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Medicinal and Aromatic Plant Series, No. 8

CITRONELLA

(*Cymbopogon nardus*)

Information Services Centre
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(Successor to CISIR)
Colombo, Sri Lanka

Medicinal and Aromatic Plant Series, No. 8

Citronella

- a literature survey -

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1.0 INTRODUCTION

Citronella is a kind of a grass with narrow, long leaves. It is an economically valuable herb as it produces a very important natural essential oil named citronella oil. The main constituents of this essential oil, citronellal, citronellol and geraniol are widely used in soap, perfumery, cosmetic and flavouring industries throughout the world.

Citronella oil is classified in trade into two types – Ceylon citronella oil, obtained from *Cymbopogon nardus* Rendle, and the Java type citronella oil obtained from *Cymbopogon winterianus* Jowitt. Java citronella is considered to be superior to Ceylon citronella. Both of these have probably originated from Mana Grass of Sri Lanka, which according to Finnemore (1962) occurs today in two wild forms – *Cymbopogon nardus var. linnaei* (typicus) and *Cymbopogon nardus var. confertiflorus*. Both of these forms are not known to be used for distillation to any appreciable extent. The Java citronella, which is called 'Maha Pangeri' in Sri Lanka is the result of selection from the Ceylon citronella. The name *Cymbopogen winterianus* is given to commemorate Mr. Winter an important citronella oil distiller of Sri Lanka, who first cultivated and distilled Maha Pangeri type of citronella in Sri Lanka.

Cymbopogen nardus Rendle, which is called 'Heen Pageri' or 'Lena batu' is Sri Lanka, is the source of Ceylon citronella oil. It is widely grown in Sri Lanka due to its drought resistant and hardy qualities, which makes it ideal for the climate in the Hambantota District.

2.0 HISTORY

Citronella is one of the oldest industrial crops in Sri Lanka. Two Dutch surgeons Paul Hermann and Nichola Grim introduced it to this country in the 17th century. In the early 18th century the first shipment of 'Oleum Siree' was sent to England and in 1851 and 1855 samples of the oil were displayed at the world fairs in London. In 1885, Lenabatu was first discovered in Matara and five years later in 1890, a primitive still which was being used for distilling the wild grass in Java was discovered by A.K.J. Happer. He later grew Java citronella on an experimental scale, in his fields. At this time Sri Lanka was the sole exporter for citronella and had about 50,000 acres of citronella in the Southern province of Sri Lanka.

Maha pengiri was introduced to Java from Sri Lanka in 1899. Subsequently Java replaced Sri Lanka as the major producer of citronella to the world.

In 1901, citronella was replaced by tea at Akuressa and Baddegama in Sri Lanka. Although the first experiments with the systematic botanist, Simpson, started citronella, in 1936, in Sri Lanka, the citronella industry started to drop. In 1959, with establishment of the Coconut Cultivation Board and the lower price quoting from the traders to the farmers, gradually drop in citronella cultivation was seen. By late 1960's nearly 20,000 acres of citronella were replaced by coconut and other cultivation.

Citronella cultivation went down drastically during last four decades mainly due to the price instability. There were numerous malpractices in the testing and grading of oil at the dealer's collection centres whereby good quality oil was sometimes declared as the small farmers was the method of buying the oil by the dealers. The unit of payment to the farmer was on a "per bottle – containing 24 ounces of oil" basis.

As mentioned above, a few private dealers dominated the whole marketing structure in the absence of government institutions for purchasing citronella oil. This made unsatisfied farmers give up citronella plantation and start on new sources of revenue.

The other main problem the farmers were facing was, the difficulty in renovating or repairing their units due to high cost of spare parts.

In 1972 after the formation of Department of Minor Export Crops, special attention was given to citronella. From 1978 onwards loans were given to the farmers to replant citronella and to repair the distilleries that are not in a working condition.

3.0 BOTANY [24,27,44,52,98,102]

3.1 TAXONOMY

The genus *Cymbopogon* comprises about 140 species. The grasses, many of which have a pleasant aroma, yield essential oils, which are of commercial importance. Formerly, *Cymbopogon* was classified as a sub-genus of *Andropogon*, but today, it is considered as a separate genus.

Family : Graminae
Genus : *Cymbopogon*
Species : *nardus*
winterianus

Other Names :

Cymbopogon nardus

Sinhala	:	Lenabatu, Heenpengiri
Tamil	:	Vaanaipul, Kamachipillu
English	:	Citronella
Sanskrit	:	Guchcha

3.2 PLANT DESCRIPTION

Cymbopogon nardus:
This is said to be a hybrid of *Cymbopogon winterianus* and *Cymbopogon confertiflorus*. It is a perennial herb, up to about 2-2.5m high, with rhizome, whitish, sometimes tinged with purplish red, nodes often swollen, tips drooping.

Leaf sheath glabrous, often auricled; basal sheath purplish red outside. Leaf blades up to 1m long, 5-20 mm wide, the upper smaller, edges and surface rough, glabrous except near the base.

Spathate panicle decompound, internode up to 1 mm long, ultimate branches slender, zig-zag. Racemes 15-17 mm long. Sessile spikelets 4-4.5 mm long. Lower glume glabrous, flat, acuminate, narrowly winged on the keels towards the back. Wings minutely toothed, 2-4 nerved between keels; edges narrowly inflexed throughout.

Upper glume boat shaped, one-nerved, keel toothed towards back, lower lemma. 3mm long, thin, fringed, nerveless, upper lemma shorter, thin, fringed, apex shorter, bilobed with bristiles in the notch. Anthers 1-4 mm long, pedicelled spikelets smaller to slightly smaller; upper floret male without lemme.

Cymbopogon winterianus
A tufted, aromatic, perennial herb over 2 m in height. Leaf blades up to 1m long, 10-50 m wide, usually light green, glabrous, smooth on the upper surface, slightly rough below and along margins, leaf sheath glabrous, yellowish green, basal sheath glabrous, green to reddish. Inflorescence a very large 30cm long decompounded panicle, racemes 20 mm long; one sessile or short and the other longer-pedicelled with two lower spikelits.

Cymbopogon confertiflorus:
This grass is said to be the parent plant of the citronella species. The leaves and stems are similar to those of *Cymbopogon nardus*, but the plants are larger.

4.0 HABITAT

Cymbopogon nardus
It is found mainly in Sri Lanka. In India it has been grown on an experimental basis. It also grows in Seychelles.

Cymbopogon winterianus
It is found mainly in Indonesia, Taiwan and Guatemala, also found to a small extent in Sri Lanka, East and Central regions of Africa, Argentina, Brazil, Burma, China, Comoros, Dominican Republic, Ecuador, El Salvador, Fiji, Haiti, Honduras, India, Leeward Islands, Madagascar, Malaysia, Mexico, Nicaragua, Philippines, Seychelles, Tanzania, West Indies and Zaire.

Cymbopogon confertiflorus
Occurs wild in Sri Lanka. Also found in South India.

5.0 AGRONOMY [17,18,24,27,52,55,93,94,97,102]

5.1 SOIL AND CLIMATE

Cymbopogon nardus
A hardy plant, which requires little care and not much moisture. It can be grown on any soil with an altitude below 610 m. In Sri Lanka, it is usually grown on infertile poor soils in coastal regions. It is sometimes planted on slopes on hills, to prevent soil erosion. Requires a hot, moist climate and a rainfall of 1.5 – 1.8 m per year.

Cymbopogon winterianus:
The plant grows well under varying soil conditions. Rich sandy loam soil is most preferable. It grows well at the altitudes between 1000 m and 1500 m, but an altitude of 180-215 m is the optimum. The plant grows well under wide range of pH, acidic (5.8) to slightly alkaline (8.0). However pH 6.0 is optimum for this crop. The plant is very sensitive to water logging which should be avoided to obtain maximum growth.

When calcerous soils containing a thin layer of sand were used, good yields of grass and oil were obtained at first, but when the roots reached the lime sub-soil, the citronella content of the leaves decreased.

Requires a warm climate, with plenty of sunlight. When grown in the shade, fewer shoots and growth was retarded, and the leaf blades often became hard and woody. It was also found that oil yields and total geraniol content of grass grown in the shade, were low. High atmospheric humidity (73-90%) is more favourable to crop growth than high soil moisture and also well distributed rainfall of approximately 200-250 cm.

5.2 PREPARATION OF LAND [17,18,24,52,55,94,102] :

The soil is prepared by burning old grass and weeds followed by ploughing, harrowing and planking twice. In areas where soil insects are a problem endrin or heptachlor (5% dust) at the rate of 50kg per ha. should be applied at the time of last harrowing to protect against soil-borne insect pests.

Although the planting can be started any time during the year, it is ideal to plant in Yala and Maha seasons with the rain.

Planting material consists of stools of fully-grown healthy plants. Each stool should contain at least 1-3 tillers. The fibrous roots and leaves are trimmed off the stools before planting. If the planting is delayed, the stools may partially dry up which will result in poor plant population.

The stools are planted vertically, about 10cm deep, and at a distance of 60 cm in rows, spaced 60 cm apart. However in areas where the soil is fertile and the climate conditions support luxurious growth, a spacing of 90x 90cm may be kept. In general there can be 35,000 stools per hectare of land.

5.3 FERTILIZER [12,13,15,17,18,15,24,226,27,52,55,78,80,84,87,94,100,102] :

Green manuring is considered beneficial to the crop. Since the plant is soil exhausting, liberal use of chemical fertilizers is recommended. The fertilizer requirements will vary according to the level of soil fertility. The results of most fertilizer trials in the literature suggest that the crop responds well to N application, particularly during the early years.

A good crop of citronella requires N-P-K mixture of 125kg N; 62kg P_2O_5 and 50 kg K_2O per hectare per year. N is applied in 4 or 6 equal split doses but the entire quantity of P_2O_5 and K_2O may be applied at the time of planting as basal dose. In recent studies, it has shown that 4 split dose application of K_2O has better results than basal application. Foliar application of a solution of urea (1%) at fortnightly intervals throughout the growth of the plant is recommended. Urea supergranules increase the herb yield by 25% over the prilled urea. In many cases, both herbage yield and oil yield increased with increasing N.

The effect of phosphorus and potash on yield is not appreciable, although phosphorus appears to influence fillering. Too much application of N increases the green matter but reduces the oil content.

The residue grass (spent grass) left after distillation of the oil or the ash from spent grass which had been used as a fuel, is applied twice a year, between bushes, as a green manure. Plants that had been used as green manure for the Java citronella include: *Tephrosia vogelii*, *Tephrosia candida*, *Crotolaria* and *Mimosa* species. These were applied after 5 years, in order to regenerate the soil. Farmyard manure has also been used.

The micro-nutrients such as Cu, B, Fe, Zn, Mn also has a effect on herbage yield and on diseases.

Fertilizer recommendations in the literature, are summerised below:

Sri Lanka:

Mixture	:	Grass mixture 17:11:14 ($N:P_2O_5:K_2O$)
Dose	:	750 kg/ha
Nutrients	:	128 kg N/ha
		83 kg P_2O_5/ha
		105 kg K_2O/ha

Rate of application : kg/ha

	Yala	Maha
1st year	190	190
2nd year and later	375	375

India:

Bangalore:

Nutrients:	450kg N/ha
	100kg P_2O_5/ha
	125kg K_2O/ha

Rate of application : six split doses on a 3 year's rotation.

North Bengal	N	-	200kg/ha/year
	P_2O_5	-	25kg/ha/year
	K_2O	-	60kg/ha/year
Assam	N	-	200kg/ha/year
	P_2O_5	-	80kg/ha/year
Jammu	N	–	250-340kg/ha/year, applied in 3 to 5 split doses

5.4 WEEDING [17,24,26,27,52,55,63,76,79,94-96,102]

The citronella plantation should be kept weed-free. When the plants have established themselves and formed bushes, the problem is not so severe because of the very nature of growth of the bushes. However, in the newly established plantations and after each harvest, the weeds grow in the inter-row spaces and weeding becomes essential. To keep the land free from weeds for the first 60 days is very important. This enhances tillering and leaf-growth. Weeding should be done two-four times during the first year and there after once a year, after each harvest.

In a recent research carried out at CIMAP Regional Centre, Hyderabad, India have showed that hand weeding, mulching with spent grass (5.0 t/ha), close spacing (30 cm x

30 cm) and preplanting application of herbicides like atrazine (1.0 kg a.i./ha) fluchloralin (0.7 kg a.i./ha) and butachlor (1.0 kg a.i./ha) produced higher biomass, essential oil yields and essential oil content in citronella in comparison to unweeded control.

Effective control of weeds after 45 days of application of 2,4-D with cane sugar (1.5%) controls *Cyperus rotundus* successfully. But 2,4-D sodium salt lowered the yields and essential oil content.

Application of Diuron and Simazine (2kg a.i/ha) have been observed to control the weeds.

5.5 IRRIGATION [17,24,27,55,94]

The plant requires adequate moisture for good growth and yield of leaves. In the areas where annual rainfall is about 200-250cm, well distributed over the year and the humidity is high, supplemental irrigation is not necessary. In the drier months, however, the irrigation may be provided and this increases the yield.

5.6 DISEASES AND PESTS [1,4,21,22,26,27,42,43,52,59,71,75,94,102]

Leaf blight disease:
The fungi, *Curvularia andropogonis* (Zimm) Boedijin, cause this disease. It appears in the form of small brownish spots, which enlarge into long patches along the tips and margins of the leaves. The yellowing leaves then starts leading to complete drying of leaves. As a result of this infection, there is considerable decrease in leaf and oil production. This can be controlled by prophylactic spraying of any dithiocarbamates, namely, mancozels and zinab at an interval of 10-15 days during the growing period.

Recently, in India, three leaf spots (Purple, Grey & Brown) were observed on *Cymbopogon winterianus* at various cultivation centres. Eleven fungi were found to be associated with these spots, viz. *Colletotrichum graminicola, Periconia byssoides, Spegazznia tessarthra, Curvularia andropogonis, Alternaria alternata, Cladosporium herbarum, Gyrothrix podosperma, Arthrobotyrum cymbopogonis, Monochaetiella cymbopogonis, Drechslera sacchari* and *Tetraploa aristata*.

Collar rot and wilt disease:
This was found is commercial plantations of Java citronella in India, Patnagar and the adjoining areas in Uttar Pradesh, in 1992-1993. The causal organism was identified as *F. moniliforme* (*Gibberalla fujikuroi*)

In the northern part of India, *P. aphanidermatum* was a predominant fungus recovered from roots of *Cymbopogon winterianus*, showing lethal yellowing. This disease occurred most frequently between July and October. Roots of infected plants showed marked discolouration and sloughed from the vascular tissue. Diseased plants were chlorotic and stunted. Rotting was often found to spread from roots to stem, leading to severe chlorosis and death of the infected plants.

Anthracnose:
This disease occurs generally in South India and is caused by the fungus *Colletotrichum graminicola*. The symptoms consist of brownish spots, which enlarge

with age during monsoon. The spots are dotted with fruiting bodies of the fungus. The disease can be controlled by application of Dithiocarbamate.

Yellowing and Crinkling of leaves:
The leaves of the plant crinkle and turn yellow in some stage of growth. The winter months (Dec.-Jan.) are more congenial for this abnormality. The cause is unknown but certainly it is related with the nutritional imbalance in the plants ontogenetic development. It is noted that oil yields are drastically lowered in yellow crinkled leaves. Folier feeding with area (1%) and magnesium sulphate (0.5%) eliminates yellowing and crinkling.

Chlorosis:
The chlorosis in Java citronella grass was caused by trace element deficiencies in soil, especially, those of Fe and Zn. A probability also exists that chlorosis maybe caused by S and other element deficiencies. Two or three foliar sprays of a mixture of these micro-nutrients at fortnightly intervals is recommended to combat that deficiency.

Insect Pests:
Cock-chaffer grubs, termites and white ants cause damage to the plant during June-November. The attack is more pronounced in the lighter type of soil compared to heavier type of soil. This is possibly due to less compactness more aeration and less water holding capacity in lighter type as compared to heavier type of soil. The roots were attached first which results in yellowing of leaves and death of plants.

Heavy infestation of citronella plants due to stem and shoot bores has also been observed causing about 20% damage from 2nd year onwards. This can be controlled by spraying `follidol' at 0.02% concentration, soon after harvest.

The pysalid, *Stemmatophora fuscibasalis* was recorded damaging the aromatic perennial herb, citronella in Andhra Pradesh, India for the first time in 1990.

5.7 HARVESTING AND YIELD [17,18,24,26,47,50,52,55,85,86,93,102]

Usually the crop is ready for harvest after 6-8 months of planting. Subsequent harvestings can be done at an interval of 90-120 days. The numbers of harvest, however, depend upon the growth of plants. Harvesting can be done 3-4 times a year under favourable conditions. The best time of harvest appears to be that when the stem bears 6 adult leaves, with the 7th leaf in a rolled up position. Harvesting too early or too late has an adverse effect on the quality of the oil. Only leaf blades are cut leaving behind 15-20cm of the sheath. It is usually harvested early in the morning. The plants should not be cut during rains. Once it is harvested it is allowed to dry in the field for a day or two. The dry leaves are removed with the hand or fork at the time of each harvest.

The leaf-blade excluding the leaf sheath is the only portion of plant that yields oil of standard quality. Other than the leaf-blade, the different parts of the plants are deficient in citronella and geraniol, although the content of citronella is higher in infloresence and leaf-sheath.

The yield of herbage and the oil varies with the season, fertility of the soil and method of distillation. Under favourable conditions, fresh herbage yields up to 10-12 tonnes/ha in first year and about 15-20 tonnes/ha for next seven years. Thereafter yield starts to decrease.

On an average, the oil content is 1% (fresh weight basis).

In Sri Lanka an annual yield of 10 tonnes/ha/year is obtained.

Post-harvest handling [18,52,77]

The chemicals in most of the essential oils are volatile and also prone to chemical transformations. Improper post-harvest handling will not only cause losses of these valuable chemicals but may give rise to undesired compounds.

The leaves should be spread out and dried in the shade. Direct drying in the hot sun should be avoided as far as possible. The period of drying depends on the sunshine and atmospheric conditions.It has been reported that the best oil is obtained from grass dried in the shade for 24 hours. During wet weather, the grass is dried on racks under shelter and turned frequently to prevent fermentation and mould formation, which will effect the quality of the oil.

After drying, dry leaves and foreign matter such as soil are removed and the grass tied into bundles of about 22 kg each.

6.0 PROCESSING

6.1 PRIMARY PROCESSING OF LEAVES [29,52]

Primary processing involves a wilting or drying operation. Drying of some form is necessary to lower the water content and to increase diffusibility constituents of the oil. Citronella leaves, which have terpene oils needs only 24-36h, wilting. At this time moisture content is 30-40%.

In distillation, insufficiently dried leaves leads to a low rate of oil recovery and smaller quantities of oil per distillation, although oil recovered, on dry basis, may be slightly greater.

6.2 DISTILLATION [17,18,19,24,27,30,52,57,76-78,95,101]

Essential oils are mixtures of volatile liquid (and solid) compounds, which vary widely in regard to chemical composition and boiling point. Every substance possesses a definite vapour pressure, at a given temperature which depends upon the prevailing temperature.

Two methods are used for the distillation of the essential oil from the grass. These are (a) water and steam distillation, where the plant material is supported on a grid, above boiling water, and (b) steam distillation, where the steam is passed over the plant material which is supported on a grid. The former involves direct heating of the still, while in the latter, the steam is generated in a boiler, away from the still. Higher yields have been obtained using steam distillation.

There are different types of distillation units used for the field distillation of essential oils in Sri Lanka. The most common type used for distillation of citronella oil is traditional type C. These stills are used in the region from Galle to Hambantota.

The boiler is of the horizontal type, insulated by a bank of mud. It is fired by a furnace, which extends almost through its length and should theoretically produce a high rate of steam. Steam should be introduced into the still under pressure, to enable it to rise through the charge with sufficient force and penetrate all parts evenly. A steam pressure of 1-2 atmospheres has been recommended. Under these conditions yields are slightly lower, but the resulting oil has a higher geraniol content. Yields are higher with steam pressure of 3-4 atmospheres but the geraniol and citronellal contents of the oil are lower. Prolonged contact with steam may cause decomposition of the oil.

Stills are made of galvanized iron, with a diameter of about 135 cm and height of about 240 cm. Most frequently double still bodies are used in each unit so that they can be used alternately. Such still bodies, have a capacity for about 50 kg of grass. The stills are insulated to prevent heat losses. They are embedded in a stone hearth or surrounded by a layer of kieselguhr or finely chopped citronella grass.

The grass is cut before being charged into the still to enable even distribution in the still and thus prevent steam channelling. Cut grass has been found to yield a higher percentage of oil when compared with uncut grass. When loaded into the still, the grass is trampled down tightly.

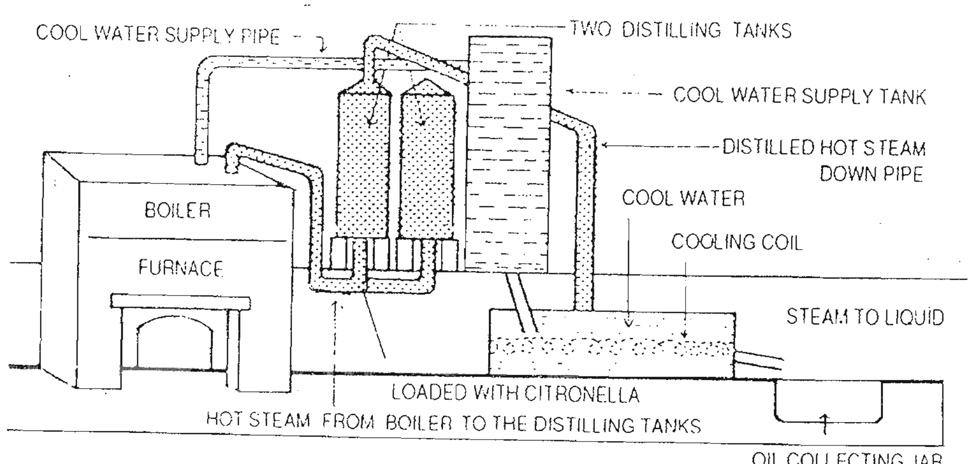


Figure 1 : Simple distillation apparatus

6.2.1 DISTILLATION TIME

Distillation times vary with the weight of the charge. It takes about 2 hours to complete the distillation of 500-600 kg of charge and 3-4 hours to 1000-1500 kg charge. It was found that 80% of the oil is distilled during the first hours, 19% in the second hour and 5% in the third hour. If the distillation is extended till the grass is completely exhausted, an inferior oil with low citronellal is obtained. If the distillation is stopped early, the oil contains a higher content of citronellal.

The order in which the various constituents are distilled is low boiling terpenes, citronellal, mixture of citronellal and geraniol, alcohols and esters, geraniol and sesquiterpenes, sesquiterpene alcohols.

6.2.2 COOLING SYSTEM (Condenser)

As the name suggests the responsibility of the condenser is to change the phase of oil and water vapour back into liquid so that as immiscible liquid, they can be separated.

Usually a condenser is a tube or a series of tubes that are water cooled, so that the vapour emerging from the vapour tube will rapidly change into liquid phase. Condenser tubes are made out of lead, aluminium or stainless steel. Copper tubes are avoided, since they tend to colour the oil. Unsatisfactory cooling can cause resinification of the oil.

6.2.3 OIL SEPARATOR

Once the oil and water have condensed, the oil droplets must have time to coalesce. This is done in a separating can or Florentine flask made of aluminium. Oils separate from water according to their density because they are immiscible or only sparingly soluble.

The most important factor of an oil separator is that it must be large enough to give the coalescing oil particles, time to form distinct oil droplets that readily separate from the oil. If a green colour is present, after the water layer is drained off, it is removed by treatment with dilute acids, especially tartaric acid. The separated oil is then filtered twice, to remove any minute particles or debris that have unobtrusively found their way into the oil.

Security:

Since the oil is very expensive, the distillers take strict security measures. The oil separator and the container holding the separated oil are often placed in an underground room, which is locked. The entire distillation unit may be housed within walls and protected by a protruding roof.

Table 1 : Distribution of Citronella oil stills in Sri Lanka.

Area	No. of Stills
1. Kirambe -Katuwana	63
2. Walasmulla – Weeraketiya	17
3. Beliatta	01
4. Tangalla - Ranna	14

7.0 PACKAGING AND STORAGE [24, 52]

Citronella oil must be packed in air tight containers which are completely filled, without any air space. Glass, tin-lined or aluminium containers may be used, or galvanized iron drums. Jayawardena, A.L. *et.al.* found that of the metals, aluminium and zinc remained partically unattacked by citronella oil for a short period of time, like for export containers.

The containers are stored in a cool place away from light. Guenther (1940) reported that on storage, the specific gravity of citronella oil increased and solubility in 80% alcohol decreased. When exposed to light and air, the oil may change colour, from yellow to green. Long periods of storage may cause the oil to become dark brown in colour, due to oxidation. The oil may become more viscous on storage.

Waterman and Elsbach found that on keeping, in a closed bottle, the refractive index of Java citronella oil changed only slightly in 7 months, from n_D 1.4688 to n_D 1.464. When stored in open tube the refractive index increased to a larger extent, the increase being greater for the Ceylon citronella oil than for Java citronella oil. The greater stability of the Java oil, it was claimed, was probably due to a higher geraniol content. The geraniol prevented oxidation to citronellic acid.

8.0 CHEMISTRY OF GRASS [27,52]

8.1 PHYSICO – CHEMICAL CHARACTERISTICS

8.1.1 ESSENTIAL OIL

Colour:

Ceylon type	-	Pale yellow to brownish liquid
Java type	-	Yellow to pale brown

Density:

Ceylon type	-	0.894 – 0.910
Java type	-	0.880 – 0.895

Dielectric constant:

Italian oil	-	at 16 °C	3.233
		at 27 °C	0.326

Flash point - 84 °C for unadulterated oil

Moisture content:

Ceylon oil	0.4%	after 1 year
Java oil	1.1%	

After saturation with water:

Ceylon oil	0.9%
Java oil	1.4%

Odour:

Rose or lemon-like. odour of Java oil is said to be superior to that of Ceylon oil.

Refractive index:

Ceylon oil	-	1.479 – 1.487
Java oil	-	1.466 – 1.473

Solubility in water :
Surface tension: Albert has shown that soap assists in increasing the water solubility of citronella oil.
Citronella oil (25 ml) + 0.88 ammonia (8.5 ml) + soap solution (50% ammonium ricinoleo-sulphate) to give 100ml.
Citronella oil (20 ml) + cyclohexanol (7.5 ml) + potassium linoleate solution (20%) to give 100 ml.
Citronella oil (33 ml) + 25% sodium chloride (6.5 ml) + 33% potassium ricinoleate solution to give 100ml.
Citronella oil (40 ml) + Basic triethanolamine ricinoleate to give 100 ml.

Ceylon oil	28.7 (density 0.9)
Java oil	29.2 (density 0.8896)
Java oil	27.7 (density 0.887)

Using the capillariscopic method, the following values have been obtained for the increase in diameter of the oil spot during the first minute of observation (k) and the original diameter of the oil spot (d) :

Ceylon oil	k = 0.4136	d = 3.82
Java oil	k = 0.4248	d = 2.71

Ultrasonic velocity:
1076 m/sec at 29 ^{0} and frequency 10.02 Mc/s

Viscosity:

Ceylon oil	5.467 (at 20 ^{0}C)	(density 0.90)
Java oil	5.467	(density 0.8896)
Java oil	5.549	(density 0.887)

It was found that there is no relationship between viscosity and the citronella content of the crude and rectified oil (Java variety).

X-ray diffraction:
Inter-planar distance (d) for citronella oil : 4.92 A^0

8.1.2 COHOBATION WATER : ESSENTIAL OIL [37]

Cohobation of distillation water obtained on steam distillation of Ceylon citronella, yielded 0.05% essential oil. When the distillation water were re-distilled, the distillate concentrated and the free oil separated by decantation, and by extraction of the residual waters with ether, the mixture of these oils, had the following physical characteristics:

d_{20}	0.913 at 20 ^{0}C
n_D	1.4829 at 20 ^{0}C
Acid value	0.3
Ester value	18.1
Ester value after acetylation	88.2
Carbonyls as $C_{10}H_{18}O$	38.2%

The chemical composition of this was:

1-carvotan acetone	10.7%	Geraniol	20.0%
d-citronellal	4.2%	Geranyl acetate	6.25%
Ethyl alcohol	2.5%	Perillaldehyde	12.1%
Furfural	2.3%	Phellandrene	8.43%

8.1.3 DISTILLATION RESIDUE [52]

This is a liquid, which comprises the oxidation and polymerization products that are non-volatile. In the case of Java oil, this residue was 0.5-3%. In Sri Lanka, this residue is referred to as 'Goda'.

8.1.4 SPENT GRASS [24,52]

The residue thrown out after extracting the oil is termed as 'spent grass'. It was found to have high moisture content of 82.68%. The dry matter content was 17.32% of which, 84.09% was organic matter. The following analysis has been reported for decayed spent grass of Ceylon citronella.

Organic matter	84.09% (contains 2.24% N)
Oxides of Fe & Al	0.97%
Phosphoric acid	0.30%
Lime	0.61%
Potash	0.09%
Other constituents	0.74%

Pandittesekera obtained the following figures for Ceylon citronella grass ash:

Lime	-	3.28%
Phosphoric acid	-	1.39%
Potash	-	7.06%

Georgi gave the following figures for dry spent grass from *Cymbopogon winterianus* grown in Malaysia.

Ash	-	5.6%
Organic & Volatile matter	-	94.4%
Nitrogen	-	1.11%
Potash (as K_2O)	-	1.23%
Phosphoric acid (as P_2O_5)	-	0.13%

It has been reported that spent grass is an excellent source of manure. It is applied either after composting or in the form of ash by burning. There is a report from Puerto Rico that spent grass is dried and ground to a powder and then mixed with molasses and soya proteins which form a good feed for the cattle.

The dried spent grass is also used as fuel for the distillation of the oil. The spent grass can also be used as cheap material for packing glassware. It is also reported that spent grass can be used for manufacture of paper and cardboard.

8.2 CHEMICAL CONSTITUENTS OF GRASS [14,26-28,37,38,58,76,99,102]

The main chemical differences between the oil from the two varieties, *Cymbopogon nardus* (L) Rendel and *Cymbopogon winterianus* Jowitt were the relative amounts of total acetylisables. The Java type oil were characterized by low concentrations of monoterpenes (2.9-3.8%) and high concentrations of citronellal (34.8-36.6%), citronellol (9.9-11.5%) and geraniol (22.1-25.4%) as compared to the Ceylon type. The

Ceylon type contained 23.8% monoterpenes, 13.3% Citronella and 6.2% citronellol. The concentration of geraniol was slightly lower than the Java type at 20.9%.

The Ceylon types contained significant amounts of borneol (5.2%), methyl eugenol (8.42%). Bornyl acetate was also present in the Ceylon type. These compounds were either not detected in the Java-type or were present at much lower levels. The Java-type contained 0.13-0.17% citronellic acid which, was not detected in the Ceylon type.

The Java citronella oil has been characterized as fresh and sweet revealing the high content of citronellal, geraniol and citronellol. These compounds are not predominant in the odour of the Ceylon type oil, which is characterized by the comphene-borneol-methyl engenol complex.

Table 2 : Chemical Constituents of *Cymbopogon nardus*.

Constitutent	Percentage
T-amorphol / bulnesol	0.55
Benzylacetate	0.5
∝-Bergamontene	1.0
Borneol	4.8 – 6.6
Bornyl acetate	0.5
Bourbonene	1.0
γ-cadinene	1.02
δ--cadinene	0.6
Camphene	6.6-31
Camphene	0.5
Carene	trace
δ-3-carene	0.12
Caryophyllene	0.9 – 3.2
Caryophyllene oxide	0.1 – 0.3
1, 8-Cineole	
Citronellal	13.3 – 14.7
Citronellyl acetate	1.1 – 1.2
Citronellol	6.2 – 6.5
Citronellyl butyrate	trace
α-cabaene	0.04
β-cubebene	3.77
p-cymene	0.1
Decanal	0.18
3,3-dimethyl bicyclo [2.2.1] heptan-2-one	0.07
Dipentene	
α-elemene	0.7
β-elemene	0.7
δ-elemene	0.03
Elemicin	
Elemol	0.7-1.7
10-epi-γ-eudesmol	0.23
Farnesol	0.2-0.3
Cis α -farnesol	0.07
Trans α - farnesol	0.06

Geraniol	17.5-40
Geranyl acetate	2.1
Geranyl butyrate	0.6-1.5
Geranyl formate	0.2-4.2
Hexanol	0.1
α-humulene	0.21
Limonene	9.7-44.5
Linalool	0.5-1.2
Linalyl acetate	0.8
Melonal (2,6-dimethyl-2-heptenal)	0.11
Menthol	trace
Methyl eugenol	1.7
Cis-methyl isoeugenol	10.1-11.3
Methyl heptenone	0.2
6-methyl-5-hepten-2-one	0.16
α - muurolene	0.46
δ - muurolene	0.36
Trans-muurolol	0.33
Myrcene	0.8-2.4
Nerol	0.6-0.9
Nerolidol	0.3
Neryl acetate	0.10
Cis-ocimene	2.1
Trans-ocimene	1.1
Pelargonaldehyde	
α- Phellandrene	0.1-0.8
β- Phellandrene	0.4-3.4
α- Pinene	2.2-8.1
β- Pinene	0.2
Iso – pulegol	0.4
Iso(iso) pulegol	0.87
Sabinene	0.2-11.3
Scadinene	0.6
Sesqui citronellene	
α - Terpinene	
δ - Terpinene	0.06
α - Terpineol	trace
Terpinen-4-o1	0.7-1.2
α - terpineol	0.5-1.2
Terpinolene	0.6-0.7
α - terpinyl acetate	0.4
α - thujene	0.02
Thujyl alcohol	
Tricyclene	1.2-1.6
Iso – valeraldehyde	

Table 3 : Chemical constituents of *Cymbopogon winterianus*

Constituents	Percentage
T- amorphol / bulnesol	0.65
Benzaldehyde	
α - Bergatomene	trace – 2.3
Borneol	0.2
β - Bourbonene	0.1 – 0.39
Cadina-1,4-diene	0.05
β - cadinal	
γ - cadinene	1.7
δ - cadinene	3.18
α - cadinol	0.5
δ - cadinol	0.05
Epi- α- cadinol	0.57
Calaminene	
δ - 3 – carene	0.01
Camphene	
Carvone	
β - caryophyllene	0.20 – 2.1
α - Celanene	
Chavicol	
Citral	
Citronellal	12.0-46.8
Citronellic acid	
Citronellol	13.4 – 15.7
Citronellyl acetate	0.9 – 7.3
Citronellyl butyrate	trace
Citronellyl citronellate	2 – 4
α - copaene	0.08
β - Cubebene	2.25
Cymbopol	
p– cymene	0.04
Decanal	0.1 – 0.3
Dicitronelloxide	
Dipentene	
β - elemene	2 – 3.94
δ -elemene	0.01
Elemol	1.4 – 6.65
10 – epi - γ - eudesmol	0.17
α - eudesmol	2.64
β - eudesmol	0.75
Eugenol	0.5 – 0.9
(Z,E) farnesol	0.07
(E,E) farnesol	0.59
Furfural	
Geronial	0.5 – 1.4
Geraniol	14.3 – 24.3
Geranyl acetate	2.87 – 4.7
Geranyl butyrate	
Geranyl formate	2 – 2.5

Hexanol	
2 Hexene – 1- ol	
3 Hexene – 1 – ol	
α - Humulene	0.2
Iso – amyl alcohol	
Iso – butyl alcohol	
Iso pulegol	0.07 – 2
Juniper camphor	1.28
Limonene	2.6 – 4.0
Linalyl acetate	2.0
Linalool	0.5 – 1.5
Melonal	0.09
Menthone	
1 – methyl – 3 – cyclohexanone	
Methyl eugenol	trace
Methyl isoeugenol	2
Methyl heptenone	
6 – methyl – hept – 5 – en – 2 – one	0.2
1 – methyl pentanal	
α - muurolene	0.47
γ - muurolene	0.67
Myrcene	0.72 – 1.3
Neral	1.0
Nerol	1.0 – 7.7
Neryl acetate	trace
(Z) - β - ocimene	0.08 – 0.3
(E) - β - ocimene	0.14 – 0.4
Octanal	0.2
α - phellandrene	0.1
β - phellandrene	3.4
α - Pinene	0.2
β -Pinene	0.5
Pulegone	0.03
Rose oxide	
Sabinene	0.07
Selinene	0.52
Sesquicitronellene	
α - terpinene	
Terpinolene	0.04 – 0.1
Terpinen – 4 – ol	0.05 – 0.1
α - terpineol	0.08 – 0.1
Tricyclene	0.01
Thujyl alcohol	
Vanillin	

Table 4 : Chemical constituents of *Cymbopogon Confertiflorus*:

Constituent	Percentage
Total alcohols	39 – 61%
Geraniol	19 – 43%
Citronellal	17 – 33%

Table 5 : Chemical constituents of *Andropogon schoenanthus*:

Constituent	Percentage
Geraniol	13.6%
Citronellal	20.0%
Citral	18.0%

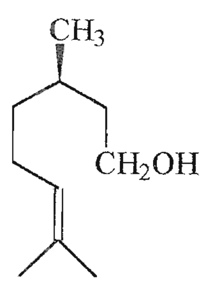
Table 6 : Chemical Composition of Various Commercial Citronella Oils

Compound	China	Argentina	S.America	Java	Ceylon
Cis-3-hexenol*	0.02	0.01	0.01	0.01	-
Tricyclene	-	-	-	0.01	1.09
α-thujene*	-	0.01	-	0.01	1.09
α-pinene	0.01	0.02	0.01	0.05	1.87
Camphene	-	-	-	0.04	6.97
Sabinene	0.07	0.09	0.05	0.07	0.06
6-methyl-5-hepten-2-one	0.01	0.01	0.01	0.01	0.16
β-pinene	-	0.03	0.01	0.01	0.06
Myrcene	0.07	0.08	0.08	0.09	0.83
α-phellandrene	-	-	-	-	0.12
δ-3-carene	0.01	0.01	0.01	0.01	0.12
α-terpinene	0.01	0.01	0.01	0.01	0.06
p-cymene	0.01	0.01	0.01	-	0.12
β-phellandrene/1,8-cineole	0.05	0.05	0.06	0.07	0.06
Limonene	2.62	3.21	2.93	2.81	8.66
cis-β-ocimene	-	0.01	0.01	0.37	1.92
Melonal	0.09	0.09	0.07	0.09	0.11
Trans-β-ocimene	0.02	0.01	0.02	0.19	1.07
3,3-dimethyl bicyclo [2.2.1] heptan-2-one*	0.01	0.01	0.01	-	0.07
Terpinolene	0.05	0.06	0.06	0.06	0.74
Linalool	0.77	0.86	0.47	0.72	0.56
Citronellal	35.27	36.63	36.39	34.79	6.09
Iso (iso)pulegol*	0.29	0.41	0.34	0.22	0.87
Borneol	0.06	0.08	0.06	0.05	5.23
Terpinen-4-ol	0.04	0.05	0.04	0.04	0.65
α-terpineol	0.06	0.06	0.06	0.05	1.05
Decanal	0.10	0.09	0.12	0.10	0.18
Citronellol	9.92	11.47	10.63	11.19	6.15

Compound	China	Argentina	S.America	Java	Ceylon
Geraniol	23.13	22.06	25.40	23.18	20.91
Bornyl acetate	-	-	-	-	0.42
Citronellic acid	0.17	0.17	0.15	0.13	-
α-terpinyl acetate	0.23	0.23	0.3	0.16	0.01
Citronellyl acetate	1.01	0.97	1.97	1.88	1.10
Eugenol	2.29	1.99	1.10	2.45	-
Neryl acetate	0.03	0.03	0.03	0.04	0.10
δ-elemene*	0.01	0.03	0.01	0.01	0.03
Geranyl acetate	3.78	2.89	3.80	5.07	2.40
Methyl eugenol	-	-	-	0.09	0.99
α-copaene*	1.13	0.12	0.09	0.08	0.04
β-bourbonene	0.12	0.11	0.12	0.10	0.18
β-elemene	2.80	3.17	1.89	1.96	1.10
β-caryophyllene	0.08	0.10	0.06	0.22	0.44
Cis-methyl isoeugenol	-	-	-	-	1.18
α-humulene	0.12	0.15	0.14	0.13	0.21
Trans-methyl isoeugenol	-	-	-	-	8.42
β-cubebene*	1.76	2.03	1.79	2.25	3.77
α-muurolene*	0.52	0.70	0.49	0.46	0.46
γ-muurolene*	0.56	0.71	0.49	0.67	0.36
γ-cadinene	1.87	2.25	1.81	1.74	1.02
Elemol	5.58	3.81	3.05	3.16	1.14
δ-cadinene	0.66	0.55	0.52	1.17	0.09
Cis-α-farnesol*	0.20	0.13	0.12	0.10	0.07
10-epi-γ-eudesmol*	0.59	0.31	0.37	0.17	0.23
Trans-muurolol	0.82	0.55	0.74	0.53	0.33
T-amorphol*/bulnesol*	1.37	0.79	1.12	0.65	0.55
Trans-α-farnesol*	0.19	0.07	0.14	0.08	0.06
Total % of oil	97.58	97.26	97.22	97.54	90.48

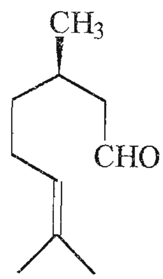
Legend: * = Not previously reported in citronella oil

The β-phellandrene/1,8-cineole and T-amorphol/bulnesol peaks did not consistently separate.



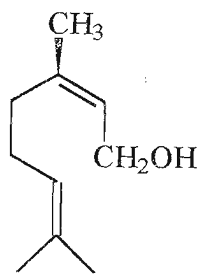
Citronellol

Chemical structure of Citronellol



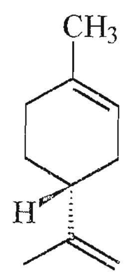
Citronellal

Chemical structure of Citronellal



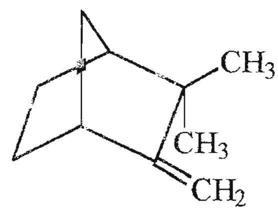
Geraniol

Chemical strucuture of Geraniol



Limonene

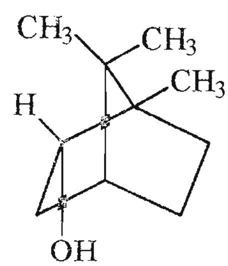
Chemical structure of Limonene



(-) form

Camphene

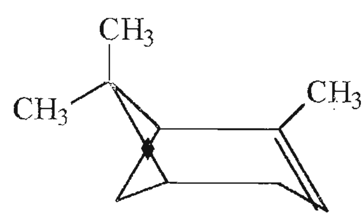
Chemical structure of Camphene



(+) form

Borneol

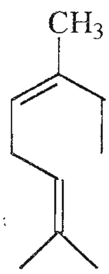
Chemical structure of Borneol



(+) form

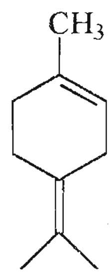
α-Pinene

Chemical structure of α-Pinene



β-ocimene

Chemical structure of β-ocimene



Terpinolene

Chemical structure of Terpinolene

Figure 2 : Constituents of Citronella

8.3 BIOCHARACTERISTICS [8,20,31,34,35,39,40,52,62,68,70,71,102]

Antibacterial activity:
The vapour of citronella oil inhibits the growth of gram-positive organisms. The oil shows antibacterial activity against pathogenic bacteria such as *Escherichia coli*, *Bacillus mycoides*, *Bacillus pumilus*, *Sarcinalutea* and *Shigella nigesta*.

It has been reported that citronella oil inhibits the growth of *Micrococcus pyogenes var. aureus*. At a dilution of 1:16,000, Okazaki and Oshima found citronella oil effective against avian *Mycobacterium tuberculosis*. The Formosan citronella oil had antibacterial activity against *Bacillus subtilis* var. *aterrimus*.

Using *Bacillus typhosus* as the test organism, obtained the following values for citronella oil:

Rideal Walker coefficient = 10.0
Phenol coefficient (Garrod's test) = 4.4

Anti-fungal activity:
The oil of citronella exhibits a very good antifungal activity. Dube Gita et. al. found that it shows good antifungal activity against *Aspergillus niger*, *Aspergillus flavus*, *Aspergillus fumigatus* and *Fusarium oxysporum*.

Cymbopogon nardus strongly inhibited germination of fungi, *Sclerotium rolfsii*, *Rhizoctonia oryzae-sativae* and *Sclerotium hydrophyllum*.

Insect repellent activity:
Citronella oil isolated from *Cymbopogon nardus* at 1.0 concentration exhibited significant insect repellent activity against two stored grain pests viz., *Tribolium castaenum* and *Bruchus chinensis* and a household pests, cockroaches and mosquitoes.

It was found the repellant and toxic effects of citronella oil against *Sitotroga cerealella* (Olivier) an important pest of stored paddy in Sri Lanka. They further showed that β-pinene was the most effective repellent followed by p-cymene, camphene, α -phallandrene and α -pinene when the terpene hydrocarbons were examined individually, p-cymene was found to be the most effective at causing inactivation and mortality.

Larvicidal activity:
The essential oil of Ceylon citronella shows a significant activity (6.3ml/l) against *Culex quinquefasciatus* and lesser activity against *Aedes aegypti* (9.3 mg/l). Ratnaweera et. al. found that myrcene was the major active principle of hydrocarbon fractions responsible for the larvicidal activity. γ-terpinene also shows has considerable activity.

Skin irritation:
Citronella oil when tested at a concentration of 8% in petrolatum, in a 48-hour closed patch test, on 25 human subjects, did not cause irritation. There have been a few reports of eczematous, contact-type hypersensitivity, folliculitis of the acne form, papulovesicular eczema of the hands, fingers and forearms, caused by citronella oil. Citronellal is said to be the allergen in the oil. Citronella oil has received listing as a primary irritant in perfumes by some authors.

Toxicity:
The acute oral LD_{50} of citronella oil in rats in greater than 5g/kg. The acute dermal LD_{50} in rabbits is 4.7ml.kg.

9.0 ANALYSIS OF CITRONELLA OIL [52,94,99]

9.1 CHROMATOGRAPHY

Gas liquid Chromatography
Gas or gas liquid chromatography is a method of separating a volatile complex mixture into its separating a volatile complex mixture into its separate components by making use of the different partitions of the components between a mobile gas phase and a stationary liquid phase.

A stream of an inert `carrier gas' like Argon, Helium or Nitrogen flows by way of a pressure value, through the chromatographic column which is maintained in an oven compartment. The sample to be analysed is injected into the injection port where it is flash volatilised into the stream of carrier gas prior to entering the column. The column is a coiled tube, which contains the liquid ` stationary phase'. Columns are of two main types viz: packed columns and open tubular columns. Open – tubular columns have much greater powers of resolution. They are more sensitive than packed columns, but can tolerate only minute doses of material. The selection of the type of column, the appropriate stationary phases and its temperature, play an important role in the success of analyses by GLC. Some stationary phases that have given particular good results are Carbowax 20M, FFAP, SE 30, OV 101 and OV 225. In order to achieve optimum separation the temperature of the column compartment has to be gradually increased during analysis. The separated constituents of an essential oil emerging from the column enters the `detectors' which monitors the entry of each compound. The emergence of each separated constituent alters the electrical conductivity with respect to that of the carrier gas. These variations in each case are converted into electrical signals and recorded on a strip chart recorder. This `gas chromatogram', takes the form of a series of peaks which correspond to each component separated by the column. Please refer SLS 572 : Part 3 : 1984; ISO 7359 and ISO 7609.

Thin layer chromatography (TLC)

TLC is a simple separation technique where a mixture is separated on a glass plate coated with a layer of silica gel powder, aluminium powder or cellulose powder. Silica gel is the most useful matrix for analysis of essential oil components. The mixture is applied to the lower edge of the coated plate of glass and then developed in a suitable solvent by being placed in a glass tank. The solvent will ascend along the plate and when a distance of about 15cm is covered the plate is removed and allowed to dry. The separated components are then visualized by spraying of a number of reagents. The most widely used reagents are;

(i) Vanillin in Ethanol containing a small amount of concentrated sulphuric acid
(ii) Anisaldehyde treated similarly
(iii) Dipping in Iodine vapour

Among the other reagents , 2,4 Dinitrophenyl hydrazine in diluted hydrochloric acid will detect ketone and aldehydes, while diazotized, sulphanillic acid and nitro anillin will detect phenolic compounds.

Faruq, et.al. in their study divided the lemongrass oil into different fractions and was subjected to tlc studies separately.

9.2 SPECTROSCOPY

Infra red Spectrometry

One of the most characteristic properties of organic molecules is its infra red (IR) spectrum, which originates from the absorption of IR radiation by the molecule. When IR radiation strikes the bonds of molecules, the bond energy will be absorbed, when the correct energy for excitation of some bond in the molecule is present. The IR spectrometer will thus record each such absorption and intensity of which this occurs. Samples can be analysed as pure films, dilute solutions or made into transparent discs after dispersing in potassium bromide or as a paste made in Nujol (white oil). IR spectra are so characteristic for compounds that the fine structure in the spectrum is a fingerprint of each such compound. Even for complex mixtures such as essential oils an IR spectrum would be useful for checking authenticity quickly. The spectrum which is recorded can then be compared with a similar spectrum from a genuine sample of oil.

9.3 DETERMINATION OF TOTAL GERANIOL

All acetylizable constituents calculated as geraniol.

Acetylation method

This method involves heating the oil gently, with 95% acetic anhydride and anhydrous sodium acetate for 2 hours, decomposing the excess acetic anhydride by heating with water, washing with 10% sodium chloride, drying overnight over anhydrous sodium sulphate and determination of the saponification numberof the resulting acetylated oil. Saponification is carried out with ethanolic 0.5N potash and the excess KOH titrated against 0.5N sulphuric acid.
An oil bath, sand bath or electric hot plate is used for heating the acetylation flask, not an open gas flame.

The presence of traces of water and sulphuric acid in the reaction is said to cause enolisation of citronellal and formation of citronellal diacetate, which gives a high total alcohol value.

Low results for total alcohols are obtained when the purity of acetic anhydride used is less than 95% and when the period of acetylation is less than 2 hours.

Oximation method

The oil is oximated using aqueous solutions of hydroxylamine hydrochloride and potassium carbonate and the nitrogen content determined by the Kjeldahl method. From this, the % citronellal can be calculated. The geraniol content is then determined by acetylation of the oximated oil, the total alcohols being the sum of the 2 values thus obtained.

Phthalic anhydride reaction

Geraniol reacts with phthalic anhydride, forming acid esters, while citronellal does not react with this reagent. Thus, by heating the oil with phthalic anhydride and benzene for 2 hours, conversion of the geraniol ester formed, to its potassium salt, with aqueous potassium hydroxide and titration of the excess alkali against sulphuric acid, the amount of geraniol in the oil can be calculated.

Method of Petrova and Novikova

In this method, the citronella oil is refluxed with toluene and p-toluene sulphonic acid and the settled out water titrated with Fisher's reagent, to determine the geraniol content. Citronellal is said to interfere with the dehydration reaction.

Colorimetric method

Picric acid gives a red colour with geraniol in glacial acetic acid on heating.

9.4 DETERMINATION OF CITRONELLAL

Hydroxylamine method

(i). Total geraniol is determined by acetylation method, the citronellal removed by addition of hydroxylamine hydrochloride (neutralised with sodium carbonate) and heating at 20 – 25 0C for 2 hours and the geraniol content of the supernatent oil again determined. From the difference in the 2 values the approximate citronellal content is calculated.

(ii). The oil is reacted at –2 ^{0}C with a 5% alcoholic solution of hydroxylamine hydrochloride then titrated with 0.5N alcoholic potash using bromophenol blue as indicator, and a slight excess of KOH added. The excess KOH is titrated with 0.5N alcoholic hydrochloric acid. Adding the excess alcoholic KOH before adding the hydroxylamine hydrochloride reagent has modified this method.

Phenyl hydrazine method
In this method the oil is allowed to stand with a alcoholic solution of phenyl hydrazine for about 1 hour, then shaken with hydrochloric acid and the excess acid titrated against sodium hydroxide or potassium hydroxide, using ethyl orange as indicator.

10. CHEMICALS FROM THE OIL [11,52]

Geraniol:
Geraniol is a colourless liquid, with a flowery – rose like odour. Waterman *et. al.* separated geraniol from citronellal in Java citronella oil, by fractional distillation of the oil in vacuo (1-2 mm) and re-fractionation in a cathode vacuum. In the conventional method, the oil is shaken with an equal volume of saturated sodium bisulphite solution, a little neutral sulphite and 1-2 ml ether, extracted with water and citronellal precipitated with barium chloride. The remaining oil is hydrolysed by alcoholic potash and the geraniol separated through its crystalline double compound with calcium chloride. This compound is decomposed with water and steam-distilled to give geraniol.

Commercially geraniol is prepared by fractional distillation from Java or Ceylon citronella oil, and freed from traces of citronellal, by boiling with dilute caustic soda solution. The citronellal is converted into high boiling products, which are eliminated by distillation. Pure geraniol is obtained through its calcium chloride compound. The geraniol can also be purified through the hydrogen phthalate. According to British Patent 547,420 citronellal can be separated from the geraniol in Java citronella oil by converting the citronellal into a high boiling condensation product with a suitable amine and removing the geraniol by distillation.

Citronellal:
Pure citronellal is a colourless liquid with a refreshing ordour. Crude citronellal (10 kg) obtained by fractionation of citronella oil and concentrated sodium bisulphite solution (9 kg) are run into an enamel vessel fitted with a cooling jacket and stirrer and caustic soda solution (1.25 kg, 39° Beaume) added, keeping the temperature below 0 ^{0}C. After an hour when the mixture sets to a pasty mass, benzene (5 kg) is added and stirring continued for 5 hours. The product is pressed in a hydraulic press; the press cake is kneaded with benzene (5 kg) and pressed again. The pure citronellal is liberated from this bisulphite compound by steam distillation in the presence of soda ash.

Citronellol:
Citronellol is a colourless liquid with a sweet rose like odour. Citronellal is obtained by distillation of Java citronella oil and is hydrogenated to citronellol in the presence of a catalyst like Raney nickel. Also it can be done electrolytically using lead electrodes and dilute alkali as a electrolyte.

Hydroxycitronellal:
Java citronella oil is distilled under reduced pressure (4mm) and the fraction with a boiling range 70-114°C is hydrogenated with Raney – Cobalt catalyst at 30-48 °C for 2 hrs at 100 kg /sq. cm of hydrogen pressure. Distillation gives citronellal (bp 80 – 85 °C/3 mm Hg). Hydrogenation of citronellal gave hydrocitronellal. Dehydrogenation in the vapour phase under reduced pressure with a copper – zinc catalyst gave hydroxycitronellal.

Menthol:
(-) - Menthol has a characteristic peppermint odour and also exerts a cooling effect. The process uses the readily occurring cyclization of citronellal to isopulegol. (+) – citronellal can be isolated with an optical purity of about 80% from citronella oil. Alternatively, it can be synthesized with a purity of 98% from dialkyl – geranylamine by enantioselective isomerization to (+) - citronellal dialkylenamine followed by hydrolytic cleavage to (+) – citronellal. Isomerization is effected in the presence of chiral rhodiumm-phosphine complex as a catalyst. (+)- Citronellal is cyclized in the presence of acidic catalysts (eg. silica gel) to give a mixture of optically active isopulegol isomers containing ca. 20% of the corresponding racemates. (-) – Isopulegol can be isolated from this mixture and hydrogenated to (-) menthol. The remaining isopulegol stereoisomers can be partly reconverted into (+) – citronellal by pyrolytic cleavage and reused in the cyclization procedure.

11.0 STANDARDS AND SPECIFICATIONS

11.1 STANDARDS
Three grades of Ceylon citronella oil, differentiated according to the total acetylisable constituents are specified in the Sri Lanka Standard (SLS 170)

Grade	Minimum Total acetylisable Constituents (as geraniol) present by mass,min.	Ester value after Acetylation min.
Grade 1 (Estate quality)	55.0%	174
Grade II (fair average quality	52.5%	167
Grade III (Ordinary quality)	50.0%	160

Table7 and Table 8 gives the requirements for the 2 types of citronella oil as specified in various standards.

Abbreviations for Table 7 and Table 8
SLS = Sri Lanka standards
BS = British Standards
BPC = British Pharmaceutical Codex
IS = Indian Standards
ISO = International Standards
EOA = Essential Oil Association Standard.
n.s. = not specified.

Table 7 : Citronella oil : Requirements for *Cymbopogon nardus*

	SLS 170	BS 2999/18	BPC 1973	IS 512	ISO 3849	EOA 12
Specific gravity	0.910	0.893 - 0.910	0.895 - 0.905	0.587 - 0.908	0.894 - 0.910	0.898 - 0.910
Optical rotation	-22 to -12°	-9 to -18°	-9 to -18°	-9 to -18°	-22 to 12°	-9 to -18°
Refractive index	1.465 – 1.487	1.479 – 1.485	1.408 – 1.485	1.4745 – 1.4805	1.479 – 1.487	1.4790 – 1.4850
Solubility	1 vol. in 2 vol of 80% alcohol	1 vol. in 2 vol of 80% alcohol	1 vol. in 4 vol of 80% alcohol	1 vol. in 2 vol of 80% alcohol	1 vol. in 2 vol of 80% alcohol	1 vol. in 2 vol of 80% alcohol
Total aldehydes (as citronellal)		7 – 15%		7 – 15%		7 – 15%
Carbonyl value		25 – 55			18 – 55	
Total alcohols (as geraniol)		59 – 65%			85%	55 – 65%
Ester value		185– 201	not less than 175		157– 200	
Steam distillation residue present by mass. Max.				not greater than 4		

Table 8 : Citronella oil : Requirements for *Cymbopogon winterianus*

	SLS 170	BS 2999/19	BPC 1973	IS 512-1988	ISO 3848	EOA 14
Specific gravity	n.s.	0.880 - 0.892	0.880 - 0.895	0.8743 - 0.8893	0.880 - 0.895	0.883 - 0.900
Optical rotation	n.s.	0 to -5°	-5 to +2	-0.5 to 5°	-5 to 0°	-0.30 to -6°
Refractive index	n.s.	1.466 – 1.473	1.468 – 1.473	1.4624 – 1.4730	1.4660 – 1.4730	1.4660 – 1.4745
Solubility	1 vol. in 2 vol of 80% alcohol	1 vol. in 2 vol of 80% alcohol	1 vol. in 4 vol of 80% alcohol	1 vol. in 2 vol of 80% alcohol	1 vol. in 2 vol of 80% alcohol	1 vol. in 2 vol of 80% alcohol
Total aldehydes (as citronellal)		35% minimum		35 – 45%	35% minimum	30 – 45%
Carbonyl value		not less than 127			not less than 127	
Total alcohols (as geraniol)		85%				85 – 97%
Ester value		not less than 251	not less than 250		Not less than 250	
Steam distillation residue present by mass. Max.				3		

11.2 ADULTERANTS [52]

The following are among the adulterants which have been detected in citronella oil : kerosene, camphor oil, coconut oil, petroleum or mineral oil fractions, rosin spirits, lemon oil, alcohol, terpineol, wood oil from *Dipterocarpus* species. Sometimes the oil has been found to contain fractions left after removal of the geraniol and/or citronellal from citronella oil. Adulterated oil also results when weeds or root material are mixed with the grass that is distilled.

11.2.1 DETECTION OF ADULTERANTS:

Fixed oil

Saponification of the essential oil with alcoholic potash and precipitation of the fat can determine the amount of fixed oil. When the amount of fat present is about 0.1%, after saponification with methanolic caustic potash the resulting glycerol is oxidised with acidified potassium periodate to formaldehyde and formic acid. The excess periodate is removed using phenyl hydrazine and ferric ammonium sulphate and sulphuric acid added successively. A red product results. The % transmittance or optical density is determined at a wave length of 5200 A^0 using an absorptiometer or spectrophotometer.

Viscosity measurements have been used for detection of 10% or more coconut oil in citronella oil, since the viscosity of the adulterated citronella oil is much higher than that of the pure oil.

Adulteration with wood oils of the *Dipterocarpus* species results in a higher fraction boiling between 215-225 ^{0}C and a higher saponification value (48-54 as against 35-40 for the pure oil)

Kerosene, Petroleum or Mineral oil fractions

Citronella oil with a flash point below 75 0C is suspected to be adulterated with benzene or gasoline. The presence of kerosene cannot be detected through flash point determinations. Kerosene has to be fractionated out and detected by its odour.
Wijesekara et. al. have described a gas chromatographic method for detection of kerosene in citronella oil.

Ethyl alcohol

When the oil is shaken up with a crystal of fuchsin, the oil should remain colourless if ethyl alcohol is present. Oils with low specific gravity may be adulterated with alcohol.

Solubility tests

Schimmel's test or old Schimmel's test

Schimmel & Co. introduced this test in 1898 as a simple quick field test for detection of adulterants before purchase of oil. To pass this test, 1 vol. of the citronella oil must be soluble in 1-2 vol. 80% alcohol at 20 ^{0}C and the solution must remain clear or be only slightly opalescent when further alcohol is added upto 10 vols. alcohol. This test permits 10% adulteration of the oil and far from being a deterrent, permitted adulteration to the limits of the test.

New Schimmel's test

In this test, 1 vol. of the oil is first dissolved in 1-2 vols. 80% alcohol at 20 ^{0}C. Then, further alcohol is added dropwise, carefully, till the point of maximum cloudiness or turbidity is reached. Not more than 10 vol. alcohol are added. If the oil separates out on prolonged standing the oil has failed to pass this test. This test allows up to 4% kerosene.

Raised Schimmel's test
The oil is mixed with 5% petroleum and the old Schimmel test applied, adding up to 10 vol. alcohol, disregarding any cloudiness during addition. An oily separation on standing indicates adulteration.
The Schimmel's tests however, were not satisfactory, as certain freshly distilled oils did not pass the tests.

London Solubility test
This test was put forward by Essential Oils Sub Committee of the Analytical Methods Committee of the Society for Analytical Chemistry. To pass this test, 1 volume of the oil should be soluble in 2 vols. 80% v/v alcohol and should be not more than faintly opalescent with no separation of oily drops when a further 4 vols. 80% v/v alcohol are added and the sample kept overnight in a stoppered cylinder at 20 ^{0}C.

Bamber's test
M.K. Bamber suggested this test to determine the amount of adulterant insoluble in alcohol. His test involves the shaking up of 2ml 83% w/v alcohol followed by centrifuging for ½ - 1 min. This test however was found to be qualitative only and did not gain wide acceptance.

12.0 PRODUCTION AND TRADE [52]

Sri Lanka continues to be the main producer of Ceylon citronella oil. In 1892, the total area under citronella in Sri Lanka was 25,000 acres and there were 450 stills. This had increased to 40,000 acres in 1911 and fallen to 30,000 acres in 1940 and fallen further to 16,800 acres in 1969 and at present it is around 15,627 acres. It is mainly cultivated in the Hambantota district with small areas under cultivation in Matara and Matale districts.

Although production of Citronella oil in Sri Lanka is nowadays at a much lower level than once it was, it appears currently to be stable and is likely to remain so, particularly as demand for it is declining only slowly, although periodic shortages in supplies of citronella oil from other sources may also help to maintain the level of demand for Sri Lanka's product. Details of exports are given in table 9.

Indonesia was the first supplier of commercial quantities of Java-type citronella oil and it has been one of the world's most important suppliers of citronella oil, although China has challenged it.

In recent years, Citronella oil, which typically sees price hikes prior to the summer, has not budged. The situation has got so bad that sellers are now lowering prices to entice buyers back to market. Sri Lanka distillers note that current prices are below the cost of production.

Market Price for Ceylon Citronella in US market:

	1998	1997	1996
Price for 1 lb	$ 3.30 – 3.50	3.30	4.00 – 4.25

The USA is the world's largest importer of Citronella oil. Details of imports are given in Table II & III. Although no published figures are available, it would appear that a small proportion of imports is re-exported. Imports of the Ceylon-type oil from Sri Lanka have held up fairly well, which is to be expected, since consumption of citronella oil as a perfumery oil per se has declined far less sharply than has been the case where isolate extraction is concerned. However, of Java-type oils, there has been a sharp fall in imports from Indonesia although, a rather higher proportion of Indonesian oil is now purchased via Taiwan. Chinese oil is marginally favoured over Indonesian oil as it is less likely to be adulterated.

The basic uses for the derivatives of citronella oil and the comparable derivatives of turpentine apply in the USA. Some US users still prefer natural, rather than synthetic, geraniol and hydroxycitronellal, but for the latter, *Eucalyptus citridora* oil is often the preferred source. Sri Lanka oil appears to be favoured for the manufacture of mosquito-repellent citronella candles.

The other major import of citronella oil is United Kingdom. The United Kingdom purchases its supplies of citronella oil from many sources. The Sri Lankan oil continues to be imported in fair, although in the long-term gradually declining, quantities for per se applications in low-cost products, while for the Java-type oils China & Indonesia predominate as suppliers, other significant, if irregular suppliers having included Taiwan, Vietnam, Brazil and Guatemala.

Table 9 : Export Performances of Ceylon Citronella oil:

Year	Vol./kg.	Value/Rs.
1980	107000	11,930,000
1981	153000	17,670,000
1982	90000	8,220,000
1983	133000	11,010,000
1984	125000	12,590,000
1985	93,000	10,350,000
1986	78,500	8,380,000
1987	96,100	16,500,000
1988	103, 770	29,066,692
1989	-	
1990	49,590	8,526,381
1991		
1992	83,135	16,989,141
1993	41,500	11,315,105
1994	80,900	34,100,000
1995	73,500	41,600,000
1996	71,500	33,100,000

External Trade Statistics

Table 10 : Citronella oil imports to USA.

Year	Vol./kg.
1991	360,000
1992	580,000
1993	890,000
1994	630,000
1995	1,300,000
1996	564,000
1997	347,000

Chem. Market Reporter

Table 11 : Imports to USA (Kg.)

	1995	1996	1997
Sri Lanka	42,000	11,000	30,000
Vietnam	80,000	72,000	130,000
Indonesia	1,43,000	63,000	1,000
China	7,71,000	2,20,000	1,73,000
Russia	-	1,15,000	-
India	1,22,000	<1000	-
Argentina	49,000	14,000	-
Other	1,59,000	8,000	12,000
Total	1,302,000	564,000	347,000

Chemical Market Reporter – Feb. 1998

13.0 USES [27,52,53,91]

13.1 Perfumery

In applications where the oil is used as such, Ceylon oil is preferred especially in USA, because its olfactory properties are finer than Java oil. Citronella oil is said to enhance the floral and woody notes of perfumes. As early as 1893, oil of citronella had been described by Schimmel & Co. as a perfume with no rival. It has been used as an odour-masking agent in a wide range of products: soaps, detergents, polishes, floor waxes, disinfectants, ointments, anointing oils, animal feeds etc. Ceylon citronella oil is not popular in detergents, since it is not considered as sufficiently stable. Ceylon citronella oil is used as a masking agent of foul smelling chemicals in deodorisers and bleaches, insect repellents and cleaning products.

Opdyke gives the following values for the concentration of citronella oil is products, when used as a perfume:

	Soap	Detergent	Creams, Lotions	Perfumes
Usual	0.03%	0.01%	0.03%	0.2%
Maximum	0.60%	0.03%	0.30%	0.80%

Although geraniol and citronellal are the main constituents of oil of citronella, it has been suggested that camphene-borneol-methyl eugenol complex, characterised the odour. The most popular use of oil of citronella is as a soap perfume, for which purpose, it is expected to contain not less than 85% geraniol. The Java oil is used for higher quality soaps, while the Ceylon oil is used as a cheap perfume for soaps, of a lower grade. By fractionation of the oil, a mixture of Geraniol:citronellal 65:35 comprising a mixture of alcohols, partly free and partly as esters is obtained and sold as crude geraniol or geraniol C, for use in scenting soaps, detergents, aerosols, etc.

Formulary of Perfumes:

1. Citronella for soap.

Benzaldehyde	25g
Bergamot	200g
Caraway oil	225g
Citronella oil	275g
Geranium palmarosa oil	225g
Musk xylene	25g
Terpineol	25g
	1000g

2. Eau de Cologne for soap:

Cidarwood oil	100g
Cinnamyl Butyrate	30g
Citronella oil	100g
Clove oil	50g
Diphenyl oxide	100g
Lavender oil	100g
Linalyl acetate	50g
Musk xylene	30g
Rosewood oil	200g
Stynax, Resinoid	20g
Terpineol	200g
Thyme oil	20g
	1000g

3. Imitation Geranium for soap

Cedarwood oil	150g
Citronella oil	150g
Clove oil	25g
Diphenyl oxide	75g
Linalyl acetate	75g
Musk xylene	25g
Rose wood oil	150g
Spike lavender oil	150g
Stynax, Resinoid	25g
Terpineol	150g
Thyme	25g
	1000g

4. Almond, Bitter for soap

Benzaldehyde	300g
Caraway oil	25g
Cedarwood oil	25g
Citronella oil	50g
Geranium Palmarosa oil	150g
Phenyl ethyl alcohol	150g
Terpineol	300g
	1000g

5. Cheap soap perfume:

Lemon grass oil	400 parts
Citronella oil	150 parts
Bois de Rose oil	100 parts
Bergamot oil	100 parts
Lemon oil	200 parts
Musk ambrette residue	50 parts
	1000 parts

6. Perfume for Tallow soap

Spike lavender oil	50 parts
Java citronella oil	12 parts
Geranium bourbon oil	25 parts
Mace oil	13 parts
	100 parts

7. Perfume for Transparent soap

Bergamot oil	5 parts
Cananga oil	10 parts
Citronella oil	10 parts
Eugenol	10 parts
Lavender oil	25 parts

Amala Hair oil Perfume:

Citronella oil	4 dram
Lemon oil	8 dram
Neroli oil	2 dram
Lavender oil	20 drops
Bergamot oil	20 drops

In the following patent by Tabekoff, Citronella oil is a constituent of a cleaning composition for sanitary equipment:

NH_4SO_3H	50 parts
Bu_2NH	300 parts
Ammonium stearate	100 parts
H_3PO_3	30 parts
Diethylene glycol Ethyl ether	505 parts
Oil of citronella	15 parts

The volatility index and odour intensities of oil of citronella after various time periods, are quoted by Appell in the following Evaporation charts.

Oil of citronella, Ceylon.

Volatility Index	150	
Odour intensity	5	
1 hour	150 mg	
2 hours	80	
1 day	320	(odour intensity 3)
1 week	350	
Residue	199	(odour intensity 2)
	1,000	

Oil of Citronella, Java

Volatility Index	100	
Odour intensity	6	
1 hour	100 mg	
6 hours	300 mg	
2 days	550 mg	
Residue	50 mg	(odour intensity 2)
	1,000	

Chicopharna in a Netherland patent describes a method for retaining the odour of oil of citronella for several months by incorporation of 1.5 g. oil of citronella, under 3.5 atm. Pressure, in 30 g of a polyetheylene wax and then casting in 2.5 g moldings.

Java oil is used for the preparation of many aroma chemicals which are used in synthetic perfumes. Some of these isolates include: Geraniol, citronellol and their esters (e.g. formates, acetates, butyrates, iso-butyrates, valerates, benzoates), citronellal, hydroxy-citronellal, menthol, geranyl anthranilate, geranyl methyl ether, citral, citronellyl cinnamate, citronellal dimethylacetal, isopulegone, pulegone. Young claims that d-citronellal can be removed from oil of citronella by fractional distillation under reduced pressure and replaced by synthetic dl-citronellal without loss of odour value.

13.2 PESTICIDE

Insect repellent action:
Citronella oil has been widely used as an insect repellent. Mixed with cedarwood oil, 'Virginia' , it has been a popular remedy against mosquito attacks for many years prior to the appearance of DDT and other modern insecticides. It is a constituent of many mosquito creams and insect repellent candles. Formulations of some insect repellents are given below:

Anti-mosquito cream:

Citronella oil	18.25%
Camphor	1%
Cedar wood oil	1%
Hard paraffin	17.25%
White soft paraffin	45%
Stearic acid	30g

Janet Citronella milk

- Citronella
- Neem
- Maduruthala (Holy Basil)
- Lavender
- Vegetable oil.

These can be applied to hands, face, neck, ears. It keeps off mosquitoes. It is reported to have a protective action against sand flies as well.

Mosquito repellent Candle Stick

Wax	530g
Vaselene colour	120g
Eucalptus oil	50g
Citronella oil	30g
Stearic acid	30g
Camphor	20g

Melt wax and stearic acid in a pan and mix other ingredients.

Dicophane application:
(DDT application for external used on the skin.)

Dicophane	20g
Emulsifying wax	40g
Citronella oil	5ml

Xyiene	150ml.
water to make	1,000ml.

In the following preparation by show, the citronella oil is said to assist in retarding the evaporation of the preparation:

Castor oil	25%
Bear oil	25%
Citronella oil	10%
Pennyroyal oil	10%
Dimethyl phthalate	30%

Steiner reports that Ceylon citronella oil is an effective repellent against the Oriental fruit fly.

A report from Pakistan states that the maximum protective time when using citronella oil as a repellent is 1 hour 18 min. and % repellency against mosquitoes:

100%	immediately after application.
45%	30 mins. after application
43%	1 hour after application
0	1 ½ hours after application

% repellency after washing with soap and water.

67%	after 30 mins.
23%	after 1 hour

Travis et al report that the repellent time against buffaloe gnats was 400-600 min. for *Prosimulium hirtipes* and *Simulium venustuma* repellent time was 240 min.

Gouck et. al. tested the efficacy of citronella oil against water leeches, while Saxene et. al. studied the efficacy of the oil against land leeches.

The histopathological effects of the oil on the nervous system of insects was studied by Richards and Cutcomp.
In Marclu's patent for an insect – repellent, candle, citronella oil has been dispersed in a hydrocarbon wax and held in a windproof plastic stand.

Citronella oil is a constituent of pyrethrum-based insecticides.
An example of such a formulation is

Pyrethrum (35% extract)	2-50% by weight
Pine needle oil	10-75%
Eucalyptus oil	20-75%
Citronella oil	1-10%
Peppermint oil	0.5-5%

Prasad and Jamwal patented the following formula for insecticidal coils and incense sticks:

Pyrethrum marc	45.3%
Sawdust	10.6%
Litsea sebifera bark	39.9%
Pyrenthrum oleoresin	2%
Benzoic acid	0.2%
Citronella oil	2%

Oil of Citronella has been recommended for use as a preservative for books and natural history specimens.

Dog – repellent

Citronella oil is one of the constituents of the following formulation which is a dog repellent:

Oil of Citronella	8.5 parts
Oil of Anise	1 part
Oil of Eucaliptus	0.5part

The weather-resistance of this mixture is said to be increased by the addition of polyacrylic acid or polymethacrylic acid (3 parts) dissolved in alcohol or acetone (95 parts)

13.3 FOOD

The recommended usage level of oil of citronella, as a flavour in foods is as follows:

Non-alcoholic beverages	17 ppm
Ice creams, ices, etc.	26 ppm
Candy	25 ppm
Baked goods	31 ppm

13.4 MISCELLANEOUS USES

Flotation – Oil of citronella treated with H_2S has been recommended for ore flotation. In another Patent, 300g of oil of citronella, is treated with 400ml of 5% H_2SO_4, the H_2SO_4 layer separated, washed with water, neutralised with $NaHCO_3$ and separated from the aqueous layer to give a light yellow viscous liquid, which is said to be an excellent frother for flotation.

Electrolysis – In the electrolysis of silver fluoride solutions, smooth matty deposits of silver are said to be obtained, when boric acid and citronella oil are added. Oil of citronella is a constituent of printing inks for polythene and of stiffening and sizing agents for the textile industry.

Grass :

Although fresh grass is not eaten by cattle, spent grass is used as a cattle feed. Spent grass is also used for thatching roofs, for growing mushrooms, as a mulch for tea bushes, and for making paper. It is usually used as a fuel for the steam boiler in distilleries.

Guhu et. al. obtained the following proximate analysis for Java citronella grass dust, passing through 60 mesh and retained in 80 mesh sieve:

Ash content	5.5%
Alcohol-benzene solubility	15.5%
Ether solubility	9.2%
Cold water solubility	6.2%
Hot water solubility	15.5%
1% NaOH solubility	39.0%
Pentosans	15.5%
Lignin	20.8%
Cellulose	50.6%

Fiber length : 0.56 – 1.68 mm
Fibre diameter : 0.007 – 0.028 mm

The best pulping conditions for the grass, based on the soda process, were found to be: 3 hour cooking at 142 ^{0}C, with 17% chemicals, yielding 37.1% unbleached pulp and 32.2% bleached pulp.

Permanganate number	11.5
Burst factor	47.9
Folding end (double folds)	168
Brightness (MgO – 100)	65
Breaking strength	8490 mm
Tear factor	85.6

It was found that extracted grass could also be used for pulping.
Ash has a high silica content, used as a fertilizer for sugarcane.

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