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RESEARCH ARTICLE

STRATEGY FOR HABITAT SELECTION FOR LEMONGRASS (*CYMBOPOGON CITRATUS* STAPF.) CULTIVATION IN NON- RESERVE FORESTS OF WESTERN GHATS, KERALA, INDIA

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ABSTRACT

In certain low hills of Western Ghats of Kerala, the tribal communities *viz.,* Kattunaikans, Paniya and Uralis (Wayanad district), Malappandarum, Mala-aryan, Malavedan and Malakuruva (Pathanamthitta district) and Mala-aryans and Muthuvans (Idukki district) are the integral part of ecosystems. These tribal communities did cultivation of lemongrass and distilled oil. After the declaration of study sites as protective areas for biodiversity conservation, they are not permitted to continue the practice of lemongrass cultivation. However, they are allowed to extract oil from the existing populations, without adapting any cultivation practices. Therefore, while rehabilitating these tribes to other non-reserve forests of adjoining regions, habitats suitable for lemongrass cultivation with good oil quality similar to that of the sites in protected areas must be identified. The present study aims to evaluate favourable habitat for lemongrass growth in non-reserve forests of Western Ghats, Kerala by analyzing certain areas where the lemongrass oil distillation is under practice by the tribal communities. The results of the study show that among the 11 sites, Vadasserikara and Meppadi are more favourable for lemongrass growth and oil yield. Correlation and regression analyses showed that the maximum and minimum temperatures, rainfall and relative humidity, pH, N, P, K Ca and Mg contents of soil and altitude are largely determining the biomass production, oil concentration in biomass and citral percent in oil. Therefore, it is suggested to identify habitats in nearby non-reserved forests with more or less similar climatic conditions, soil pH and nutrients and altitude as in Vadasserikara and Meppadi for practicing agroforestry by lemongrass cultivation and oil distillation for tribal communities.

INTRODUCTION

Low hills of Western Ghats of Kerala at Wayanad, Pathanamthitta and Idukki districts, have an undulating topography and climatic variation which support a wide variety of flora and fauna. The tribal communities *viz.,* Kattunaikans, Paniya and Uralis of Wayanad district, Malappandarum, Mala-arayan, Malavedan and Malakuruva of Pathanamthitta district and Mannan and Muthuvans of Idukki district, who inhabit the reserve forests of this landscape are an integral part of these ecosystems. These tribals have cultivated lemongrass (*Cymbopogon citratus*) in fragile areas and rocky slopes and are getting good economic returns (Paulsamy *et al.,* 2000). But after the declaration of this region as Reserve forests, cultivation of any sort has been banned in this region even for tribals. However, the tribals are permitted to harvest the existing lemongrass populations for oil extraction in some localities of low lying areas in these regions without posing any environmental problem (Paulsamy, 2004). For the better conservation of flora and fauna in recent years, no human activities including lemongrass oil distillation are permitted and strict legal measures are imposed against violators. Therefore, to achieve the high degree of species conservation, the tribal communities may be rehabilitated to the adjoining non-reserve forests of nearby areas in coarse of time. For this purpose of rehabilitation, potential areas for lemongrass cultivation with similar environmental conditions of certain areas in Wayanad, Pathanamthitta and Idukki district of Kerala where the lemongrass production is higher along with better yield and quality of oil must be identified. As the tribals have vast experience with lemongrass production and oil extraction, other non-reserved localities of these study sites that have favourable habitat for better lemongrass cultivation needs to be identified. By considering these facts, the present study was aimed to evaluate the best suited habitat among the sites where lemongrass oil distillation is being made by the tribals.

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MATERIAL AND METHODS

Study areas

Eleven study areas situated in different places of southern Western Ghats of Kerala were selected for the present study (Fig. 1). Mananthavady (site - I - 760m above msl), Pulpally (site - II - 907m above msl), Meppadi (site - III - 874m above msl) and Ambalavayal (site - IV - 938m above msl) are the study areas located in the Western Ghats of Wayanad district, Kolamala (site - V - 148m above msl), Malayalapuzha (site - VI - 136m above msl), Pazhakulam (site - VII - 146m above msl), Vadasserikara (site - VIII - 150m above msl) and Konni (site - IX - 152m above msl) are the study areas located in Pathanamthitta district and Marayoor (site - X - 990m above msl) and Kandalloor (site - XI - 1524m above msl) are the study areas located in Idukki district of Kerala state.The data on soil pH and climatic factors for the study period of one year (June, 2014- May, 2015) are presented in Table 1 and Fig. 2. These data were obtained from the respective taluk head quarters. Both south- west monsoon (June- August) and north-east monsoon (October- November) were effective almost in all sites studied.

Tribal communities

The tribal communities *viz*., Kattuunaikans, Paniya and Uralis have settled in Pulpally, Mananthavady, Meppadi and Ambalavayal of Wayanad district, Malapanadaram, Mala-arayan, Malavedan and Malakuruva have settled in Kolamala, Malayalapuzha, Pazhakulam, Vadesserikara and Konni of Pathanamthitta district and Mannan and Muthuvans have settled in Marayoor and Kandalloor of Idukki district respectively. In addition to the maintenance of lemongrass community by eradicating dicot weeds and other unwanted monocots, these tribal communities are engaged in a host of other activities like cattle rearing, honey collection, casual labour for forest department etc.

Soil attributes

Soil samples from A_1 layer (0-10cms) (1kg in each site) in triplicate were collected at all times of harvesting the lemongrass and mixed thoroughly to obtain composite sample. Working samples were obtained to analyze the soil pH (Ghosh *et al*., 1983), total nitrogen (Jackson, 1962), available phosphorous (Bray and Kurtz, 1945) and potassium, calcium and magnesium by flame photometric method (Stanford and English, 1949).

Biomass production

The tribals harvested lemongrass from the study sites 6 times in the months of June, August, October and December of 2014 and February and April of 2015during the study period. The harvested grasses were sun dried adequately for 3-5 days and weighed before oil distillation. Thus the data on dry weight of total aboveground lemongrass for the total area of all the sites during different harvesting times were collected from the tribals. These biomass data of six harvesting times collected for respective site were pooled together over a study period to arrive the annual production of lemongrass (Singh and Yadhava, 1974). As the grass was completely scraped at two months interval, the biomass harvested at every time is its production in the total area of the respective site.

Oil yield

The data on oil yield was collected site-wise from the respective tribal community directly after distillation every time. Percentage of oil content in biomass was arrived by using the data on total grass biomass harvested and oil content (%) available in grass. Oil yield in all harvesting times in each site were summed to get annual production of lemon grass oil.

Citral estimation

Oil samples collected from the tribal communities for each site were analyzed for citral content by following sodium bisulphate method (Guenther, 1972). Ten ml of oil was taken in a beaker to which 30g sodium bisulphate and 100 ml distilled water were added. This mixture was boiled and shaken well for 10 min. After the formation of a white precipitation, the beaker was dipped in water bath for 45 min to dissolve the precipitation completely. Then the beaker was cooled under tap water. The non-citral portion of the oil separates as an oily layer which has been measured conveniently in the neck of a Cassia flask and there by determined the citral content of the oil.

Statistical analysis

Statistical significance between the sites for oil and citral contents were determined using one-way analysis of variance (ANOVA) (SPSS 10.0) and the means were separated by Duncan's Multiple Range Test (DMRT) (P<0.05). Statistical analysis was not performed for the attribute, lemongrass biomass production between the study sites as there were no replicates and the data on harvested biomass were collected from the respective tribal communities directly for the whole area. Correlation coefficients were calculated (SPSS, 1998) to determine the relationships between production attributes of lemongrass (biomass production, oil content in biomass and citral percentage in oil) and certain climatic and soil attributes and altitude. Multiple regression analysis was used to test the interactive effect of climatic, soil and altitudinal factors on the production attributes of lemongrass.

RESULTS AND DISCUSSION

The range of minimum and maximum temperatures (18ºC and 28°C and 23ºC and 35°C respectively) and annual rainfall (4 - 516mm) recorded across the study sites during the study period of one year indicate the prevalence of suitable climate for lemongrass cultivation (Nambiar and Matela, 2012) in the study area (Fig. 2). The relative humidity generally ranged between 61.5 % and 82.5%. The soil of all study sites was sandy loam with the pH varied between 6.2 and 6.9 during the study period (Table 1). The alkaline pH noted in Ambalavayal (site- IV) and Vadasserikara (site-VIII), Meppadi (Site III), Pazhakulam (Site VII) at all times of sampling during the study period showed the preference of alkalinity in soil for this grass growth (Quadry, 2008-2009). The nutrient contents of soils of the study sites were generally varied significantly between the sites studied (Fig. 3). The percentage variations of nutrients (mean of the year) among the soils of study sites are as follows: N – 0.04 (Vadasserikara) and 1.6 (Kandalloor), P – 0.01 (Meppadi and Kolamala) and 0.5 (Meppadi and Kolamala), K – 0.06 (Marayoor) and 0.29 (Mananathavady, Kolamala, Vadasserikara, Konni and Marayoor), Ca – 0.07 (Mananthavady) and 0.12 (Pulpally, Meppadi, Ambalavayal, Pazhakulam, Vadasserikara and Konni) and Mg – 0.04 (Mananthavady, Pulpally, Meppadi, Kolamala, Malayalpuzha, Pazhakulam, Vadasserikara, Konni, Marayoor and Kandalloor) and 0.06 (Mananthavady, Pulpally, Meppadi, Ambalavayal, Kolamala, Pazhakulam, Vadasserikara, Konni, Marayoor and Kandalloor).

continued rain since June, 2014. Less nutrient content in the soils of Chrysopogon zeylanicus dominated grassland communities of Anaimalais, the Western Ghats coupled with

Table 1. Soil pH of the lemongrass communities in the study sites during the study period

Year &	Sites*									
month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
2014Jun	6.8	6.5	6.9	6.3	6.6	6.6	6.9	6.9	6.5	6.5	6.5
Aug	6.7	6.5	6.9	6.2	6.7	6.7	6.8	6.9	6.5	6.5	6.4
Oct	6.6	6.5	6.9	6.4	6.5	6.7	6.6	6.8	6.6	6.4	6.5
Dec	6.7	6.4	6.8	6.3	6.5	6.7	6.6	6.9	6.5	6.6	6.6
2015Feb	6.8	6.6	6.8	6.4	6.5	6.6	6.7	6.8	6.6	6.5	6.6
Apr	6.7	6.7	6.8	6.5	6.6	6.5	6.8	6.8	6.6	6.5	6.6
Mean	6.7	6.5	6.8	6.3	6.5	6.6	6.7	6.8	6.5	6.5	6.5

*Site1-Mananthavady, Site II - Pulpally, Site III - Meppadi, Site IV - Ambalavayal, Site V - Kolamala, Site VI -Malayalapuzha, Site VII - Pazhakulam, Site VIII - Vadasserikara, Site IX - Konni, Site X - Marayoor, Site XI –Kandalloor.

Table 2. Annual biomass production and area of lemon grass community, oil content and production and revenue generated in the study sites

Sites*	Annual production of lemon grass (kg/ha)	Area of lemon grass community (ha)	*Oil content (%)	Oil production (kg/ha/yr)	**Annual revenue (Rs/total area of grass community)
I	6440	2	0.40	25.76	25760
II	8380	3	0.45	37.71	56565
III	7540	2.5	0.42	31.66	39575
IV	7800	3	0.44	34.32	51480
V	8910	2	0.41	36.53	36530
VI	7090	2.5	0.43	30.48	38100
VII	7660	2.5	0.42	31.40	39250
VIII	6480	2	0.41	26.56	26560
IX	7680	3	0.44	33.79	50685
X	6480	2.5	0.40	25.92	32400
XI	6340	2.5	0.43	27.26	34075

*Site1-Mananthavady, SiteII - Pulpally, SiteIII - Meppadi, SiteIV - Ambalavayal, SiteV - Kolamala, SiteVI -Malayalapuzha, SiteVII - Pazhakulam, SiteVIII - Vadasserikara, SiteIX - Konni, SiteX - Marayoor, SiteXI –Kandalloor.

Table 3. Correlation coefficient (r) between citral (%) in the lemongrass oil extracted from *Cymbopogan citratus* and certain environmental variables of the study sites

	Mat	Mit	Rf	Rh	Alt	pH	N	P	K	Ca	Mg
Oil yield	0.277*	- 0.068	- 0.035	- 0.265*	- 0.011	0.094	- 0.598**	0.194	- 0.292*	- 0.275*	0.029
Biomass	0.383**	- 0.020	0.760**	0.548**	- 0.091	- 0.065	- 0.028	0.380**	- 0.597**	- 0.100	0.056
Citral	- 0.035	0.044	- 0.434**	-0.265*	0.117	0.194	- 0.109	- 0.170	0.174	- 0.049	-0.069

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

It shows that Vadasserikara and Meppadi sites registered higher nutrients in their soils than that of the other sites. The aboveground biomass production estimated during the harvesting times in the study year (Jun, 2014-April, 2015) was higher at the end of the south-west monsoon period, August, 2014 in all the study sites and ranging between 450 kg/ha and 2700 kg/ha in Mananthavady and Pulpally respectively. It may be attributed to the fact that with the onset of monsoon in June, there was an active biomass build up and it attained maximum during August after two months of vegetative growth. Singh and Krishnamurthy (1981) reiterate that the temporal variation exhibited in the attainment of peak biomass in grassland communities of tropical climate is related to quantity of rainfall. Paulsamy *et al.* (2000) showed an enhanced biomass production of lemongrass at the end of south-west monsoon season in some parts of Anaimalai hills, the Western Ghats. The lemongrass production decreased progressively towards summer from August at all sites. Low or no rainfall except in the month of October, 2014 perhaps be the reason for this fact. However, lower biomass production during the rainy month of October, 2014 in all sites may be due to less quantity of nutrients available in soil caused by leaching owing to lower primary production has already been reported in Anaimalais (Wilson, 1964). The annual aboveground biomass production of lemongrass was greater in Kolamala (8910 kg/ha) followed by Pulpally (8380kg/ha), Ambalavayal (7800 kg/ha), Konni (7680 kg/ha), Pazhakulam (7660 kg/ha), Meppadi (7540 kg/ha),Malayalapuzha (7090 kg/ha), Marayoor (6480 kg/ha), Vadasserikara (6480kg/ha),Mananthavady (6440 kg/ha) and Kandalloor (6340 kg/ha) (Fig. 3 and Table 2). However, the production estimates for all these sites are not comparable to that of other cultivated fields of lemongrass elsewhere (Evans, 2002; Aradhna and Yashpal, 2014) as no cultivation practices like weed control, either organic or inorganic fertilizer application, annual burning, reseeding, etc are followed in the study sites. As in tropical regions, rainfall is the most influential factor for the vegetative growth of plants (Swamy *et al.,* 2010), the higher rainfall occurred in Kandalloor ranked first with respect to biomass production. Further, the levels of annual production in different study sites varied considerably according to the rainfall in the respective sites. This clearly indicates that rainfall is the major factor that determines the lemongrass production in the study areas. In addition, high alkalinity in the soils of the study sites, Vadasserikara (6.8) and Meppadi (6.8) was also found to be a favourable factor for the higher biomass production of lemongrass (Srivastava *et al.,* 2013).

collectively alter the quantitative and qualitative aspects of essential oils in plants by making changes in metabolism so as to produce defense chemicals against the adverse conditions.

Table 4. Best multiple regression obtained between lemongrass production attributes (biomass production, oil yield and citral per cent in oil) and certain environmental variables maximum and minimum temperature (Mat and Mit respectively) rainfall (Rf), relative humidity (Rh),altitude (alt)soil pH and soil characters like nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg)

Lemongrass production attributes	Equation	*r*	*p*
Biomass	Y= - 48.686 - 6.808 Mat + 39.213 Mit + 2.600Rf	R=0.770	0.936
	Y= - 38.602 + 2.278 Rf +13.808 Rh - 0.296 Alt	R=0.793	0.961
	Y= -125.357- 6.275 Mat+ 38.909 Mit + 2.572 Rf + 1.042 Rh	R=0.770	0.910
	Y = - 230.032 + 55.045 Rh - 0.376 Alt -182.790 pH - 1.879 N + 354.860 P - 4294.847 K	R=0.778	0.916
	Y = - 32.206 + 55.202 Rh - 0.375 Alt -196.438 pH – 7.861 N + 320.829 P - 4273.929 K – 1243.411Ca	R=0.779	0.988
	Y = -150.662 + 54.979 Rh - 0.374 Alt + 187.139 pH+ 5.075 N + 336.630 P + 336.630 – 4266.686 K – 1259.252 Ca + 1377.571 Mg	R=0.779	0.948
	Y = 171.853 + 55.286 Rh - 0.384 Alt -183.834pH- 1.464 N +370.879 P - 4556.520 K – 1061.035Ca +1268.155 Mg - 10.119 Mat	R=0.780	0.943
Oil yield	Y = 0.020 - 0.241 N- 0.226 P + 0.187 K - 3.688 Ca - 0.021 Mg + 0.022 Mat	R=0.729	0.955
	Y = - 0.018 - 0.244 N - 0.225 P + 0.196 K – 3.757 Ca – 0.087 Mg + 0.021 Mat + 0.003 Mit	R=0.730	0.961
	Y = 0.094 + 0.036 Mat- 0.026 Mit + 0.000 Rf – 0.003 Rh- 1.679E-5 Alt + 0.018 pH- 0.207 N- 0.091 P	R=0.720	0.923
	Y = 0.113 + 0.485 Mg + 0 .035 Mat- 0.026 Mit + 0.000 Rf- 0.004 Rh-1.533E-5 Alt + 0.021 pH- 0.202 N	R=0.719	0.908
	Y = 0.076 + 0.348 Mg + 0.036 Mat- 0.026 Mit + 0.000 Rf- 0.004 Rh-1.620E-5 Alt + 0.021 pH- 0.206 N - 0.088 P	R=0.720	0.939
	Y = 0.058 + 0.000Rf- 0.001 Rh-3.321E-6 Alt + 0.011 pH- 0.247 N- 0.280 P- 0.218 K – 3.871 Ca- 0.145 Mg + 0.028 Mat	R=0.786	0.949
	Y = 0.058 + 0.028 Mat + 0.000 Rf- 0.001 Rh – 3.321E-6 Alt + 0.011 pH- 0.247 N- 0.280 P- 0.218 K- 3.871 Ca- 0.145 Mg	R=0.786	0.949
Citral	Y= 51.748 + 0.288 Mat - 0.137 Mit - 0.009 Rf 0.077 Rh + 0.001 Alt +2.357 pH - 0.668 N - 3.623 P	R=0.628	0.001
	Y= 49.994 + 0.315 Mat - 0.082 Mit - 0.009 Rf + 0.092 Rh + 0.001 Alt +2.255 pH - 0.872 N - 3.620 P +3.633 K - 15.836 Ca	R=0.651	0.001
	Y= 53.635 -15.059 Ca -27.687 Mg + 0.295 Mat - 0.090 Mit - 0.009 Rf + 0.102 Rh + 0.001 2.073 pH - 0.891 N - 4.512 P	R=0.657	0.001
	Y=50.144 - 0.009 Rf + 0.106 Rh + 0.001 Alt +2.164 pH -1.032 N -3.844 P +3.970 K -17.216 Ca -27.923 Mg + 0.284 Mat	R=0.658	0.001
	Y= 51.545 + 0.313 Mat - 0.073 Mit - 0.009 Rf + 0.106 Rh +0.001 Alt +2.085 pH - 0.964 N – 3.933 P +3.385 K -15.983 Ca -26.992 Mg	R=0.660	0.001
	Y=50.144 +0.284 Mat - 0.009 Rf + 0.106 Rh +0.001 Alt +2.164 pH -1.032 N - 3.844 P +3.970 K -17.216 Ca -27.923 Mg	R=0.658	0.001
	Y= 53.635 + 0.295 Mat - 0.090 Mit - 0.009 Rf + 0.102 Rh + 0.001 Alt + 2.073 pH - 0.891 N - 4.512 P -15.059 Ca -27.687 Mg	R=0.657	0.001
	Y= 49.994 + 0.315 Mat - 0.082 Mit - 0.009 Rf + 0.092 Rh + 0.001 Alt + 2.255 pH – 0.872 N -3.620 P + 3.633 K -15.836 Ca	R=0.651	0.001

The oil content in the aboveground biomass of lemongrass for the studied sites varied significantly between the harvests (Fig. 5). Higher oil content was recorded in the study sites, Pulpally (0.45%), Ambalavayal (0.44%) and Konni (0.44%) while the sites at Mananthavady and Marayoor contained less oil content of 0.40%. This may be attributed to the synergetic effect of all climatic and soil variables (Pirzad *et al.,* 2006). Brant *et al.* (2008) also explained that various environmental factors

Citral is (37-dimethyl-2,6-octadien-1-al) the main constituent of lemongrass oil (Wilson *et al.,* 2002; Dudai *et al.,* 2005; Nhu-Trang *et al.,* 2006) varied markedly between the sites and harvests (Fig. 6). Significantly higher percentage of citral (77.1%) was found in Meppadi (site III) and (77.0) Vadasserikara (site VIII) during the summer month of April, 2014 and that of the lower occurred in Konni (site IX), Pazhakulam (site VII) and Pulpally (site II) during the rainy month of August, 2014. Generally at all sites, the citral content in the oil was more during dry months (February and April) and less during wet months (June-October). Oliveros and Aureus (1977) explained that the variation in citral content is the function of weather conditions like dry environment with higher incidence of sunlight which promotes the formation of such chemicals for resisting the adverse conditions. The mean annual percentage of citral content was higher in the lemongrass of Meppadi (site III) and Vadasserikara (site VIII) while the lower was determined in Konni (site IX), Pazhakulam (site VII) and Pulpally (site II), Alsafar and Al-Hassan (2009) reiterate that different communities of same macroclimatic zone exhibit variation in their metabolites according to the combined action of microclimatic factors. Therefore, the coupled actions of environmental factors exist in the studied sites perhaps be the reason for this fact. As the concentration of oil in the lemongrass biomass at different periods of harvest varied, the oil production is also varied markedly between the sites. The lemongrass from Pulpally (site II) recorded the highest oil production of 37.7kg/ha/yr and the lowest of 25.76 kg/ha/yr was recorded in Mananthavady (site I). This was also reflected in the annual revenue generated from lemongrass oil distillation in the studied sites (Table 2). The tribal communities at Pulpally (site II) site earned greater returns of Rs. 56565 through lemongrass oil extraction. On the other hand, the tribals at Mananthavady (site I) got less economic return due to poor oil concentration and hence the oil production in their sites.

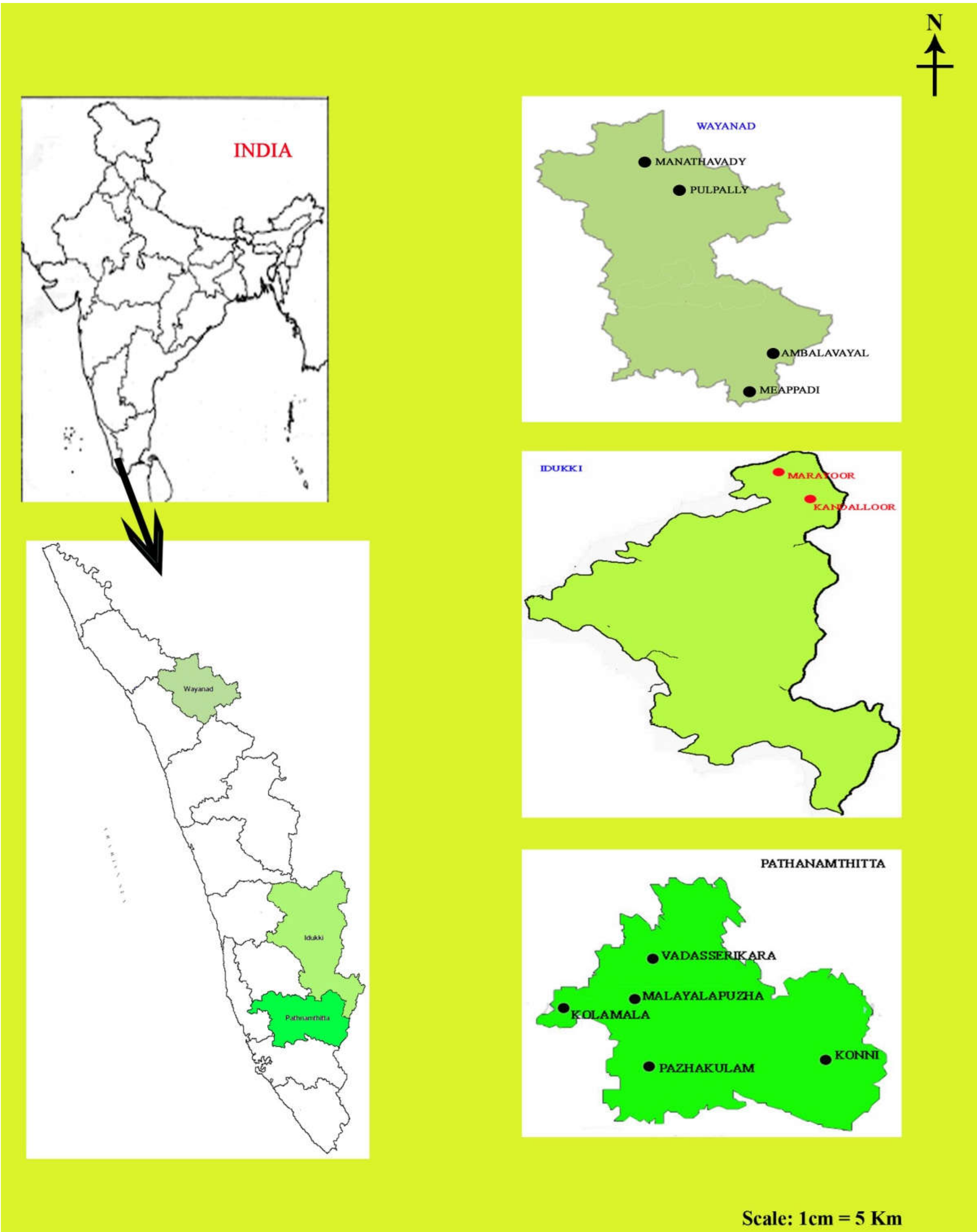
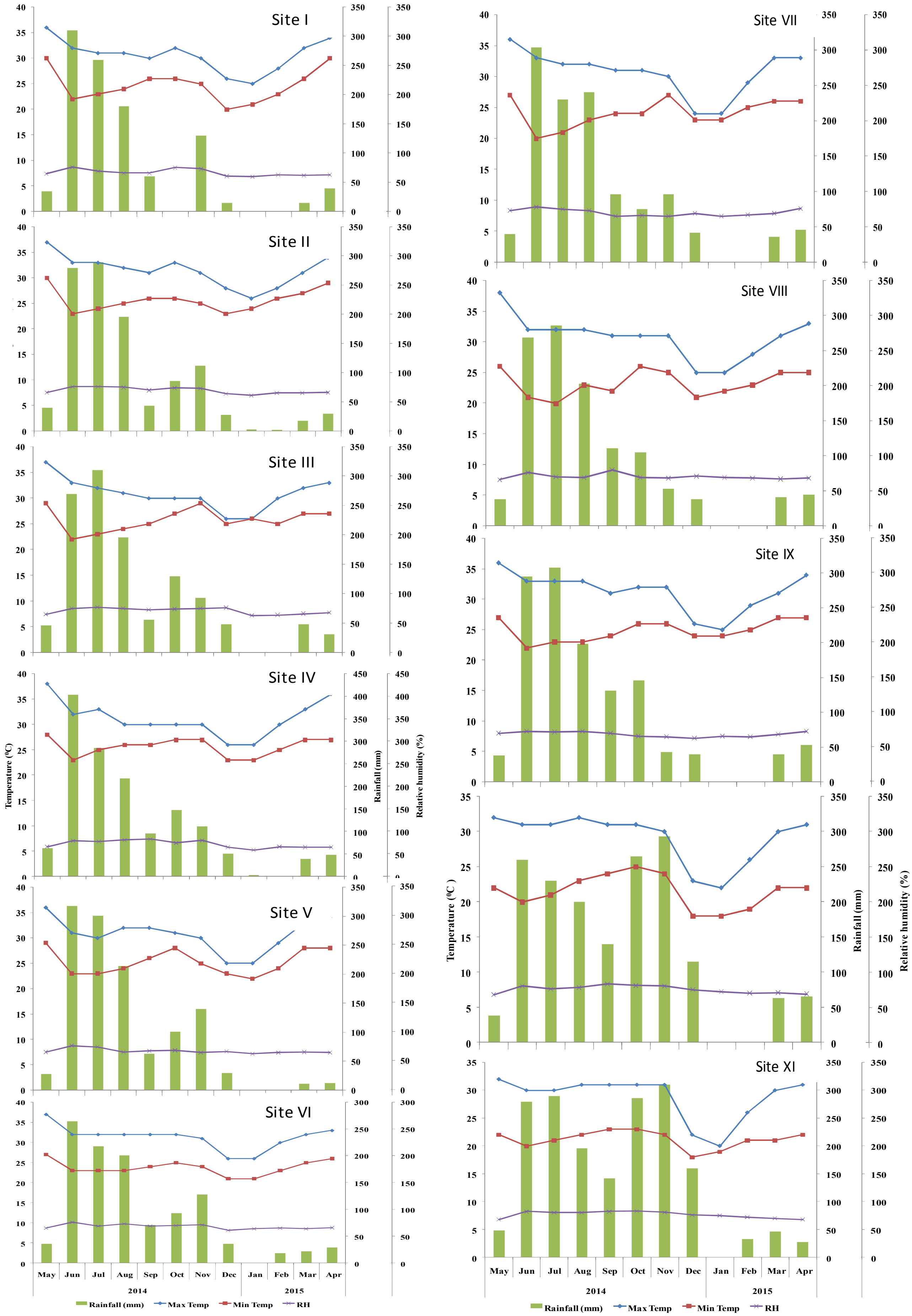
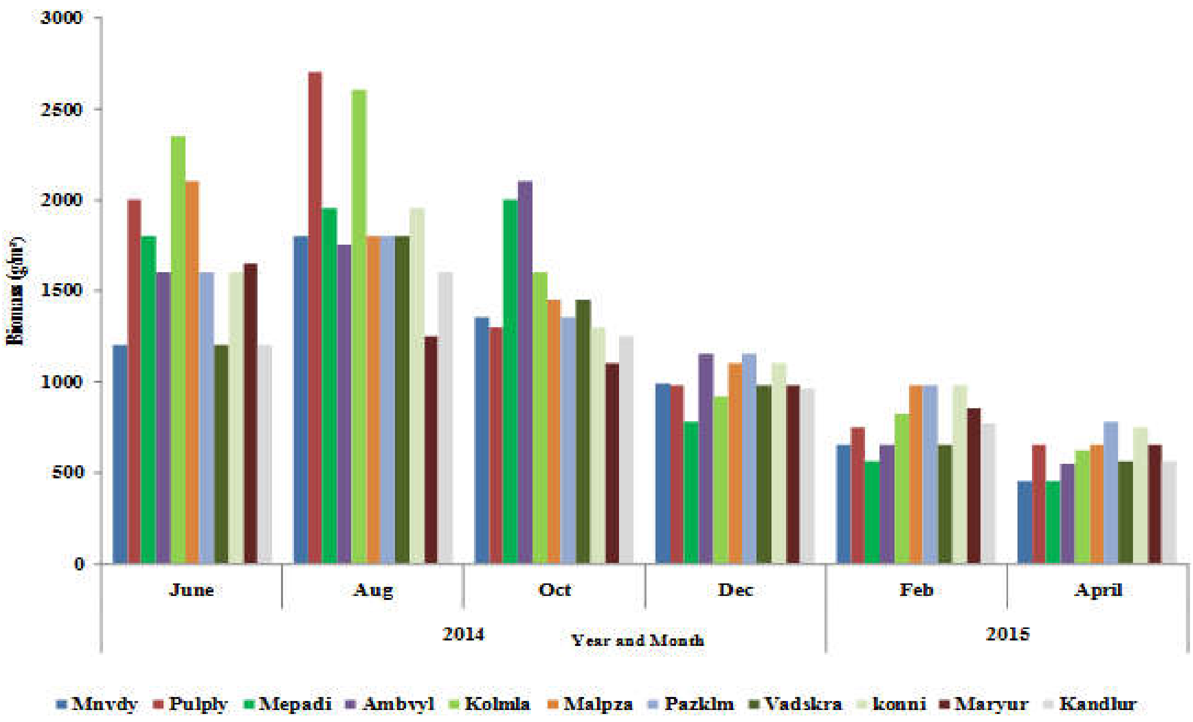


Fig. 1. Location of the study areas



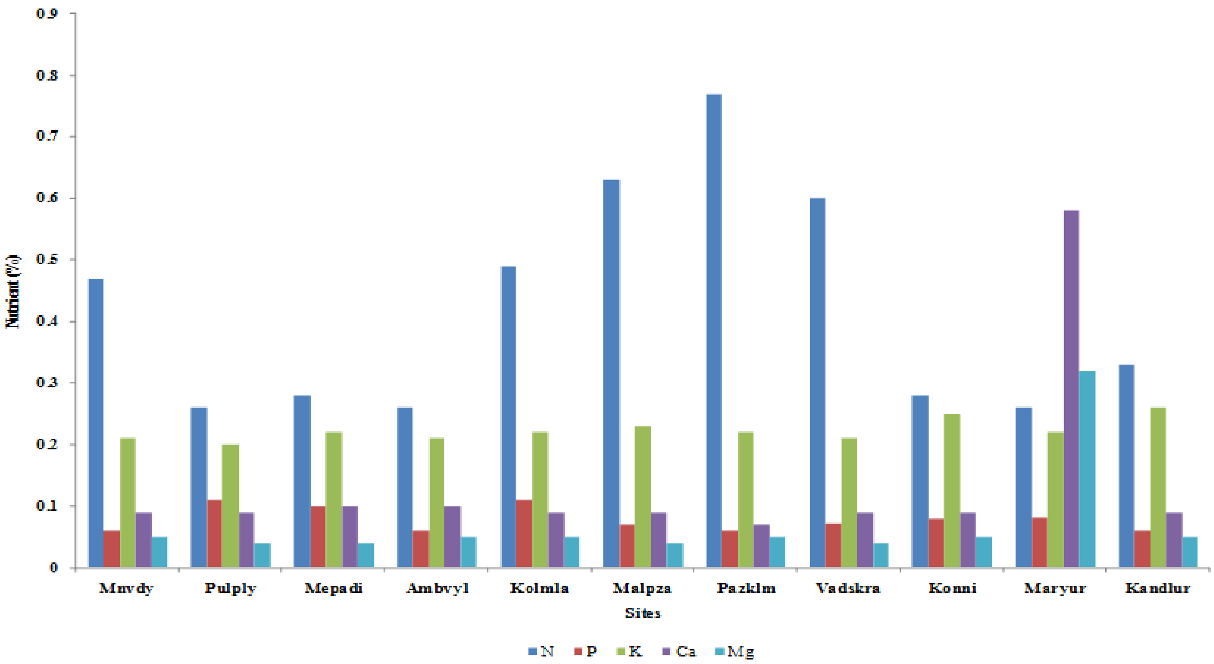
Sites: I -Mananthavady,II -Pulpally, III -Meppadi,IV-Ambalavayal,V-Kolamala,VI-Malayalapuzha. VII-Pazhakulam, VIII-Vadasserikara, IX-Konni, X-Marayoor, XI-Kandalloor

Fig. 2. Monthly maximum and minimum temperatures, rainfall and relative humidity of the study sites during May, 2014- April, 2015



I –Mananthavady (Mnvdy),II –Pulpally (Pulply) , III –Meppadi (Mepadi),IV-Ambalavayal (Ambvyl), ,V-Kolamala (Kolmla),VI-Malayalapuzha (Malpza).VII-Pazhakulam (Pazklm), VIII-Vadasserikara (Vadskra), IX-Konni (Konni), X-Marayoor (Maryur), XI-Kandalloor s(Kandlur).

Fig. 3. Aboveground biomass of lemongrass in the study sites of Western Ghats in Kerala during the sampling months

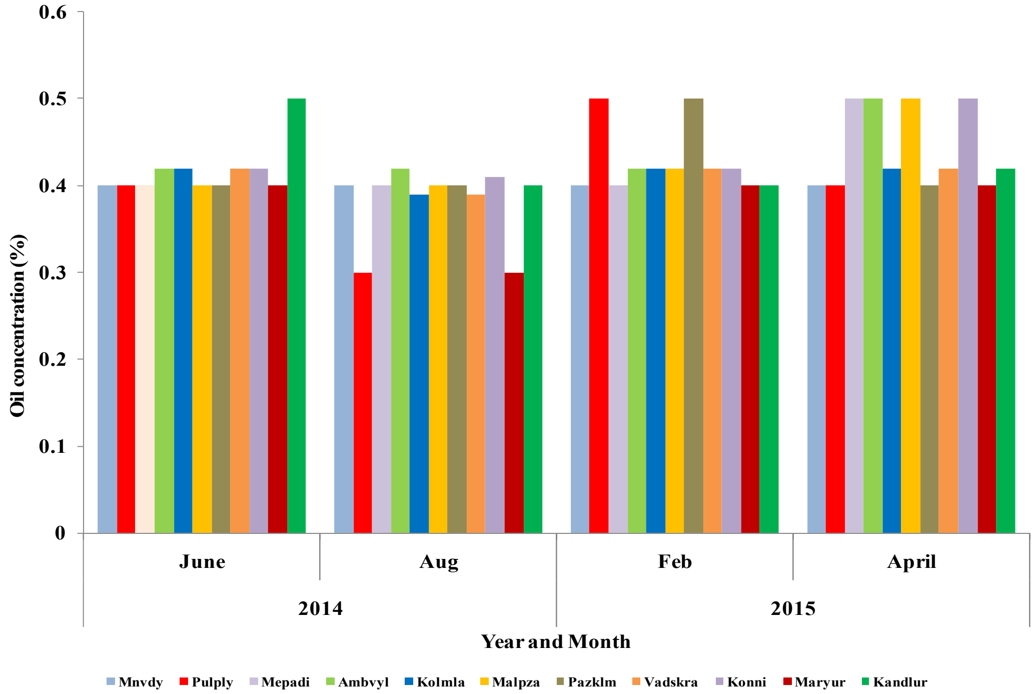


I –Mananthavady (Mnvdy),II –Pulpally (Pulply), III –Meppadi (Mepadi), IV-Ambalavayal (Ambvyl), V-Kolamala (Kolmla),VI-Malayalapuzha (Malpza).VII-Pazhakulam (Pazklm), VIII-Vadasserikara (Vadskra), IX-Konni (Konni), X-Marayoor (Maryur), XI-Kandalloor (Kandlur).

Fig. 4. Annual mean percentage of N, P, K, Ca and Mg in the soil of A_1 horizon of the study sites in Western Ghats, Kerala during the sampling months

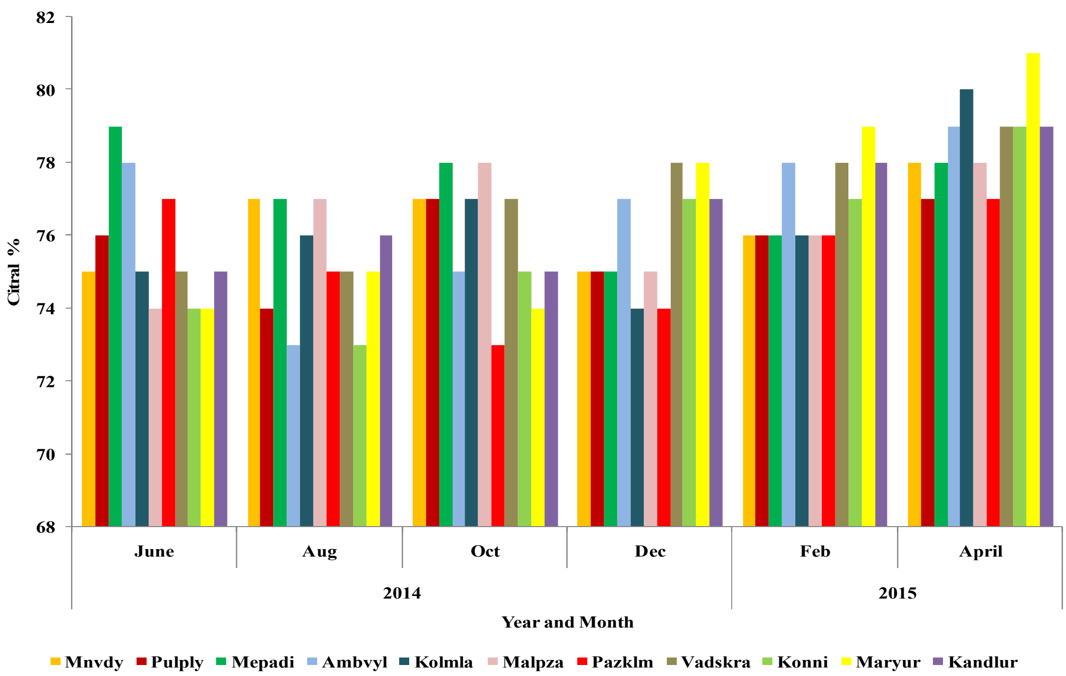
An analysis of data elucidated several functional relations among the variables of lemongrass production (biomass, oil yieldand citral content) and certain climatic, soil and altitudinal factors (Table 3). The rainfall and relative humidity, and maximum temperature were positively correlated to biomass production (r = 0.760 and 0.548, P<0.01 and 0.383, P<0.05).

It is well known that in tropical communities, rainfall being a limiting factor influences largely on growth and biomass production (Gunarathne and Perera, 2014). Taiz and Zeiger (2004) explained that high relative humidity favours stomatal opening which causes free flow of gases for photosynthesis, results in increasing of biomass production, provided adequate rainfall occurs.



I –Mananthavady (Mnvdy),II –Pulpally (Pulply) , III –Meppadi (Mepadi),IV-Ambalavayal (Ambvyl), ,V-Kolamala (Kolmla),VI-Malayalapuzha (Malpza).VII-Pazhakulam (Pazklm), VIII-Vadasserikara (Vadskra), IX-Konni (Konni), X-Marayoor (Maryur), XI-Kandalloor (Kandlur).

Fig. 5. Oil concentration (%) in the aboveground lemongrass biomass of the study sites during different periods of harvest in the study sites of Western Ghats, Kerala



I –Mananthavady(Mnvdy),II –Pulpally(Pulply) , III –Meppadi (Mepadi),IV-Ambalavayal(Ambvyl), ,V-Kolamala(Kolmla),VI-Malayalapuzha (Malpza). VII-Pazhakulam (Pazklm), VIII-Vadasserikara (Vadskra), IX-Konni (Konni), X-Marayoor (Maryur), XI-Kandalloor (Kandlur).

Fig. 6. Variation in mean annual citral percentage in the lemongrass oil of study sites

The nutrient of soil, phosphorus was also having positive correlation with the biomass production of lemongrass (r=0.380, P<0.01). Similar kind of observation on the requirement of nutrients like, N, P, K, Ca and Mg for better growth of *Cymbopogon* spp. was made already (Jayalakshmimituala and Mohanaraopuli, 2013; Singh *et al*., 2014).

As the variations in altitude and annual rainfall in the study sites were directly related to each other, it is presumed to have the negative correlation between biomass production and altitude. Other studies have also demonstrated the positive relation of soil pH to lemongrass biomass (Jayasinha *et al.,* 1999; Paulsamy *et al.,* 2000). Relative humidity was negatively correlated to per cent oil content in lemongrass (r = -0.265, *P*<0.01). Barua and Bardoloi (1992) explained that essential oil content in plant parts is directly related to carbohydrate level which tends to increase during the days of higher relative humidity. The minimum temperature was negatively correlated to oil per cent (*r* = -0.08, *P*<0.01). Low temperature generally results in closure of stomata in plants there by reducing oil volatilization, a defence mechanism to resist such adverse condition (Salisbury and Ross, 1991; Castelo *et al.,* 2012). This fact may be the possible reason for the inverse relationship of low temperature with oil per cent in lemongrass. The soil pH was positively correlated to the important chemical constituent of the oil, citral (*r* = 0.194, *P*<0.01). Results of many studies report that alkaline pH generally enhanced not only the biomass production but also the chemical constituents of lemongrass oil (Jayasinha *et al.,* 1999; Siribel *et al.,* 2001). It is evidenced from the present study that the citral content determined was higher in Vadasserikara (site VIII) (77.0%) and Meppadi (site III) (77.1%) where the soil contained significantly higher alkalinity at all times of sampling during the study period when compared to other sites (Table 1).

Plants growing in well drained soils like hilly slopes are highly adapted to alkalinity and may be more sensitive to changes in soil pH by producing certain secondary metabolites like essential oils (Evans, 1996). This is practically true for lemongrass which is known to grow better in alkaline soils (Quadry, 2008-2009) and is producing high citral content in its vegetal parts. Except potassium, the other soil nutrients *viz.,* N, P, Ca and Mg were correlated negatively to citral per cent (*r*= -0.194, -0.170 and -0.49, *P*<0.01). It exhibit that potassium is the major soil factor triggered the production of citral in lemongrass oil. These findings were in conformity with those of Singh *et al.* (2005). In Pearson's correlation analysis, no significant correlation was found between biomass production and soil pH, oil percent in rainfall, and citral percentage in maximum and mimimum temperature. On the other hand the nitrogen content exhibited negative correlation to biomass production. Similarly, oil content were negatively correlated to minimum temperature, soil K content, rainfall and relative humidity and citral percentage were negatively correlated to maximum temperature, rainfall, relative humidity and soil phosphorus respectively. A number of synergistic effects of climatic, soil and altitudinal factors on biomass production, oil content and citral percentage in the oil of lemongrass were detected, but for the sake of brevity, only the best equations for production variables are presented (Table 4).

Therefore, despite the dominant role played by the maximum temperature rainfall, relative humidity, soil phosphorus for dry matter production, maximum temperature, soil pH, phosphorus and magnesium for oil content and minimum temperature altitude, soil pH, potassium and magnesium of soil for citral percentage in oil, the multiple regression analysis showed relationships involving almost all climatic and soil variables studied. Previous literature also documents many complex interactions between climatic and soil factors on growth and oil yield variables of lemongrass (Kulkarni*et al.,* 1997; Paulsamy *et al.,* 2000; Paulsamy, 2004). The present investigation clearly suggests that lemongrass biomass production, oil content in biomass and citral percentage in oil are the functions of climatic factors like rainfall and relative humidity, soil nutrients and pH and altitude but their intensity of influence vary according to other climatic variables like maximum and minimum temperatures. Further, the environmental factors that exist in Vadasserikara (site VIII) and Meppadi (site III) are more favorable for lemongrass growth and quality production of oil. Therefore, areas with similar climatic conditions as in these two sites may be identified in the adjoining non-reserve forest areas for the successful rehabilitation of tribal communities of Western Ghats regions of Wayanad, Pathanamthitta and Idukki districts of Kerala by better agroforestry practices through lemongrass cultivation.

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