Journal of Agriculture and Social Research (JASR) VOL. 8, No. 2, 2008

LAND SUITABILITY ASSESSMENT AND PRECISION FARMING PROSPECTS FOR IRRIGATED MAIZE-SOYBEAN INTERCROPPING IN SYFERKUIL EXPERIMENTAL FARM USING GEOSPATIAL INFORMATION TECHNOLOGY

M.E. MOSHIA[1, *], M.B. MASHATOLA[2], P. SHAKER[2], P.S. FOUCHÉ[2] & M.A.W. BOSHOMANE[3]
[1]Dept. of Soil & Crop Sciences, 1170 Campus delivery, Colorado State Univ., Fort Collins, CO 80523, USA
[2]Dept. of Soil Sciences & Remote Sensing, Univ. of Limpopo, P/Bag x1106, Sovenga, 0727, RSA
[3]International Institute for Geo-info. Sci. & Earth Observation (ITC), 7500 AA Enschede, The Netherlands [*]Corresponding author: moshia@rams.colostate.edu

ABSTRACT

To maximize maize-soybean production, and ensure efficiency and sustainability in land use, there was a need to conduct an intensive qualitative land suitability assessment. The objective of the study was to digitize the University of Limpopo experimental farm map, produce expert knowledge based land suitability map, and quantify the suitable areas for maize-soybean production under irrigation. The qualitative land suitability assessment approach study was conducted over five consecutive years from 1999 at Syferkuil experimental farm, Limpopo Province, South Africa. The evaluation of land in terms of the suitability classes was based on the method described in FAO guidelines for land evaluation for irrigated agriculture. A 1:10 000 corrected scale aerial photograph of the farm was georegistered using MapInfo Professional software, with a differential global positioning system coordinates. The soils on the farm were sampled and profiles classified using South African Binomial system of soil classification. The farm was divided into suitability classes of highly suitable (S1), suitable (S2), and unsuitable (N1), and permanently unsuitable (N2) classes. Maize-soybean suitability maps were produced based on soil characteristics and crop requirements. About 16.5% of the study area was found to be suitable for maize-soybean production, and 19.7% highly suitable. Even though there was a huge area suitable for maize-soybean production, the current land use indicated that

most of it has already been used for Orchards production and horticultural research. The permanently unsuitable area (60.1 %) had shallow soils dominated by stones and plinthic horizon which had a combination of properties that restrict water movement and the penetration of roots. About 3.7%, which was classified as unsuitable was characterized by deep well weathered salt affected soils with a clay textured topsoil. The results of the study serve as a good foundation for precision farming practices with favourable environmental conservation. Geospatial information technology and soil expert knowledge are potentially powerful tools to save the land from degradation through high-quality land suitability assessment for agricultural sustainability and resource management.

Keywords**: Geospatial information technology; Land suitability assessment, and Maize-soybean intercropping**

INTRODUCTION

The successful development of sustainable and innovative land suitability assessment for better agricultural practices is as much reliant on environmental conservation as it is dependent on the use of new technology. The Food and Agriculture Organization of the United Nations (FAO, 1993) has indicated that there is an urgent need to match land types and land uses in the most practicable and logical way to continue sustainable production and to meet the needs of society while conserving fragile ecosystems. New developments in information and technology have presented scientists with geospatial information technology tools such as, geographic information systems (GIS), global positioning systems (GPS) and remote sensing. Remote Sensing techniques and GIS are not any more new tools in the field of land suitability assessment and evaluation (Zonneveldi, 1979). Pilot studies have proved the capability and applicability of these geospatial information tools as the legitimate tools for land suitability assessment.

Van Ranst *et al.* (1996) suggested that derivation of physical land suitability is a prime requisite for land utilisation planning and development, since it guides decisions on land utilisation for optimal utilisation of the land resources. Land suitability assessment and mapping in the context of agriculture is the process of assessing the possible uses of agricultural land, for example, arable farming, extensive grazing, or irrigated agriculture (Triantafilis *et al.*, 2001). The process involves identifying land use patterns and assessing whether the current use is the most feasible both economically and environmentally. Geospatial information technology has the potential to precisely identify and map the field for economical and environmental advantage (Swinton et al., 1998).

A land suitability assessment should be viewed from three different perspectives; productivity, workability and sustained use of the land (Baja *et al*., 2001a). Regardless of the approach, the final result is usually a map that describes the suitability of land for the particular crop of interest, in such terms as suitable with no limitations, suitable with some limitations, or not suitable (Triantafilis *et al*., 2001). To maximize crop productivity, and ensure efficiency and sustainability in land use, there was a need to conduct an intensive qualitative land suitability assessment (Van Lanen, 1991), and soil management units mapping for maize-soybean intercropping under irrigation at Syferkuil experimental farm. Farmers and researchers were interested in the land suitability for maize-soybean production so that they can estimate the production or productivity potential of their lands.

Maize (Zea Mays L.) and Soybean (Glycine max) are the major agronomic crops under irrigation in Syferkuil experimental farm. Most importantly, maize and soybean are South Africa's chief stable and supplementary crops respectively (Tsubo *et al*., 2003). Maize-soybean intercropping has also emerged as a common traditional cropping technique among the rural farming communities and other small scale farmers within the country (Mukhala, 2000). That's because intercropping cereal and legume species enhance nitrogen in the soil (Ayisi *et al*., 2004). Most government owned agricultural land in South Africa is prioriticized for maize and soybean production and research because they are a source of a better livelihood for the nation of South Africa.

Syferkuil is the experimental farm of the University of Limpopo, South Africa. The farm is 1 650 ha in size. For almost 35 years now, Syferkuil experimental farm served as the main centre of university's horticultural, agronomic, and animal production researches, on which both undergraduate and graduate student researches along with hands-on trainings are conducted. The farm is bordered by five populated

rural farming communities. Local farmers have always relied on the agricultural research output and extension from Syferkuil exp. farm since their climate, and the soils they farm on developed from the same parent material as the ones at Syferkuil. On this farm, about 25 ha are currently allocated for rainfed crops, 80 ha for irrigated crops, and 40 ha are used for rotation of winter and summer crops. The 80 ha irrigated crops are served by an automated linear move irrigation system.

The Syferkuil experimental farm records showed that the grain yield for maize-soybean production under irrigation was barely above the averages for a period exceeding a decade. In search for the cause of lower production yields, preliminary soil classification and survey data using South African taxonomic system (Soil Classification Working Group, 1991) indicated that there is a spatial variability in soils. And these soils were managed uniformly as a general unit for all agricultural production on the farm. The generalization of information within mapping units is not recommended, especially for large-scale mapping (Davidson, 1992). Soils exhibiting spatial variability are not supposed to be managed uniformly, but by the use of small management units or zones (Fleming et al., 2004). This type of soil management, which involve geospatial information technology, has been reported to improve yields and decision making processes (Ortega & Santibanez, 2007).

The suspicion about lower production yields was that, intensive land suitability assessment was probably an omitted process in syferkuil experimental farm prior to irrigated maize-soybean production. That was most likely because the farm records indicated that the farm was established by experts with more knowledge on farm structure and management than soil survey and land use planning. The major reason why land suitability assessment could be regarded as a gateway to effective agricultural

land use is that, land suitability assessment is the prerequisite process for sustainable agricultural production (Prakash, 2003).

The current project was also a foundation to establish precision farming practices at Syferkuil experimental farm. The objective of the study was to (i) digitize the farm map, produce expert knowledge based land suitability map, and quantify the suitable areas for maize-soybean production under irrigation.

MATERIALS AND METHODS

Study area

The qualitative land suitability assessment approach (Klingebiel & Montgomery 1961; FAO, 1976) study was conducted over five consecutive years from 1999 to 2004 at Syferkuil experimental farm (23^{o}49' S; 29 ^{o}41' E), Limpopo Province, South Africa. The climate of the study site was classified as semi-arid with the annual precipitation of roughly ±495 mm per annum. The mean annual temperature of 25±1^{o}C (max) and 10±1^{o}C (min) was common during the years of study. Annually, the farm averages 170 frost-free days extending from late October to mid April.

Soil map production

A corrected scale aerial photograph (orthophotograph) scaled 1: 10 000 (Fig 1) was used during the study. The soils on the farm were classified using South African Binomial system of soil classification (Soil Classification Working Group, 1991). A soil auger was used for drilling the holes. Where a different soil profile was found during soil classification, a point was logged using a differentially corrected global positioning system (DGPS Ag132). The high resolution orthophotograph allowed us to pick out individual roads, buildings, mountains and vegetation change. A map and ground truth change in vegetation over an area of 1 600 ha was a guide for soil type change (Bragg, 1978), which helped us to pick areas to be drilled for soil classification. The orthophotograph was used as a base map with a transparent sheet, on which the vector soil map units were delineating.

Soil sampling and Analysis

Each soil map unit was intensively sampled with a soil auger and soil samples were analyzed at soil and Plant Analysis Research laboratory of the University of Limpopo. The soil color was determined using a Munsel colour chart. Soil P content of the soil was analyzed using Bray 1 method and the concentration was determined using Spectrophotometer (Watanabe & Olsen, 1965). Soil pH was analysed by saturated paste extract (Rhoades, 1982). The exchangeable cations were determined from the extract by inductively coupled plasma-ICP (Sahn & Miller, 1992). Soil texture was determined by hydrometer method (Bouyoucos, 1962).

Suitability Map

Each soil map unit represented a soil profile or a specific soil type. A digital soil map of the farm was produced. The image of the farm was georegistered using MapInfo Professional software, and DGPS coordinates. The DGPS coordinates and farm features were verified through Google earth software (Google ^{TM}). The suitability classes were also delineated with MapInfo Professional software (Figure 2). The farm was divided into suitability classes of highly suitable (S1), suitable (S2), and not suitable (N1), and permanently unsuitable (N2) classes (Ritung *et al*., 2007; FAO, 1977). Soybean-Maize suitability maps were produced based on soil characteristics and crop requirements (Sys *et al*., 1993). The produced maps and soil data were part of the decision support system that ensured efficiency in land use for soybean-maize production under irrigation.

RESULTS AND DISCUSSION

The division of land into suitability classes was the major step to determining the size of land which was suitable to make economically and environmentally sound maize-soybean intercropping production under irrigation. On a 1650 ha farm, 325 ha were classified highly suitable, 273 ha suitable, 61 ha unsuitable and 991 ha permanently unsuitable for maize-soybean production (Table 1). Even though there was a huge area suitable for maize-soybean production, the current land use indicated that most of it has already been used for Orchards production and horticultural research.

The permanently unsuitable area had shallow soils dominated by stones (Table 2) and plinthic horizon. A plinthic horizon has a combination of properties that restrict water movement and the penetration of roots (Kelley *et al*., 2008). These permanently unsuitable areas had good soil chemical properties. The physical characteristics such as soil texture and presence of stones in the rooting depth made it permanently unsuitable. That's because water cannot permeate below a depth of 0.74 meters. During rainy seasons, erosion by water can be a problem since the topsoil texture is sand (Table 2).

The 61 ha which were classified as unsuitable, was characterized by deep well weathered salt affected soils with a clay textured topsoil (Table 2). Unsuitable area had high sodium content inherited from the parent material. At syferkuil experimental farm, conventional tillage is practiced and during the planting season the soil is bare and evaporation is high. Salts can easily kill the seedling. Soybeans and corn are unable to absorb phosphate at pH of 8.5 and above while also lead to Calcium toxicity (Scott, 1963). The clay content of these soils also restricts its suitability for corn-soybean production under irrigation.

Most soils at syferkuil experimental farm are mineral soils of an immature and skeletal type. Concerns about leaching in these soils are little because of low precipitation levels of the semi-arid environment. In such soils, soluble salts tend to accumulate in the profile at a depth related either to the position of the water table or to the depth of moisture percolation (Goudie, 1984). The unsuitable soils, which were found at the foot slope with high clay content and salts accumulations, could not be considered to be suitable for irrigated maize and soybean (FAO, 1985). Guided by FAO guidelines on land evaluation for irrigated agriculture, it was concluded that the costs of correcting that piece of land towards suitability will not make any economic sense under irrigation because of salinity, slope and the quality of water used in irrigation.

One of the major factors which were considered during suitability assessment for irrigated maize-soybean intercropping was irrigation effects since the climate of the area was classified as semi-arid. Under semi-arid condition, soil drainage is an important factor to be considered to avoid irrigation-induced secondary drainage (Fischer *et al*., 2000). A very important effect of salinization is its influence on the deterioration of physical properties of a soil. An increase in exchangeable sodium leads to clay dispersion and the consequent destruction of aggregates and loss of structure (Shainberg & Singer, 1990). Apart from salts accumulation, soil chemical properties were not the major determining factor for suitability evaluation but soil physical properties. That was because most soil chemical properties are easily correctable with economically reasonable methods.

However there were other factors of determination such as high clay content that immensely affected the decision making process. Hard clay soils limit water permeability and roots penetration and as a result, they are subjected to water logging. Maize and soybean growth is directly affected by soil water, soil aeration, and by soil resistance to root penetration (Tormena *et al*., 1999).

Soils classified as suitable and highly suitable had a good topsoil texture, deep soils without stones within 1.5 meter depth, and lower salt content. Such soils were characterized by good water and nutrient holding capacity. Soil pH was either within the desired range (6.5

to 7.2) or few units away from the range. Such pH values could be easily corrected with minimum economic resources that a government-dependant farmer can afford.

The topsoil texture of the suitable soils (silty clay loam) had higher clay content as compared to the topsoil texture of the highly suitable soils (sandy loam) (Table 2). These soils were classified as suitable with an option of opting in the chisel tillage that would increase infiltration and soil water storage (Baumhardt *et al*., 1992**);** hence the climate of the region is classified as semi-arid.

The classification of the farm into suitability classes was a major decision to divide the field into zones of restricted and permitted maize-soybean production under irrigation. The unsuitable and permanently unsuitable were merged and labeled as restricted for maize-soybean production. These two zones are for efficient use of soil resources and better management decisions (Lund *et al*., 1999).

The highly suitable and the suitable areas of the field were further merged together as one zone of permitted for maize-soybean production. The merger resulted in area of 598 ha of suitable land. The major step after division of the field into two zones was the management of spatial variability within a large suitable area of 598 ha which had a huge spatial variability. The presence and absence of stones in the topsoil was used as a factor for the planning of management zones delineation. Since this project was the first step of an on-going project that seeks to implement precision agricultural techniques, the new zone of permitted for soybean-maize production will be divided into areas of low, medium and high management zones in the second phase of the project. This management of infield spatial variability for successful maize-soybean production would be a step forward towards precision agricultural practices and environmental conservation.

CONCLUSION

The study has shown that conducting land suitability assessment prior to crop planting is a skillful and sustainable act that could be done precisely with the use of geospatial information technology. The land suitability map was finally produced as part of resource management. The best soils according to management practices for maize-soybean production were eventually set aside according to their economic value for maximum production. Poor land use to such a limited piece of land that serve such a great educational purpose can lead to change in physical and chemical properties for worse. Geospatial information technology and soil expert knowledge are potentially powerful tools to save the land from degradation through high-quality land suitability assessment for agricultural sustainability and resource management. Geographic information and global positioning systems application have proved to be effective tools in land suitability variability assessment. Despite the fact that economic analysis has not been carried out in this project, such activities will be part of the second phase which is management of spatial variability through precision agriculture techniques.

Acknowledgements

The authors acknowledge the hard work of the Land use planning students (class of 1999 through 2004) in the Department of Soil Science and Remote Sensing, University of Limpopo. The institutions that funded the studies of the students were Limpopo province Department of Education, ARC-Institute for Soil Climate and Water, and Limpopo province Department of Agriculture.

REFERENCES

Ayisi, K.K., Mpangane, P.N.Z. and Whitbread, A. (2004). Grain yield and symbiotic activity of cowpea cultivars grown in sole and intercropping systems with maize

in the Limpopo Province of South Africa. 4th international crop science congress. Queensland, Australia.

Baja, S., Chapman, D. M., and Dragovich, D. (2001a). A conceptual model for assessing agricultural land suitability at a catchment level using a continuous approach in GIS. In Proceedings of the Geospatial Information and Agriculture Conference. 17–19 July, Sydney, 828–841.

Baumhardt, R.L., Wendt, C.W. and Keeling, J.W. (1992). Chisel tillage, furrow diking and surface crust effects on infiltration. Soil Sci. Soc. Am. J. 56:1286–1291.

Bouyoucos, G.J. (1962). Hydrometer method improved for making particle size analysis of soils. Agron J. 54: 464-465.

Bragg, T.B. (1978). Effect of burning cattle grazing and topography on vegetation of the choppy sand range site in the Nebraska sandhills prairie. Proceedings of the First International Rangeland Congress, Society for Range Management, Denver, Colorado, USA, pp. 248–253.

Davidson, D.A. (1992). The Evaluation of Land Resources, Longman, Harlow.

FAO. (1985). Guidelines: land evaluation for irrigated agriculture .Soils Bulletin 55. Food and Agriculture Organisation of the United Nations. Rome.

FAO. (1993). Guideline for Land Use Planning. FAO Development Series No: 1, FAO, Rome, pp 96.

FAO. (1976). A framework for land evaluation. FAO Soils Bulletin No. 52, Rome.

Fischer, G., van Velthuizen, H., Nachtergaele, F. and Medow, S. (2000). Global Agro-Ecological Zones (Global-AEZ) [CD-ROM and FAO/International Institute for Applied Systems Analysis (FAO/IIASA).

Fleming, K.L., Heermann, D.F. and Westfall, D.G. (2004). Evaluating soil color with farmer input and apparent soil electrical conductivity for management zone delineation. Agron. J. 96:1581–1587.

Goudie, A. (1984). The Nature of Environment: An Advanced Physical Geography, Blackwell, Oxford.

Kelley, J.A., Ogg, C.M. and Wilson, M.A. (2008). Rationale for a Plinthic Horizon in Soil Taxonomy. Proceedings of the southern regional cooperative soil survey conference. July 14-17. Gainesville, Florida.

Klingebiel, A.A., and Montgomery, P.H. (1961). Land capability classification. Agricultural Hand Book No. 210. U.S. Department of Agriculture, Soil Conservation Service.

Lund, E.D., Christy, C.D. and Drummond, P.E. (1999). Practical applications of soil electrical conductivity mapping. p. 771–779. *In* J.V. Stafford (ed.) Precision agriculture '99. Proc. Eur. Conf. on Precision Agric., 2nd, Sheffield Academic Press, Sheffield, UK.

Mukhala, E. (2000). An evaluation of communication effectiveness between metereological scientists and farmers in the Free State province. Masters thesis, Univ. of Free State, Bloemfontein.

Ortega, R.A., and Santibáňez, O.A. (2007). Determination of management zones in corn (*Zea mays L.*) based on soil fertility. Computer and Electronics in Agriculture, 58(1):49–59.

Prakash, T. N. (2003). Land suitability analysis for agricultural crops: A fuzzy multicriteria decision making approach. International Institute for Geo-information Science and Earth Observation. The Netherlands.

Rhoades, J. D. (1982). Soluble salts. p. 167-179. *In:* A. L. Page et al. (ed.) Methods of soil N analysis: Part 2: Chemical and microbiological properties. Monograph Number 9 (Second Edition). ASA, Madison, WI.

Sah, R. N. and Miller, R.O. (1992). Spontaneous reaction for acid dissolution of biological tissues in closed vessels. Anal. Chem. 64:230-233.

Shainberg, I. and Singer, M.J. (1990). Soil responses to saline and sodic conditions. Ch. 5. *In* Tanji, K.K. (ed.). *Agricultural salinity assessment and management.* ASCE Manuals and Reports on Engineering Practice, No. 71, Am. Soc. Civil Eng., New York.

Soil Classification Working Group (1991). Soil classification: A taxonomic system for South Africa. Memoirs on the Agricultural National Resources of South Africa, 15: 1–257.

Swinton, S.M., and Lowenberg-DeBoer, J. (1998). Evaluating the profitability of site-specific farming. J. Prod. Agric. 11:439-446.

Sys. C., Ranst, V., Debaveye, J. and Beernaert. F. (1993). Land Evaluation Part III, crop requirements. Agr publication No. 7, ITC Ghent.

Tormena, C.A., da Silva, A.P. and Libardi, P.L. (1999). Soil physical quality of a Brazilian Oxisol under two tillage systems using the least limiting water range approach. *Soil and Tillage Research* 52, 223–232.

Triantafilis, J., Ward, W. and McBratney, A., (2001). Land suitability assessment in the namoi valley of Australia, using a continuous model. Australian Journal of Soil Research 39: 273–290.

Tsubo, M., Mukhala, E., Ogindo, H.O. and Walker, S. (2003). Productivity of maize–bean intercropping in a semi-arid region of South Africa, Water SA 29: 381–388.

Van Lanen, H.A. (1991). Qualitative and quantitative physical land evaluation: an operational approach. Ph.D thesis. Agricultural University Wageningen, The Netherlands.

Van Ranst, E., Tang, H., Groenemans, R. and Sinthurahat, S. (1996). Application of fuzzy logic to land suitability for rubber production in peninsular Thailand. Geoderma 70: 1–19.

Wahyunto, R.S., Agus F., and Hidayat, H. (2007). Land Suitability Evaluation with a case map of Aceh Barat District. Indonesian Soil Research Institute and World Agroforestry Centre, Bogor, Indonesia.

Watanabe, F.S. and Olsen, S.R. (1965). Test of an ascorbic acid method for determining phosphorus on water and $NaHCO_3$ extracts from soil. Soil Science Society Proceedings 29, 677–678.

Zonneveldi, S. (1979). "Land Evaluation and Landscape Science", In Use of Aerial Photographs in Geographical and Geomorphology, ITC Textbook of Photo-interpretation, 37. Enschede, the Netherlands.

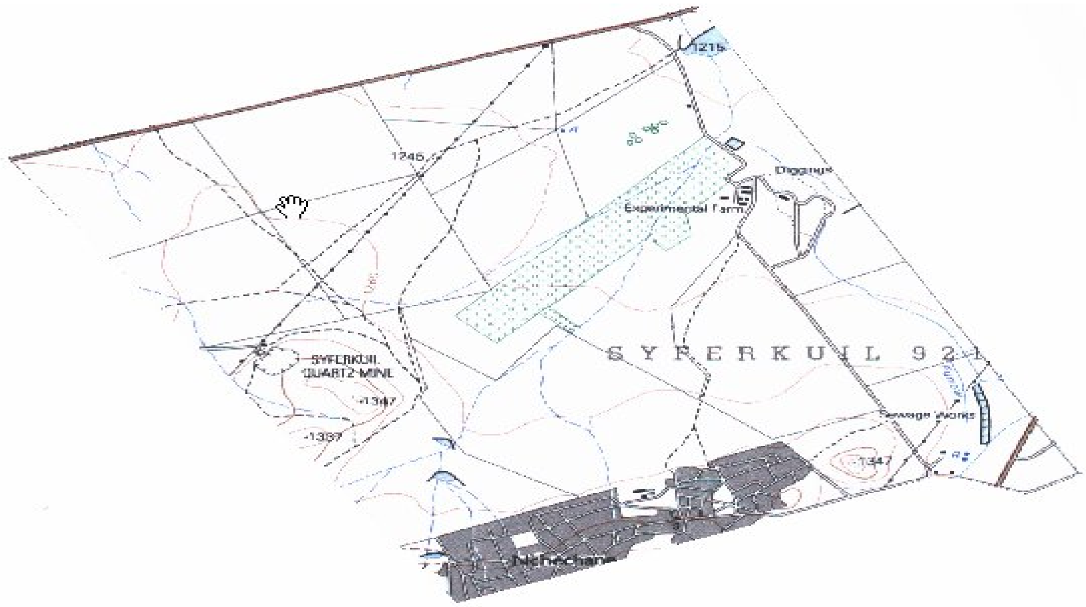

Fig 1. A corrected scale aerial photograph (scaled 1: 10 000) of Syferkuil experimental farm

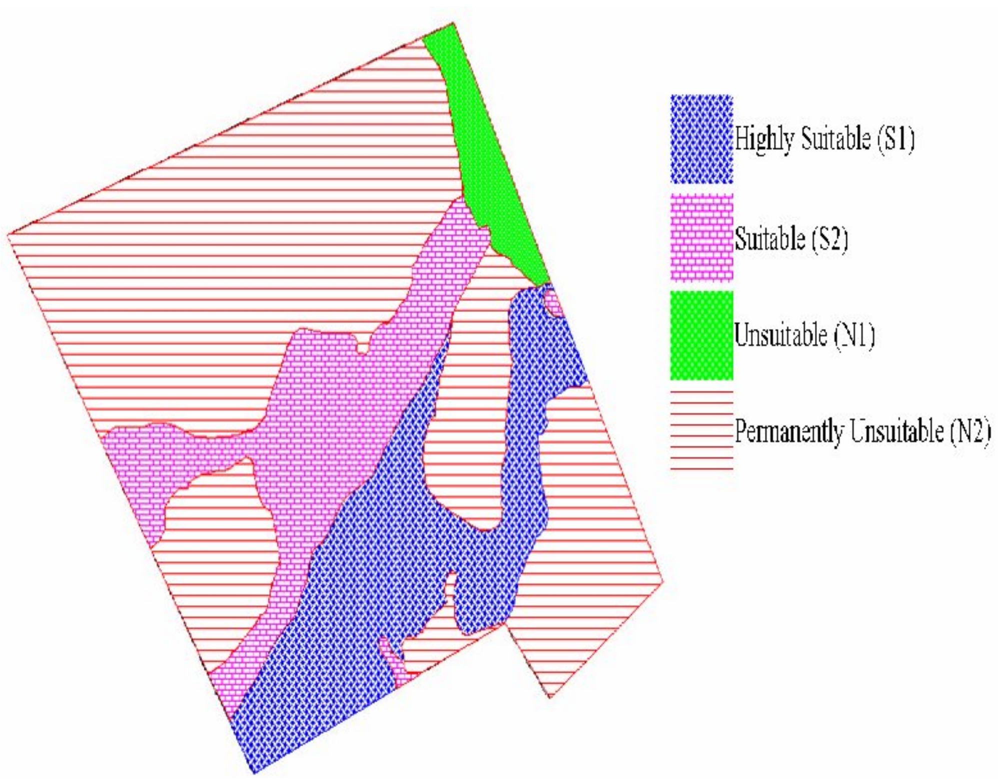

Fig 2. Land suitability map of Syferkuil experimental farm with four suitability classes of S1, S2, N1 and N2

Table 1.Suitability ratings according to the FAO classification levels (FAO, 1977)

Symbol	Suitability Class	Area (ha)	% of Total Area
S1	Highly suitable	325	19.7
S2	Moderately suitable	273	16.5
N1	Unsuitable	61	3.7
N2	Permanently unsuitable	991	60.1
Total		1650	100

Table 2. Selected characteristics of the suitability classes

Suitability Class	pH Min	pH Max	Na (mg kg^{-1}) Max	Soil depth (m) (no stones)	Stones	Topsoil texture
Highly suitable	6.5	8.0	82.5	1.49+	none	Sandy loam
Moderately suitable	6.54	7.90	191	1.59	few	silty clay loam
Unsuitable	9.0	9.24	568	1.55+	none	clay
Permanently unsuitable	6.30	8.75	34.7	0.74	†abundant	Sand

†There is underlying bedrock from 740 cm downwards