.311	0.325	0.310
2	0.283	--	0.320	--
C.D. (0.05)	0.026	0.017	0.026	0.017

In the case of nitrogen there is no significant difference between 0 and 1 levels. But between 0 and 2 and 1 and 2 levels there is significant difference. A significant reduction in oil yield due to the application of 200 kg. of N per hectare can be noticed. In the case of potash there is a significant increase in percentage recovery of oil. A steady increase is noticed upto k_1 level and then there is a slight reduction. Phosphorus and calcium do not seem to have any influence on percentage recovery of oil.

TABLE IX (b)

Mean percentage recovery of oil per plot corresponding to different treatment combinations

(Second harvest)

		N_o		N_1		N_2	
		P_o	P_1	P_o	P_1	P_o	P_1
	K_o	0.265	0.315	0.320	0.345	0.310	0.255
Ca_o	K_1	0.350	0.325	0.350	0.330	0.285	0.215
	K_2	0.307	0.350	0.390	0.285	0.305	0.300
	K_o	0.180	0.330	0.295	0.230	0.305	0.305
Ca_1	K_1	0.350	0.405	0.375	0.365	0.250	0.300
	K_2	0.325	0.376	0.340	0.305	0.285	0.300

C.D. (0.05) = 0.095

The interactions N and K and N x P are significant.

Alcohol percentage

Composite samples of the oil obtained from two harvests have been analysed to determine the total alcohol content. The data have been statistically analysed and the analysis of variance table is given in Appendix X.

It is seen that nitrogen significantly influences the alcohol percentage.

The mean percentage of alcohol in the oil corresponding to N, P, K and Ca are presented in table X (a). The mean percentage of alcohol corresponding to the treatment combinations are presented in table X (b).

TABLE X (a)

Mean percentage of alcohol corresponding to different levels of nitrogen, phosphorus, potash and calcium

Levels	Nitrogen	Phosphorus	Potash	Calcium
0	56.09	55.40	55.44	55.60
1	56.07	55.93	55.76	55.73
2	54.06	--	55.77	--

Nitrogen upto N_1 level (100 kg/hectare) showed only a slight reduction in alcohol content of the oil. But at N_2 level there was a significant reduction in the percentage of alcohol in the oil. Other nutrients 'phosphorus, potash and calcium' did not affect the quality of oil significantly.

TABLE X (b)

Mean percentage of alcohol corresponding to different treatment combinations

		N_o		N_1		N_2	
		P_o	P_1	P_o	P_1	P_o	P_1
	K_o	55.60	56.10	54.70	55.80	55.40	54.75
Ca_o	K_1	55.95	56.30	56.75	56.90	53.75	54.50
	K_2	56.45	57.65	55.50	55.90	54.35	54.30
	K_o	55.65	55.10	55.75	55.90	55.35	55.20
Ca_1	K_1	54.10	56.85	55.00	57.75	56.00	55.25
	K_2	57.05	56.05	55.90	56.75	53.80	55.65

Maximum alcohol percentage is recorded in the treatment N_1 K_1 Ca_1 P_1 i.e. 57.75 as against a minimum of 53.75 in the treatment N_2 K_1 Ca_o P_o. The interactions do not differ significantly with regard to the percentage of alcohol.

DISCUSSION

DISCUSSION

Citronella oil as a source of perfumery isolates like geraniol and citronellal has created a vast demand in soap and perfumery industry in India. The demand of the oil is increasing every year and the requirement of the oil is being met by imports from outside. This has given sufficient impetus in India to start citronella cultivation on a large scale. Information regarding the cultural&manurial requirements of this crop is inadequate and no systematic work has been reported in India.

The results of the present investigations to study the effect of fertilisers on growth, and yield of citronella grass and quality of its oil are discussed in the following pages.

Height of plants

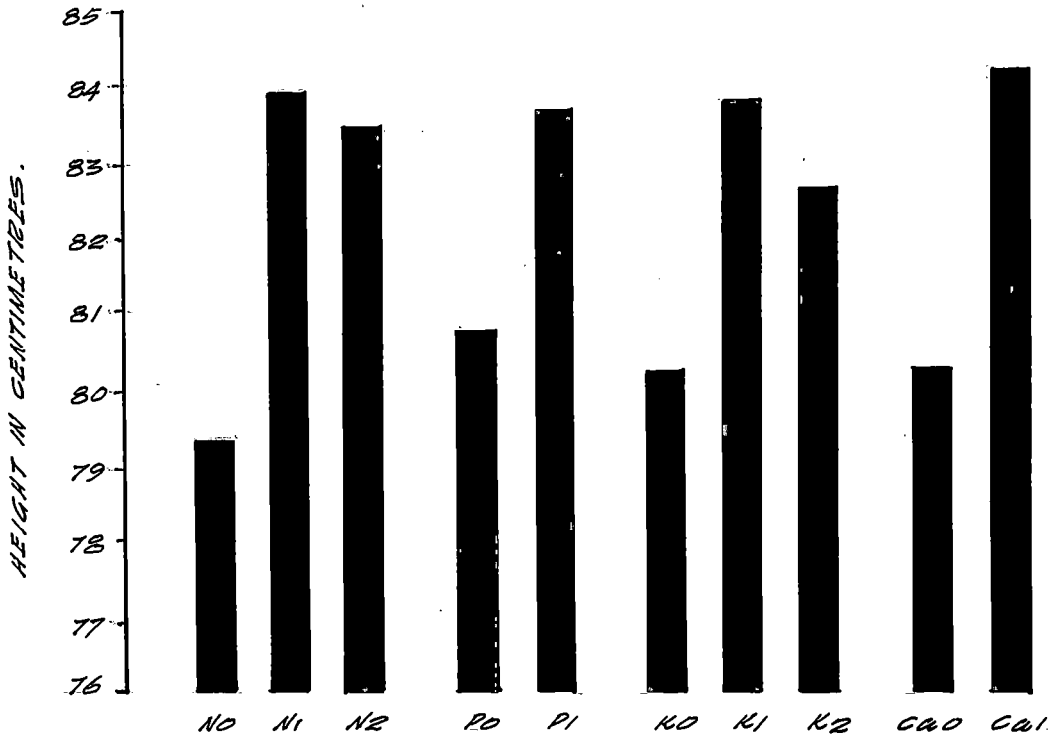
Results presented in table I shows that nitrogen and calcium significantly increase the height of plants. The 200 kg. level recorded a very slight decrease in height than the 100 kg. level indicating that the optimum level is

below 200 kg. and around 100 kg. per hectare. Plant height is an important growth index. Within genetical limits, it is influenced by environment. In general nitrogen is the most important nutrient which influences plant height. The height responses reported in this work are in consonance with the reports of other workers on essential oil crops. Guenther (1949) Shil and Young (1964) have reported high response of citronella grass to nitrogenous fertilisers with regard to height and other growth characteristics. Powers (1947) in peppermint and Guenther (1949) in peppermint and lavender, have also recorded significant increase in height due to nitrogenous fertilisers.

The significant increase in height due to lime application appears to be due to the importance of calcium as an essential element for the growth of meristems and for the proper growth and functioning of root-tips. A good calcium supply is also considered to be helpful in neutralising bad effects in the soil (Russel, 1962).

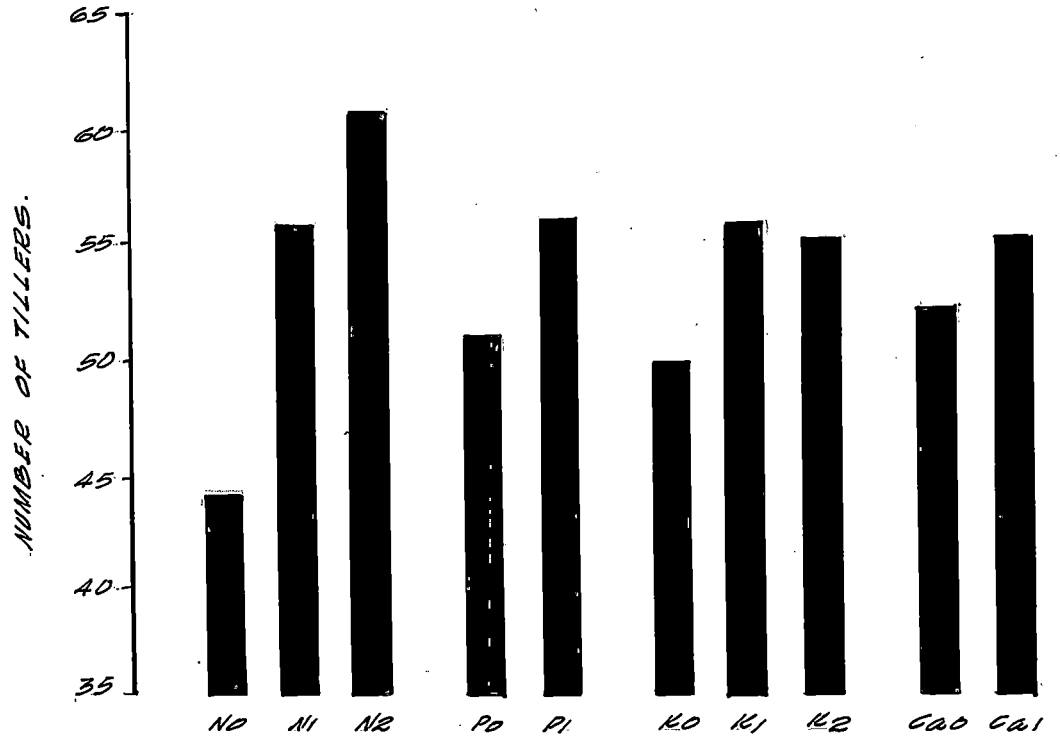
Unusual height of plant is not a desirable character as far as citronella is considered. Increase in height of citronella grass is mainly due to the elongation

MEAN HEIGHT OF PLANTS.



.a- LEVELS OF NUTRIENTS.

MEAN NUMBER OF TILLERS.



.b. LEVELS OF NUTRIENTS.

FIG: 2

of culm. Increase in height due to elongation of the culm is unfavourable for oil yield. The percentage of oil content in the grass stem, is only 15 to 20% of the content of the leaves (Guenther 1949).

Number of leaves per tiller

The results presented in table II shows that none of the treatments has influenced the production of leaves, significantly. However, though not significant, it is seen that the interactions N x P, K x P and Cax P show a positive influence on the number of leaves produced per tiller. From Table II (a) it can be seen that the average number of leaves per plant is less in the zero level treatment in all the nutrients tried. But the increase in the average number of leaves is only slight at 100 kg. level. From this it will appear that the fertilisers did not influence leaf formation markedly. This may be partially true.

Number of tillers

Results given in Table III show that fertilisers have a marked influence in the production of tillers. The

nutrients nitrogen, phosphorus and potash significantly influences the production of tillers. Table III (a) shows that the influences of N, P and K is positive. The effect of calcium is also positive even though it is not significant.

Nitrogen has shown a steady increase in the number of tillers upto 200 kg. level (Table III a). The maximum average number of tillers, among the various levels of nutrients tried in noticed in the 200 kg. level of nitrogen. Thus nitrogen has a positive influence on tiller formation. Takashi et al (1956) reported that nitrogen absorption by rice plant plays a significant role in the production of tillers. Nair and Nair (1964) observed profuse branching in mint due to nitrogen application. The soil under investigation is poor in nitrogen and the crop responded significantly by profuse tillering due to the application of nitrogen.

Results in Table III (a) show a steady increase in tillering upto K_1 level and afterwards slight reduction. It is well known that grasses need a fairly good supply of potash for higher yields Drake et al (1953) stated that

grass roots with a lower cation-exchange capacity tend to favour absorption of monovalent cations such as potassium and grassses will respond to potassium at lower rates of application.

Phosphorus has also given a significant positive response. The above result is in confirmity with the findings in the experiments with lemongrass at the lemon grass Research Station, Odakali (Ann. Progress Report 1962-63). The above response to phosphorus obtained in this investigation may be due to the influence of phosphorus in the cell division & development of meristamatic tissues.

Tillers are lateral shoots coming from axillary buds at the nodes of grass plants. The extent of tillering is one of the factors which affect the yield of crops belonging to the grass family. Guenther (1949) stated that profuse tillering is a characteristic of citronella grass under favourable soil conditions. The results of the present investigation show that the three major nutrients N, P and K have a significant positive influence in the production of tillers in citronella grass, under loamy soil conditions of Vellayani where the soil is poor.

Grass yield

Results presented in tables IV and V, show that the effect of N and interaction N x K, increases the grass yield in both harvests. The effects of K, Ca and K x Ca were found to be significant only during first harvest.

The first item of interest is a steady increase in grass yield up to N_2 level of nitrogen (Tables IV a and V a). It is fairly well established in many crop plants that nitrogen increases the green matter yield (Russel 1962). Steady response to nitrogen is due to the low nitrogen status in the soil. A general increase in green matter yield of essential oil yielding crops has been obtained due to nitrogen application in experiments on lemongrass at Agricultural Experiment Station, Puertorico. Dejoe as stated by Guenther (1949) and Lin and Li'an (1962) on citronella grass, Baird (1956) and Steige Wald (1958) in peppermint have also observed the same relationship of nitrogen.

This high influence of nitrogen may be due to the increased production of protein. Consequently the leaf size also will be increased, resulting in the synthesis of more carbohydrates.

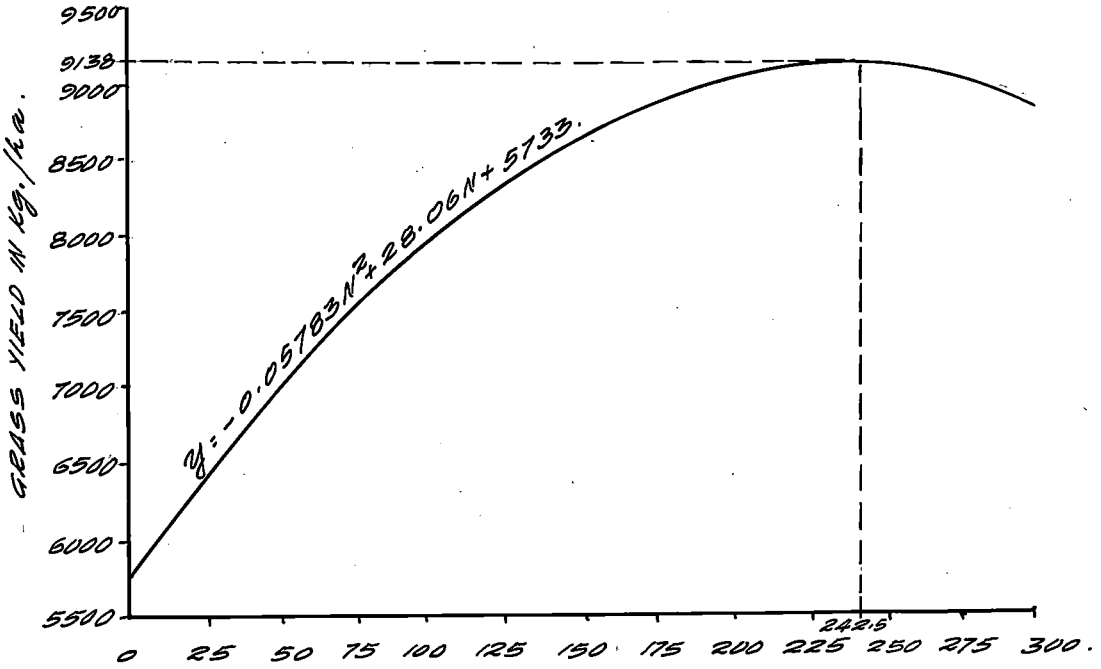
The interactional effect of N x K is in conformity with the findings of Maslennikov (1939), experiments on lemongrass in Puertorico reported in 1941 and that experiment conducted at Odakali (1959-1963). This interactional effect may be due to the utilization of more potash in the presence of nitrogen.

Abundant supply of potassium causes other nutrients especially nitrogen to be deficient in soil due to rapid absorption (Russel (1962). This may be the reason for the failure of potassium to show significant response during second harvest when probably other nutrients would have become limitting. The interactional effect of K x Ca can be attributed to the increased availability of potash in soils with a high saturation of calcium in the exchange complex.

The lack of response to phosphorus found in this investigation is similar to the effect of phosphorus reported by other investigators. Barner (1938) in Salvia officinalis and Artemesia absenthium, Maslennikov (1939) in geranium and Baird (1957), Steigerwald (1958) and Skrubis (1964) in peppermint have all failed to notice any positive influence as a result of phosphorus application.

But Dejoe as stated by Guenther (1949) has recommended

RESPONSE CURVE FOR THE YIELD OF GRASS FOR DIFFERENT LEVELS OF NITROGEN.



RESPONSE CURVE FOR THE YIELD OF GRASS FOR DIFFERENT LEVELS OF POTASH.

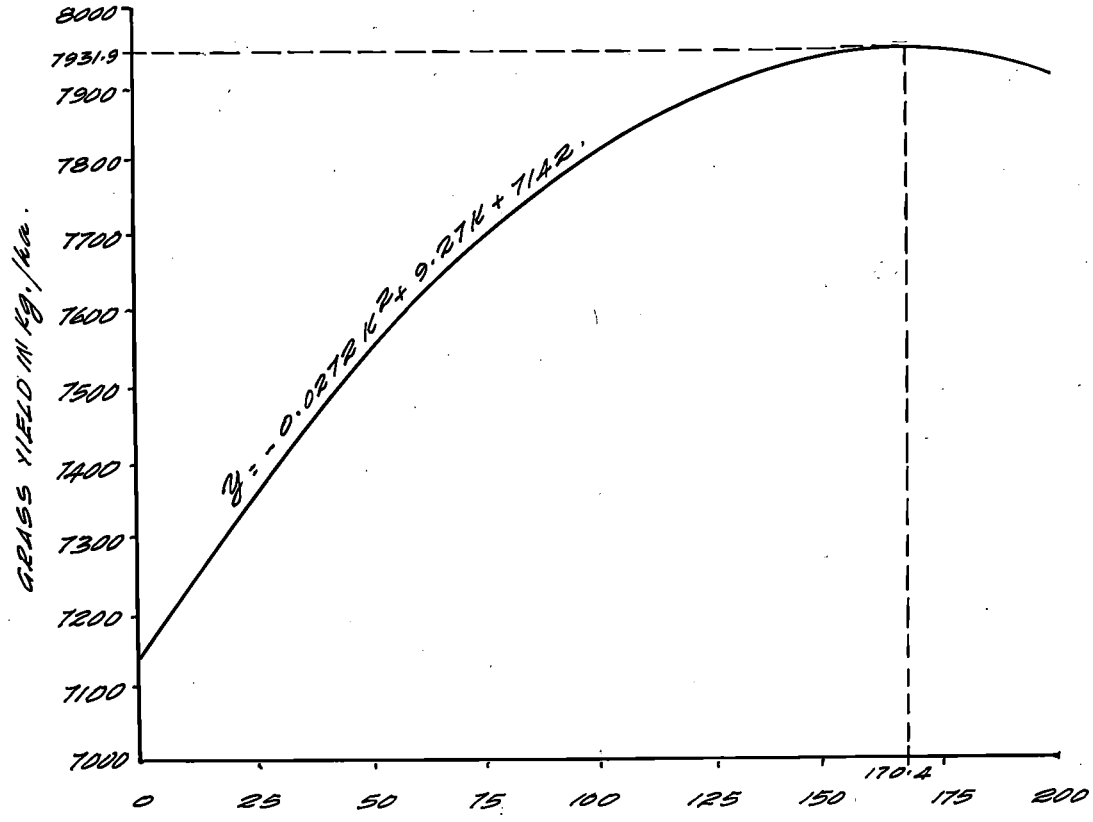


FIG: 3.

300 lb. of superphosphate per acre for citronella grass. Similarly Joachim and Panditttsekera also have stated the importance of manuring citronella with phosphatic fertilizers. However the present finding is that phosphorus is not as important as other nutrients in manuring citronella under the conditions prevailing in Vellayani. Just as all grasses citronella also is able to absorb more phosphorus from any soil, than other field crops. Whyte (1961) reported that phosphorus becomes deficient to grasses only in markedly deficient soils.

The grass yield in general is a result of increased growth, tillering, height, size and number of leaves, thickness of stems etc. In general all the three major nutrients are important in increasing grass yield. The results of the investigations have shown that nitrogen and potash are more important than other nutrients.

Response curve for yield of grass

Nitrogen application has increased the yield of green matter and the magnitude of response was higher than that of other nutrients. By fitting response curve for yield of grass for different levels of nitrogen (Fig. 3a) it is found that the optimum level of nitrogen is 242.5 kg./ha. which is above the maximum level tried i.e. 200 kg./ha.

The corresponding yield of grass is calculated to be 9138 kg./ha. which is only 24 kg. more than that obtained for the maximum level tried and hence not economical.

The response curve for different levels of potash is given in Fig. 3(b). It shows that optimum level of potash is 170.4 kg./ha. and the corresponding yield of grass is 7931.9 kg./ha. which is 23.9 kg. more than the yield obtained for 200 kg. treatment.

Oil yield

Results presented in Tables VI and VII show that N, K and interaction N x K significantly increases the oil yield during both harvests. The interaction K x Ca was found to be significant only during second harvest.

The results obtained in the case of nitrogen are in agreement with the findings of Puertorico experiments on lemongrass reported in 1940. Ilin (1940), Scharatz (1949) and Khotins (1950), Chamura (1955), Baird (1955), Latypov (1960) and Cutting (1961) in peppermint, Lin and Lian (1962) and Shii, Young and Hu (1964) in citronella grass have also obtained similar results.

Results obtained in the case of potassium also agree

with the findings of Barner (1938) in Salvia and artemesia, Bourne (1941) and L.G.R.S. experiments (1959-63) on lemongrass, Guenther (1949) Davis et al (1956) and Latypov (1960) on peppermint, and Joachim and Panditt sekera and Shil et al on citronella grass. Positive response in oil yield due to the interaction of N x K as obtained in the experiment has been reported by Maslennikov (1939) in geranium, Bourne (1941), Puertorico experiment reported in (1941) and L.G.R.S. experiments from (1959-63) in lemongrass and Skrubis (1964) in peppermint.

In general, the increase in oil yield can be due to the increase in grass yield, increase in oil content of the grass or both. Tables IV and V show that nitrogen and interaction N x K significantly increased the grass yields during both harvests and the observed effect of nitrogen in oil yield is due to this increased grass yield. The significant superior response to potash in the first cutting is due to the increased grass yield (Table IV a) and in the second harvest is due to the influence of increased percentage recovery of oil (Table VIII b). Russel (1962) states that increased nitrogen supply produces extra protein and the grass grows larger. The surface area of leaves is also increased. Such an increase in the surface area of leaves

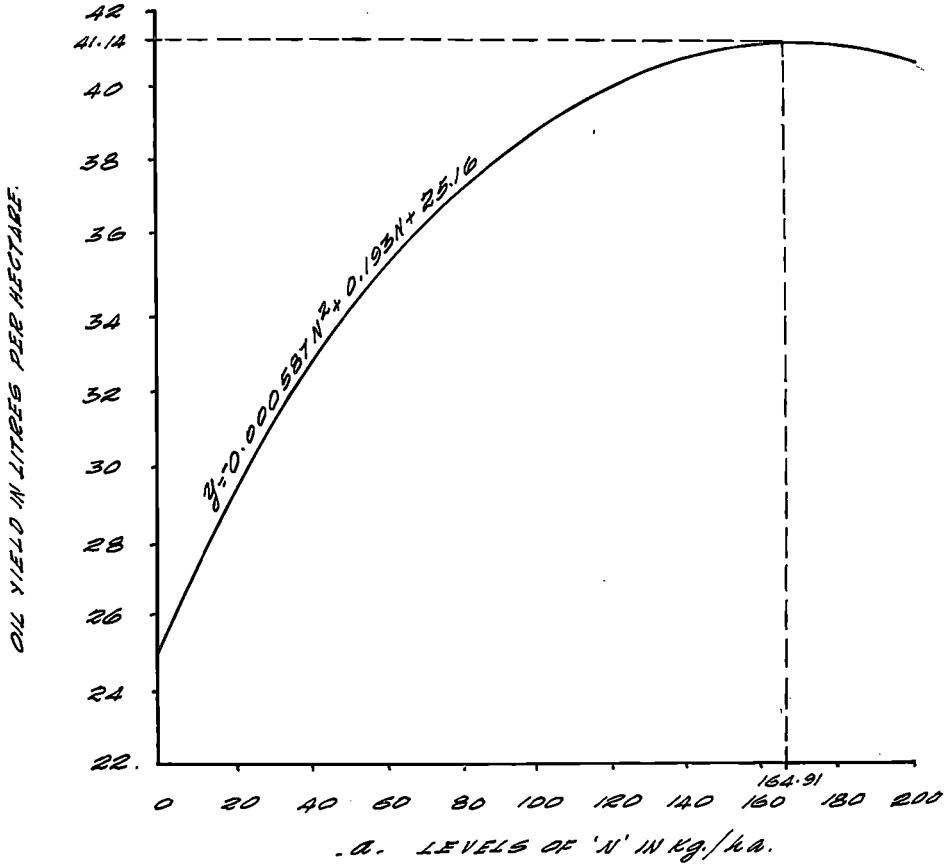
may increase the number of oil glands resulting in the production of more oil. It can be noted from the results of second harvest (Table V a) that 200 kg. of N/ha has caused a significant increase in grass yield but not a corresponding increase in oil yield (Table VII a). According to Russel (1962) a high nitrogen supply rapidly converts the carbohydrate to proteins and protoplasm. Only a small portion of carbohydrate is left behind for cell wall formation. Protein and protoplasm increases the size and number of cells. But dearth of carbohydrates results in thinner cell walls. This in turn induces rapid diffusion and loss of essential oils from the numerous cells formed. Moreover the sacculent nature of the grass due to the influence of high nitrogen absorption also causes reduction of essential oil by hydrolysis.

Response curve for oil yield

Response curve for oil yield for different levels of nitrogen is given in Fig. 4 (a). The optimum dose of nitrogen works out to be 169 kg./ha. and the corresponding oil yield is 41.14 litres per hectare as shown in the curve.

Response curve for different levels of potash given in Fig. 4(b) shows that the optimum dose is 157.5 kg./ha. and corresponding yield is 38.27 litres/ha. Optimum doses

RESPONSE CURVE FOR THE YIELD OF OIL FOR DIFFERENT LEVELS OF NITROGEN.



RESPONSE CURVE FOR THE YIELD OF OIL FOR DIFFERENT LEVELS OF NITROGEN.

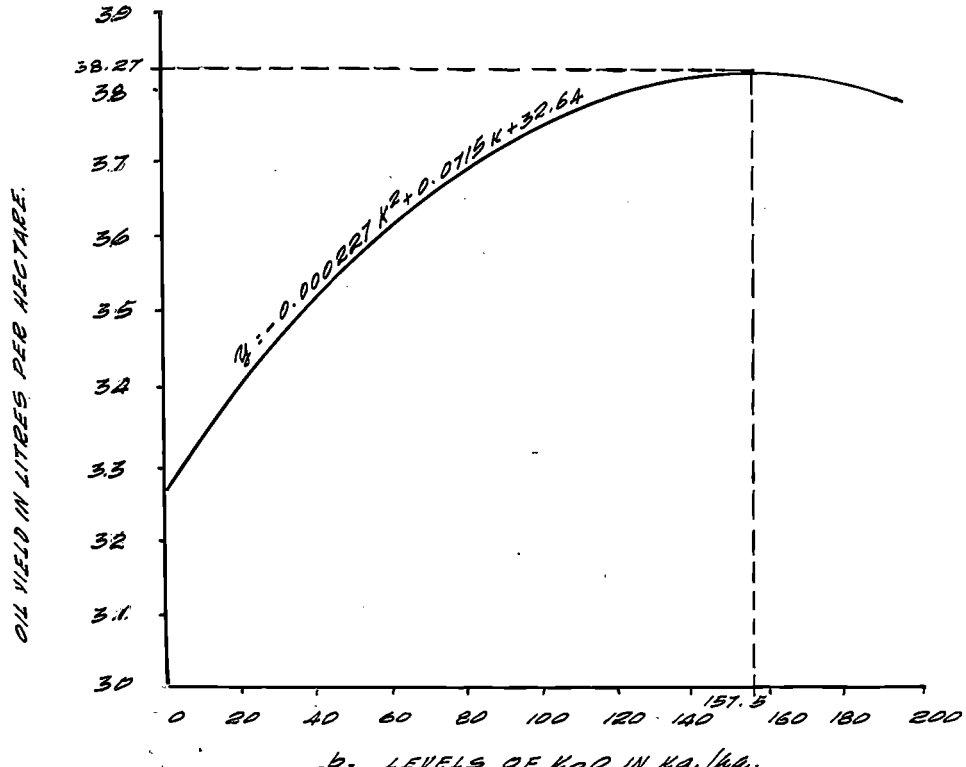


FIG:4

of nitrogen and potash for yield of oil lie within the range of levels of nutrients tried.

Results on fertilizer experiments on lemongrass at the Lemongrass Research Station from 1959-1963 have shown that optimum levels of nitrogen and potash was 179 and 282 lb. respectively per acre for maximum yield of lemongrass oil (Ann. Progress Report of L.G.R.S., Odakali, 1963-64).

Percentage recovery of oil

Results presented in Table VIII shows that, only interactions N x K, K x Ca and P x K x Ca significantly influence the percentage recovery of oil in the first harvest. Appendix No. IX shows that N, K and interaction N x K and N x P significantly influence the percentage recovery of oil during second harvest.

Tables VIII(a) and IX(a) shows that the percentage recovery of oil is reduced at higher levels of nitrogen in both harvests. This may be due to the unbalanced nutrition of the crop. During second harvest higher level of nitrogen has given highly significant increase in grass yield (Table Va). On analysis of the percentage recovery of oil a significant reduction is noticed at higher level of nitrogen.

It is thus seen from the results that above 100 kg. of N/ha. the green matter increase is not accompanied by a corresponding increase in oil content. Similar results are obtained in the case of potash also. The above results are in conformity with the results reported by Guenther (1944) and Joachim and Panditt sekera (1953) on citronella grass.

The positive influence of nitrogen in combination with K, P or Ca may be due to the greater balance in nutrition. Brown and Matthews (1951), Joachim and Panditt sekera (1953) Lin and Lian (1962) recommended the application of balanced fertilizers for optimum results. Percentage recovery of oil is an important quality which determines the economics of citronella oil production. Any fertilizer treatment which increases the grass yield and the percentage oil content in the leaves will keep the cost of production of oil low, as the extraction of oil alone involves nearly 50% of the cost of its production.

Alcohol percentage in the oil

Analysis of variance table given in Appendix X shows that alcohol percentage in the oil is affected only by nitrogen. Between 0 and 100 kg. level of nitrogen there was not much difference in the alcohol content. But at 200 kg. level there was a significant reduction in alcohol

percentage (Table Xa). This reduction in alcohol is accompanied by a higher tonnage of grass in the plots treated with higher dose of nitrogen. Trials conducted at L.G.R.S., Odakali (1959-63) on lemongrass, by Cutting (1961) in geranium and Shii, Young and Hu (1964) on citronella grass have shown that the application of a higher dose of nitrogen increases the yield of green matter and oil but the quality of oil is reduced. According to Russel (1962) high nitrogen increases the sacculence of leaf and proportion of water to dry matter. This high proportion of water to dry matter affects the quality of oil adversely.

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

The present investigation was undertaken at the Agricultural College and Research Institute, Vellayani during 1964-66 to study the influence of fertilizers on growth yield and quality of oil in citronella.

The effect of nutrients nitrogen and potash at three levels each and phosphorus and calcium two levels each were studied in a mixed confounded factorial experiment, in Randomised Block Design.

Soil analysis was made to determine the nutrient status of the soil. Growth characters like height of the grass, number of leaves per main tiller, and number of tillers per clump were studied. Yield characters like grass yield and oil yield were investigated. Studies were also made regarding the percentage recovery of oil and total alcohol content in the oil. Results of the investigations are summarised below:-

The height of plants is significantly influenced by nitrogen and calcium. Maximum height is attained by the treatment $N_2K_1Ca_1P_0$ (i.e.) 40% more than the control plot.

None of the nutrients tried has significantly

influenced the production of leaves. However the interactions N x P, K x P and Ca x P showed a positive trend.

Fertilizers have a marked influence in the production of tillers per clump. A significant positive influence is noticed in the case of nitrogen, phosphorus and potash. Maximum tillering is noticed in plots receiving $N_2K_1Ca_1P_1$ treatment (i.e.) 129.5% more than control.

Effect of nitrogen and interaction of nitrogen with potassium have given significant increase in grass yield during the two harvests done during the period of investigation. Effect of K, Ca and interaction K x Ca was found significant only during first cutting. The optimum dose of nitrogen for the maximum yield of grass (9138 kg./ha.) was found to be 242.5 kg./ha. The optimum dose of potash for maximum yield of grass (7931 kg./ha.) was found to be 170.4 kg./ha.

Oil yield was significantly increased by N, K and interaction N x K during both harvests. The interaction K x Ca was found significant only during second harvest. The optimum dose of nitrogen for maximum yield of oil (41.14 litres/ha.) was found to be 169 kg./ha. Likewise

the optimum dose of potash for maximum yield of oil (38.27 litres/ha.) was found to be 157.5 kg./ha.

Percentage recovery of oil was found to be influenced significantly by interaction N x K, K x Ca and P x K x Ca during first harvest and by N, K and interactions N x K and N x P during second harvest. The percentage recovery of oil was found to be reduced in plots treated with 200 kg. of N per hectare. A balanced fertilizer was found to be important in giving a favourable influence on the percentage recovery of oil.

The alcohol percentage in the oil was found to be affected only by nitrogen. A significant reduction in alcohol percentage was noticed at N_2 level (200 kg./ha.). Only a negligible difference was noticed between N_0 and N_1 levels. The maximum alcohol content was recorded by the treatment $N_1K_1Ca_1P_1$ which is 3.8% more than control plots.

It is evident from the results of the present investigation that it is possible to grow citronellagrass successfully under the agroclimatic conditions of Trivandrum.

Fertilizers profoundly influence the growth and yield of the grass. Fertilizers other than 200 kg. level of N had no significant influence in the quality of oil,

determined by total alcohol percentage. Higher levels of N was also found to reduce the percentage recovery of oil. Thus it is seen that an optimum dose of nitrogen 169 kg. and that of 157.5 kg. of potash per hectare do materially increase the yield of oil without producing any deleterious effect on the quality and percentage recovery of the oil. These facts indicate that citronella grass requires manuring with fertilizers containing nitrogen and potash as the predominant constituents.

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APPENDICES

APPENDIX I

Height of Plants

(Analysis of variance)

Source	S.S.	D.F.	Variance	F.
Total	6056.72	71	..	..
Block	2449.17	5	489.83	10.81
N	303.95	2	151.97	3.35*
K	161.05	2	80.52	1.77
NK	137.08	2	68.54	1.30
NK^2	10.57	2	5.28	1
P	158.70	1	79.35	1.40
N x P	59.89	2	29.94	1
P x K	64.41	2	32.20	1
N x P x K	150.51	4	37.63	1
Ca	281.85	1	281.85	6.20*
N x Ca	36.22	2	18.11	1
K x Ca	6.02	2	3.01	1
N x K x Ca	161.04	4	40.26	1
P x Ca	134.01	1	134.01	2.95
N x P x Ca	126.32	2	63.16	1.39
P x K x Ca	55.71	2	27.85	1
N x P x K x Ca	136.75	4	34.19	1
Error	1403.83	31	45.28	..

*Significant at 5% level

APPENDIX II

Number of leaves per main tiller

(Analysis of variance)

Source	S.S.	D.F.	Variance	F.
Total	6.500	71	..	..
Block	0.130	5	0.026	1
N	0.050	2	0.025	1
K	0.260	2	0.130	1.02
NK	0.080	2	0.040	1
NK^2	0.010	2	0.005	1
P	0.020	1	0.010	1
N x P	0.480	2	0.240	2.26
P x K	0.560	2	0.280	2.64
N x P x K	0.250	4	0.062	1
Ca	0.110	1	0.110	1.04
N x Ca	0.130	2	0.065	1
K x Ca	0.280	2	0.140	1.32
N x K x Ca	0.260	4	0.065	1
P x Ca	0.240	1	0.240	2.26
N x P x Ca	0.006	2	0.003	1
P x K x Ca	0.260	2	0.130	1.02
N x P x K x Ca	0.100	4	0.025	1
Error	3.280	31	0.106	..

APPENDIX III

Number of tillers per clump

(Analysis of variance)

Source	S.S.	D.F.	Variance	F.
Total	14124.58	71	..	..
Block	4365.02	5	873.00	15.52**
N	3440.10	2	1720.05	30.57**
K	571.19	2	285.59	5.07*
NK	865.28	2	432.64	7.69**
NK^2	158.20	2	79.10	1.40
P	493.01	1	493.01	8.76**
N x P	216.28	2	108.14	1.92
P x K	485.86	2	242.93	4.31*
N x P x K	128.28	4	32.07	1
Ca	146.26	1	146.26	2.60
N x Ca	141.69	2	70.84	1.25
K x Ca	48.90	2	24.45	1
N x K x Ca	187.86	4	46.96	1
P x Ca	101.25	1	101.25	1.80
N x P x Ca	188.57	2	94.28	1.67
P x K x Ca	705.88	2	302.94	5.38**
N x P x K x Ca	135.42	4	33.85	1
Error	1743.81	31	56.25	..

*Significant at 5% level

**Significant at 1% level

APPENDIX IV

Grass Yield (First harvest)

(Analysis of variance)

Source	S.S.	D.F.	Variance	F.
Total	70.67	71	..	..
Block	4.50	5	0.90	2.36
N	24.60	2	12.30	32.36**
K	4.04	2	2.02	5.31*
NK	7.31	2	3.65	9.60**
NK^2	2.35	2	1.17	3.07
P	0.79	1	0.79	2.07
N x P	0.41	2	0.20	1
K x P	2.09	2	1.04	2.73
N x K x P	1.76	4	0.44	1.18
Ca	2.63	1	2.63	6.92*
N x Ca	0.53	2	0.26	1
K x Ca	3.18	2	1.59	4.18*
N x K x Ca	0.72	4	0.18	1
P x Ca	0.005	1	..	..
N x P x Ca	1.88	2	0.94	2.47
K x P x Ca	0.94	2	0.47	1.24
N x K x P x Ca	0.99	4	0.25	1
Error	11.95	31	0.385	..

*Significant at 5% level

**Significant at 1% level

APPENDIX V

Grass yield (Second harvest)

(Analysis of variance)

Source	S.S.	D.F.	Variance	F.
Total	1695.10	71	..	..
Block	259.00	5	51.80	6.20**
N	631.70	2	315.85	37.60**
K	28.80	2	14.40	1.72
NK	188.10	2	94.05	11.25**
NK^2	7.50	2	3.75	1
P	26.90	1	26.90	3.20
N x P	21.70	2	10.85	1.25
K x P	10.10	2	5.05	1
N x K x P	22.90	4	5.72	1
Ca	25.00	1	25.00	3.00
N x Ca	36.20	2	18.10	2.16
K x Ca	17.80	2	8.90	1.00
N x K x Ca	41.10	4	10.27	1.20
P x Ca	6.10	1	6.10	1
N x P x Ca	7.90	2	3.95	1
K x P x Ca	22.80	2	11.40	1.40
N x K x P x Ca	79.80	4	19.95	2.37
Error	261.70	31	8.44	..

**Significant at 1% level

APPENDIX VI

Oil yield (First harvest)

(Analysis of variance)

Source	S.S.	D.F.	Variance	F.
Total	6017.4	71	..	..
Block	243.7	5	48.74	1
N	1714.6	2	857.3	14.43**
K	346.8	2	173.4	2.93*
NK	448.6	2	224.3	3.77*
NK^2	182.0	2	91.0	1.54
P	69.1	1	69.1	1.20
N x P	26.3	2	13.15	1
K x P	74.0	2	37.0	1
N x K x P	61.6	4	15.4	1
Ca	175.8	1	175.8	2.95
N x Ca	36.0	2	18.0	1
K x Ca	210.3	2	105.15	1.77
N x K x Ca	226.4	4	56.6	1
P x Ca	0.0	1	0.00	..
N x P x Ca	108.6	2	54.3	1
K x P x Ca	56.6	2	28.3	1
N x K x P x Ca	50.6	4	12.65	1
Error	1843.0	31	59.45	..

*Significant at 5% level

**Significant at 1% level

APPENDIX VII

Oil yield (Second harvest)

(Analysis of variance)

Source	S.S.	D.F.	Variance	F.
Total	17615.06	71	..	..
Block	1967.20	5	393.44	3.72**
N	4328.50	2	2164.25	20.05**
K	1096.40	2	548.20	5.20*
NK	2795.00	2	1397.50	13.23**
NK^2	460.20	2	230.10	2.16
P	199.60	1	199.60	1.92
N x P	61.50	2	30.75	1
K x P	171.60	2	85.80	1
N x K x P	127.80	4	31.95	1
Ca	323.00	1	323.00	3.15
N x Ca	189.10	2	94.55	1
K x Ca	848.90	2	424.45	4.02*
N x K x Ca	596.80	4	149.20	1.32
P x Ca	261.90	1	261.90	2.51
N x P x Ca	15.00	2	7.50	1
K x P x Ca	468.90	2	234.45	2.22
N x K x P x Ca	428.40	4	107.10	1.01
Error	3275.20	31	105.65	..

*Significant at 5% level

**Significant at 1% level

APPENDIX VIII

Percentage recovery of oil (First harvest)

(Analysis of variance)

Source	S.S.	D.F.	Variance	F.
Total	43.40	71	..	..
Block	7.00	5	1.4	5.62*
N	0.50	2	0.25	1
K	0.90	2	0.45	1.80
NK	1.20	2	0.60	2.40
NK^2	4.50	2	2.25	8.99**
P	..	1	..	..
N x P	1.00	2	0.05	1
P x K	1.60	2	0.80	3.20
N x P x K	2.70	4	0.67	2.70
Ca	0.10	1	0.10	1
N x Ca	..	2	..	..
K x Ca	4.80	2	2.40	9.51**
N x K x Ca	4.60	4	1.15	4.60*
P x Ca	1.00	1	0.50	2.00
N x P x Ca	0.90	2	0.45	1.80
P x K x Ca	2.60	2	1.30	5.21
N x P x K x Ca	2.81	4	0.70	2.42
Error	7.81	31	2.51	--

*Significant at 5% level

**Significant at 1% level

APPENDIX IX

Percentage recovery of oil (Second harvest)

(Analysis of variance)

Source	S.S.	D.F.	Variance	F.
Total	23.80	71	..	..
Block	1.08	5	0.21	1
N	2.67	2	1.33	6.01**
K	1.91	2	0.95	4.32*
NK	1.64	2	0.82	3.73*
NK^2	1.22	2	0.61	2.77
P	0.00	1	..	..
N x P	2.23	2	1.11	5.05*
P x K	0.23	2	0.12	1
N x P x K	1.01	4	0.25	2.05
Ca	0.01	1	0.01	1
N x Ca	0.28	2	0.14	1
K x Ca	1.12	2	0.56	2.55
N x K x Ca	0.60	4	0.15	1
P x Ca	0.55	1	0.55	2.54
N x P x Ca	0.39	2	0.19	1.
P x K x Ca	0.27	2	0.13	1
N x P x K x Ca	1.85	4	0.46	2.10
Error	6.74	31	0.22	..

*Significant at 5% level

**Significant at 1% level

APPENDIX X

Alcohol percentage in the oil

(Analysis of variance)

Source	S.S.	D.F.	Variance	F.
Total	129.50	71	..	..
Block	16.50	5	3.30	2.60
N	23.30	2	11.65	8.48**
K	1.80	2	0.90	1
NK	4.50	2	2.25	1.70
NK^2	7.10	2	3.55	2.57
P	5.20	1	5.20	3.80
N x P	1.80	2	0.90	1
K x P	2.60	2	1.30	1
N x K x P	3.20	4	0.80	1
Ca	0.30	1	0.30	1
N x Ca	4.70	2	2 .35	2
K x Ca	0.00	2	..	..
N x K x Ca	3.40	4	0.85	1
P x Ca	0.30	1	0.30	1
N x P x Ca	0.90	2	0.45	1
K x P x Ca	3.20	2	1.60	2
N x K x P x Ca	8.00	4	2.00	2
Error	42.70	31	1.38	..

**Significant at 1% level

APPENDIX XI

Composition of the soils of the experimental area

Mechanical composition in percentage			Chemical composition in percentage		
Sand	..	20.82	Total nitrogen	..	0.04880
Fine sand	..	38.36	Total phosphoric acid	..	0.04200
Silt	..	7.31	Available phosphoric acid	..	0.0020
Clay	..	32.50	Total potash	..	0.0780
			Available potash	..	0.0009

PLATES

Plate I
A Citronella Grass

Plate II

A General view of the standing crop