DISCUSSION
Cyamopogon flexuosus (L.C.) Stapf, commonly known as East Indian lemongrass, yields an essential oil of commerce on steam distillation. The essential oil is a metabolic product and accumulates, comparatively in larger proportions in essential oil bearing plants whereas in some other plants, this accumulates as a minor metabolite (Loonis and Croteau, 1980).

In view of the wide internal usage, as well as export possibilities, the business potential of this oil in India has expanded to a large extent. Because of the recent availability of high citral containing lemongrass oil in some of the countries like Guatemala, West Indies, Brazil, Paraguay, Zaïre, Tanzania and Madagascar, the export of Indian lemongrass oil declined considerably for last few years, but the position has gradually improved due to the development of high citral yielding varieties of Cymbopogon flexuosus.

The use of citral as such in perfumery industry has started recently but its synthetic conversion to ionones, vitamin A and geraniol is quite old. The utilization of lemongrass oil in perfumery, cosmetics and pharmaceutical industries had been dealt with by Guenther
Although the lemongrass was known to be distilled in the Philippines during 17th century and it was also known in India since early times, but its systematic cultivation and distillation were started in Kerala only 85 years ago (Kair, 1977) and gradually it has assumed the status of a plantation crop like rubber, coffee, pepper, etc. Research on this crop has contributed to the high yielding varieties like SD-68 and 01-19.

Despite of better performance of SD-68 and 01-19, than that of CIM90, these two improved varieties as well as CIM90 suffered very seriously due to a leaf blight fungal disease at their preflowering stages which caused deterioration of health and vigour of the plant and ultimate loss in oil yields. The occurrence of this leaf blight due to Curvularia verruciformis Agarwal and Sahni on lemongrass as a new host was reported by Farua and Bordoloi (1983). Experimental findings indicated that out of all the organisms, encountered during isolation of diseased leaf tissues, Curvularia verruciformis the only pathogenic one, showing its predominance over the others during preflowering and flowering stages. However, intensity of the disease was higher on CIM90 than that of the two improved varieties.
The infection of leaves due to *Curvularia verruciformis* brings about changes in metabolic activities. It is well known that most of the pathogenic fungi produce toxic enzymes which kill the cell wall contents of the host plants. It is of primary interest to find out the nature and extent of production of cellulolytic and pectinolytic enzymes by the present *Curvularia* pathogen as there are reports that *Curvularia pallescens*, *Curvularia lunata*, *Curvularia clavata*, *Curvularia eragrostidis*, *Curvularia affinis* and *Curvularia inaequalis* secrete cellulolytic enzymes (Vidhyasekaran et al., 1966; Upsher, 1975) and pectinolytic enzymes (Vidhyasekaran et al., 1966). Experimental evidences indicate that these two enzymes of the present pathogen are responsible in cell wall break down. However, activity of the enzymes mostly depends on the period of incubation. The cellulolytic activity is more pronounced in a lesser incubation time, whereas pectinolytic enzyme needs longer incubation period. Such differences of enzyme activity in relation to incubation time for cellulolytic and pectinolytic enzymes were emphasised by Bateman (1964) and Ayers et al., (1969), respectively. However, a reduced cellulase and pectinolytic enzyme activity was observed in the enzyme extract of diseased leaves, and this reduced activity is possibly due to increased level of tannin, which prevents
enzyme activity of the host tissues (Farkas et al., 1962; Mahadevan et al., 1965; Rai et al., 1979). The present finding is in conformity with that of Deese and Stahman (1962).

Along with the process of infection, the observation on electrolyte leakage of the infected plant cells is of considerable importance (Luke et al., 1966; Goodman, 1972). Losses of electrolytes from the infected tissues, causes accumulation of nutrients in the infection sites and nutrient thus accumulated are utilized by the pathogens for their growth and initial colonization on the host tissues (Gardener et al., 1972; Dube, 1973, Roy, 1977)

The present findings revealed that Curvularia verruciformis also induces losses of electrolyte from the host tissues as a result of pathogenic actions. However, degree of leakage of electrolyte may vary from variety to variety as more of the electrolyte leakage for CIM 30 was recorded than that of improved varieties, i.e. SD- 68 and OI- 19.

The source of this pathogen might be air, soil and other infected host tissues as mainly the soil and the lower layers of the atmosphere were reported to be a common reservoir of microplankton of fungal spores and their distribution seemed to be governed by complex
Compared to the reports available on pathogenic behaviour of causal organisms, the relevant accounts on physiological factors of the host alone or host-pathogen interactions which control the pathogenicity are still lacking. Therefore, experiments were designed to determine the correlations of certain host metabolic factors of lemongrass with that of leaf blight disease. Since symptoms of disease are only the end products of altered metabolism of invaded tissues, so any such metabolic changes should normally have first repercussion on respiration of the host plants (Sadasivan, 1964). Plant "disease" was the result of disturbances in the host metabolism induced by diffusable metabolites of the parasite (Allen, 1953).

Growth behaviour of plant in general is known to be related with environmental factors, time of sowing or planting (Kanda, 1978). Likewise the good growth of lemongrass is very much associated with proper range of temperature (21.32 - 26.9°C) and rainfall (90.9 - 298.1 mm) as compared to the range of temperature 29°C - 25°C and rainfall 90.48 - 335 mm, when reduced growth rate was recorded. Further decrease of temperature (22.1 - 15.5°C) and rainfall (5.00 mm - 26.00 mm) associated with short
Photoperiod caused reduction in vegetative growth and the plants were stimulated for reproductive phase. The effect of humidity is not significant in the growth of lemongrass plant. On the other hand, growth activity is influenced by internal metabolic activities of the plant tissue system and is controlled by metabolic chain reactions that are triggered off by some internal factors (Wareing and Hillis, 1970). Wetmore and Steeves (1971), are also of the opinion that the physiology of growth and development is concerned primarily with metabolic activities of the protoplasm which underlie these phenomena and the factors, internal or external to the growing system, control the successive growth of the plant.

Metabolites of healthy lemongrass and their relationships with that of the oil yield and quality:

Experimental evidences indicate that carbohydrate like reducing sugar and non-reducing sugar metabolism in healthy lemongrass plant was increased gradually from the vegetative stage to preflowering stage and at flowering stage the concentration of carbohydrates decreased considerably. The fall of carbohydrate in flowering stage may be due to the ageing of the leaf, depletion of endogenous growth substances or possibly due to active synthesis of essential oils in the leaf tissues. It is quite possible that some of the carbohydrates are
utilised in cellular metabolism during anthesis.

The initiation of flowering stages was found to be related with metabolic drifts and flower inducing hormones are known to be related with high carbohydrate content of the plant before flowering. Such cases of carbohydrate increase from one stage to the other and then gradual fall at flowering of respective plants were recorded by Ito and Saito, (1961); Chinoy and Mansuri, (1965); Devlin (1970); Mitchell, (1970) Randhawa and Singh, (1972); Singh et al., (1973); Säimbhi and Nandanuri (1981).

Carbohydrate synthesis in leaves depends upon chlorophyll content. The present findings indicate that during vegetative stage chlorophyll content was higher than the subsequent stages. But carbohydrate content was not proportional to the chlorophyll content. Although SB-68 recorded higher carbohydrate content during vegetative stage, the other two varieties exhibited higher concentration of it during preflowering stage.

This is in agreement with those of Gabrielsen, (1948) Broughman (1960), Nieman (1962), and Hedge (1974) who observed that the increase in chlorophyll content does not necessarily contribute to the higher photosynthetic rate. That carbohydrates are the vital factors as
the prime sources of energy for growth and starting
material for other metabolic processes of plants have been
elaborated by Hanson and Edelman (1972) and Hildebrandt

Analysis of carotene in healthy tissues reveals
that, the concentration of carotenoids gradually decreased
from vegetative stage to flowering stage. It seems that
along with the decrease of chlorophyll a and b, the synthe­
sis of carotenoids were also decreased. Chlorophylls do not
increase above a particular level and also it is protected
from photooxidation by the carotenoids present in the leaf
Devlin (1975), Goldberg (1970), Baker (1973), Lewandowska
and Jarvis (1977). This decrease of carotene in lemongrass
leaves may also be due to environmental factors as sugges­
ted by Horvath and Daniel (1972).

Leaf proteins are enzymatic in nature and is in a
continuous state of flux between synthesis and degradation.
Protein synthesis occurs most vigorously in young leaves
than in older leaves (Devlin, 1975). High protein metaboli­
sm in non essential oil bearing plants like barley is
known to be linked with initiation of reproductive growth
of the plants (Chinoy and Mansuri, 1965). In lemongrass
protein metabolism was higher in vegetative stage which
decreased in subsequent stages. Higher amount of protein
metabolism during this vegetative stage might be due to greater demand of protein for enhanced growth rate.

Working on palmarosa and lemongrass, Ghosh and Chatterjee (1976) recorded such reduction of protein content at preflowering stage of respective plants and they were of the opinion that decomposition of protein provides necessary substrates for synthesis of respective essential oils. The low amount of protein which was observed in preflowering stage or flowering stage of the plant was possibly due to the utilization of it during reproductive growth stage or due to declining ability of the leaves for synthesis of new protein (Chinoy and Mansuri, 1965).

Ascorbic acid is considered to be an important metabolite for regulating growth and development in plants together with other metabolites. In lemongrass high ascorbic acid in vegetative stage is due to high amount of chlorophyll in the leaves, as ascorbic acid metabolism is known to be linked with high amount of chlorophyll (Isherwood and Manson, 1962). In the non essential oil bearing plants like barley, wheat and oats the ascorbic acid activity is known to be linked with transformation of vegetative stage to reproductive stage (Chinoy and Mansuri, 1965). In the present finding it was observed
that ascorbic acid level was highest during the vegetative stage and then declined in the preflowering and flowering stages. Although in non essential oil bearing plants its prime role in induction of flowering has been implicated, (Chinoy and Mansuri, 1965; Nanda and Tayal, 1976), its involvement in other physiological and biochemical processes can not be ruled out. It is possible that ascorbic acid has been diverted to play a role in the synthesis of essential oil in lemongrass.

Peroxidase enzyme activity of lemongrass increased from vegetative to preflowering stage and then declined in mature leaf stage. It was further observed that high peroxidase enzyme activity at preflowering stage of lemongrass was linked with high sugar containing stage at plants maturity except in SE- 08. A high quantity of peroxidase enzyme at the transformation stage from vegetative to reproductive stage was observed in oat by Srinivason and Rao (1971) and Vora and Vyas (1971), Vora(1978). Working on muskmelon Salimbhi and Mandapuri (1981) observed the increased level of peroxidase with that of the increased level of carbohydrate at the transformation of vegetative stage to reproductive stage. The above observations are almost in parallel with that of the peroxidase activity of lemongrass.
A high concentration of phenolic compounds is known to retard the plant growth process (Marigo and Alain, 1975). The tannin contents in lemongrass gradually decrease from early stages of growth towards maturity. The decrease of such phenolic compounds might help the plant in the initiation of the reproductive stage, by modifying the indole acetic acid (IAA) oxidase (Singh et al., 1980). On the other hand, phenols are known to inhibit the IAA-oxidase stimulation and therefore drop in the level of phenol with advancing age of the plant might help the IAA-oxidase for degradation of IAA. This manifests in reduced vegetative growth and onset of flowering stage.

Besides, tannins are also known as G_{A_3}-antagonists (Nanda, 1978) and therefore, gradual fall in tannin content might induce synthesis of G_{A_3} resulting in the stimulation of reproductive growth. The present finding of decrease tannin content towards leaf maturity is very much similar to that of the observations recorded on banana leaves (Haghunathan et al., 1966) and cotton (Imrailiev and Muritdinova, 1975).

The relationships between essential oil and metabolic constituents in lemongrass appear to be linked with sugars, protein, and peroxidase enzyme. Burbott and Loomis (1967) in their study with peppermint observed that carbohydrate level might serve as substrate for essential
oil metabolism. The essential oil are produced in special types of cells or glands and the oxidation-reduction state of these cells depend upon the carbohydrate level of the cells. They observed that, high quantity of sucrose maintains the reducing conditions in the oil glands. The reduction of protein content during maximum oil formation stage was also observed by Ghosh and Chatterjee (1976) in lemongrass and in palmarosa. Loomis et al. (1979) observed that such secondary plant metabolites are closely associated with protein constituent of the tissues. Loomis and Croteau (1980) opined that although nothing is known about such monoterpene metabolism it is likely that sugars and proteins might be the primary metabolites linked with monoterpene metabolism.

In this present investigation, the high quantity of sugar at highest oil formation stage and reduced protein content is in conformity to that observed by Burbott and Loomis (1967) and Ghosh and Chatterjee (1976). The accumulation of essential oil at different stages of growth with maximum concentration at the preflowering stage have been reported on several essential oil bearing plants, e.g. on Mentha (Batta, 1966), palmarosa (Virmani and Dutta, 1969), Hysson (Khodzhimatov et al., 1976), Japanese mint (Singh and Garg, 1976), and palmarosa (Hazarika et al., 1978), and is similar to the present investigation.
The oil and citral content depend upon seasonal and environmental factors (Burbott and Loomis, 1967; Von Rudlof, 1969; Shahi et al. (1981), on the enzyme system which depends upon the maturity of plants (Croteau and Hooper, 1978) and growth and differentiation balance (Loomis and Croteau, 1980). In lemongrass, it is observed that, high amount of oil containing stage (preflowering stage) was accompanied by low amount of citral or low amount of citral was attended with high amount of oil. This observation is in agreement to that of Croteau and Hooper (1978) in peppermint where accumulation of menthol was accompanied by depletion of oil content. Recently Tyagi et al. (1983) have reported similar findings in Mentha arvensis where increase in oil content was accompanied by decrease in menthol content.

Metabolites in relation to disease and their relationships on yield and quality of oil:

A comparative study on healthy and diseased tissues reveals that sugars, chlorophyll (a+b), carotene, protein, ascorbic acid, are reduced while peroxidase enzyme activity and tannin contents are increased in case of diseased tissues. Since fungal attack causes a shift in metabolic activities hence perhaps the most metabolites are altered.
Chlorophyll breakdown may be the initial step for infection and subsequent establishment of the parasite (Allen, 1942). According to Goodman et al. (1967) the chlorophyll molecule disintegrates and as the chlorophylls are destroyed and further synthesis is inhibited, therefore, the synthesis of sugars is very much disturbed. Further, it has been observed that in infected lemongrass leaf, carotene content is greatly reduced. Such observation were also made other plants infected by other pathogens (Reutskaya 1967; Ver and Main 1970).

The pathogen, however, for its nourishment, growth and development utilizes the host sugar, the basic material for the growth of the pathogen (Wood, 1967). The low quantity of sugar in diseased condition may be for reduced quantity of chlorophyll and utilization of sugar by the pathogen. Curvularia trifolii (Anwar, 1972), Curvularia pallescens (Bais et al., 1976), Curvularia affinis, Curvularia lunata, Curvularia clavata, Curvularia pallescens, Curvularia prasadii, Curvularia senegalensis (Upsher, 1975) are known to utilize sugars for their growth and development. It appears that Curvularia verruciformis like other species utilizes the sugars for its growth and development and thereby the host sugars are depleted. On the otherhand the increase in tannin content following infection is likely
due to rapid utilization of sugars for synthesis of tannin (Uritani, 1963; Singh and Badi, 1976). Such increased phenolic reactions on infected tissues have been reported by Mata et al. (1969); Chinnadurai (1970); Urohit et al. (1979); Thite et al. (1980).

Considering the relationships between synthesis of ascorbic acid and chlorophyll (Isherwood and Mapson, 1962) it is observed that along with low content of chlorophyll, the synthesis of ascorbic acid is also reduced. Several fungal plant parasites are known to utilize ascorbic acid for their growth and development. Such observations were also recorded on infected safflower leaves (Tasad and Daftari, 1976), on papaya fruits (Tasad and Verma, 1976), on infected sweet potato (Thomson, 1979). The present finding substantiates the above findings.

The reduced quantity of protein in infected leaves of lemongrass might be due to degradation of protein by the pathogen. The species like Curvularia ovoidea and Curvularia lunata utilize the nitrogen for their growth (Singh, 1976). Singh (1976) observed utilization of nitrogen by Curvularia ovoidea and Curvularia lunata from capsicum and mango. The protein content in infected lemongrass leaves was possibly reduced as Curvularia verruciformis utilized it as a source of nitrogen. Further,
degradation of protein might occur due to increased synthesis of tannin, because synthesis of polyphenols is closely linked with protein synthesis (Hanson and Zucker, 1963). A reduced quantity of protein is also observed by Johnson et al. (1968) in rust infected wheat leaves. The amino acid phenylalanine which is a constituent of protein, is known to be depleted in ground nut infected by Cercospora arachidicola (Aulakh and Sandhu, 1970). The reduced quantity of protein following infection might be due to increased synthesis of peroxidase enzyme. However, increased peroxidase activity on the other hand, is connected with breakdown of cellular protein (Farkas and Stahmann, 1966), which is similar with that of the present investigation in case of essential oil yielding lemongrass varieties. Such increase of peroxidase enzyme activity on infected tissues was also reported in cabbage (Heitfuss et al. 1960), maize (Jennings et al. 1969) and barley (Hislop and Stahmann, 1970).

Increase of respiration in the disease infected tissues may be due to formation of toxins produced by the pathogen which uncouples phosphorylation from electron transferring host cells (Sadasivan, 1964). Such was the observation recorded in case of lemongrass leaf blight respiration. Various records on increased respiration due to fungal attack are available e.g. in cotton plants infected by Fusarium vasinfectum (Lakshmanan, 1959), in wheat
infected by *Puccinia graminis* (Samborski and Shaw, 1956), in ragi plant and in *earlmillet* infected by *Sclerospora graminicola* and *Helminthosporium nodulosum* (Garg and Mandalhar, 1975; Vidhyasekaran, 1975) respectively.

High transpirational loss of water due to loss of cuticle was noted (Subramanian and Saraswati Devi, 1959; Daly, 1976; Ayors, 1978). Nutrients absorbed by the plant or accumulated in plant tissues are related to synthesis of metabolic products of plant tissues. Alteration of metabolic products due to loss of water and fungal infections changes the status of nutrients of the host (Milikan, 1966; Daly, 1976; Ahmed, 1982).

In the present observations the nutrients like nitrogen, phosphorous, potash and magnesium were reduced considerably affecting the host metabolic activity during disease development. Because of the reduction of supply of nitrogen, phosphorous, potash and magnesium, photosynthesis is greatly reduced as these factors are necessary for proper photosynthetic activity. The inadequate supply of these nutrients particularly nitrogen and magnesium causes the chlorophyll pigment ineffective for photosynthesis. Under deficit water conditions metabolic reactions are greatly altered and sugar, chlorophyll and protein contents are degraded (Mitchell, 1970). The reduction of nitrogen and
Phosphorous in the diseased tissues of lemongrass may be due to utilization of these nutrients by the pathogen. The utilization of these nutrients by *Curvularia ovoidea* and *Curvularia lunata* for their growth was reported (Singh, 1969; 1976). Similarly, the reduction of phosphorous and potash in brinjal plants infected by *Verticillium dahliae* and in coriander leaves infected by *Fusarium macrospororum* was reported by Sivaprakasam et al. (1974) and Gupta (1975).

Although nutrients like calcium and silica are studied in diseased lemongrass tissues to correlate their status with that of the other metabolites, it is however not yet known clearly their role in the host tissue metabolism. However, they are known to favour disease resistance (Corden, 1965; Moore and Cunch, 1968; Tasugi and Yoshida, 1958; and Tanaka and arak, 1960).

The reduced amount of oil in diseased leaves appears to be due to reduction in the vital metabolites like sugars, chlorophylls, protein and ascorbic acid level of the host. The destruction of the oil producing cells or reduced supply of oil producing substrate to secretary tissues may cause reduced synthesis of oil. On analysis of major host substrates responsible for yield performance of oil, it has been observed that carbohydrates particularly...
glucose, mannose and sucrose are the probable factors which accelerate disease infection and resulted on the total yield of oil. This finding substantiates that of Burbott and Loomis (1967) who envisaged sucrose as one of the major substrate for synthesis of essential oil. The reduction in the amount of different types of sugars in infected leaves may be due to reduced photosynthetic activity on one hand and rapid breakdown of the same due to host-parasite interactions on the other. Glucose, mannose and sucrose were present in healthy leaf tissues, whereas glucose and mannose were absent in infected leaf tissues. Thereby establishing that the former two were completely consumed and the latter one was only partially utilized by the pathogen for its growth and metabolism.

Sugars play a significant role on accumulation of secondary metabolites and at the same time the pathogen after complete utilization of carbon sources derives its energy requirement from the proteins and ascorbic acid is evident from the gradual loss of these substrates in the infected tissues of lemongrass. Further experiments conducted on growth and germination of conidia in presence of sugars indicated differential germination percentage and preferential utilization of simple sugars (Sridhar, 1972). The loss of essential oil and its chief constituent due to disease is in conformity to that reported by Goto (1968).

Metabolic constituents, oil and quality in relation to environmental factors:

Studies on various metabolic constituents together with essential oil and citral in different seasons of the year, revealed that environmental factors play significant role on metabolic activities of plants resulting in variations in oil and citral content. It has been observed that moderate temperature (21.31 - 26.9°C) and rainfall (90.9 - 298.1 mm) are favourable for synthesis of photosynthetic pigments, ascorbic acid, protein and tannin, while a temperature range of 24.95 - 22.1°C and rainfall 94.8 - 5.0mm are favourable for formation of sugars, peroxidase enzymes and essential oil. However, with further fall of temperature the metabolic activities were also reduced.

It has been observed that in lemongrass the growth and metabolic activities were closely related with photo-period, temperature and rainfall. Similar effects of environmental factors on lemongrass was also recorded by
Shahi et al. (1982) and thus lends support to the present investigation.

In lemon grass flowering primordia appear with the onset of short photoperiods i.e. from October onwards when the day length began to decline. The differences in the day length, temperature and rainfall have remarkable effect on the growth rate. Ultimately physiological behaviour is reflected by the various metabolic constituents of the plant.

During the initiation of flowering stage complex physiological changes take place and is strictly controlled by day length (Singh and Garg, 1976). The increase in essential oil and decrease in menthol content at the preflowering stage have been reported by Croteau and Hooper (1978) in peppermint and Tyagi et al. (1983) in Mentha arvensis. The increased amount of oil during preflowering stage is possibly due to favourable weather conditions for rapid synthesis and utilization of metabolites for synthesis of oil (Burlott and Comis, 1967; Singh and Garg, 1976; Ghosh and Chatterjee, 1976).

The fall of carbohydrate levels during flowering stage (i.e. under short photoperiods) may be due to the fact that shorter photoperiods provided lesser opportunities for photosynthesis and thereby disturbed the
physiological balance necessary for optimum vegetative growth (Sinha and Garg, 1976).

In addition to shorter photoperiods the low atmospheric temperature (10.6 - 20.4°C) pushes the crop towards dormancy and thereby normal physiological balance is further disturbed and due to disturbed photosynthesis low amount of oil was produced in flowering or slow growth stage. The present finding is in conformity to that observed by Shahi and Singh, 1981).

It thus appears that although a large variety of metabolic constituents are available in the host tissues, all of them are not important from view point of disease development and yield and quality of the oil. However, there may be some other metabolites like glucose, mannose, sucrose and amino acids which may be more potent for yield of oil and alteration of its quality. Hence, to explore more about the physiological basis of oil yield, its quality and due to host-parasite metabolic interaction, needs further investigation to elucidate other factors concerned on this aspect.