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LAND SUITABILITY FOR SPECIFIC CROP RANGES USING DYNAMIC LAND SUITABILITY EVALUATION GUIDELINES FOR SMALL-SCALE COMMUNAL IRRIGATION SCHEMES

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Abstract

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Small-scale communal irrigation schemes that are not top-down managed comprise an important agricultural activity in many deep rural areas of South Africa. Farmers in these irrigation schemes, rely on basic indigenous knowledge of soil, climate and empirical observations of crop performance to make crop production decisions. Such knowledge is not sufficient to make appropriate land use decisions on crop suitability. Land suitability evaluation systems and approaches used in South Africa are often geared to commercial skilled farmers with better knowledge and technological resources for crop production. Objective of the study was to assess land suitability for specific crop ranges at Rambuda irrigation scheme using dynamic land suitability guidelines for small-scale irrigation schemes. The first step in these guidelines is community engagement through consultations and ensuring community participation in land utilization choices. This is followed by detailed survey of biophysical resources and assessment by matching land utilization type requirements and tolerances against land characteristics or qualities of each mapping unit to generate suitability ratings. Results showed that majority of mapping units were well suited (WS) and suited (S) for majority of specific crop ranges and only mapping unit *Ao* was marginally suited (MS) for citrus because of crusting, prone to compaction, crusting and moderate drainage. Dynamic land suitability evaluation guidelines were successful for assessing land suitability for specific crop ranges at Rambuda irrigations and will have to be tested in other irrigation schemes under different socio-cultural and biophysical conditions.

Key words: dynamic land suitability guidelines, irrigation scheme, specific crop ranges, suitability rating

Introduction

Small scale irrigation schemes play an important role in local livelihood in rural areas of South Africa (Van Averbeke and Mohamed, 2006). Proper planning of land resources development is paramount to sustainable crop production of any agricultural project (Beek, 1981). Land evaluation provides important information for land use and development planning (Rossiter, 1996). Assessment of land resources for agriculture in Sub-Saharan Africa countries and around the world is primarily based on the principles of USDA land capability system (Laker, 2004a). The USDA land capability classification system and its derivatives have often been criticized for being risk oriented (Van Niekerk, 1983); being too static and inflexible (Smyth, 1981); not addressing the complex interactions of suit abilities for specific crops (Ellis, 1994); its negative approach incapable of incorporating the varying needs of different land uses (Davidson, 1982) and of being inconsiderate of the interaction of land, land use and land user/people (Laker, 1982; Hewitt and Van Wambeke, 1982).

Land evaluation systems and approaches used in South Africa are more relevant for commercial farmers with good financial resources and crop production skills and top-down managed small-scale farmer schemes. The land capabil-

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ity classification systems for South Africa by Scotney *et al.* (1987) lacked consideration for the local people and the issues of importance regarding land use planning and land resource allocation (Laker, 2004a). These systems were designed for a production system which is virtually fixed: large mechanized farming; high management levels; good infrastructure; uniform cropping system and management practices, etc. (Laker, 2004a). Such systems do not suit the needs of small-scale farmers, particularly in communal irrigation scheme where technological transformation – both modern and traditional land use operate side-by-side, sometimes linked by a land use characterized by intermediate technologies (Beek, 1981).

Land suitability evaluation in developing countries, in particular requires simple dynamic land suitability evaluation guidelines that cater for the needs of different and specific land uses and recognize the interaction between land use and land users. Good South African examples of guidelines for planning and development of irrigation projects are the procedures by Hensley and Laker (1981) and the guidelines by Turner and Scotney (1993). However, these guidelines did not provide land suitability ratings for various land utilization types (Laker, 2004a). He also suggested the development of a "South Africanized" version of the FAO (1976) framework for land evaluation and their guidelines for land evaluation for irrigated agriculture (FAO, 1985). There was no information or basis for crop choices at Rambuda irrigation scheme. Farmers have been growing crops on a trial-and-error basis using local knowledge of soil and climate to decide on which crops to grow in the irrigation scheme. This has led to inappropriate crop selections and consequently poor crop performance and yield.

The objective of the study was to assess land suitability evaluation for specific crop ranges using dynamic land suitability evaluation guidelines for small-scale irrigation schemes in Vhembe District of Limpopo Province, South Africa.

Materials and Methods

Description of study site

Rambuda irrigation scheme is a communal irrigation scheme situated in Vhembe District of Limpopo Province (22°59'30"S and 30°25'30"E), South Africa at an altitude of 635 m to 665 m above sea level. The total area of the irrigation scheme is 120 ha, demarcated into 104 terraced plots. Plot sizes vary from 0.6 to 1.28 ha. It is situated in the subtropical climatic region characterized by warm to hot moist summers and cool to cold winters (Table 1). The annual rainfall varies between 956 to 1200 mm with most rain falling from November to March. The mean minimum average temperature is 15°C and the mean daily maximum temperature is 27°C. The topography of the study area can be described as level with undulating gentle slopes with 0.5 to 2% gradient. The soil was classified according to the taxonomic soil classification system for South Africa (Soil Classification Working Group, 1991) as belonging to Hutton soil *(Rhodic, mesotrophic, luvic, haplic)* and Oakleaf soil form *(Neocutanic, chromic, luvic; haplic)* according to the World Reference Base for Soil Resources (ISSS-ISRIC-FAO, 1998). Soils are generally, deep and well-drained with only a small portion of moderately drained soil without signs of wetness found in the area occupied by Oakleaf form soil. Such soils were pointed out by farmers as being slow to dry-up after rains or irrigation. The main crops grown in the irrigation scheme are sweet potatoes, maize and winter vegetables planted on ridges under furrow irrigation with very limited use of pesticides

Table 1
Climatic conditions from 1982-2010 at Rambuda irrigation scheme

Climatic variable	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall, mm	178.39	208.33	154.73	39.94	15.72	20.71	17.16	8.89	21.3	61.55	103.44	126.04
Daily maximum temperature, °C	29.96	29.14	28.53	27.21	25.62	23.48	23.07	25	27.4	28.04	29.17	29.73
Daily minimum temperature, °C	19.59	19.61	18.53	15.77	12.03	9.38	9.23	10.86	13.73	15.96	17.76	18.99
Mean temperature, °C	24.78	24.38	23.53	21.49	18.82	16.44	16.16	17.93	20.56	22	23.46	24.36
Wind speed, km/h	108.3	104.1	90.77	78.12	75.04	79.54	88.89	100.22	115.76	121.58	113.08	104.99
A-Pan Evaporation, mm	197.83	160.79	163.08	131.07	122.59	100.36	111.35	143.22	175.06	191.2	203.52	195.81
Maximum daily relative humidity, %	84.66	84	87.24	86.47	87.81	87.05	86.54	84.17	84.06	81.3	83.26	84.02
Minimum daily relative humidity, %	40.47	41.42	42.84	38.54	34.97	32.44	32.15	30.08	32.67	35.67	38.88	39.25
Daily average sunshine hours	7.06	7.03	6.65	7.07	7.63	6.99	7.35	7.76	7.54	6.86	6.8	6.86

and inorganic fertilizers. Cattle, goats and chicken manure are the main source of plant nutrients used for soil fertilization in the irrigation scheme.

Principles and procedures of dynamic land suitability evaluation guidelines for small-scale communal irrigation schemes

Dynamic land suitability guidelines use a step-by-step procedure to assess the land, starting from the identification of the project to suitability assessment of each mapping unit for a specific crop range as follows.

Identification of the land for an irrigation scheme

Rambuda irrigation scheme was selected during the training needs assessment survey by the author. The author realized that the crops which were being grown in the irrigation scheme were not growing properly and enquired from the extension officer if there was a report of land suitability assessment for the crops that are grown in the irrigation scheme. In realizing that there was no such information in the irrigation scheme, the author asked a few farmers on how they decide on the crops that they were growing. Farmers indicated that they were just growing whatever they saw is simple to grow and which was useful to grow irrespective of their suitability. The authors then decided to conduct a detailed investigation on the scheme, which led to the current study.

Consultations and community engagement

An initial visit to the irrigation scheme was conducted to discuss an overview of the irrigation scheme and prevailing production problems with the local extension officer. The extension officer then organized a meeting with farmers as well as the tribal chief. A follow-up meeting was held with a group of farmers to get a general overview and perspectives on land use at Rambuda irrigation scheme to pave the way forward for this research. Soil criteria used by farmers for land suitability for specific uses.

Criteria used by indigenous people to assess land suitability for given uses included slope, texture, organic matter content, depth, drainage, climate and socio-cultural issues (Table 2).

Table 2
Criteria used in indigenous soil suitability for crop production

Criteria	Meaning	Crop suitability
Colour	Dark soils considered as fertile and having good moisture holding capacity whereas light soil considered as less fertile, low moisture holding capacity.	Dark soils - maize, *nawa* (beans), pumpkins. Light soils - millet.
Texture	Coarse sandy soil less fertile while fine clayey soil fertile.	Millet, bambara beans, sorghum, water melon.
Depth	Soils on steep slopes considered shallow and also soils with lot of stones.	Millet.
Stoniness	Soil with stones associated with shallow depth and difficult to work (*lukwara* or *lukwalangwanda*).	Millet.
Drainage	Poor drainage associated with soils in flat low lying in wetland or near rivers (*mutanga*).	*Nawa*, sweet sorghum.
Fertility	Soils under trees, dark coloured, clayey, soils near termite mounds or with earthworms are considered fertile.	Maize, *nawa*, pumpkins groundnuts.
Organic matter content	High organic matter content indicates highly fertile, good moisture holding soils and soils found under trees and low lying wetland areas.	Maize, *nawa*, pumpkins.
Moisture content	Associated with soils with clay or high organic matter content normally soils under trees or in wetlands.	Maize, *nawa*, pumpkins.
Wetness	Low lying flat areas with high organic matter consistent with wetlands.	Maize, *nawa*, pumpkins.
Slope	This include direction and gradient – west facing slopes considered drier and less fertile while east facing slopes less dry and fertile. Steep slopes considered shallow, less fertile, prone to erosion and difficult to work.	Millet west slope and maize east slope.
Flora and fauna	Trees and grass are used as indicators of fertility or drainage. Earthworms and termite mounds are indication of fertility of the soil.	Associated with moist and wetlands for maize, *nawa*.
Socio-cultural issues	Soils in religious groves are considered sacred and not suitable for any other use except religious purposes.	Not suitable.

Organic matter and clay content of the soil are considered as the main determinants of soil fertility. Soil with lower clay or organic content is considered less fertile. Clay content is considered the most important indication of soil fertility status. Land characteristics used by indigenous people were not different from those used in modern land suitability systems used elsewhere. The most important climatic variable is rainfall, particularly pattern and distribution. Cultural norms are considered as important and are very complex because of myths around certain crops e.g. bambara/jugo beans cannot be planted at the beginning of rainy season because it is believed to inhibit rainfall (Nethononda, 1996). There are no quantitative limits to determine land suitability for given crops. Suitability assessment is based purely on long term empirical observations of crop performance in a specific area. Land suitability assessment using these criteria is simple and subjective.

Selection of crops and generation of specific crop ranges for land suitability evaluation

Firstly, farmers decided on the crops that they aspire to grow in the irrigation scheme irrespective of their suitability. Farmers at Rambuda irrigation scheme listed forty crops that they want to grow in the irrigation scheme. The list of crops that was compiled by farmers was used to generate ten specific crop ranges (Table 3). Crop ranges were grouped according to their growth requirements such as rooting patterns and growth pattern, following the approach of Protz (1981).

Detailed biophysical resource survey and delineation of mapping units

Climatic conditions

The rainfall at Rambuda irrigation scheme is above 900 mm per annum (Table 1) and thus falls within a high rainfall climatic zone. There is frequent severe hailstorms have not been recorded in the area, only occasional light hailstorms and thus the area is considered hail-free. Hot, dry conditions during August-September months necessitate supplementary irrigation during this period. The area has dry cool winters coupled with low afternoon relative humidity of 32-34% and low mean monthly rainfall from 9-21 mm. Such low relative humidity and low temperatures are less favourable for pests and diseases, particularly fungal diseases. Climatic conditions of Rambuda irrigation scheme are suitable (S) for crops like tomatoes and potatoes that are sensitive to fungal infections.

Soils of Rambuda irrigation scheme

Soils were classified according to the taxonomic classification system for South Africa as belonging to Hutton and Oakleaf forms. Soils with luvic B1 horizons belonging to Suurbekom (Hu 2200) and Ventersdorp (Hu 3200) families of Hutton form are characterize by high clay content in the subsoil horizons and are susceptible to traffic compaction. Dipene (Oa 1220) family of Oakleaf form are characterized by soils with moderate drainage without signs of wetness that are prone to crusting, subsoil compaction and difficult to till when dry. Soils belonging to Hayfield (Hu 2100) and Caledon (Oa 1210) families of Hutton and Oakleaf forms respectively are non-luvic with coarse texture and have low water holding capacity.

Soil mapping units of Rambuda irrigation scheme

Map units were delineated by using spatial maps of map able soil properties that influence crop production and other agronomic practices. The irrigation scheme was delineated into six soil mapping units (Figure 1). A summary of the characteristics of each mapping unit is presented in Table 4. The area is considered flat and thus, topography was not used in the delineation of the soil mapping units

Table 3
Crop ranges generated from the list of crops listed by farmers

Range	Crops in specific range
I. Alliums range	Garlic, onion, spring onion
II. Root range	Beetroot, carrot, potato, sweet potato
III. Leaf vegetable range	Cabbage, Chinese cabbage, *muxe* (African night-shade), spinach
IV. Oil range	Ground nuts, sunflower
V. Pulses range	Cowpea, dry beans, Green beans, okra, peas
VI. Cereals range	Maize, wheat
VII. Curcubit range	Baby marrow, Gem squash, pumpkin, sweet melon, water melon,
VIII. Fruit range	Avocado, Banana, Leech, Mango
XI. Citrus range	Lemon, naartjies, orange
X. Tomato range	Chilli, green/red pepper, tomato

A list of soil characteristics important to crop growth was generated, with other useful characteristics for crop production (Figure 1). Each mapping unit was evaluated in terms of its suitability for the production of a specific crop that might be grown in the irrigation scheme.

Water resources

There are no quantitative data on water resources for the Tshala River

Empirical information on flow pattern of the river was obtained from the local people. Farmers indicated that the river flow is high during and just after the rainy months but, subsides in dry season. The river flow is very low during June to October, when the mean monthly rainfall is less than 22 mm (Table 1). Water demand for all crops is high due to high evaporative demand caused by hot, dry conditions during this period. These findings are similar to the serious problems found at Dzindi irrigation scheme found in the same region (Van Averbeke et al*.,* 2007; Van Averbeke, 2008)

Crops requirements and tolerances of crops in specific ranges

Summaries of the soil and climatic requirements for the different crop ranges are presented in Table 5 and Table 6. Requirements and tolerances of each crop in the specific crop range were obtained from the literature (Janick et al., 1981) and useful information on the performance of some crops were provided by farmers as they have observed them either growing as volunteer crops in the bush or hedge crops planted at their homesteads or along the plot boundaries.

Management requirements for Rambuda irrigation scheme

Land suitability evaluation is done on agronomic aspects as well as management requirements for soil fertility, irrigation, tillage practices, conservation measures and costs of land improvements. Land improvement costs relating to land clearing were not considered because this suitability evaluation was conducted on an existing irrigation scheme. However, when considering new land for development, costs of land clearing should be considered during the evaluation process. Socio-economic factors were also not separately considered during the land suitability evaluation process and will be only briefly discussed because the objective of this study was to assess physical land suitability of the irrigation scheme for specific crop ranges. Management requirements that were considered at Rambuda irrigation scheme are explained below.

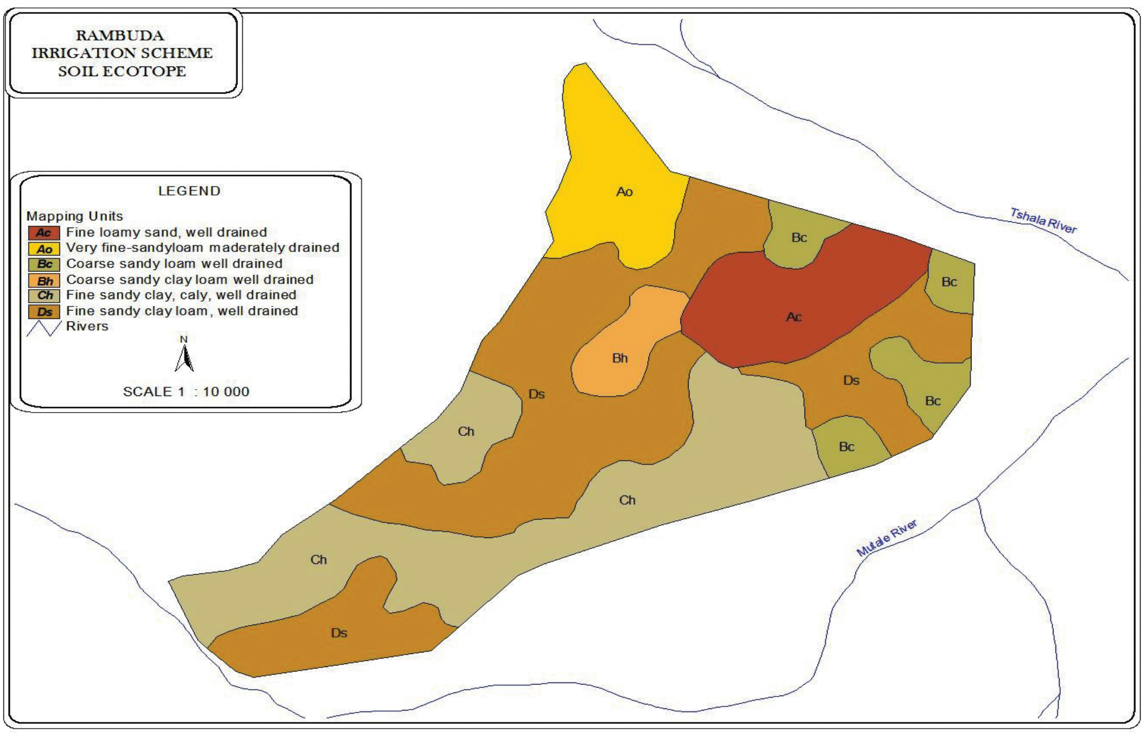

Fig. 1. Map units of Rambuda irrigations scheme

Irrigation management requirements

The most critical aspects of irrigation are the choice of an appropriate irrigation method for each soil type and its adaptation to specific soil. Any inappropriate selection of irrigation method to soil can result in high running costs, direct and indirect loss of soil quality through erosion or crusting. Three irrigation methods were considered based on what farmers suggested as the most preferred methods of irrigation. Class-determining factors relating to management and costs of each irrigation method were used to determine the suitability of different soil mapping units for rating of each irrigation system according to their irrigation requirements. Drip irrigation cannot be used on coarse texture (sandy) soils due to too fast infiltration which promote vertical percolation of water leading to poor lateral distribution. Thus, only a small area below the dripper is wetted which is insufficient to support the crop. Another limiting factor is the clogging of emitters by sand particles resulting in some areas of the field not irrigated. This method cannot be used on soils that are prone to surface crusting. Surface crust prevents water percolation resulting in water ponding below the dripper instead of reaching the roots of the crop. Sprinkler irrigation can used on sandy soil, however, soils should not be prone to surface crusting or located on slopes > 8%. Care should be taken even on soil with 5% slopes to prevent soil loss through erosion, particularly under annual cropping. Sprinkler irrigation can be used on medium to clay soil provided they are not susceptible to surface crusting. Furrow irrigation cannot be

Table 4
Brief description of mapping units of Rambuda irrigation scheme

Map Unit	Topsoil clay content, %	Effective soil depth, cm	Slope, %	Limitations
O	18-36	>120	0.5-1	Soil prone to subsoil compaction and surface sealing, moderate drainage.
Ac	12-32	>120	1-2	Low water holding capacity.
Bc	12	>120	0.5	Low water holding capacity.
Bh	8-32	>120	0	No limitations.
Ch	10-44	>120	0.5-2	No limitations, except small patches that may be susceptible to subsoil compaction particularly in the low lying areas.
Ds	36	>120	0-1	Few limitations, if any. Deep, slightly friable soil. Moderate drainage without signs of wetness, restrictive layer at lower depths.

Table 5
Summary of crop requirements used in assessing the soil suitability for specific crop ranges

Specific crop range	Rooting depth, cm	Texture	Clay content, %	Drainage	pH	Tolerance				
						Water-logging	Drought	Clayey texture	Acid	Salinity
Alliums	30-60	S, CL	<35	W	5.0-6.8	Low	Low	Medium	Low	Sensitive
Root	25-40	S-L	<35	W	5.6-6.6	Medium	Low	Low	High	Sensitive
Leaf vegetables	45-60	S-C	>15	W	5.5-6.8	Low	Low	Moderate	Moderate	Moderate
Cucurbits	90	S-LS	15-35	W	5.5-6.8	Low	Low	Moderate	Low	Sensitive
Tomato	45-60	S,L-C	<20	W	5.5.6.8	Low	Low	Moderate	Moderate	Sensitive
Oil	30-60	S to loam exclude sands and heavy clays	<20	W	5.3-6.0	Low	Moderate	Moderate	Moderate	Moderate
Pulse	45-100	S- CL	10-35	W	5.5-7.5	Moderate	Moderate	Low	Low	Sensitive
Cereals	90-120	L	10-80	W	6.0-7.0	Low	Moderate	Low	Low	Moderate
Fruit	90-120	S, L-C	15-25	W	5.6-7.2	Moderate	Moderate	Moderate	Moderate	Sensitive
Citrus	90-120	S-C	<30	W	6.5-7.5	Low	Low	Moderate	Moderate	Sensitive

C = Clay; CL = Clayey loam; L = Loamy; LS = Loamy sand; S = Sandy used on coarse texture (sandy) soil as it is difficult to manage control water from eroding the furrows. It is most suitable for soil with crusting problems as the irrigation water flows in the furrows preventing crusting effects on seed germination and the crops planted on ridges between furrows that are not affected by crusting.

Evaluation of suit abilities of soil mapping units for specific crop ranges

This section presents procedures for land suitability evaluation of each mapping unit for specific crop ranges for Rambuda irrigation scheme. Rambuda irrigation scheme is an existing irrigation scheme and thus, class-determining factors relating to management, land development, conservation and socio-economic conditions of the area did not have adverse influence on land suitability for irrigation. The influence of these class-determining factors will be briefly explained in the next section. Matching is selection of a crop or group of crops that closely match the conditions of the land (FAO, 1985) through the comparison between the land qualities or characteristics, and the requirements or tolerances of the land utilization type to give factor ratings. After consideration of class-determining factors for irrigated agriculture, suitability ratings were determined on the basis of the agronomic aspects related rooting conditions (effective depth, rooting room penetration resistance), aeration (drainage) and water quantity (stream flow, rainfall pattern). Suitability ratings relating to salinity sensitivity were not included since this irrigation scheme falls within a high rainfall area, where salinity is not found. The water quality is considered to be good and there is no chance of developing salinity problems in the area.

The process of the evaluation of mapping units that was used to assess suitability ratings for different mapping units for specific crop ranges is illustrated in Figure 2. This is an example of how mapping units Ao and Ac were evaluated for the citrus crop range using a decision-tree approach reach to the suitability rating decision (Van Lanen et al., 1992).

A crop suitability Table 7 and Figure 3 showing sizes of mapping units and a suitability rating for each crop range are drawn up. Such crop suitability a table could be given to economists. Economists could thereafter calculate all possible alternative combinations to decide on the most profitable crop combinations and economic suitability. This was not done for this study because it was only aimed at determining the physical suitability of land for specific crop ranges.

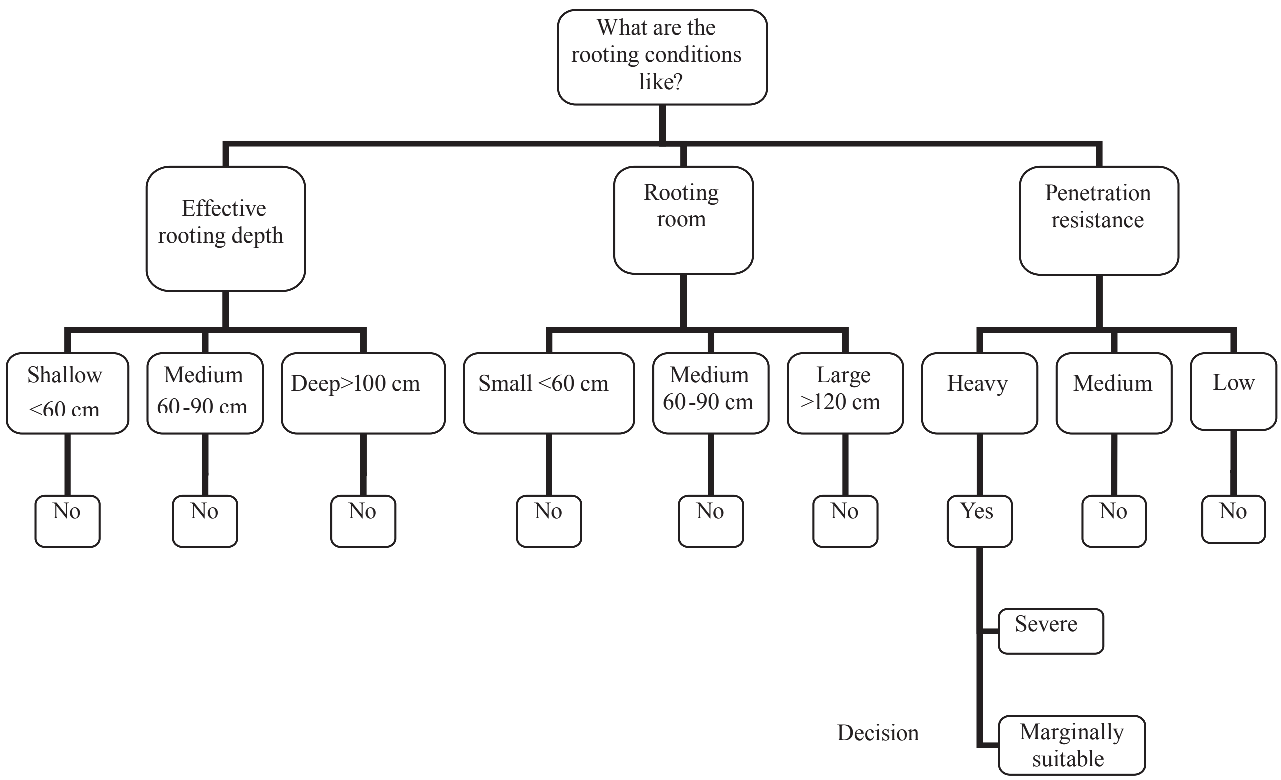

Fig. 2. Class-determining rooting conditions for citrus

Results and Discussion

Evaluation of bio-physical resources for irrigated crop production

This section presents the results of land suitability evaluation for irrigated crop production for Rambuda irrigation scheme using dynamic land suitability evaluation guidelines for small-scale communal irrigation scheme that were developed in this study.

- ***Topography -*** The area is considered flat with gentle undulating slopes ranging from 0.5-2% (Table 4). According to Turner and Scotney (1993), slopes less than approximately 8% are in general, considered suitable for irrigation development. The slopes of all mapping units at Rambuda irrigation scheme are less than the threshold slope of 8% for irrigable land (Turner and Scotney, 1993) and thus, the whole area is from a slope perspective classified as suitable for irrigation. However, selection of an appropriate irrigation method requires a suitability evaluation for each soil mapping unit.
- ***Climate -*** The area falls within a subtropical climatic region with warm to hot summer and cool to cold winter temperature. The area falls within an 11-year drought cycle region of the country. Knowledge of the rain cycle is useful in mitigating the effects of dry spells through selection of cropping programs that require less water for irrigation. The seasonal water deficits, coinciding with periods of low relative humidity, must be taken into consideration when developing cropping patterns. The climate of the area is considered as suitable (S) for growing a wide variety of crops under irrigated crop production.
- ***Soils and water resources -*** The soils of Rambuda irrigation scheme are deep, well-drained with a soil depth > 120 cm. The soils are generally, considered to be suitable (S) for

Table 6
Summary of crop requirements for assessing climatic suitability for specific ranges

Crop range	Temperature tolerance limits, °C	Optimum growth temperature, °C	Climatic rating of mapping unit					
			Ao	Ac	Bc	Bh	Ch	Ds
Alliums	7-29	12-24	WS	WS	WS	WS	WS	WS
Root	5-29	5-18	WS	WS	WS	WS	WS	WS
Leaf vegetables	7-27	15-24	WS	WS	WS	WS	WS	WS
Cucurbits	12-35	22-24	WS	WS	WS	WS	WS	WS
Tomato	12-35	18-33	WS	WS	WS	WS	WS	WS
Oil	12-25	15-21	WS	WS	WS	WS	WS	WS
Pulse	8-34	19-20	WS	WS	WS	WS	WS	WS
Cereals	32	18-30	WS	WS	WS	WS	WS	WS
Fruit	14-29	24-27	S*	S*	S*	WS	S*	WS
Citrus	14-32(40)	21-27	S*	S*	S*	WS	S*	S*

WS = well suited, S = suited * Low-lying parts of mapping units ***Ao,Ac, Bc,Bh, Ch*** and ***Ds*** are prone to light frost during June-July and fruit trees are likely to suffer leaf damage.

Table 7
Suitability rating for each mapping unit

Mapping unit	Size, ha	Suitability rating for each crop range									
		I Alliums range	II Root range	III Leaf vegetable range	IV Oil range	V Pulse range	VI Cereals range	VII Cucurbit range	VIII Fruit range	IX Citrus range	X Tomato range
Ao	10.928	WS	$S_{d,c}$	WS	S_c	WS	WS	WS	WS	$MS_{d,i,c}$	WS
Ac	13.416	WS	WS	WS	WS	WS	WS	WS	WS	$MS_{d,i,c}$	WS
Bc	8.863	WS	WS	WS	WS	WS	WS	WS	WS	S_c	WS
Bh	4.462	WS	WS	S_m	WS	WS	WS	S_m	WS	WS	WS
Ch	41.049	S_d	S_c	Ws	S_c	WS	WS	WS	S_c	WS	WS
Ds	41.497	S_d	S_c	WS	S_c	WS	WS	WS	WS	WS	WS

Notes: WS: Well Suited; S**:** Suited; MS: Marginally Suited; m= moisture availability; d= drainage; i= slow infiltration rate and c = susceptibility to soil compaction.

irrigation. Tshala River is a perennial with low flows during the June to October when the rainfall is low; however the water quantity is sufficient to irrigate 120 hectare land for just few months after the rainy seasons.

Land suitability evaluation for irrigated crop production

Land suitability evaluation was conducted on ten specific crop ranges generated from forty crops that were listed by farmers of Rambuda irrigation scheme (Table 3).

Climatic suit abilities of mapping units for specific crop ranges

The results of climatic suitability are summarized in Table 6. The most critical climatic variable for crop production is temperature. Temperatures at Rambuda irrigation scheme are within the ranges for all specific crop ranges selected for the irrigation scheme (Table 3). Therefore, climatic conditions are considered well suited (WS) for majority of crops in specific crop ranges for Rambuda irrigation scheme. Hot, dry conditions experienced from the months of August to October may be limiting, particularly for mapping units *Ac* and *Bh* which are characterized by coarse textured soils. These mapping units fall within the area that was reported by farmers to have soils that dry too quickly. The water flow can be increased through construction of diversion weir upstream and water flows to the secondary canals through the pipeline, thus, reducing wastage and increasing amount of water available for irrigation. In general, biophysical resources for agriculture at Rambuda irrigation scheme are classified as suitable (S) for irrigated crop production.

Low lying parts mapping units *Ao, Ac, Bc* and *Ds* are prone to light winter frost (Figure 1), particularly in the months of June-July. The eastern parts of mapping units *Ao, Ac, Ds* and *Bc* towards Tshala river are prone to light frost. The southern parts of mapping units *Ch* and *Ds* as well as mapping unit *Bc* are prone to frost. Citrus fruits are sensitive to frost and may suffer leaf damage. Relative humidity of an area is critical for crop growth and plant health. Rambuda irrigation scheme has high morning relative humidity levels (> 80%). Such high RH values coupled with warm temperatures are ideal for fungal diseases infections. However, a proper spraying programme should be followed to eliminate chances of fungal infection as a result of high morning RH (> 80%) that when coupled with warm afternoon temperatures may create favourable conditions for fungal infection.

Suit abilities of soil mapping units for specific crop

Each soil mapping unit was assessed as to its suitability for the production of each crop in the specific range. Land suitability evaluation was conducted on specific crop ranges to determine suitability rating for each crop range through the matching process. Summary of suitability ratings for different mapping units for specific crop ranges (Table 7 and Figure 3). Mapping unit *Ac* was well suited (WS) most crop ranges, suited (S) for Alliums and Oil crop range. Citrus trees are sensitive to compaction layers and poor drainage. This mapping unit has a moderate drainage which may be problem for irrigated project considering poor irrigation management by farmers.

Mapping unit *Ac* was suitable for Oil range because of high clay content and crusting which are not favourable for

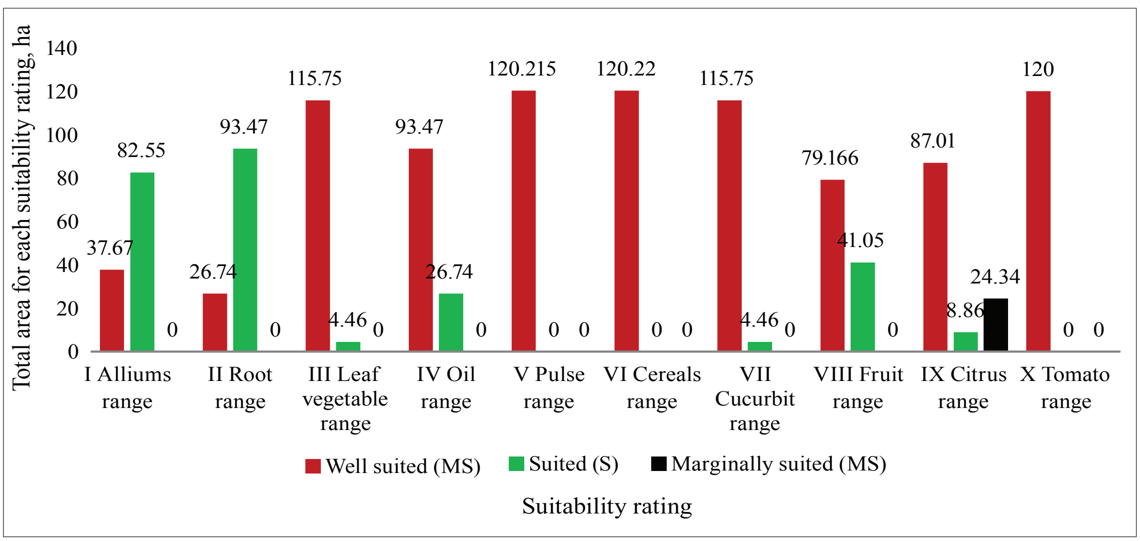

Fig. 3. Land suitability and total area for specific crop ranges

the crops in this range and is marginally suited (MS) for citrus because of crusting, compaction and drainage (Nel & Bennie, 1984). Mapping units *Bc* is well suited (WS) for all ten specific crop ranges. Mapping unit *Ao* which is well suited (WS) for most crop ranges, suited (S) for root range and oil range, but marginally suited (MS) for citrus. It was down-graded to suited (S) for root range and oil range which are sensitive to compaction because of its susceptibility to compaction and such soils may cause deformation of sweet potato tubers. Mapping unit *Ds* was well suited (WS) for all crop ranges and suited (S) for root range and oil range because of high clay content and susceptibility to compaction. Oil range sunflower, in particular is sensitive to compaction due to deep rooting system. Mapping unit *Bh* is well suited (WS) for all crop ranges and suited (S) for leaf vegetables and cucurbits crop ranges because of low moisture holding capacity. This mapping unit was reported to have soils that dry too quickly after irrigation and rains. Mapping unit *Ch* is well suited for most crop ranges and suited (S) to alliums; fruit; oil and root crop ranges because of high clay content and susceptibility to subsoil compaction.

Management requirements

Management aspects relate to soil fertility, cultivation, soil conservation measures, irrigation and costs involved in crop production. These issues determine suitability of specific crops for an area.

Soil fertility management

The soils of Rambuda irrigation scheme generally have pH (H_2O) ranging from moderately acid (5.5-5.9), slightly acid (6.0-6.7) to neutral (6.8-7.2). This soil pH is considered optimum for growth of all crops listed in the specific crop ranges (Table 3). However, a liming programme should be followed to keep soil pH at optimal levels for crop production in the unlikely event that the pH levels decrease, something which is usually not expected under irrigation. Phosphorus status of the soil is very low and the application of phosphate fertilizers is crucial to raise P status of the soil to optimal level for crop production. Phosphorus deficiency was observed on maize during the field survey and was severe particularly on sandy loam soil. Quantities of fertilizers applied, will be guided by the norms for various crops. Over-fertilization with P is sometimes found and should be guarded against (Eloff and Laker, 1978). Potassium was low and very low in certain sections of the irrigation scheme. It is an important plant nutrient element, particularly for vegetables, potatoes, sweet potatoes and fruit crops in terms of quality and taste. A proper management strategy of these and other nutrient elements, especially nitrogen, is imperative to ensure production of good quality crops. Some information can be drawn from the major report by Van Averbeke (2008) on research at the nearby Dzindi irrigation scheme, with similar soils. Management of nutrients like N may be a challenge under small-scale irrigation scheme due to leaching. Split application of N and K through top-dressing is the appropriate strategy to deal with such a challenge to ensure constant supply of these nutrient elements during different stages of crop growth (Van Averbeke et al., 2007).

Soil fertility management is a great challenge among farmers at Rambuda irrigation scheme mainly due to the lack of financial resources to purchase fertilizers and lack of training in soil fertility management. Fertilizers and pesticides can be purchased from the co-operative which is found in the irrigation scheme if enabling financial resources are available to farmers.

Majority of farmers have resorted to the use of kraal manure and fresh chicken manure which may cause temporary imbalances in the soil C: N ratio and bring new weed species. Another critical aspect of soil fertility is the Ca:Mg ratio. The average Ca:Mg ratio of the soils at Rambuda irrigation scheme ranges was 1:2-1:4 and 1:3-1:6 for the topsoil and subsoil, respectively (Nethononda et al., 2012).

Tillage management

Farmers do not have tractors and tillage implements. They rely on individuals who own old tractors for tillage. Individual tractor owners do not have implements for deep tillage and they thus, use mould board plough and disc cultivators to till and prepare the soil for planting. These implements only till the top 22 cm of the soil resulting in compaction soil just below the tillage depth. Subsoil horizons are highly compacted. Subsoil compaction is difficult to detect (Rooney et al., 2006) and may lead to substantial yield loss, particularly, in the eastern part of the irrigation scheme.

Mapping units *Ao, Bc, Bh* and *Ch* have very high subsoil compaction and may require periodical deep tillage with tined implements to prevent subsoil compaction (Figure 1). Soil compaction does not occur uniformly across the field. Its distribution varies with soil physical properties, particularly texture and soil organic carbon content, volume of traffic, and other agronomical practices (Kees, 2005). Mapping units (*Ao, Bc, Bh* and *Ch*) are found in areas that farmers indicated as compacted, difficult to till and give low yield. Soils in mapping unit *Ao* in particular are prone to compaction and should not be tilled when they are too wet. In general, ripping is urgently required and a deep tillage program needed for soils at Rambuda irrigation scheme. The use of strong enough tractors in a good working condition is important so as to avoid wheel slip, which seriously aggravates compaction and, furthermore, using a system of controlled traffic over fields is of paramount importance (Laker, 2012). Soil compaction is also very serious at Dzindi irrigation scheme, basically due to the use of a tractor with inadequate power. One old farmer successfully overcame the problem by using a final cultivation by means of ox-drawn implements after the last cultivation by tractor and planting only thereafter (Laker, 2012). The use of ox-drawn rippers is also well-known in South Africa (Laker, 2004b).

Irrigation system management and soil suitability ratings

Farmers suggested three irrigation systems namely, drip, sprinkler (dragline) and furrow irrigation. Mapping units were assessed for their suitability for each of these irrigation systems. Mapping unit *Ao* is susceptible to surface sealing/ crusting and *Bc* has coarse texture which is problematic for the drip irrigation method. Thus, drip irrigation is not suitable for soils in *Ao* mapping unit and is marginally suitable (MS) for soil in *Bc* mapping unit because of their too fast infiltration rate. Management is crucial as drippers require constant monitoring of blockages of emitters at all times. Any blockage can result in crops not being irrigated. During a NIRESA (Network on Irrigation Research and Extension in Small-scale Agriculture) workshop at Port St. Johns in the Eastern Cape a case was seen where a farmer was growing tomatoes successfully, with one part being under furrow irrigation and the other under drip irrigation. The part under furrow irrigation was excellent, but the part under drip irrigation was starting to show serious drought stress, because water could not be applied due to problems with the system (Laker, 2005). The problem seemed to be drippers clogged as a result of the silt content of the water and lack of infrastructure to ensure their proper maintenance. The farmer could lose his crop in the drip irrigated area if the problem was not solved soon. Such situation may also pose a serious problem for small-holder farmers at Rambuda irrigation scheme who do not have the financial resources to employ labourers to look after dripper maintenance, but performs all tasks by him/herself except if a family member is available. In addition, Van Averbeke and Mohamed (2006) at the Dzindi irrigation scheme found that all farmers who employed one or more full-time labourer worked at a loss. The majority of plot-holders at Rambuda are women who are embroiled in family chores and need a system that will allow them to perform other tasks, like weeding while irrigating. Furrow irrigation enables the latter. Majority of mapping units at Rambuda irrigation scheme are not susceptible to crusting except soils in mapping unit *Ao* of the irrigation scheme. In general, soils at Rambuda irrigation scheme are well suited (WS) for sprinkler irrigation except mapping unit *Ao* which is marginally suitable (MS) for sprinkler irrigation.

Another aspect of management is the cost both for establishment and running the system during crop production period, particularly pumping costs in this regard. Furrow irrigation method is well suited (WS) for all mapping units except *Bs* and *Bc* which are marginally (MS) suited for furrow irrigation because of their coarse texture. Farmers at the irrigation scheme are more experienced in working with furrow irrigation and have gained lot of experience to manage and resolve problems of furrow irrigation. The system is low in running costs as the water is flows from the weir, balancing dams to the plots by natural gravity.

Soil conservation

The topography of the all mapping units is considered flat with gentle undulating slopes (0.5-2.5%) that require minimum conservation in the form of terracing. All plots are correctly demarcated on terraces and any change in land use such as overhead irrigation, management practices or technology must not disregard the existing conservation measures. It is recommended that terraces be protected, as any disturbance will result in huge problems through erosion and extreme costs of reconstructing terraces which are by now fully stabilized.

Conclusions

The guidelines showed that Rambuda irrigation scheme is well suited for most crops in the specific ranges. Furrow irrigation system was found to be generally, the most appropriate and economical method of irrigation for Rambuda irrigation scheme. Dynamic guidelines for land suitability evaluation for small-scale irrigation schemes can be used under different conditions. These guidelines are not static and can be adapted to different conditions and the end results will produce reliable suitability ratings that are easy to follow and understand. The dynamic land suitability evaluation guidelines were able to assess the suitability of crops in the specific ranges and the information required to make land use decisions at Rambuda irrigation scheme. The guidelines are a good basis for the development of a uniform land suitability evaluation system for small-scale irrigation schemes in South Africa and should also be tested under large farming conditions for further refinement.

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