Agropedology 2021, 31 (01), 23-42
doi.org/10.47114/j.agroped.2021.jun3

Land Suitability Assessment using GIS for Davana (*Artemisia pallens*) Cultivation in Karnataka, India

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Abstract: Davana is one of the commercially important aromatic crops grown in Karnataka state, India. Agro-ecological conditions of davana growing areas of Karnataka state was characterized and evaluated. Soil parameters were correlated with herbage yield, oil content and its quality to establish soil-site suitability criteria. To identify the suitable zones for davana cultivation elsewhere in Karnataka, a GIS based agro-ecological evaluation was carried out by using soil resource information (121 soil mapping units on 1:250 K scale) of Karnataka state. Each mapping unit was evaluated by matching soil-site suitability criteria with climate and soil parameters to identify the suitable areas for davana cultivation. Around 45.2 lakh ha area is highly suitable, 65.3 lakh ha is moderately suitable, and 54.2 lakh ha is marginally suitable for davana cultivation. Highly and moderately suitable areas need to be focused for expansion of davana as a component of major cropping or farming systems and also to establish forward and backward linkages.

Key words: *Davana, evaluation, GIS, agro-ecology, soil resources, suitability*

Introduction

Davana (*Artemisia pallens* wall ExDC. Fam. *Asteraceae*) is an aromatic plant which is being commercially grown in the states of Karnataka, Tamil Nadu, Andhra Pradesh and Maharashtra, India. Its leaves and flowers are highly valued in the making of floral decorations, bouquets and oils. The oil of davana is used in expensive perfume compositions, flavouring of cakes, pastries, tobacco and some of the costly beverages. Steam distillation of herbage yield an essential oil which contains 20% hydrocarbons, 65% esters and 15% oxygenated compounds. Davana oil is yellow-brown in color with persistent fruity odour and it is expensive oil (Rs.63-65,000/$850/kg) and is exported to countries like USA, Japan *etc.* thus providing good commercial profits. Davanone is a major constituent in davana oil and price of davana oil depends on davanone content.

In south India, davana is mainly grown in red soils and it can also come up well in loamy soils. At present, davana is grown in all types of land due to this lot of variability is observed in productivity and oil content of the crop. To enhance the productivity of herbage, farmers apply nitrogen in excess of crop requirement which leads to increased cost of production and environmental degradation. Season is an important aspect to be considered when davana is grown for

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extracting oil and it is not so important when it is grown for ornamental purpose. The yield oil content and its quality in the plants was observed to be better, when the crop was grown during the winter season preferably in first week of November. India stands third in essential oil production in the world and the production of davana oil is estimated to be around 2.5 t (Lawrence 2009). Yield of fresh herbage is 13.86 to 18.7 t ha^{-1}. High temperature and heavy rains at the time of flowering affect the plant growth and also reduce the oil content and yield. A few light showers in the season, bright sunshine, a crisp winter with no frost and heavy morning dew, all contribute to a good crop. A temperature range of 20-30^{0}C with less diurnal difference is suitable. Davana plant is accredited with antihelmintic, antipyretic and tonic properties. The oil possesses antispasmodic, antibacterial, antifungal and stimulant properties (Suresh *et al.* 2011; Shreyas *et al.* 2018). *Artemesia pallens* possesses anti-inflammatory, antipyretic and analgesic properties and is used in Indian folk medicine for the treatment of diabetes mellitus (Al-Harbi *et al.* 1994; Suresh *et al.* 2011).

In recent days, contract farming of medicinal and aromatic plants (MAPs) is picking up in Karnataka and there are several business houses, which are willing to buy entire produce, provided a single species is grown over a larger area. At present, MAPs are not evaluated for their suitability for different soils and agro-ecological zones. If, suitable MAPs are identified with less variability in yield and quality over large areas, this can help in an integration of these plants in the existing farming / cropping systems. Moreover cultivable wastelands and marginal lands can be brought under these plants. A large scale adoption would offer both producers and traders to evaluate different potential species suitable in the biophysical set up of the region so that viable rural industries could be set up. Additional income generated by these introductions can be ploughed back in to the system to improve potential of land resources. Hence, there is a need to identify agro-ecologically suitable areas and adopt modern agro-techniques to increase the productivity and quality of MAP. The present study was carried out to identify agro-climatically suitable areas for davana cultivation in Karnataka as such information provides basis for creating clusters of farmers/villages in different regions of Karnataka who can cultivate profitably, process and market davana, thus creating value chains.

Materials and Methods

Study area

Karnataka state (11° 30' to 18° 30' N; 74° 15' to 78° 30' E) and covers an area of 19.1 m ha. The state has been divided into three major physiographic divisions, *viz.,* the Deccan Plateau, Hill ranges and Coastal plains (NATMO 1980). These divisions further sub-divided into four regions based on their geographic locations, as South Deccan plateau, Western Ghats, Eastern Ghats and West Coast plains. The state has 30 administrative districts (Fig. 1) divided into 175 talukas.

Fig. 1. Administrative map of Karnataka. Figure created in ArcGIS v10.4.

Climate

The climate varies widely from arid and semi-arid in the plateau region, sub-humid to humid tropical in the Ghat region and humid tropical monsoon type in the West coast plains. The mean annual rainfall of Karnataka is around 1355 mm and it covers 80% of the annual rainfall in the south west monsoon period, 12% in the post-monsoon period, 7% in the summer and only 1% in winter (Krishnan 1984). Karnataka has three meteorological zones, namely, Coastal Karnataka, North Interior Karnataka and South Interior Karnataka. Coastal Karnataka receives an average annual rainfall of 3,456 mm, South Interior Karnataka gets an average rainfall of 1286 mm and North Interior Karnataka receives just 731 mm average rainfall annually. The state has been divided into seven agro-ecological sub-regions (AESR) based on physiography, soils, bio-climate and length of growing period (Sehgal *et al.* 1992). Further, the state has been divided into 17 agro ecological zones based on variations in soils, rainfall, length of growing period (LGP) and physiographic features (Naidu *et al.* 2006).

Data sets used

Soil resource information

The soil resource data (1:250K scale) was prepared for Karnataka state (Shivaprasad *et al*. 1998) using three tier approach *viz.*, landform analysis (Landsat 7/8 imagery), field survey and laboratory investigation, cartography and printing. Soils of the state have been mapped with 121 map units, which are an association of soil families with dominant phases. The Alfisols are the dominant soils covering 27% of the total area followed by Inceptisols 25%, Entisols 16%, Vertisols 15%, Ultisols 8%, Aridisols 5% and Mollisols 1%.

Source of Davana growing areas

Information on extent of area (830 ha) under davana crop was obtained from state Horticulture Department, Krishi Vignana Kendra's (KVKs) located in each district and from farmers besides the data-base available with CIMAP Research Centre, Bangalore. Based on the extent of davana area, sampling strategy was designed for characterization and evolving suitability criteria.

Soil sampling procedure and laboratory analysis

Twenty five surface soil samples (0-20 cm) in two Agro-ecological zones of 7 and 8 (Bangalore rural, Chikkaballapur and Kolar districts) were collected from the davana-growing areas during 2013. In addition to surface samples, five soil profile studies (AEZ-7/8) were carried out in davana-growing areas, where there is high crop spread (>10 ha). Collected soil samples were air dried, sieved through 2mm sieve and processed for laboratory analysis. Soil properties *viz.,*pH (1:2.5 soil water rato) using a pH meter (Jackson 1973), organic carbon (Walkley and Black 1934), available N (Subbiah and Asija 1956), P_2O_5 (Bray's and Olsen's extraction methods, as per soil pH), K_2O (1 *N* Ammonium Acetate extraction method), S (0.15% $CaCl_2$ method), exchangeable Ca and Mg (Jackson 1973) were estimated. Micronutrients (Fe, Mn, Zn and Cu) were extracted (Lindsay and Norvell 1978) by using DTPA extracting solution buffered at pH 7.3 and their concentrations were estimated. Available boron was determined by Hot Water Soluble (HWS-B) method (Berger and Truog 1939).

Plant sampling and analysis

At twenty five soil sites, plant samples were collected at flowering stage (75-90 days after planting) for estimating the herbage yield and oil and its composition.

Isolation of essential oil (%)

The 48 hours shade dried upper whole plant material of different sites were subjected to hydro-distillation in Clevenger apparatus for six hours in order to determine the essential oil content in percentage (Clevenger 1928). The oil was dehydrated with anhydrous Na_2SO_4 and stored in refrigerator until further use.

Gas chromatography analysis

The GC analysis of the essential oils samples were performed on a Varian CP-3800 model gas chromatograph with Galaxy software system equipped with Flame Ionization Detector (FID) and an electronic integrator. Separation of the compounds was achieved employing a Varian CP-Sil 5CB capillary column (ID: 50 m X 0.25 mm; film thickness 0.25 µm). Nitrogen was used as a carrier gas at the constant flow rate of 0.4 mL min^{-1}. The column temperature was programmed from 60 °C (held for 2 min) to 220 °C (held temperature were set at 250 °C and 300 °C, respectively). The relevant 0.2 µL samples were injected for 6 min at a rate of 5 °C min^{-1} then at an elevated temperature of 245 °C applying a rate of 5 °C min^{-1}. The injector and detector tem: 100:20 split ratio. Retention indices were generated with a standard solution of n-alkanes (C6 -C19). The composition was reported as a relative percentage of the total peaks are without FID response factor correction (Mallavarapu *et al*. 1999; Sastry *et al*. 2015).

Identification and quantification of compounds

Chemical compounds were identified by comparison of their Kovats retention indices from GC FID peaks relative to C6 -C19 alkanes as per the their elution order on varian CP-SIL 5CB column and with those reported for compounds in the literature.

Development of soil-suitability criteria for davana

Davana is mostly grown in irrigated condition during winter season (November to February) in red soils region of Karnataka. Realizing the importance of this crop for commercial use, Government of Karnataka is giving more impetus for horizontal expansion and financial support to growers. ICAR-National Bureau of Soil Survey and Land Use planning has repository of soil information of Karnataka and entrusted to develop suitability map for davana. The steps involved in developing suitability criteria of davana (Fig. 2).

Step 1: Identification and selection of soil-site parameters and climatic parameters.

The information on soil-site and climatic requirements for davana is scanty; hence, the authors gathered information from experts working at CIMAP and davana-growing farmers. Parameters identified were soil depth, texture, soil reaction, drainage and diurnal temperatures.

Step 2: Development of soil and climatic relationship with herbage yield and oil content ant its composition.

Soil profile characteristics and surface soil fertility parameters were correlated with davana crop productivity and oil quality to establish crop requirements for identifying soil suitability criteria (Fig. 2).

Step 3: Evolving criteria for soil-site suitability for davana

The correlation studies carried out to identify the critical soil parameters, which influence the crop productivity and oil content and its composition. The standardized ratings of each soil-site parameters were given for suitability classes as presented in table 6.

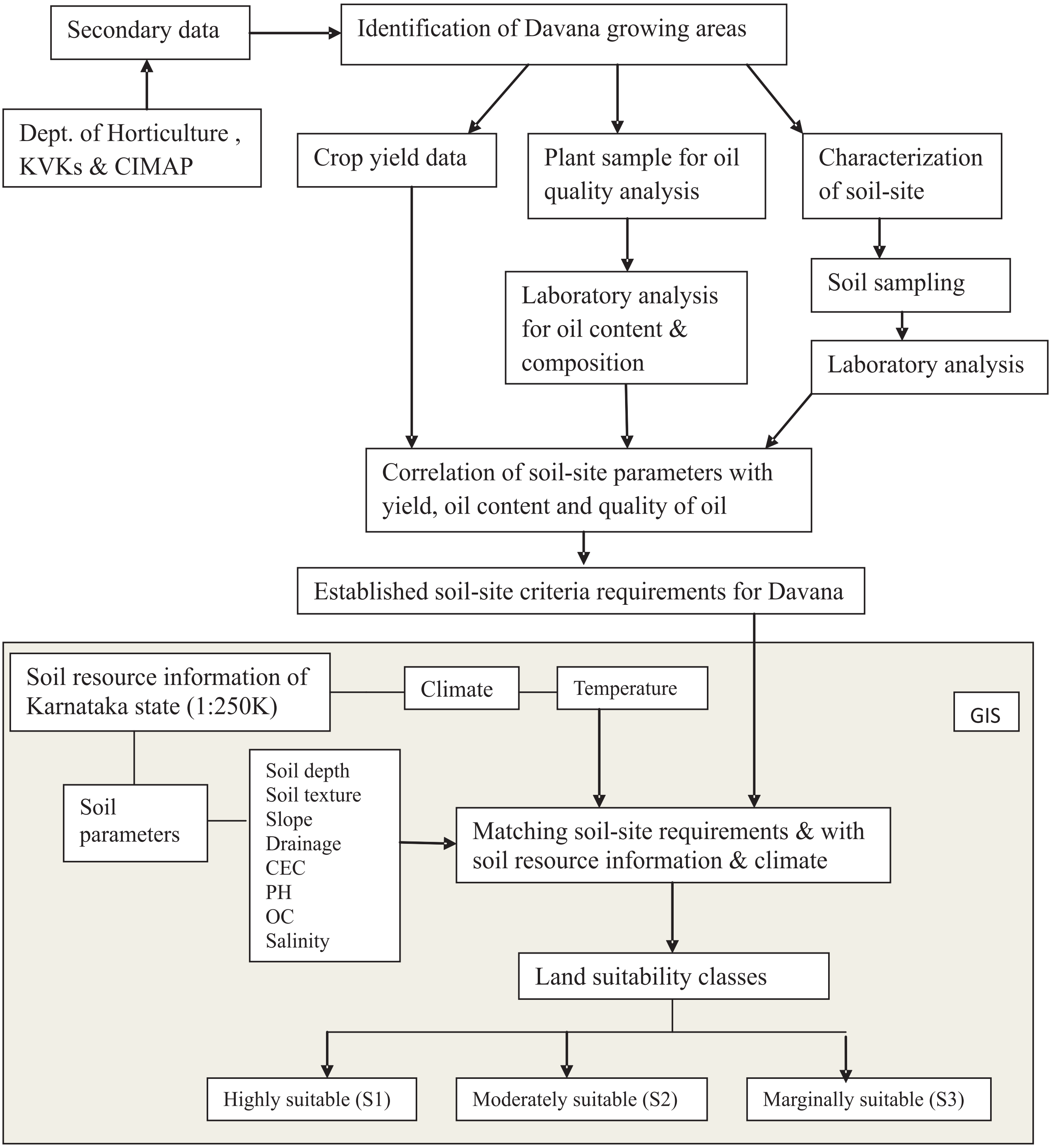

Fig. 2. Methodology followed in land suitability assessment

Land suitability evaluation

Land suitability evaluation for davana was carried out by matching the characteristics of 121 mapping units of Karnataka state (1:250K) with crop requirements (Table 6). The procedures followed as per FAO (1976) guidelines and Sys (1985) framework of matching specified crop requirements was performed as per maximum limitation method. Suitability map of davana was prepared by linking suitability ratings of each map unit under GIS environment using ArcGIS (version 10.4) software.

Statistical analysis

Data were subjected to descriptive statistics analysis and correlation with regression equations using MS-Excel software and on-line software (Stats. Blue). Histograms and box-plot diagrams were constructed using Stats. Blue.

Results and Discussion

Edaphic and climate parameter play crucial role in davana plant growth, foliage and oil yield and quality of oil. In Karnataka, davana is mostly grown in the red soils (Alfisols). Among the soil parameters, soil depth (Fig. 3), texture (Fig. 4), pH and fertility factors decide the crop growth and productivity. Since, davana is grown mostly under irrigated conditions in winter months, climate parameters like rainfall and length of growing period may not affect the plant growth and yield. However, late sowing coincides with high temperature which affects crop productivity and quality of davana oil (Jayanthi *et al.* 2013).

Soil factors

The descriptive properties of top soil (0-20 cm) of davana growing soils are presented in table 1. Soil texture varied from clay to sandy loam at different sites with slightly acid to slightly saline (6.75-7.39). The high variability of soil organic carbon is recorded with a CV of 207.85 (Fig. 5) and mean of 0.39 ± 0.81%. The available N, P_2O_5, K_2O, Ca and Mg content showed high variability (>35% of CV) in the top soils of davana-growing sites (Table 1). Mean values are 120.23±56.03 kg ha^{-1} for N, 169.16±101.56 kg ha^{-1} for P_2O_5, 362.30±403.9 kg ha^{-1} for K_2O. The soils are rich in Ca with a mean of 1427.89 mg kg^{-1} and magnesium of 292.71 mg kg^{-1}. The sulphur content of the soils varied from 1.17-6.72 kg ha^{-1} (Table 1). The variability of micronutrients of top soils is presented in box-plot diagram (Fig. 5). Box-plot diagram showed high variability for all micronutrients except Cu with moderate variability (CV=33.82%).

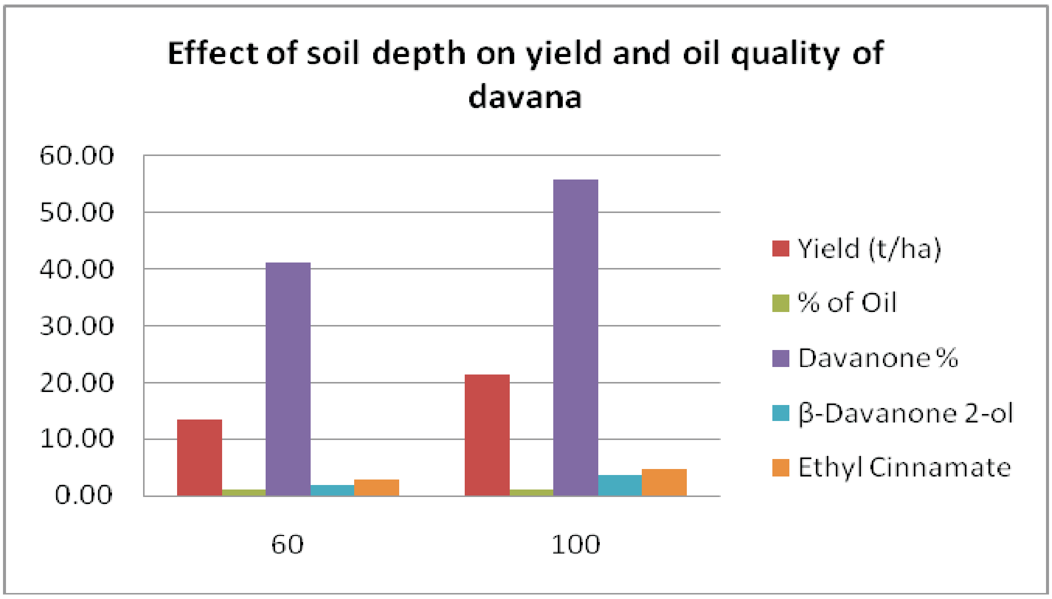

Fig. 3. Effect of soil depth on productivity and oil quality of davana

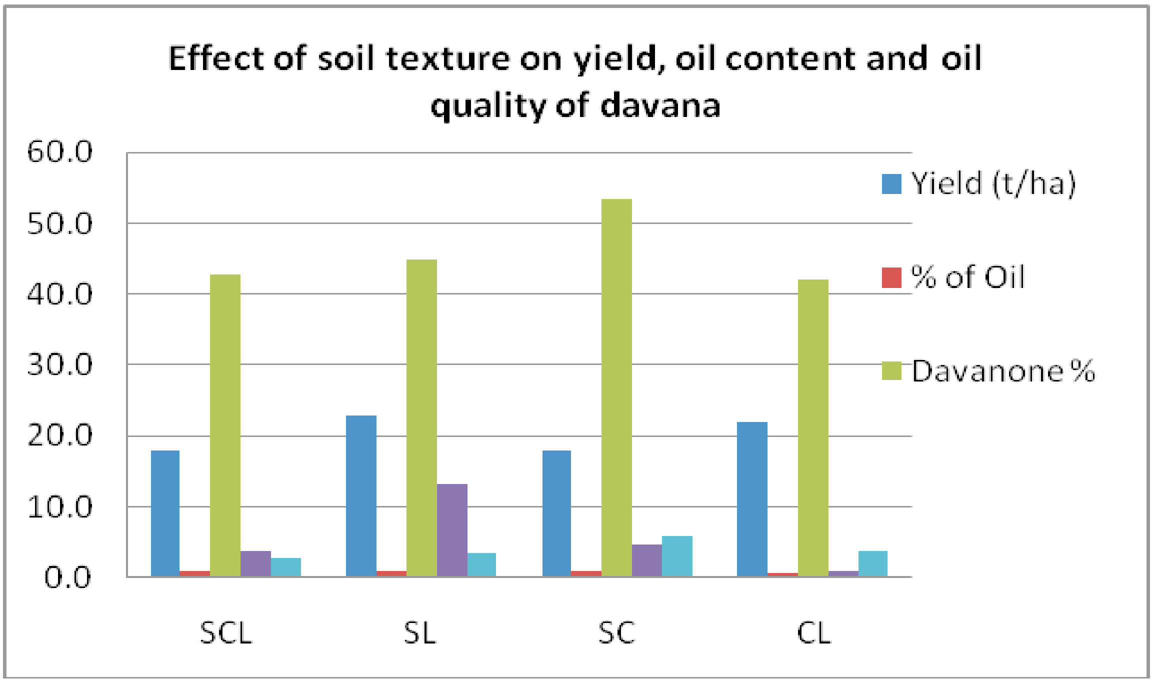

Fig. 4. Effect of soil texture on productivity, oil content and quality of davana

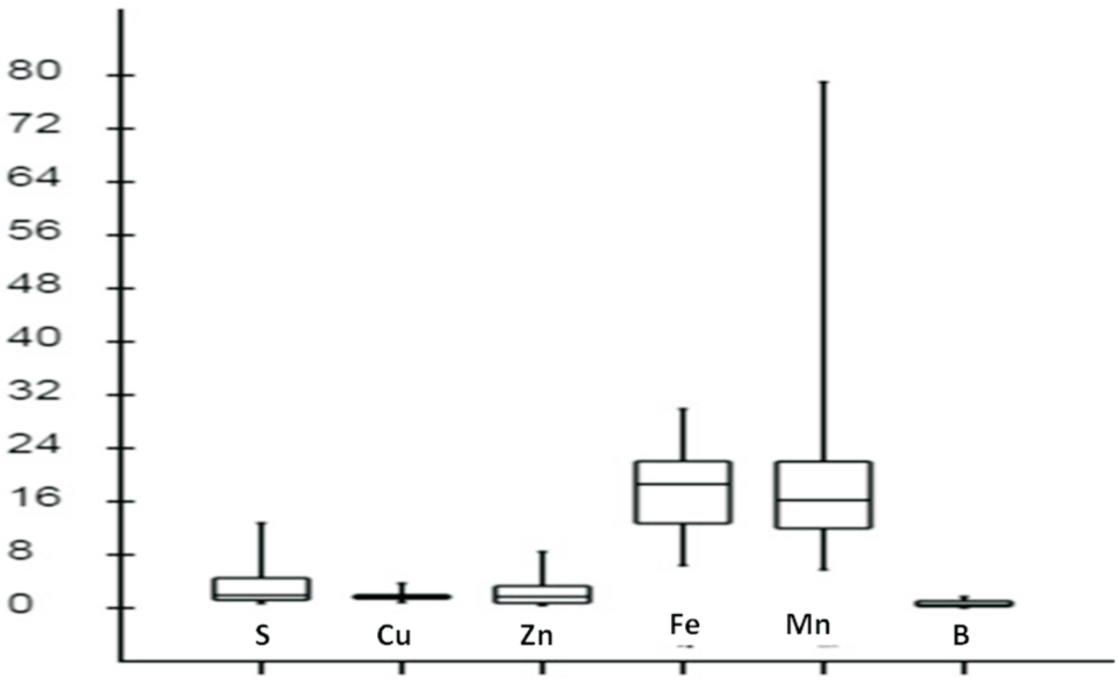

Fig. 5. Box plot for available sulphur and DTPA extractable micro nutrients (mg/kg)

Table 1. Depth wise soil characteristics

Soil Depth	AEZ	Texture	pH	EC (dsm^{-1})	OC (%)	N ($kg\ ha^{-1}$)	P ($kg\ ha^{-1}$)	K ($kg\ ha^{-1}$)	Ca (ppm)	Mg ($mg\ kg^{-1}$)	S ($kg\ ha^{-1}$)
60 cm	7	scl	7.39	0.43	0.13	120.21	148.93	234.63	1365.24	348.43	6.72
>100cm	7	c,sl,scl	6.93	0.56	1.32	168.40	180.66	1069.97	2143.68	455.77	3.24
60	8	sl,scl	6.75	0.26	0.09	94.08	187.73	100.76	1359.16	149.82	1.57
>100	8	sl,scl,cl,sc	7.37	0.35	0.18	109.76	163.70	200.06	1188.19	261.10	2.64
Mean	-	-	7.11	0.40	0.43	123.11	170.25	401.35	1514.07	303.78	3.54

Performance of Davana in different soil depths

High herb yield of davana was recorded in the sites where soil depth is >100 cm (deep soils) than 60 cm soils (Fig. 3). Whereas, there was no much difference in per cent oil content of davana herb due to variation in soil depth. Davanone, β-davanone 2-ol and ethyl cinnamate content of oil is comparatively more at soil depth >100cm than 60 cm (Fig 3). Out of 25 sites, seven sites are 60 cm depth and remaining 18 sites soil depth was >100 cm. The *t* test was performed to study the effect of soil depth on herbage yield, the calculated *t* value is 2.06, which is significant at 95% level supporting the null hypothesis of depth on herbage yield of davana. Mean yield is 19.02 t ha^{-1} with a deviation of 5.92 t ha^{-1} at 95% confidence interval.

Performance of Davana on different textured soils

One way ANOVA was performed to know the effect of soil texture on herbage yield, per cent oil, Davanone percentage, β-Davanone 2-ol and Ethyl Cinnamate. The results showed that the soil texture doesn't have significant influence. However, histograms showed that highest herb yield of 22.9 t ha^{-1} in sandy loam soils as compared to clay loam soils (Fig. 4). Whereas, the oil content of the herb was highest in sandy clay loam soils compared to others. Davanone is more in sandy clay soils, β-davanone 2-ol in sandy loam soils and ethyl cinnamate content of oil in sandy clay soils (Fig. 4). Considering the yield of herb and quality of oil (Davanone content), sandy clay soils are most suitable. Since Davana is being grown mostly as an irrigated *rabi* crop, it needs soils which can hold more moisture. Therefore, davana performed well on sandy clay soils (Fig. 4).

Correlation of Davana yield, oil percentage and oil soil parameters

Among 14 soil parameters, available phosphorus (r=0.46**) and zinc (r=0.40*) content of soil found to be highly significant and positively correlated with davana herbage yield. Manganese (r= -0.44*) was negatively correlated and significant with the crop herbage yield (Table 2). Oil content was not affected by soil parameters.

Davanone content found to be significant and negatively correlated with manganese (r= -0.591*) and copper (r= -0.501*) (Table 3). Davanone 2-ol content was highly significant and positively correlated (Table 4) with copper (r= 0.658 **). Ethyl cinnamate content was significant but positively correlated to pH (r=0.501*), whereas iron (r= -0.512*) was significant but negatively correlated (Table 5).

Soil-site suitability criteria for Davana

From the preliminary investigation of 25 sites, the soil-site suitability criterion for davana was made with the relation of soil parameters, herbage yield and oil content and its composition. Soil-site suitability criteria were evolved considering climatic regime and land quality as given in table 6.

Identification and delineation of suitable land areas for Davana

To identify and delineate potential areas, crop requirements of davana (Table 6) were matched with soil and climatic parameters (mean temperature) of 121 mapping units of the Karnataka state. Soil mapping units are family associations of Alfisols (27% of the TGA), Inceptisols (25%TGA), Entisols and Vertisols (15% TGA each). The major soil constraints for crop production are shallow rooting depth, coarse surface texture, high sub-soil gravel, low moisture retention and low fertility with surface crusting. Salinity, sodicity and drainage are major constraints in valley region and command areas (Shivaprasad *et al*. 1998).

Based on the criteria, 121 mapping units were evaluated and delineated suitable areas for davana in Karnataka state (Fig 6). GIS output showed that highly suitable areas for davana cultivation cover 45.19 lakh ha (23.5 % of TGA). Most of the areas delineated in the districts of Bangalore urban (86%), Kolar (78%), Bangalore rural (77%), Mysore (74%), Chikkaballapur (64%), Chamarajnagar (64%), Ramanagaram (62%),

Table 2. Correlation matrix for Davana yield and soil parameters

	Yield	pH	EC	N	P	K	Ca	Mg	S	OC	Cu	Zn	Mn	Fe	B
Yield	1.000														
pH	-0.133	1.000													
EC	0.219	-0.094	1.000												
N	-0.019	-0.214	0.691	1.000											
P	**0.464***	-0.132	0.365	0.145	1.000										
K	0.011	0.035	0.401	0.395	0.052	1.000									
Ca	-0.304	0.153	-0.173	-0.009	-0.518	0.372	1.000								
Mg	-0.127	0.001	-0.277	-0.092	-0.406	0.243	0.376	1.000							
S	-0.237	0.004	0.677	0.602	-0.179	0.151	0.006	-0.054	1.000						
OC	-0.204	0.041	-0.167	0.190	-0.488	0.452	0.752	0.421	-0.116	1.000					
Cu	-0.055	-0.163	-0.092	0.070	-0.083	0.293	0.478	0.252	-0.267	0.723	1.000				
Zn	**0.401***	0.077	0.406	0.190	0.736	0.466	-0.259	-0.209	-0.159	-0.236	0.090	1.000			
Mn	**-0.436***	-0.157	-0.181	0.130	-0.453	0.138	0.418	0.474	0.014	0.615	0.696	-0.265	1.000		
Fe	0.006	-0.677	0.092	0.199	0.387	-0.170	-0.290	-0.112	-0.008	-0.120	0.054	-0.126	-0.010	1.000	
B	-0.038	0.213	0.334	0.310	0.122	0.369	-0.042	-0.034	0.246	-0.196	-0.245	0.408	-0.196	-0.378	1.000

Significant at 5%

Table 3. Correlation matrix for davanone (A) content of oil and soil parameters

	A	RF	pH	EC	N	P	K	Ca	Mg	S	OC	Cu	Zn	Mn	Fe	B
A	1															
RF	-0.016	1														
pH	0.377	-0.405	1													
EC	-0.402	0.614	-0.310	1												
N	-0.229	0.539	-0.306	0.802	1											
P	-0.120	0.511	-0.330	0.383	0.385	1										
K	-0.253	0.747	-0.178	0.770	0.626	0.289	1									
Ca	-0.395	-0.157	-0.117	-0.207	-0.326	-0.426	0.072	1								
Mg	0.042	-0.457	0.589	-0.219	-0.260	-0.639	-0.069	0.415	1							
S	-0.488	0.039	-0.149	0.717	0.662	-0.166	0.465	0.037	0.157	1						
OC	-0.042	0.249	0.569	0.135	-0.105	0.017	0.389	0.125	0.265	-0.070	1					
Cu	**-0.501***	0.027	-0.165	0.147	-0.009	0.524	-0.090	0.019	-0.216	-0.104	0.113	1				
Zn	-0.055	0.573	-0.059	0.373	0.358	0.808	0.292	-0.305	-0.379	-0.182	0.280	0.599	1			
Mn	**-0.591***	-0.249	0.213	-0.015	0.023	-0.059	-0.084	0.326	0.402	0.208	0.131	0.393	0.193	1		
Fe	-0.309	0.294	-0.664	0.342	0.322	0.665	0.224	-0.195	-0.621	0.075	-0.372	0.338	0.250	-0.211	1	
B	-0.061	0.281	0.312	0.227	0.303	-0.288	0.580	0.292	0.448	0.307	0.396	-0.280	-0.036	0.327	-0.391	1

·Significant at 5%

Table 4. Correlation matrix for β - davanone-2-ol (B) content of oil and soil parameters

	B	**RF**	**pH**	**EC**	**N**	**P**	**K**	**Ca**	**Mg**	**S**	**OC**	**Cu**	**Zn**	**Mn**	**Fe**	**B**
B	1															
RF	-0.045	1														
pH	-0.169	-0.405	1													
EC	0.409	0.614	-0.310	1												
N	0.301	0.539	-0.306	0.802	1											
P	0.250	0.511	-0.330	0.383	0.385	1										
K	-0.045	0.747	-0.178	0.770	0.626	0.289	1									
Ca	-0.140	-0.157	-0.117	-0.207	-0.326	-0.426	0.072	1								
Mg	-0.201	-0.457	0.589	-0.219	-0.260	-0.639	-0.069	0.415	1							
S	0.390	0.039	-0.149	0.717	0.662	-0.166	0.465	0.037	0.157	1						
OC	-0.036	0.249	0.569	0.135	-0.105	0.017	0.389	0.125	0.265	-0.070	1					
Cu	**0.658***	0.027	-0.165	0.147	-0.009	0.524	-0.090	0.019	-0.216	-0.104	0.113	1				
Zn	0.272	0.573	-0.059	0.373	0.358	0.808	0.292	-0.305	-0.379	-0.182	0.280	0.599	1			
Mn	0.424	-0.249	0.213	-0.015	0.023	-0.059	-0.084	0.326	0.402	0.208	0.131	0.393	0.193	1		
Fe	0.104	0.294	-0.664	0.342	0.322	0.665	0.224	-0.195	-0.621	0.075	-0.372	0.338	0.250	-0.211	1	
B	-0.067	0.281	0.312	0.227	0.303	-0.288	0.580	0.292	0.448	0.307	0.396	-0.280	-0.036	0.327	-0.391	1

·Significant at 5%

Table 5. Correlation matrix for ethyl cinnamate (C) content of oil and soil parameters

	C	RF	pH	EC	N	P	K	Ca	Mg	S	OC	Cu	Zn	Mn	Fe	B
C	1															
RF	-0.137	1														
pH	**0.501***	-0.405	1													
EC	-0.366	0.614	-0.310	1												
N	-0.149	0.539	-0.306	0.802	1											
P	-0.128	0.511	-0.330	0.383	0.385	1										
K	-0.232	0.747	-0.178	0.770	0.626	0.289	1									
Ca	-0.108	-0.157	-0.117	-0.207	-0.326	-0.426	0.072	1								
Mg	0.413	-0.457	0.589	-0.219	-0.260	-0.639	-0.069	0.415	1							
S	-0.283	0.039	-0.149	0.717	0.662	-0.166	0.465	0.037	0.157	1						
OC	0.250	0.249	0.569	0.135	-0.105	0.017	0.389	0.125	0.265	-0.070	1					
Cu	-0.238	0.027	-0.165	0.147	-0.009	0.524	-0.090	0.019	-0.216	-0.104	0.113	1				
Zn	0.018	0.573	-0.059	0.373	0.358	0.808	0.292	-0.305	-0.379	-0.182	0.280	0.599	1			
Mn	0.387	-0.249	0.213	-0.015	0.023	-0.059	-0.084	0.326	0.402	0.208	0.131	0.393	0.193	1		
Fe	**-0.513***	0.294	-0.664	0.342	0.322	0.665	0.224	-0.195	-0.621	0.075	-0.372	0.338	0.250	-0.211	1	
B	0.197	0.281	0.312	0.227	0.303	-0.288	0.580	0.292	0.448	0.307	0.396	-0.280	-0.036	0.327	-0.391	1

·Significant at 5%

Table 6. Soil suitability criteria for Davana

Land use requirement			Rating			
Soil-site characteristics						
		Unit	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Mean temperature in growing season	°C	24-28	29-32 20-23	15-19 33-36	<15 >36
Land quality						
Oxygen availability to roots	Soil drainage	Class	Well drained	Moderate	Imperfect	Poorly drained
Nutrient availability	Texture	Class	sl, l, scl, cl, sil	sic, sc, sicl, c(m/k)	c(ss)	ls, s
	pH	1:2.5	6-7.5	5.5-6.0 7.5-8.0	5.0-5.5 8.0-8.5	<5.0 >8.5
	CEC	C mol (P+)/kg	>15	10-15	<10	
	$CaCO_3$ in root zone	%	Non-calcareous	Slightly calcareous	Strongly calcareous	
	Available nutrient status (NPK)	Fertility rating class	High	Medium	Low	
Rooting conditions	Effective soil depth	cm	>100	75-100	25-50	<25
	Coarse fragments	Vol %	<15	15-35	>35	
Soil toxicity	Salinity (EC saturation extract)	dS/m	Non-saline	1-2	2-3	
	Sodicity (ESP)	%	Non-sodic	10-15	>15	
Erosion hazard	Slope	%	1-3	3-5	5-10	>10

Tumkur (51%), Shimoga (48%) and Bellary (43%). The soil of these districts are Alfisols and Entisols having deep to very deep soils, sandy clay to sandy clay loam texture, slightly acid to neutral in soil reaction and good drainage but have low CEC, water holding capacity and high infiltration capacity. Even though availability of highly suitable area in the state is high, cultivated area under davana is 830 ha (2017-18), Kolar district recorded the highest area under cultivation with an area of 657 ha followed by Chikkaballapura district with 101 ha, Bangalore urban (35 ha) and Bangalore rural (21 ha) and percent area utilized under cultivation of davana in the state is only 0.018 % (Table 7) and thus there is a good scope to increase area under davana cultivation. In highly suitable areas of Northern Karnataka, Davana may be planted in such a way that harvesting should be

Table 7. State-wise highly suitable area and current area under cultivation

States	Highly suitable area (ha)	Current area under cultivation (2017-18) (ha)	Utilization of suitable area under cultivation (%)
Bagalkot	52406	-	-
Bangalore	189568	35	0.018
Bangalore Rural	394159	21	0.005
Belgaum	147745	-	-
Bellary	361621	1	0.0003
Bidar	107110	-	-
Bijapur	37137.9	-	-
Chamaraja Nagar	363581	15	0.004
Chikkaballapura	34599.7	101	0.292
Chikmagalur	1752.94	-	-
Chitradurga	7720.33	-	-
Davanagere	113746	-	-
Dharwad	62034.2	-	-
Gadag	81023.2	-	-
Gulbarga	46991.2	-	-
Hassan	3101.49	-	-
Haveri	2144.51	-	-
Kodagu	2798.13	-	-
Kolar	565866	657	0.116
Koppal	7418.64	-	-
Mandya	216558	-	-
Mysore	457640	-	-
Raichur	202927	-	-
Shimoga	397373	-	-
Tumkur	529662	-	-
Udupi	170.064	-	-
Uttara Kannada	4989.82	-	-
Yadgir	113329	-	-
Total	4505174	830	0.018

completed by end of February (before temperature rises to more than 30°C). List of sub-districts suitable for area expansion and establishment of small-scale industrial corridors is given in table 8.

The area under moderately suitable areas is estimated at 65.28 lakh ha, extensively distributed in Gadag (67%) followed by Belagum (63%), Bagalkot (57%), Dharwad (55%), Davanagere (54%), Bijapur (45%), Gulbarga (37%), Bidar (32%), Chitradurga (38%) and Chikkamaglur (31%) districts (Fig. 6). These areas though have deep to very deep soils (Vertisols and Vertic Inceptisols) posing a problem of drainage, surface cracks and low infiltration capacity. The winter temperatures exceed more than 30°C and often coincide with grand growth stage, thereby reducing quality of oil and herbage yield (Jayanthi *et al*. 2013).

Marginally suitable area for growing davana covers 54.2 lakh ha (28.2%) (Fig. 6). The command areas in Bellary, Koppal, Bidar and Bijapur. Plantation areas of Chikmagalur and Hassan, hot climate regions with compact sub-soil in granitic terrain of Chitradurga are evaluated as marginally suitable. Besides drainage, also pose problem of high salinity and sodicity (in dry tracts) and high rainfall and sloppy terrain in Malanadu areas.

The coastal sandy regions and parts of lateritic and sloppy terrain with high rainfall were evaluated as not suitable. These areas cover 25.4 lakh ha (13.2%). Similar findings are in agreement with in findings of Ingle *et al.* (2019) in Central India.

Fig. 6. Suitable areas for Davana production in Karnataka. Figure created in ArcGIS v10.4.

Table 8. Potential areas in different districts for Davana cultivation

Sr. No.	District Name	Taluks (sub-districts)		
		Highly suitable	**Moderately suitable**	**Marginally suitable**
1	Bagalkot		Mudhol, Badami, Bilgi, Jamkhandi, Bagalkot	Hungund
2	Bangalore rural	Devanhalli, Hoskote, Nelamangala, DodBallapur		
3	Bangalore urban	Bangalore south, Anekal, Bangalore north		
4	Belgaum	Khanapur	Raybag, Soundatti, Ramdurg, Gokak, Bailhongal, Hukeri, Belgaum, Chikodi	Athni
5	Bellary	Kudligi, Sandur Hagaribommanahalli, Hospet		Huvvinahadagalli, Bellary, Siruguppa
6	Bidar	Homnabad	Aurad	Bhalki, Basavakalyan, Bidar
7	Bijapur		Bijapur, Muddebihal	Indi, Sindgi, Basavana bagevadi
8	Chamrajnagar	Gundlupet, Kollegal, Yelandur, Chamrajnagar		
9	Chikballapur	Sidlaghatta, Chintamani, Bagepalli, Chikballapur, Gudiband, Gauribidanur		
10	Chikmagalur		Koppa	Mudigere, Narasimharajapura Tarikere Sringeri, Chikmagalur, Kadur
11	Chitradurga		Hosdurga	Challakere, Molakalmuru Holalkere , Chitradurga, Hiriyur
12	Dakshin Kannada	**Not Suitable**		
13	Davangere		Honnali, Harihar, Channagiri, Davangere Harpanahalli, Jagalur	
14	Dharwad		Navalgund, Kalghatgi Hubli, Dharwad	Kundgol
15	Gadag		Gadag, Nargund, Ron, Shirhatti, Mundargi	Kushtagi
16	Gulbarga		Chincholi, Gulbarga	Afzalpur, Chitapur, Seram, Jevargi, Aland

Cont.....

17	Hassan		Arkalgud	Sakaleshpur Belur, Channarayapatna, Arsikere Hassan, Holenarsipur, Alur
18	Haveri			Byadgi, Savanur, Hangal Ranibennur, Haveri Shiggaon, Hirekerur
19	Kodagu	Virajpet, Madikeri, Somvarpet		
20	Kolar	Malur, Mulbagal, Srintamani, Bangarapet, Kolar		
21	Koppal		Yelbarga	Gangawati, Koppal
22	Mandya	Nagamangala, Krishnarajpet Malavalli	Maddur, Pandavapura Mandya, Shrirangapattana	
23	Mysore	Mysore, Heggadadevankote, Piriyapatna, Nanjangud, Hunsur, Tirumakudal narsipur, Krishnrajanagara		
24	Raichur	Lingsugur	Sindhnur, Manvi	Raichur, Deodrug
25	Ramanagara	Ramanagaram, Channapatna, Magadi, Kanakapura		
26	Shimoga	Hosanagara, Tirthahalli, Sagar, Sorab		Shikarpur, Shimoga, Bhadravathi
27	Tumkur	Pavagada, Sira , Tiptur, Tumkur, Koratagere,	Chiknayakanhalli, Gubbi, Kunigal, Turuvekere, Madhugiri	
28	Udupi	**Not Suitable**		
29	Uttar Kannada	**Not Suitable**		
30	Yadgir	Yadgir	Shahpur, Shorapur	

Conclusion

The study employed two way approaches to establish relationship with basic soil properties and crop requirements using surface soil data base in davana-growing areas. The surface soil parameters were evaluated and established relationship with herbage yield and oil content. The results showed a positive relationship with soil depth, texture, soil pH, organic carbon, copper and manganese content. Based on soil factors, soil-site suitability criteria was evolved for davana and applied this criteria for delineating suitable areas using soil map of Karnataka state. The results showed that the 45.2 lakh ha area is highly suitable for davana as against the current growing (830 ha). The exercise strongly advocates expansion of aromatic and medicinal plants in suitable areas in adjoining urban areas with the economic incentives to growers. Government should initiate a policy to promote davana in highly suitable areas for expansion of area under davana crop as a component of cropping or farming system and also establishment of processing and marketing linkages. There is a need of policy interventions to establish davana corridor in suitable areas.

Acknowledgement

We express our sincere thanks to Director, ICAR-NBSS&LUP and Director, CSIR-CIMAP, Lucknow, for their continuous support and providing the laboratory facilities required to carry out this research. The financial support from the DST, New Delhi is gratefully acknowledged.

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Received: January, 2021 *Accepted: April, 2021*