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GIS based Land Suitability Modeling for the Selected Subtropical Fruit-Case of Limpopo Province, South Africa

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ABSTRACT Crop suitability defines the congruency between the crop requirements and the prevalent geo-environmental conditions. A study to evaluate the suitability of the selected subtropical crops (avocado, litchi, macadamia and, mango) was conducted with the mandate to evaluate the potential of the agribusinesses and agricultural enterprises in Limpopo Province. Crop suitability modeling was developed based on the incorporation of the agro-ecological parameters (soil, terrain and climate capability). The agro-ecological parameters were reclassified, weighted and, summed to institute the suitability model. The subsequent model enlightened that the optimal potential areas for the selected subtropical crops strongly correlate to the spatiality of the rainfall. The water intensive avocado exhibited limited potential area that correspond to Makhado and Thulamela, and Greater Tzaneen Municipality, that are renowned to experience a significant amount of precipitation in the province.

INTRODUCTION

Crop suitability model defines the congruency between the crop requirements and the geo-environmental conditions necessary for such crops (FAO 1976). This phenomenon qualitatively outlines the land performance for the agricultural commodity of interest (He et al. 2011; Mu 2006). According to Pan and Pan (2012), the principal purpose of conducting suitability assessment on agricultural land is to predict the potential and limitation of land for crop production. Moreover, the conduction of a comprehensive suitability assessment incorporates informative strategic planning, in-depth spatial planning and optimal allocation of agricultural crops.

Agricultural crop production that is not preceded by commodity suitability results in the critical destruction of the environment than the yielded resources (FAO 1976, 1983, 2007). Elsheikh et al. (2013), proposes for proper evaluation based on agriculture land use planning to eradicate this challenge. Though this is true, the scope of crop suitability analysis surpasses the environmental benefits, it enlightens the socio-economic and agricultural benefits and investment returns prior to production.

The increasing population in different regions of the world necessitate for increased supply for agricultural products. Limpopo Province, a comparatively subtropical region (Mpandeli and Maponya 2014) bears the potential for subtropical fruit production (Tshikudu 2005), but, the potential for such commodities is confined to the restrictive geo-climatological condition in responses to the persistently rising pressure on limited natural water resources. To ensure efficiency of the resource, the entire value chain of crop production should be based on rain-fed agriculture.

Geographical Information System (GIS) based approaches have emerged as standard practice for the appraisal of agricultural crop suitability modeling. Such methods encompass Boolean overlay, Remote Sensing and, land suitability modeling. Baniya (2008), employed the land suitability modeling to evaluate the suitability of vegetable crops in Nepal. Kanlaya et al. (2009), adopted similar approach to define the prospect of the cultivation of the sugarcane and cassava crops in Kanchanaburi Province. Locally, Petja et al. (2014) successfully employed the remote sensing based land suitability approach to map the prospective areas for agricultural production. Malczewski (2006) refutes GIS based crop potential mapping because they lack a well-defined mechanism for incorporating the decision maker's preferences into the GIS procedures. But it is on the same basis these approaches are preferred to retain the objectivity of the study, on the other hand, the excessive decision of the personnel may impose unnecessary subjectivity to the study.

This paper incorporated the GIS based land suitability modeling of the selected subtropical fruit (litchi, avocado, mango, and citrus) that is based on rain-fed irrigation. The rationale behind the selection of these fruit was their economic demand at both local and national market as well as the prevalent climatological setting of the province that should promote the subtropical fruit. These fruit are fundamental for the establishment of the prospective agribusinesses and agricultural enterprizes in Limpopo Province that could contribute towards economic growth, poverty alleviation, and job creation and enhance the competitiveness and profitability of the recommended commodities throughout the value chain.

Location of the Study Area

The study area is Limpopo Province, South Africa. The locality map in Figure 1, shows that the province is flanked within the following geo-

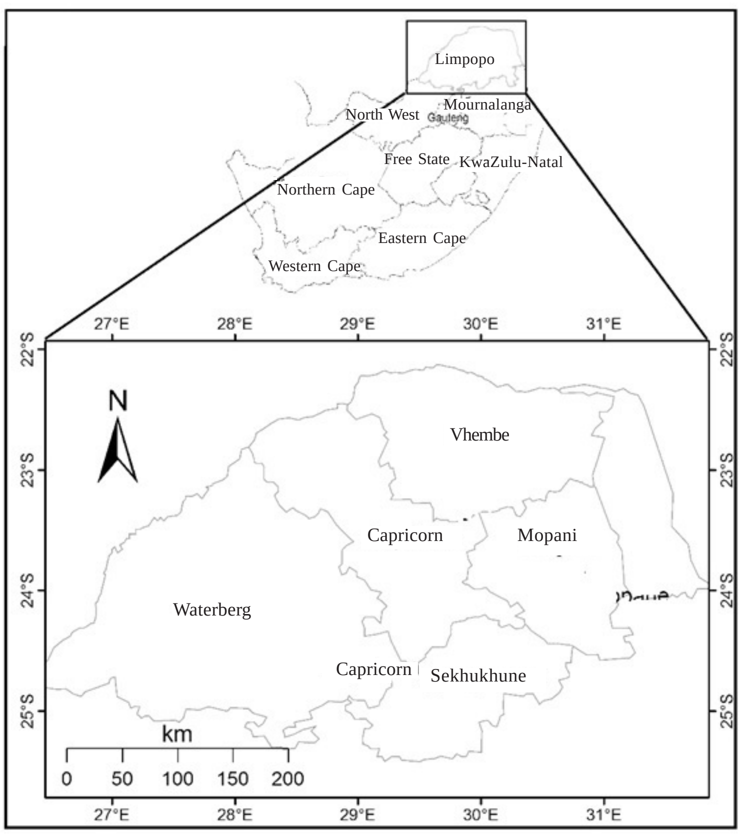

Fig. 1. The geographic coordinates and the district municipalities of the Limpopo Province

graphical coordinates; 26° and 32° east and 22° 10¹ and 25° 20¹, and, comprise of five district municipalities, viz. Vhembe, Mopani, Waterberg, Capricorn, and Sekhukhune. The study area has an area extent of about 125 750 km^2, the significant constituent of the population (75%) of about 5.7 million inhabitants are located in a rural setting (Stats SA 2016).

Limpopo Province is located within the subtropical regions of the world, and the province renowned for diverse array of agricultural commodities, especially the subtropical fruit. The climatic condition in this region is characterized by dry subhumid to semi-arid transition with intense hot summer, cold winter is generally dry with less than five percent of the total annual precipitation (Kabanda 2006). Mean annual air temperature varies from 34°C to 46°C. Winter (May-July) average temperature ranges from 6.5 to 20°C dropping to minimum 4°C (Naledzani 1999; Mpandeli 2006; Mpandeli and Maponya 2014). The annual precipitation varies spatially and temporarily from the east to the west, the former experiences an annual average rainfall of about 800 mm and the latter 400 mm (Kabanda 2006). The province is located in semi-arid that is defined with insignificant and unreliable precipitations (Nkitinca 1999; Mpandeli and Maponya 2014).

Flat terrains and the high-lying areas along the Soutpansberg mountain range with the supreme altitude of about 2000 m above mean sea (Kabanda, 2006) attribute the physiographical setting.

METHODOLOGY

The datasets employed to model the crop suitability was derived from variable auxiliary sources. Physical attributes of the soil data comprising soil form, clay percentage, soil depth and texture class were extracted from the Land Type database.

The chemical components of the soil were obtained from the Directorate Agricultural Information Services (DAIS, 2003); organic carbon, cation exchange capacity, phosphorous, salinity, and soil pH. The climatological data comprising mean annual precipitation, mean monthly rainfall, monthly potential evapotranspiration, monthly maximum temperatures, monthly minimum temperatures, and frost duration were provided by Agricultural Research Council – Institute for Soil, Climate and Water (ARC-ISCW 2016) in a spatial raster data format. The acquired themes were reclassified and ranked in accordance with their significance on the selected subtropical fruit potential assessment.

Subtropical Fruit Crop Requirements

This section presents the subtropical crop requirements. The crop requirements adopted in this section was exclusively summarized from the Directorate Agricultural Information Services (DAIS 2003). Table 1 shows the optimal conditions for the selected subtropical fruit. The ideal climatic conditions for citrus entails the absence of frost, minimum temperatures of 3°C and average temperatures for the coldest month of <13°C. Meanwhile, avocado is resistant to extremely cold condition, it can survive -4°C, however, it cannot tolerate the temperatures in excess of 25°C and has rainfall requirements of at least 1000 millimeters per annum. Apart from the Avocado, other subtropical fruits require relatively warmer minimum temperatures during the coldest month and frost is similarly undesired. The macadamia and the mango require minimum temperature of the coldest month to exceed 6°C and 5°C respectively. Mango fruit is adaptive to a hostile temperature of up to 45°C though the optimal condition ranges between 27°C and 36°C. The suitable temperatures for macadamia range between 23°C and 24°C which is significantly low in comparison to the general temperatures experience in Limpopo Province.

All the subtropical fruits under investigations have a single common pedological requirement, which is the effective soil depth of at least 1metre depth. The citrus has a very narrow soil pH requirement of 6.0-6.5 pH. The avocado can survive a pH range between 5.0-7.0, with the clay content ranging between twenty to forty percent with no structure but preferably reddish brown, red, and dark-brown. The macadamia adapts with ease to different soil type but prefers sandy soils in cooler areas and clay soil in the warmer area to hold the moisture.

The mango prefers well-drained and aerated soil with the clay content ranging between fifteen and fifty percent with the pH ranging 6.0 to 7.2.

Citrus is a high water demand commodity; it requires irrigation of 30 mm every 7 days and in drier conditions, these are subjected to increase (this sentence is not supposed to be here, its hanging, this section deals with subtropical issues). The avocado is sensitive to moisture stress; and younger plants require constant irrigation, during dry conditions 50l/tree/day is necessary. Macadamia has short irrigation cycle in sandy soil. Constant watering is necessary from flowering to ripening, though it is drought resistant, watering is necessary for optimal production.

According to Carl (1996), data processing defines a process of collection and manipulation of items to produce meaningful information. From the database, the soil, climate and physiographical attributes that spatially coincided to the study area were extracted. Each of the extracted themes was reclassified and then assigned a nominal rank that defines how suitable the parameter supports the subtropical fruit. Subsequently, the thematic layers were incorporated to issue the land suitability model based on the recommendations of DAIS (2003).

Soil Capability

The pedological attributes constituting soil capability (SC) are the soil moisture (SM) and soil fertility (SF). The soil moisture was defined by the synopsis of the internal drainage (ID) and utilizable soil volume (SV). The two parameters were respectively assigned the weighting coefficient of 0.25 and 0.75 respectively. Furthermore, the former was outlined by the moisture content rank (MC) and the porosity (ϕ) that were assigned the weights 0.4 and 0.6 consecutively.

Soil Fertility (SF) values were calculated from the ARC spatial database. The soil fertility (SF) was defined as the results of the summation of phosphorus concentration (P), Cation exchange capacity (CEC), acidity (pH) and, salinity (Sali). The relative weighting to these parameters were 01, 0.3, 0.5 and 0.1 respectively. The relative weights assigned for the wind (WiE) and water erosion (WaE), collectively known as the agents of erosion were 0.4 and 0.6.

Table 1: The optimal requirements for the selected subtropical fruit (Directorate Agricultural Information)

		Citrus	*Avocado*	*Macadamia*	*Mango*
Climate	Tolerance	No frost	No frost during flowering, Sensitiv to hot-dry conditions	Cold but No frost	Survive wide range of climatic conditions
	Coldest month	> 3°C	< -4°C	> 6°C;	>5°C
	Average cold month	< 13°C		<24°C	<45°C
	Rainfall		>1000 mm		
Soil	Soil description	Highly fertile; well drained and aerated	No structure;		Sandy soils in cooler areas; Clay soils in warmer areas
	Altitude				0 – 1200 m.a.s.l.
	pH	6.0 - 6.5 pH	5.0 – 7.0 pH		6.0 - 7.2 pH
	Effective depth (m)	1.0-2.0 m	1.0 m	1.0 m	1.0 m
	Clay (%)	(10-40)%	(20 – 40)%	Adaptive to different soil types	(15 – 50)%
	Colour	Red, yellow-brown and brown	Reddish brown, red, dark-brown;		
Water		Depending on the weather: 30 mm every 7 days	Sensitive to moisture stress	Short irrigation cycles at sandy soils.	Drought resistant

Terrain Capability (TC)

The terrain capability (TC) was designated by the terrain sensitivity (TSe) 0.4 and mechanical limitation (ML) 0.6. The TC was further defined by flooding and unfavorable temperatures that successively contribute 0.4 and 0.6. Similarly, the former is further defined by the terrain-flooding and form-flooding that account for 0.2 and 0.8 successively. The mechanical limitations that include trafficability and vehicle carrying capacity respectively account for 0.65 and 0.35. 0.85 and 0.15 were assigned.

Climate Capability

Soil moisture content (SMC) and climate constraints (CCn) defines the climatic capability (CC). The former further characterized by the length of the moisture season (LMS) and available moisture balance (AMB) and the latter defined by the temperature hazard (TH) 0.5 and frost hazard (FH) 0.5.

Land Suitability Modeling

The spatial potential of the selected subtropical crop was preceded with land suitability modeling based on agro-ecological parameters. The motive for conducting land suitability was to ensure that the prospective land for agricultural productions is appropriately defined. The agro-ecological requirements used for development of the spatial suitability modeling of the selected subtropical fruit potential were attained from the Directorate Agricultural Information Services in cooperation with DAIS (2003). Land suitability model was established on the basis of Scotney et al. (1987), Louw (1995) and Rutherfoord (2010).

The model was defined as the summation in the interactions of the soil, climate, and terrain attributes. These thematic layers were rasterized, reclassified and assigned weights based on their supremacy. Different weighting combinations were tested to best suit the conditions at Limpopo Province. Due to its analytical capability, GIS was used to build a parametric model using data variables, together with derivatives and calculations from these variables. According to Louw (1995), one land type differs from another in terms of one or more of the following: macro climate, terrain form, and soil pattern.

The land suitability model was established based on the weighted overlay of the input agro-ecological parameters. Equation 1 illustrates the combinations of the incorporations of the agro-ecological parameters and their respective weight adopted to establish the land suitability model.

[*STCP*] = [[[*MC*]. (.4) + [ϕ] (0.6).}(0.25).+[*SV*] (0.75).] (0.65)+[[P](0.1)+ [CEC](0.3) +[pH] (0.5)|+[*Sali*](0.1)+[[[*WiE*](0.4)+[WaE])0.6)] (0.5)+ [CH](0.25)+[WH](0/125)+[CH])0.125)] (0.25)]) 0.4)+[[[TF](0.2)+[FF])0.8)[Mi](0.4)+ [UnT](0.6] (.4)+ [[Tr](0.65)+[VCC](0/35)](0.6)] (0.1)+ [[[LMS](0.4)+[AMB](0.6)](0.85)+[[TH] (0.5)+ [FJ](0.5)])0.25)] ...(1)

Where *STCP* is the subtropical crop potential, *MC* is the moisture content, *SC* is the Soil Capability, *SM* is the soil moisture, *SF* is soil fertility, *ID* internal drainage. In the same manner, *SV* represents the utilizable soil volume, *MC* is the moisture content rank, (ϕ) defines the porosity, *SF* represent is the soil Fertility, *P* denotes the phosphorus concentration, *CEC* the Cation exchange capacity, *pH* is the acidity and Salinity (*Sali*). The wind and the water erosion are presented by *WiE* and *WaE* respectively, but *TC*, *TSe* and *ML* successively signify the terrain capability terrain sensitivity and mechanical limitation. *CC* symbolizes climatic capability, *MLS* is the length of the moisture season, *AMB* is the available moisture balance. Lastly, *TH* and *FH* are the temperature hazard and frost hazard respectively.

Crop Potential Modeling

After the establishment of the land capability model, the potential of the selected subtropical fruits was instituted. A GIS inbuilt structured query language (SQL) was used to develop a two class system (optimal and marginal potential) for categorization of the results. The spatiality of the optimal potential areas are instituted based on the integration of the ideal agro-ecological attributes for each of the subtropical, individually. Whereas, the marginal potential was established based on the incorporation of the minimal requirements.

The following script equations were used to establish the two respective potential areas for each of the selected subtropicals:

Citrus Optimal Potential

{Min Avg Temp July} >= 3^{o}C and {Min Avg Temp June, July, Aug} <= 13 3^{o}C; and {Effective Soil Depth} >= 100 cm; and {Avg Clay %} >= 15 and <= 35; and {Soil form} <> “Va”.

Citrus Suitable Potential

{Min Avg Temp July} >= 3^{o}C; and {Min Avg Temp June, July, Aug} <= 13^{o}C; and {Effective Soil Depth} >= 90 cm and < 100 cm; and {Avg Clay %} >= 15 and <= 35; or and {Effective Soil Depth} >= 100 cm; and {Avg Clay %} > 5 and < 15 and > 35 and < 50; and {Soil form} <> “Va, Rg, Wo, Ar”.

Avocado Optimal Potential

{Mean Annual Temp} >= 20^{o}C and <= 25^{o}C; and {Mean Annual Precipitation} >= 1000 mm; and {Mean Annual Temp, Oct-Nov} >= 15^{o}C; and {Effective Soil Depth} > 600 mm; and {Avg Clay %} < 50’.

Avocado Suitable Potential

{Mean Annual Temp} >= 20^{o}C and <= 27^{o}C; and {Mean Annual Precipitation} >= 1000 mm; and {Mean Annual Temp, Oct-Nov} >= 15^{o}C; and {Effective Soil Depth} > 600 mm’.

Mango Optimal Potential

{Avg Monthly Temp, May, Jun, Jul, Aug} > 5^{o}C; and {Mean Annual Max Temp} >= 27^{o}C and <= 36^{o}C; and {MMR Sept} <= 50 and {MMR Oct} <= 85 and {MMR Nov} < 110 and {MMR Dec} < 140 and {MMR Jan} < 140 and {MMR Feb} < 140; and {Altitude} < 1200 m.a.s.l; and {Effective Soil Depth} >= 75 cm; [vi] {Avg Clay %} <= 15 and <= 25; [vii] {Soil form} <> “Bo, Ar”.

Mango Suitable Potential

{Avg Monthly Temp, May, Jun, Jul, Aug} > 5^{o}C; and {Mean Annual Max Temp} >= 27^{o}C and <= 36^{o}C; and {MMR Sept} <= 50 and {MMR Oct} <= 85 and {MMR Nov} < 110 and {MMR Dec} < 140 and {MMR Jan} < 140 and {MMR Feb} < 140; and {Altitude} < 1200 m.a.s.l; and {Effective Soil Depth} >= 60 cm and < 75 cm; [vi] {Avg Clay %} <= 15 and <= 25; or and {Effective Soil Depth} >= 75 cm; and {Avg Clay %} (>= 10 and < 15) and (>25 and <= 50); [vii] {Soil form} <> “Bo, Ar”.

Macadamia Optimal Potential

{Mean Annual Temp} >= 16^{o}C and <= 25^{o}C; and {Altitude} <= 640 m.a.s.l; and {Effective Soil Depth} >= 100 cm; and {Avg Clay %} >= 10 and <=45.

Suitable Potential for Macadamia

{Mean Annual Temp} >= 16^{o}C and <= 25^{o}C; and {Altitude} <= 640 m.a.m.s.l; and {Effective Soil Depth} >= 90 and < 100 cm; and {Avg Clay %} >= 10 and <= 45.

The prospective subtropical potential maps were superimposed on land capability map. The subtropical potential areas that coincide with the agricultural capability were extracted into shape files for further processing and interpretations. Whereas, the potential areas that do not conform to the agriculture land capability were excluded from the results in this study.

RESULTS AND DISCUSSION

This section presents the results and the discussion pertaining the crop suitability modeling that was developed based on the agro-ecological parameters and the respective spatial extent of the two resultant prospective areas that include the optimal and the suboptimal (suitable) potential area. The discussions also shed light in the appraisal of subtropical smallholder farmers into main stream economy as well as the demarcation of the potential areas for agricultural business and agri hubs.

Subtropical Potential Mapping

According to FAO (1976), crop suitability model illustrates how well the piece of land is suited for a particular crop. In the current study, such model was developed based on agro-ecological parameters. The map in Figure 2 portrays an assemblage of the maps outlining the spatial potential of the selected subtropical fruit; a) The potential of avocado, b) The potential areas for citrus, c) The prospective area for macadamia crop and, d) The spatial potential map of mango. Similarly, Tables 3 and 4 successively portrays the spatial dimension of the optimal and the sub-optimal (suitable) potential for each of the selected subtropical in the five-district municipalities comprising the Limpopo Province.

Limpopo Province has an area extent of 11.5 million ha (mha), according to Table 2 each of the five district municipality comprising the province; Capricorn District 1.6 mha, Mopane District 1.4 mha, Sekhukhune 1.3 mha, Vhembe District 2.1 mha and, Waterberg District 4.9 mha.

On average, over ninety three percent of the land is available for utilization in each of the five districts. The crop suitability potential established based on land suitability modeling is exhibited in Figure 2. In addition, Table 3 also intensify the spatial extent of the two resultant crop potential categories and their respective extent in each of the 5 districts that were the subject of the study. The spatial extent coinciding with the optimal and the suitable potential is successively distributed in the following manner; Capricorn 74 378 and 79 115 ha; Mopane 83 472 and 81 478; Sekhukhune 70 743 and 112 274, Vhembe 94 803 and 192 057 and Waterberg 68 200 and 221 176 ha.

Figure 2a portrays a map demonstrating the spatial potential for the avocado in the Limpopo Province. According to that map, the province is generally characterized by a poor avocado potential which may be attributed to the low mean annual rainfall. According to Mpandeli and

Table 2: The spatial attributes of the district municipality comprising the Limpopo Province

District municipality	*Area (ha)*	*Available land (%)*	*Optimal potential*		*Suitable potential*	
			Area (ha)	*Area (%)*	*Area (ha)*	*Area (%)*
Capricorn	1698949	93.72	74378	4.38	79115	4.66
Mopane	1437734	93.25	83472	5.81	81478	5.67
Sekhukhune	1342922	93.75	70743	5.27	112274	8.36
Vhembe	2135570	95.52	94803	4.44	192057	8.99
Waterberg	4952144	98.2	68200	1.38	222176	4.49

Table 3: The optimal potential area for selected subtropical fruit

District municipality	*Mango*		*Citrus*		*Avocado*		*Macadamia*	
	Area (ha)	*Area (%)*	*Area (ha)*	*Area (%)*	*Area (ha)*	*Area (%)*	*Area (ha)*	*Area (%)*
Capricorn	17762	1.01	55264	3.46	1160	0.07	193	0.05
Mopane	18772	1.31	34093	2.97	13705	0.97	16902	1.46
Sekhukhune	37063	2.13	30836	3.44	294	0.07	2550	6
Vhembe	32948	1.21	37999	1.55	3551	0.15	20305	1.475
Waterberg	12350	0.15	55850	1.05	0	0	0	0

Table 4: The suitable potential area for selected subtropical fruit

District municipality	*Mango*		*Citrus*		*Avocado*		*Macadamia*	
	Area (ha)	*Area (%)*	*Area (ha)*	*Area (%)*	*Area (ha)*	*Area (%)*	*Area (ha)*	*Area (%)*
Capricorn	54840	2.99	23393	1.33	784	0.05	98	0
Mopane	59342	4.21	0	0	22136	1.7	0	0
Sekhukhune	49169	8.02	63105	5.21	0	0	687	0.05
Vhembe	71259	3.27	33315	2.24	12862	0.82	74621	2.68
Waterberg	35444	0.46	186329	2.86	0	0	403	0

Maponya (2014), the rainfall is spatial variable in Limpopo Province. Mzezewa et al. (2010), states that the average annual rainfall in the Province is about 741 millimetres per annuam (mmpa), which is lower than global mean of 860 mmpa (Ingrid and Rainier 2012). Such precipitation is insufficient to suffice avocado crop requirement of 1000 mmpa (DAIS 2003).

Moreover, this subtropical is sensitive to the heat stress, and the climatic condition of Limpopo are characterized by excessively high temperatures that are often accompanied by heatwave and relatively short rainy days; these conditions are hostile to nourish this commodity (DAIS 2003). In the contrary, incomprehensive potential classes transpire in Thulamela, Makhado and Greater Tzaneen Municipality. In Vhembe District, the high potential could be interpreted in terms of the Levubu-Tshakhuma micro climate which receive about 1000 mmpa. According to ARC-ISCW (2016), mean annual rainfall map, the three municipality that depicts optimal potential for the avocado subtropical, coincide to the high rainfall belt that out spreads from Thohoyandou to Acornhoek, through Makhado and Tzaneen towns.

Contrary to the avocado, citrus illuminate's comprehensive spatial potential. Such discrete in the prospective extent are attributed to the discrepancies in the conditions that the two subtropical fruits require. The optimal potential areas for citrus are prevalently dense in Capricorn District (Polokwane and Molemole Municipality). Such feasible regions are aligned along the north-

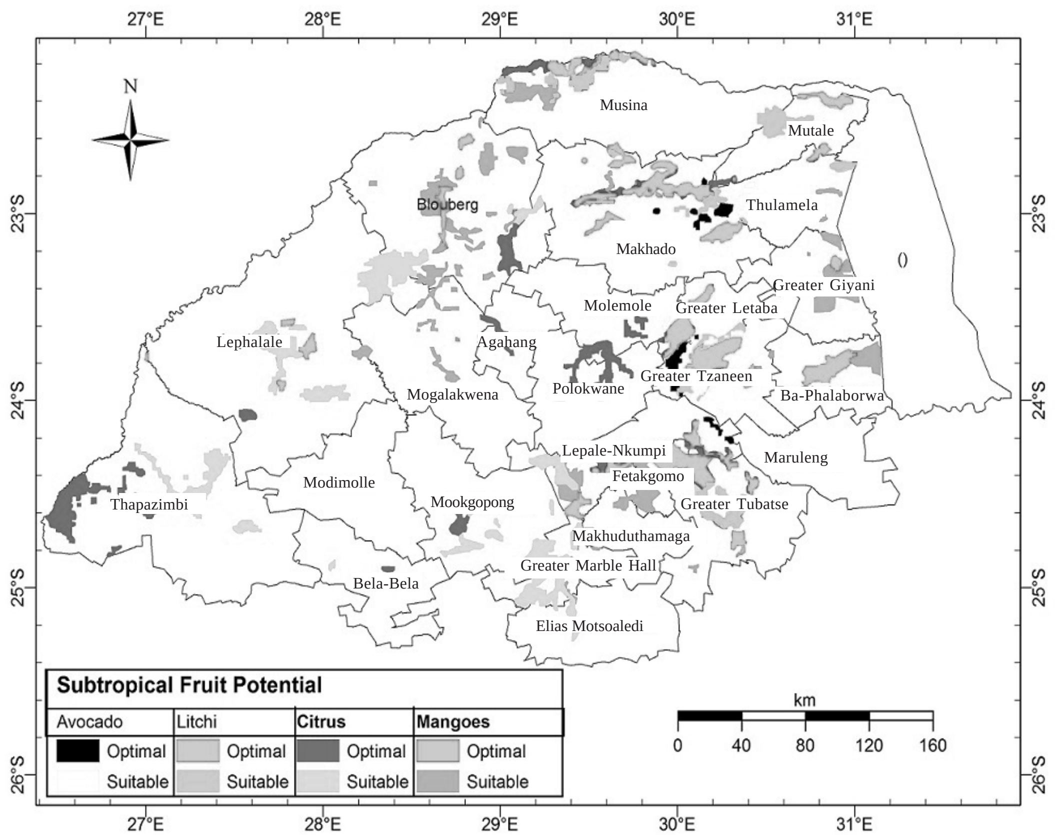

Fig. 2. a) The potential of avocado; b) The potential areas for citrus; c) The prospective area for macadamia crop and d) The spatial potential map of mango

south direction (Sekhukhune to Vhembe District). In spite of the significant relative density of the prospective areas in Capricorn District, Tables 2 and 3 affirm that the assemblage of potential area yield substantial extent in Waterberg District (Thabazimbi, Lephalale and Mogkophong Municipality), though such segments are dispersed. The primal retarding factor for this subtropical is the precipitation. According to DAIS (2003), citrus requires 30 mm watering every week, but the precipitation in the area is strictly experienced in summer.

Both the optimal and the suboptimal potential areas for macadamia are restricted to the eastern segment of the study area covering Vhembe (Makhado, Mutale, and Musina Municipality), and Mopani (Greater Letaba and Tzaneen Municipality). Capricorn and Waterberg hardly exhibit the potential for macadamia. Thus in spite of the ability of the macadamia crops to adapt to wide array of soil types (DAIS 2003), this implies that the vital determinant for optimal potential is water resources. This view is confirmed by the spatial correspondence between prospective areas and the mean annual rainfall map issued by ARC-ISCW (2016). In the contrary, the suitable areas for mango are wide spread throughout the province. According to DAIS (2003), different mango cultivars are resilient to drought. Hence the significant extent of the good potential areas irrespective of the spatial variability of the precipitation.

Agricultural Cooperatives

One of the approaches to support the smallholder farmers to be sustainable and economic viable is to commercialize them. The hindrances for such a progression ranges from intreprenuership, technicality and governmental support amongst many. For the agricultural enterprizes to break even and operate at a profit, a minimum land tenure is imperative. The minimal farm size for sustainable commercial farms for each of the selected subtropical fruit is variable; for mango, citrus, avocado, and macadamia is 40 ha, 60 ha, 50 ha, and 40 ha respectively. However, the majority of the smallholder farms are critically below that threshold.

Their extent commonly ranges between three (3) to five (5) ha and in exceptional cases, they cover up to 10 ha. This implies that, under the current operational predicament, commercialization of such farms will only remain a myth. However, this could be subjugated through the amalgamation of the individual farms to institute agricultural cooperatives. Bellostas et al. (2002), simplifies a cooperative as a legal institution comprising of the individuals who have incorporated to mutually meet their economic, social and cultural needs. According to Corbera and Marcuello (2001), agricultural cooperatives are a source of wealth and provide employment where operation in isolation is not viable. The scope of the cooperative should not be limited to the incorporation of the individual farm lot but the consolidation of the value-added activities throughout the entire value chain of the production. This in return will result in significant reduction in the investment necessary for the production to be productive as duplications are minimized. It is also convenient for the government to assist with bringing collective solutions instead of dealing with the individual entities. The productivity will subsistencely increase, resulting in the competitiveness of the subtropical.

The competitiveness of the smallholder farms has a direct correspondence with food security. Although South Africa is largely deemed as a food secure nation (FAO 2008), this is not the actual reflection of the socioeconomic state. Hart (2009) refute such claims, suggesting that is rather the case at the national level and situation at the local level is highly contrary. Statistics South Africa (STATSSA 2011) reported that an estimated twenty percent of South African households have inadequate or severely inadequate food access. A logical approach to ensure sufficient food resources will be to upscale the smallholder subtropical. In the case where there is more than necessary food production, establishing exporting channels will optimize the financial returns through export.

Economic Empowerment

Generally, the scope of crop suitability modeling is primal focused on the establishment of the agriculture database and institutionalization of the central decision-making tool in spatial agricultural resource management. In true essence, sustainable agriculture is a passport for the previously disadvantaged ethical populations into mainstream economy.

According to Matsau (2017), South Africa is one of the countries with the highest rate of income inequality in the world. In comparison with other middle-income countries, the level of absolute poverty is extremely high. Hence the central government has taken measures to reduce poverty by fifty percent between 2004 and 2014. In the NDP 2030, agriculture was defined as one of the focal areas for employment and wealth generation, mainly with the aftermath and legacy of the apartheid administration. In 2004, the Limpopo Department of Agriculture (LDA) commissioned for the development of provincial agricultural development strategy, which was aimed at providing support at the grassroots level through propelling subsistence farmers into the commercial level. Therefore, crop suitability will definitely provide the basis for decision-making and provide guidance and aid towards the identification of the areas where investment should be intensified to support the previously disadvantage subtropical farmers. The GIS estimates based on Table 2, indicated that the surface cover that comprises the optimal and suitable potential area was 491663 and 638117 ha respectively. The summation of the two potential classes brings the spatial extent to the total size of about 1 million ha.

Employment

One of the most critical socioeconomic challenges affecting the Limpopo Province is unemployment. Stats SA (2016) indicates that only thirty four percent of the economic active people in the province are employed and the agricultural sector encompasses 135 000 of the entire labor force. However, GIS determinations indicate the total potential area of 1 million ha is available in the province. In order to optimize the productivity of the semi-mechanized aggrarian operations, according to the NDP 2030, the ratio of employee to field-size (ha) often exceed 1.3 workers per hector. Therefore, that ratio was considered for the computation of the labor force absorptive capacity of the agricultural industry in Limpopo Province. Based on such estimates, and available spatial extent, 1000 000 people may be directly employed as full-time employees in the farms as compared to the current situation. These estimations are not inclusive of the employees that may be appointed on periodic basis and appointees in the entire value chain of the subtropical fruit production and post-production services (Fig. 3).

The inclusion on the subtropical that were not considered in the present study and incorporation of the other province will substantially stretch the spatial potential which will indirectly expand the required workforce. These views propose that a comprehensive agriculture development plan could significantly contribute towards the National Development Plan (NDP) 2030 that outlines that 20 million jobs should be created by the year 2030. The optimal utilization of the subtropical potential area bares the potential to contribute to the prevalent socio-economic challenges (unemployment). Bravo-Ortega and Lederman (2005), observed a significant correlation between the agricultural labour productivity with the corresponding salary in the poor communities across all-region. According to Schneider and Gugerty (2011), improved agricultural production yield to improved wages which is instrumental in a combat against poverty alleviation. Datt and Ravallion (1998), indicates that an extended agricultural production correlated to poverty reduction.

Expansion of the Potential Area

The subtropical smallholder farms in South Africa has considerable potential to expand. The existing potential model was established on the basis of rainfall as the only means of water input. Therefore, the spatiality of the subtropical potential area could be improved with the consideration of the groundwater resources as substantive water resource. The contemplation of the groundwater resources for the review of the crop suitability mapping is based on comprehension that the critical mode of water occurence in the semi-arid area occurs as groundwater since surface water is seasonal-dependent (Ntikinca 1999; Mpandeli and Maponya 2014). In this regard, groundwater provides the only means of livelihood in such regions. These views are feasible and could be realized as they conform with the remarks of Adams (2014), which outlines that the renewable groundwater in South

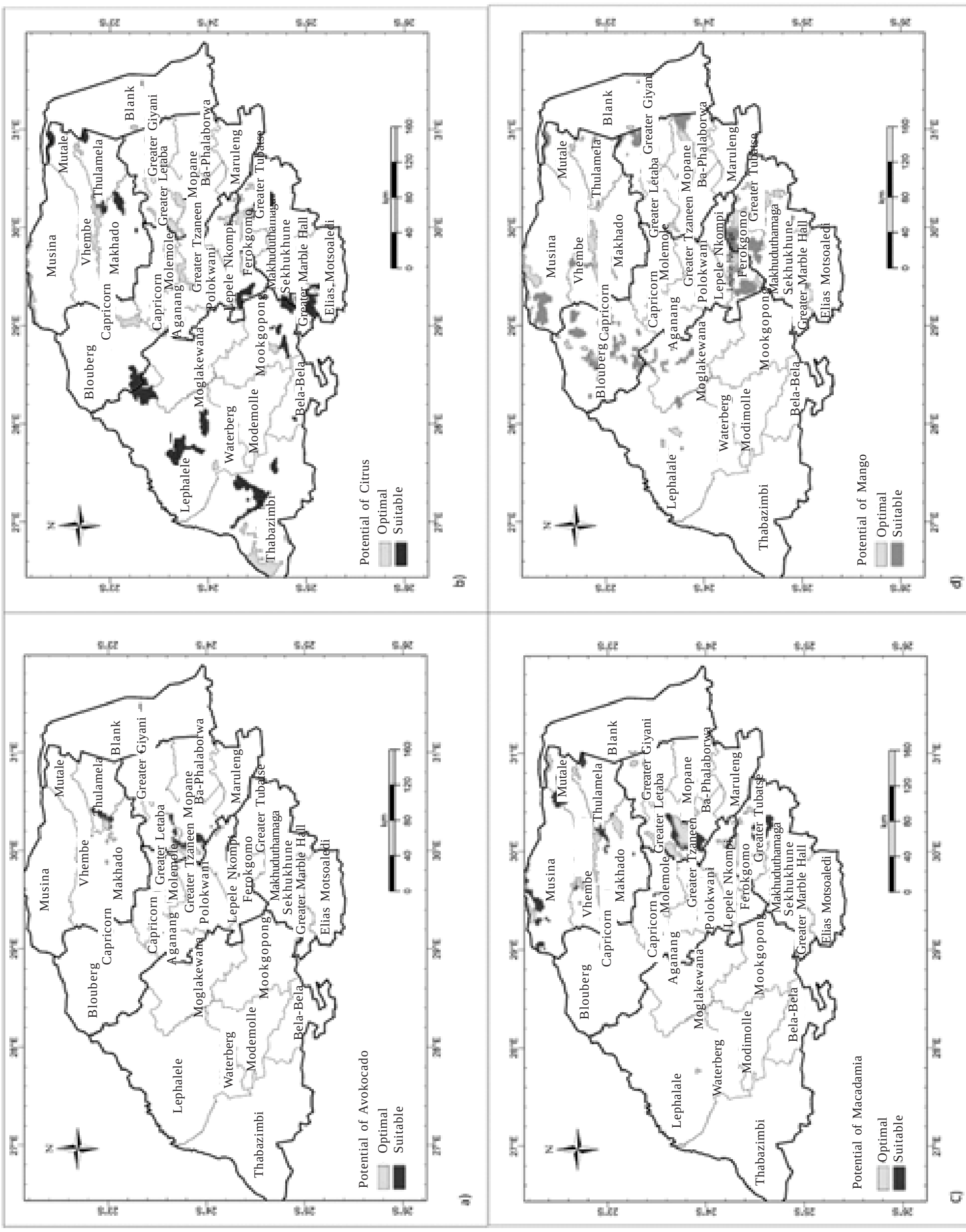

Fig. 3. An integrated subtropical fruit potential map (for selected subtrops) agricultural hubs

Africa stands at 10 billion M^3/a, and 7.5 billion M^3/a during drought conditions and the current groundwater usage ranges between 2-4 billion M^3/a which is almost half the optimal potential (Adams 2014). These imply that there is underutilization of groundwater resources in South Africa and additional 6 billion M^3/a (150%) could still be exploited for the benefits of the agricultural industry together with some other economic uses.

CONCLUSION

The study demonstrated that the crop suitability modeling could be effectively applied to demonstrate the potential of the selected subtropical fruit; 'citrus, avocado, macadamia and mango' based on the agro-ecological parameters on both the rain-fed and under irrigation. The optimal and the sub optimal potential areas are equivalent to 1 million ha for the selected subtropical. The two classes comprising the correlate to the spatiality of the rainfall. The avocado exhibit limited potential area that corresponds to Makhado and Thulamela, and Greater Tzaneen Municipality, that are known to experience a significant amount of precipitation in the province. Mango illustrated extensive potential throughout except in Waterberg, where all subtropical are attributed with insignificant extent except citrus. Water resource was found to be a principal limiting factor for the subtropical fruit potential. The smallholder subtropical farms were found to be relatively smaller than the minimal sustainable farm's sizes, this hinted that for any prospects to be sustainable, the prospects of amalgamation of the different farms into cooperatives should be explored.

RECOMMENDATIONS

Based on the findings from this study, it is recommended that the government interventions are necessary to vitalize the smallholder farms. The study illustrated that the integration of the two prospective potential areas yields to an area of 1 million ha. Upscaling and expansion of the agricultural industry could result in the creation of about 1 million permanent jobs and furthermore seasonally. The smallholder subtropical farms could also be an essential tool in the combat against poverty alleviation and economic empowerment. Hence the crop suitability model was developed based on the basis of rain-fed agriculture, the existing potential area could be significantly stretched with the consideration of the groundwater resources.

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