S. Afr. J. Agric. Ext.
Vol. 54 No. 6, 2026: 109-129
10.17159/2413-3221/2026/v54n6a21401

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# Geospatial Development of the Tree Lucerne— A Case of Limpopo and Mpumalanga Province, South Africa

Ndwambi, K.[1], Nesamvuni, A.E.[2], Mpandeli, N.S.[3], Tshikolomo[4], van Niekerk, J.[5], Hlophe-Gininza, S.N.[6] and Nhamo, L[7].

**Corresponding Author:** A.E. Nesamvuni. Correspondence Email: nesamvunie@gmail.com

***ABSTRACT***

*Climate change has resulted in a drastic shortage of pasture on communal rangelands for livestock farming. The study aimed to appraise the suitability of tree lucerne for generating additional feed for ruminants. The parameters used to assess the suitability for tree lucerne included rainfall, soil type, soil depth, soil drainage, soil pH, and groundwater level. These parameters were reclassified into three classes, class 1, class 2, and class 3, in proportion to how they influence this plant species. The spatial suitability model was established through an equal-weighted overlay of the rasterised layers. The resultant suitability map spatially characterises potential as optimal, suitable, or unsuitable. Each of the consequent classes had a spatial extent of 6,516,732 ha (32,22%), 1,253,058 ha (61,96%), and 1,177,591 ha (5,82%), respectively. The model suggested that introducing the tree lucerne will improve farmers' resilience to the impact of climate change. Most importantly, cattle farming may be expanded to over one million cattle if the pastures are*

[1] Centre for Sustainable Agriculture, University of the Free State, Bloemfontein, 9300, South Africa. Email: ndwambi.khuthie@gmail.com.

[2] Centre for Sustainable Agriculture, University of the Free State, Bloemfontein, 9300, South Africa, Email: nesamvunie@gmail.com.

[3] Water Research Commission, Lynwood Manor, Pretoria, 0081. Email: sylvesterm@wrc.org.za.

[4] Limpopo Department of Agriculture and Rural Development, Directorate of Crop Production, Private Bag X9487, Polokwane, 0700, South Africa. Email: tshikolomo@gmail.com.

[5] Vice-Dean: Sustainable Food Systems and Development, Faculty of Natural and Agricultural Sciences, University of the Free State, Bloemfontein, 9300, South Africa. Email: vniekerkja@ufs.ac.za.

[6] Water Research Commission, Lynwood Manor, Pretoria, 0081. Email: samkelisiwehg@wrc.org.za.

[7] Water Research Commission, Lynwood Manor, Pretoria, 0081. Email: Luxonn@wrc.org.za.

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*planted with tree lucerne throughout the study area. The crop also bears the potential to improve the sustainability and profitability of smallholder livestock farmers.*

**Keywords:** Smallholder, Tree Lucerne, Reclassification.

## 1. INTRODUCTION

### 1.1. The Importance of Livestock Farming in the World

Livestock farming is an integral component of the agricultural production system throughout the world. According to Rojas-Downing *et al*. (2017), approximately one billion people rely on livestock for their livelihoods. Meanwhile, the Food and Agriculture Organisation (FAO, 2021) reports that the sector accounts for about 40% of the annual global agricultural production by value. Lowder *et al*. (2016) estimated that roughly 500 million livestock farmers directly rely on this segment for their livelihoods. However, the sector's actual contribution is very high, as over a billion people across the value chain rely on this segment for their provisions (Thornton, 2010). In addition, Rojas-Downing *et al*. (2017) asserted that the sector plays a pivotal role in food security and in global kilocalorie consumption (17%) and protein consumption (33%). Should there be a decline in throughput from smallholder operations, there will be an exponential increase in joblessness, food insecurity, malnutrition, and starvation.

### 1.2. Role of Livestock Farming in South Africa

Livestock farming is an invaluable sector of the economy in South Africa (Mare *et al.,* 2018; Rust & Rust, 2013; Mapiye, 2009). This sub-section of the agricultural industry plays an undisputable role in providing a means of living for rural and informal communities in the country (Cheteni & Mokhele, 2019). It exhibits exceptional potential in combating food shortages and alleviating poverty (Mapiliyao *et al.,* 2012). According to Bahta (2021) and the Department of Agriculture, Forestry and Fisheries (DAFF, 2016; 2018), this component of the agricultural industry accounts for almost half (48%) of South Africa's agricultural output. It is also one of the principal employers throughout the country (500,000 people) (DAFF, 2016). Apart from its socio-economic contribution, the essence of this marginalised but important industry in South Africa is further reflected in its substantial contribution of 21.4% to the continent's total meat production and 1%

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to global output (Kirsten *et al.,* 2017). Given these assertions, it is evident that livestock is an important component of the country's agriculture.

### 1.3. Impact of Climate Change on Livestock in South Africa

Nonetheless, climate change is one of the prominent phenomena that is haunting livestock farming in South Africa. This phenomenon manifests through a reduction in rainfall amount, increasing temperatures, alteration of rainfall patterns and frequency, and increased regularities of climate extremes (drought and floods) (Ziervogel *et al.,* 2014; Kusangaya *et al.,* 2014; Nhemachena & Hassan, 2007; Turpie *et al.,* 2002). According to Kruger and Nxumalo (2017), O'Connor *et al*. (2014), and Kusangaya *et al*. (2014), there is a substantial reduction in mean annual precipitation in many parts of the country as a result of climate change. In addition, there has also been a considerable expansion of drought-prone areas (Koerner & Collins, 2014). Lehner (2017) presents irrefutable evidence of the increased frequency of prolonged dry spells, which are hampering pasture availability (VanderWeide & Hartnett, 2015). Ultimately, overgrazing subsides in smallholder livestock farming. This is mainly because the sector's constituents are vulnerable to the impacts of climate change. Tshikolomo *et al*. (2022) assessed the demographics and adaptability of smallholder livestock farmers to the impacts of climate change in Limpopo Province. That study revealed that the majority of smallholder farmers (99%) practice their trade on communal lands and lack access to financial support from government and private institutions. Tshikolomo *et al*. (2022), Omerkhil *et al*. (2020), Matewos (2019), and Jamshidi *et al*. (2019) infer that smallholder livestock farmers are exposed to the impacts of climate change.

### 1.4. A Need for Supplementary Feeding for Livestock

Moreover, smallholder livestock farming in South Africa is primarily practised on rangelands (Scholtz *et al.,* 2013; Palmer & Bennett, 2013). This farming approach is attributed to the total reliance of livestock on natural vegetation and grasses for their daily nutritional needs (Jordaan *et al.,* 2013). Unfortunately, the productivity of rangelands in many parts of South Africa continues to decline due to overgrazing and marginal rainfall (Stevens *et al.,* 2016; Podwojewski *et al.,* 2011). Insufficient rainfall leads to a loss of biodiversity, which constrains available feed. A reduction in grass within the rangelands leads to malnutrition and livestock loss. Such occurrences

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threaten the livelihoods of smallholder operators, as they are solely reliant on farming and are also exposed to the impacts of climate change. A study was conducted to develop agroecologically based fodder banks to ensure sufficient feed availability for smallholder farmers despite overgrazing and a general shortage of pasture due to climate change (Dhyani *et al.,* 2013).

Tree Lucerne is an ideal fodder bank crop because it is rich in protein and palatable for livestock (Rajan *et al*., 2019; Bezabih *et al.,* 2016). The added benefits associated with the crop include retention of soil moisture, reduced soil erosion, land restoration, and soil fertilisation (Rajan *et al.,* 2019). Because of these benefits, there is a pressing need to appraise the geospatial suitability of this plant in Limpopo and Mpumalanga for developing fodder banks to mitigate the impact of climate change on smallholder subtropical farmers in these areas.

## 2. RESEARCH METHODOLOGY

### 2.1. Description of Study Area

#### *2.1.1. Location*

The study area comprises the Limpopo and Mpumalanga Provinces of the Republic of South Africa. The map in Figure 1 shows the geographical location of the two provinces; they are located in the northeastern part of the country, confined to 21 ° and 26° south and 26 ° and 32° east. Limpopo Province shares international boundaries with Mozambique (to the east), Zimbabwe (to the north), and Botswana (to the west).

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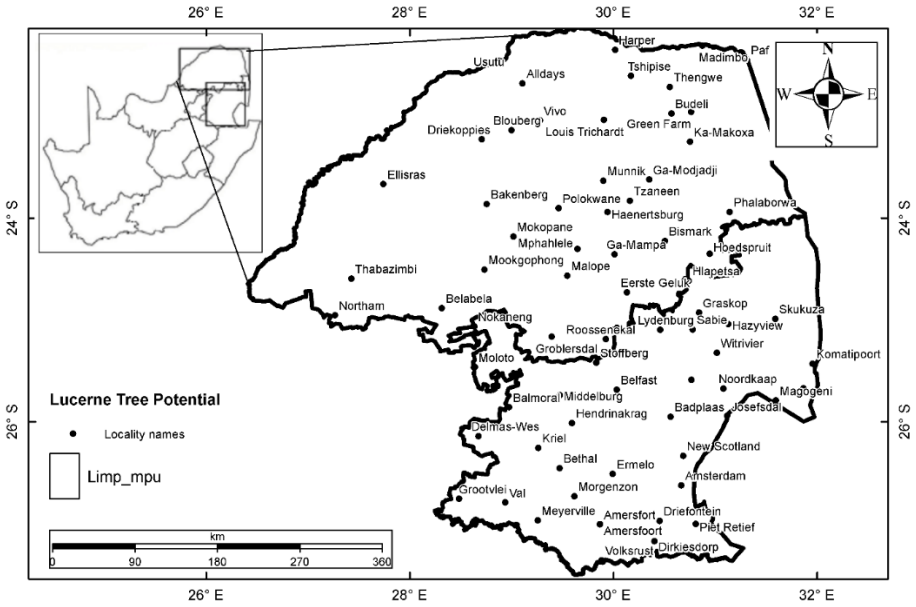


**FIGURE 1: The Geographical Position of the Study Area Within the Layout of the Country (South Africa)**

### *2.1.2. The Physiography*

The topographic overview of the Limpopo Province conforms to that of the Lowveld area (an area with an elevation ranging from 150-600 m above mean sea level (AMSL) (Nemukula *et al.,* 2023; Musyoki *et al.,* 2016). Nonetheless, numerous mountain ranges protrude within the province's plateau in the central and southern parts. Subsequently, these factors deem the overall physiographic appearance slightly complex (Nemukula *et al*., 2023; Musyoki *et al.,* 2016). The most prominent mountain range is the Soutpansberg, which extends for 130 km from east to west and reaches an elevation of over 2,000 m (Bouarakia *et al.,* 2023). Soutpansberg Mountain range is densely covered with thorn trees and shrubs (Ruwanza & Mhlongo, 2020). Meanwhile, the Lowveld extends across the northern part of the province and is covered by semi-desert vegetation (mopani and baobab trees) (Mateyisi *et al.,* 2021).

Mpumalanga comprises three major physiographic regions, namely the Highveld, the Drakensberg Mountains, and the Lowveld (Britannica, 2024). The Highveld constitutes a flat-lying area with an elevation ranging between 1,200 and 1,800 m AMSL (Britannica, 2024). The Drakensberg Mountains protrude on the western side of the province, forming the highest elevated area with elevations up to 2300 m AMSL (Britannica, 2024). Lastly, there is the Lowveld area, which is

characterised by gently undulating terrain that slopes toward the Lebombo Mountains on the Mozambique border. After the topographic settings of the province, the majority of the streams in the province are drained by the eastward-flowing tributaries of the Limpopo River.

### *2.1.3. Climatological Setting*

The climatic setting of the Limpopo Province ranges from dry sub-humid to semi-arid, characterised by wet-hot summers and dry-cold winters (Kabanda, 2004). The average annual temperature ranges from 18 °C (Winter) and 30°C (Summer) (Mpandeli & Maponya, 2013; Naledzani, 1999). There is spatial variability in rainfall;: the optimal amount is intercepted in the eastern part of the province (>1000 millimetres per annum; mmpa) and decreases westward to the west (<400 mmpa) (Mpandeli & Maponya, 2014; Naledzani, 1999). The effects of climate change are felt particularly in the agricultural industry. In the context of climate change, a semi-arid region is defined by insignificant and unreliable precipitation (< 400 mm/year) (Mpandeli & Maponya, 2014).

The climatic physiography of the Mpumalanga is altitude-dependent. The Highveld is characterised by a mean annual temperature of 16°C (Netshakhuma, 2021), whereas the subtropical Lowveld has a mean annual temperature of 23°C. Precipitation shows a similar trend to that of the Limpopo Province, with a westward decrease in frequency and quantity. The Highveld and Drakensberg receive mean annual rainfall of 510 to 760 mm, and the Lowveld receives over 1,000 mm (Netshakhuma, 2021). Most of the natural vegetation in the province consists of various types of grassland or savanna parkland, with acacia trees.

## 2.2. Data Collection

The study used auxiliary datasets because the required data were available in the archives. The climatological variables, including rainfall and temperature, were obtained from the South African Weather Service (SAWS). The variables considered as inputs for the suitability assessment of tree lucerne were recommended in the literature (Tadesse, 2016; Wiley, 2006; Assefa, 1998; Varvikko & Khalili, 1993; Borens & Poppi, 1990). Meanwhile, the geo-ecological parameters, such as elevation data (slope and altitude), were derived from the Water Resource 2012 dataset. Lastly,

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the pedological attributes (soil type, soil pH, and soil depth) were obtained from the Agriculture Research Council – Institute for Soil, Water and Climate (ARC-ISWC, 2016).

The study adopted the quantitative research design. This was in line with the main research objective, which was to establish a spatial suitability model for tree lucerne in the study area.

## 2.3. Data Processing

Carl (1996) defined data processing as the gathering and manipulation of data to produce meaningful narratives and descriptive information. The steps adopted to issue the geospatial suitability of the tree Lucerne in Limpopo and Mpumalanga Province encompass data acquisition, preparation, and modelling. All datasets used as input comprised geo-climatological components. Processing was performed in ArcGIS.

### *2.3.1. Ranking the Predictive Parameters*

Data preparation includes reclassifying the input variables for the model. The attributes in the input thematic layers were assigned scores ranging from one to three. The magnitude of the score was allocated in proportion to the extent to which the attributes within the map influence tree lucerne development.

Table 1 indicates how the scores were allocated to a different set of attributes within the predictive parameters. The plant requires the optimal rainfall range between 400-700 mm/pa (rank 3), a moderate range of 100-400 and 700-1600 mm/pa (rank 2), and rainfall below 100 mm/pa and greater than 1600 mm/pa (rank 3) may not suffice for this plant. Meaning the crop may withstand a wide array of temperatures ranging from -9 to 50°C. Because the local temperature ranges entirely conform to the optimal range, this variable was not considered for geospatial modelling.

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**TABLE 1: The Predictive Variables for the Tree *Lucerne***

| | **Rank 1** | **Rank 2** | **Rank 3** |
|---|---|---|---|
| Rainfall (mmpa) | <100 and >1600 | 100-400 and 700-1600 | 400-700 |
| Soil Depth (cm) | <100 | 100-200 | >200 |
| Soil draining | Poorly drained | Moderately drained | Well Drained |
| Soil pH | <4 and >10 | 4-5,5 and 7,5-10 | 5,5-7,5 |
| Groundwater level (mg) | <5 | 5-15 | >15 |
| Soil type | Clay soil | Loamy soil | Sandy soil |

(Source: Tadesse, 2016; Tadesse, 2016; Wiley, 2006; Assefa, 1998; Varvikko & Khalili, 1993; Borens & Poppi, 1990)

Soil is a fundamental factor in the development of tree lucerne. The soil depth ranking reflects how the crop requires a thick soil profile: rank 3 (>200 cm), rank 2 (100-200 cm), and rank 1 (<100 cm). The plant relishes well-drained soil, as moisture may lead to waterlogging and, subsequently, root rot; therefore, rank three coincided with well-drained soil, rank two with moderately-drained, and rank one with poorly-drained soil. Low water requirements also dictate that the tap root should not easily reach the groundwater table. Where the resource occurs beneath 15 m, it had a rank of three; water levels ranging between 5-10 m had a rank of two, and where the water table was shallower than 5 m, a rank of one was assigned. The ideal soil type for tree lucerne is sandy soil (rank 3), which is characterised by rapid permeability; loamy soil (rank 2) has moderate permeability; and clay soil has the lowest score of 1 because high porosity keeps water for longer, posing the threat of water clogging. Soil pH also plays a crucial role in the establishment of tree Lucerne plantations. The pH range of 5,5-7 was allocated a rank of three, meanwhile, a rank of two conforms to the values that encompass the optimal values (4-5,5 and 7,5-10 pH), and lastly, the poor rank of one was attributed to the pH values below 4,5 and greater than 10.

### 2.4. Integration of the Predictive Variables

The geospatial suitability of tree lucerne was assessed by integrating the reclassified thematic layers of the predictive variables. These were carried out in ArcGIS. Equation one (1) indicates how the suitability of the tree lucerne was established.

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$$Cp_{(\%)} = \sum_{i=3}^{i=6} w_t r_t$$

……*(1)*

Where $C_P$ is the crop suitability potential, $w_t$ is the weighting coefficient assigned to each of the thematic layers. The geospatial model was established in ArcGIS. The reclassified thematic layers were overlaid in the spatial analyst feature. Equal weights were assigned to the layers to offset the biases associated with manual weight assignments. The resultant geospatial map showed the suitability of the tree lucerne in various parts of the study area.

## 3. RESULTS AND DISCUSSION

This section presents the results on the spatial suitability of tree lucerne in Limpopo and Mpumalanga Provinces. The resulting maps define crop suitability in three categories: optimal area, suitable area, and non-suitable area.

### 3.1. The Spatial Potential of the Tree Lucerne

According to Champ and Dyte (1976), the crop suitability model indicates how well a piece of land is suited to a particular crop. In the present study, a spatial suitability model was developed by integrating climatological and geo-environmental variables. Table 2 presents the resulting suitability classes and their corresponding extents.

**TABLE 2: A Table Indicating an Area Extent Conforming to Each of the Subsequent Suitability Classes**

| Lucerne Potential | Area (%) | Area (HA) | Colour code |
|---|---|---|---|
| Optimal | 32,22133 | 65167,32 | Red |
| suitable | 61,95619 | 125305,8 | Green |
| Unsuitable | 5,822483 | 11775,91 | Blue |

According to Table 2, the area's Tree Lucerne potential is divided into three subcategories: optimal (red), suitable (green), and unsuitable (blue). The class with the least spatial extent is the unsuitable area, at 11,775 ha (5,8%).

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According to Figure 2, a prominent proportion of the unideal area for tree Lucerne plantation is found in Mpumalanga, namely Hendrinakrag, Middleburg, Ermelo, Driekopisdorp, and Volkrust. Meanwhile, such a potential class is marginal in Limpopo and restricted towards the South. The expression of such poor potential may be mainly attributed to the excess rainfall the area receives, at 900 mm/pa. Such a significant amount of the mean yearly rainfall far exceeds the 700 mm of rainfall that the plant requires.

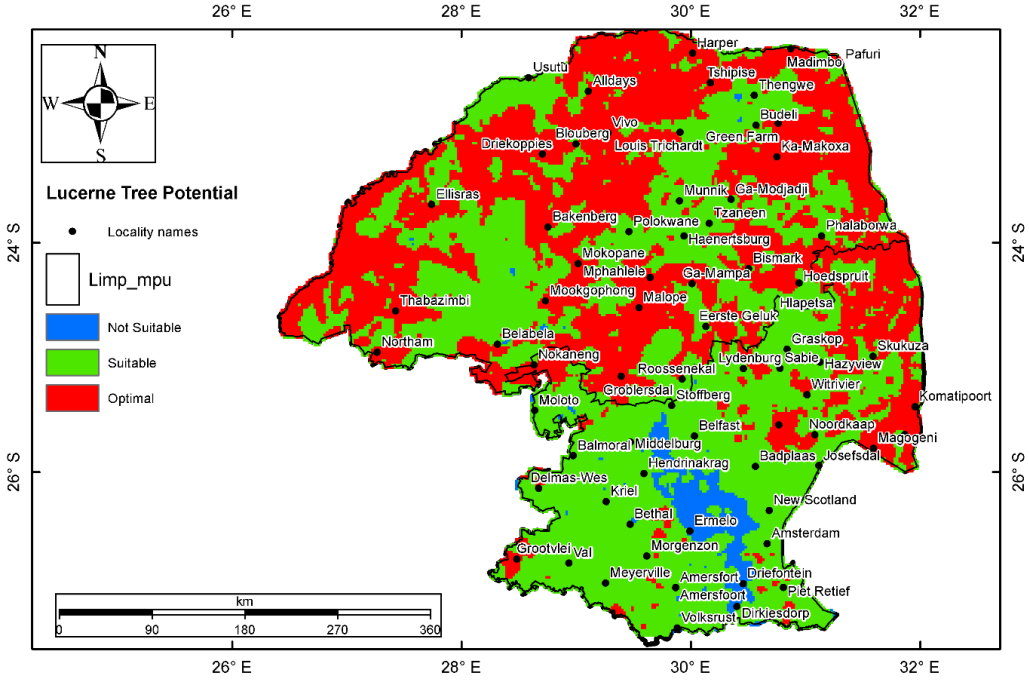


**FIGURE 2: Shows a Spatial Distribution of the Resultant Lucerne Tree Suitability Map**

The suitable potential refers to an area that does not fully exhibit all the variables the crop requires to yield optimally. This class is defined by the overlap of the predictive variables with the crop requirement. Table 3.1 indicates that such an area has an aerial extent of 125,305,8 square kilometres (61,95%). This is by far the most extensive potential in the area (indicated by the green colour). In comparison with the poor production potential, this potential spreads across the two provinces.

The optimal potential area is the area that exhibits the most favourable geo-environmental and climatological conditions for a particular crop to thrive. Crops thrive when there is congruence between the prevalent agroecological conditions of an area and the ideal crop requirements. Table

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2 indicates that a third of the study area, 65167,32 (32%), conforms to this class. According to the Map in Figure 2, the optimal potential area is dominant in the Limpopo Province. Interestingly, these areas are extensive and coincide with the arid and semi-arid regions.

### 3.2. Simplified Tree Lucerne Potential Mapping

Although the tree lucerne suitability potential map was established using equal weighting of the predictive variables, it is apparent that the most influential variables for predicting spatial potential are soil type and rainfall. While temperature was generally considered a crucial element, it was found to be unessential in the present study, mainly because the spatial and temporal variation values were all within the optical crop requirements range. Therefore, its inclusion did not add any value but data redundancy. Meanwhile, rainfall was the most integral component of the climate influencing spatial potential. Mpumalanga had higher rainfall intensity (>800 mm/pa) than Limpopo Province (500 mm/pa). Although the former exhibits exceptionally high precipitation, it shows poorer potential than the latter. This may be interpreted as lower precipitation that the crop relishes. This assertion is also supported by the prominence of the optimal potential area across most of Limpopo, with a significant spatial extent.

On the other hand, soil type was also identified as a prominent variable for suitability. Since the study areas receive higher precipitation than the crop requires, the ideal soil type should possess high drainage to avoid waterlogging. Such a soil type is prevalent in the northern part of the Limpopo Province.

The integration of rainfall and soil type may be instrumental in determining the suitability of an area for lucerne. A conditional checklist can be established for extension officers to assess the suitability of an area for this crop. If an area has a mean annual rainfall ranging between 500-mm/pa, it is ideal for lucerne tree plantation. In cases of higher rainfall (> 1000 mm/pa), the soil should be well-drained to cope with excess water and avoid clogging.

### 3.3. The Benefits of Tree Lucerne

Tree lucerne is an ideal plant renowned as forage for livestock. It is strongly believed that the ruminants enjoy the taste of this crop. It is also a nutritious plant rich in protein. Moreover, it can be grazed directly in the field or dried for future use (Heuzé *et al.,* 2016). As a fodder crop, it

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provides approximately 25% of the crude protein and anywhere between 14–30% of crude indigestible fibre. This plant has a deep taproot system that enables it to draw moisture from the subsoil. Ultimately, it is an evergreen plant that produces green leaves during the dry season.

According to Bezabih *et al.* (2021), approximately 11 tonnes of dry tree lucerne may be obtained from a hectare of land per annum. This ultimately translates to the exclusive feeding of precisely three mature cattle per hectare per year. However, for optimal forage production, a planting spacing of 8 m may be used, resulting in 144 trees per hectare. Given the total land area coinciding with the suitable and optimal potential area, an additional 800,000 cattle may be introduced, all fed only tree lucerne. Such development would not only provide supplementary feeds or forage to the ruminants, but it would also accelerate the recovery of the pastures after cutting and harvesting of the forage. Regeneration rates are improved by symbiotic relationships with nitrogen-fixing bacteria in lucerne. This unique ability enables it to capture atmospheric nitrogen, enriching the soil with this essential nutrient. The grass and other feeding crops facilitate the development of grass between the tree lucerne.

The prospective implication of Tree Lucerne-based communal grazing may not be fully comprehended at face value. There is more to this system than what meets the eye. To put this into context, in a conventional communal grazing system, a fully grown cow requires about 0,4ha of pasture (Coates, 1992). This implies that 10 cattle require 4 ha of pasture. In terms of good pasture management, a rotational system is considered an ideal approach. Such a system dictates that pasturing be divided into smaller compartments. Every second day, the livestock should be taken to a new compartment to graze, and the grass should be allowed to recover for about 30-35 days. It is therefore necessary to ensure that the range lands are supplemented with tree lucerne to enhance their grazing capacity (Mthi & Nyangiwe, 2018). The added benefits of the crop include soil moisture retention, reduced soil erosion, land restoration, and soil fertilisation (Rajan *et al*., 2019), which accelerate pasture regeneration after grazing.

The worst-case scenarios for smallholder livestock farmers entail an extended drought. Tshikolomo *et al*. (2022), in their review of the demography of smallholder livestock farmers, found that they are vulnerable to drought and its associated impacts. They do not have the financial means to obtain bale for their animals; feeding a sheep could cost between R10 and R14 a day,

and a cow between R50 and R70 a day in winter (Moorby *et al.,* 2016). This would mean that a farmer with 10 cattle would need about R700/day and about R21000/month. Such an amount surpasses their net revenue every month.

### 3.4. Increasing Kept Livestock

The pastures dictate how much livestock should be kept at any given time (Zewdie & Yoseph, 2014). Surpassing that number always leads to environmental degradation, as overgrazing is accompanied by excessive removal of grass, resulting in erosion and the total loss of pastures (Boles *et al*., 2019; Cao *et al.,* 2013). As a coping strategy, farmers tend to sell their produce prematurely, often at a loss (Mthi *et al.,* 2017; Scholtz & Bester, 2010). The introduction of fodder banks in the form of tree lucerne will significantly boost the available food resources for livestock. Tree lucern is associated with a high protein content (Rajan *et al.,* 2019). This implies that the plant may be used for exclusive feeding, provided that phosphorus and sulphur are supplemented to the food. When there is sufficient feed, livestock farmers can hold on to their stock for longer until such time as they are ready for the market.

The high protein content of tree lucern means that livestock will mature on time and be ready for the market. The operators are also able to sell their produce at the market price rather than always taking a price fall in the trade. Ultimately, the socio-economic status of the farmers improves drastically in proportion to their earnings.

### 3.5. Reduced Cost of Farming

Tree Lucerne will reduce pressure on farmers by mitigating climatic impacts through the provision of sufficient feed during times of need (e.g., drought). While the complexity of initiating a Tree Lucerne may take time for the community to comprehend, it drastically reduces farming costs. This ultimately implies that the practice's profitability and sustainability improve. Tree Lucerne is drought-resistant, and it is known that some of the adverse predicaments associated with livestock farming include a substantial increase in temperatures, reduced precipitation, and increased drought frequency. Fortunately, tree Lucerne is drought-resistant and not highly affected by limited rainfall. Approximately 30% of the land surface is optimally suitable, and another 60% is deemed suitable for the plantation. This implies that over 90% of the study area can support tree

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lucerne. This ultimately translatess to 190 000 $km^2$ of land to support smallholder livestock farming. Hence, Bezabih *et al*. (2021) report that approximately 11 tonnes of dry tree lucerne may be obtained from a hectare of land per annum; the ideal commodity production area has the potential to yield 1.1 million tonnes per year. This translates to 376 cows strictly fed on tree lucerne for a year. However, with the consideration that the crop is mainly required as a supplementary feed during the dry season, the number of the kept stock may substantially increase, especially considering that some livestock require much less feed per day compared to cattle.

## 4. CONCLUSION

The geospatial modelling of the geo-climatological variables comprising rainfall, soil type, soil drainage, soil pH, soil depth, and water level is instrumental in establishing the prospective potential of lucerne. About 30% of the land surface is optimally suitable, and another 60% is deemed suitable for planting lucerne in the study area. Only 5% is considered ideal. The development of tree lucerne as a fodder bank crop would significantly reduce smallholder livestock farmers' vulnerability to the impacts of climate change. A fodder bank will improve the sustainability of the smallholder operations and their profitability. It will also amplify the grazing capacity of the rangelands. Given the climatic setting, groundwater would be key to the sustainable management of tree lucerne.

## 5. RECOMMENDATIONS

Governments should formally adopt the crop as a supplement to livestock feed, particularly in the country's arid and semi-arid regions. The national agricultural ministry should play an integral role in supporting smallholder operations by facilitating the acquisition of seedlings for this crop to improve their resilience to the impacts of climate change. Moreover, the extension officers should be thoroughly trained on this commodity to ensure excellent support services to the smallholder farmers. With a properly coordinated support system, smallholder livestock operators will ultimately operate economically and sustainably.

## 6. ACKNOWLEDGEMENT

The authors would like to thank the **Water Research Commission (WRC)** for the funding of the study.

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