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PREFACE

Information technology is an everyday means that is found in all walks of life today. This is also true for almost all areas of agricultural management. The aim of this Journal is to improve scientific knowledge dissemination and innovation process in the agri-food sector. The Journal of Agricultural Informatics has been established in 2009 by the HAAI within a project of the Hungarian National Development Plan Framework. The peer-reviewed journal is operating with international editorial and advisory board supported by the EFITA (European Federation for Information Technology in Agriculture Food and the Environment).

Agricultural informatics serves not only the development of the management systems of the industry but also obtaining and publicising information on production, organisation and the market for the producer.

Technologies into network based business systems built on co-operation will ensure up-to-date production and supply in food-industry. The sector-level approach and the traceability of processed agricultural products both require the application of up-to-date information technology by actors of domestic and international markets alike.

This journal serves the publication as well as familiarization the results and findings of research, development and application in the field of agricultural informatics to a wide public. It also wishes to provide a forum to the results of the doctoral (Ph.D) theses prepared in the field of agricultural informatics. Opportunities for information technology are forever increasing, they are also becoming more and more complex and their up-to-date knowledge and utilisation mean a serious competitive advantage.

These are some of the most important reasons for bringing this journal to life. The journal “Agricultural Informatics” wishes to enhance knowledge in the field of informatics, to familiarise its readers with the advantages of using the Internet and also to set up a forum for the introduction of their application and improvement.

The editorial board of the journal consists of professionals engaged in dealing with informatics in higher education, economists and staff from agricultural research institutions, who can only hope that there will be a demand for submitting contributions to this journal and at the same time there will also be interest shown toward its publications.

Prof. Dr. Miklós Herdon
Chair of the Editorial Board
Content

Jan C. Thiele
Participative dendromass bioenergy modeling in regional dialogs with the open-source BEAST system ............1

Mark K. Boitt, Flomena C. Langat, John K. Kapoi
Geospatial agro-climatic characterization for assessment of potential agricultural areas in Somalia, Africa.....18

Basuti Bolo, Dimane Mpoeleng, Irina Zlotnikova
Geospatial information system land evaluation analysis for rainfed farming using multi-criteria decision
analysis approach ..............................................................................................................................36

Edmond Rexhepi, Harallamb Paçe, Hekuran Vrapi, Arbenita Hasani
Overview of the decision support system and fruit growth stages to predict the action threshold in order to
control the apple scab in Kosovo ........................................................................................................45

Pliakoura, Alexandra, Beligiannis, Grigorios and Kontogeorgos, Achilleas
Mobile device applications usability assessment: The example of an agricultural management application ....55

Adebukola Onashoga, Olusegun Ojesanmi, Femi Johnson, Femi Emmanuel Ayo
A fuzzy-based decision support system for soil selection in olericulture ..............................................65
Participative dendromass bioenergy modeling in regional dialogs with the open-source BEAST system

Jan C. Thiele

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Participatory Modeling, Decision Support System, Wooden Bioenergy, Regional Energy Policy, Short Rotation Coppice

A B S T R A C T
Regional participative decision-making processes are becoming increasingly important in the context of climate change mitigation goals and renewable energy production. Dendromass bioenergy plays an important role in climate protection planning at the local and regional levels. The 'Bio-Energy Allocation and Scenario Tool' (BEAST) is a decision support system designed to assist in stakeholder dialogues, with the goal of developing scenarios of regional wood production through scenario quantification and visualization. While it incorporates wood from forests and outside of forests as bioenergy sources, its main application area is the spatial selection of preference sites for Short Rotation Coppices on arable land, based on the integration of ecological and economic assessments in a multi-criteria analysis with preference selection using Analytic Hierarchy Process (AHP). This paper provides a comprehensive overview of the purposes of the system, its simulation and software design, and also announces the system's availability as open-source software.

1. Introduction
Climate change, increasing energy demand and shortage of fossil fuels are major global challenges affecting energy usage today and especially in the future (IEA 2016). Thus, the European Union (EU) has been promoting the use of renewable energies, with biomass for energetic use as one important component by mobilization of existing reserves and the development of new systems (EU 2009). For example, it is expected that up to 26 % of Germany’s energy demand in year 2050 can be covered by domestic biomass (FNR 2017). In Germany, a financial support for the production of renewable energies including biomass was established with the Act on the Development of Renewable Energy Sources in 2000 and its successors (German Parliament 2000). This stimulated the bioenergy production from 586 GWh in 2000 to 41’016 GW h in 2018 (Federal Ministry for Economic Affairs and Energy 2017). The largest shares of bioenergy in Germany are produced with maize and oilseed rape (Schmidt-Walter & Lamersdorf 2012). For example, the area for energy maize production increased from year 2007 to 2017 by approx. 4.5 times to 1 Million ha (FNR 2017; FNR 2018). However, the production of energy maize needs a relatively high energy input compared to perennial energy crops (Boehmel et al. 2008) and there are indications that the large maize monocultures result in a loss of biologic diversity (Eggers et al. 2009; Sauerbrei et al. 2014). Furthermore, maize and rapeseed production implies high risk of erosion, nutrient inputs in ground and surface water as well as pesticide pollution of soils and water (EEA 2006). Due to these implications, not only annual energy crops should play a significant role in the projected energy mix but also the utilization of dendromass (BirdLife International et al. 2014; Schellnhuber et al. 2009).

In addition to the usage of waste wood, which is already almost exhausted (FNR 2018), there are three possible sources for bioenergy production using wood: forests, wood from outside forests (trees and hedges of open landscapes and roadsides), and plantations of short rotation forests/coppices on

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arable land. In Germany and perhaps in most other Central European countries, there are source-specific restrictions on the usage of such sources as bioenergy, as summarized in the following.

The usage of stem wood from forests as bioenergy competes directly with the material use of stem wood and is therefore ecologically and economically problematic. Bioenergetic utilization of stem wood reduces long-term carbon sequestration and is thus inadequate for green-house gas mitigation (Schulze et al. 2012). Additionally, the usage of residues from forests is under discussion due to questions of nutrient removal and accelerated release of carbon (Vanhala et al. 2013).

Woody biomass from open landscapes, i.e., hedges and trees outside forests or woodland, could be an additional source of woody bioenergy but is often not taken into consideration. However, from this source, Seidel et al. (2015) expects an annual supply of 233 TJ, based on a district in Germany with an area of approx. 1.100 km². A study by Drigo & Veselić (2006) for Slovenia estimates a usable annual non-forest woody biomass volume of approx. 300.000 m³. As trees and hedges in open landscapes must be cut often as part of landscape tending measures, costs could be compensated by energetic usage (Schönbach & Bitter 2015). However, accessibility restrictions on machineries, missing utilization chains, and the reluctance of landowners and stakeholders all limit the usage of this biomass source (Seidel et al. 2015).

Another option is the production of woody bioenergy on arable land with Short Rotation Coppice (SRC). Planting SRC on arable land has many ecological advantages compared to the annual energy crop production. SRC is a low-intensity perennial agricultural system that can support various ecosystem functions and services, such as protection from nitrate leaching (Bredemeier et al. 2015; Schmidt-Walter & Lammersdorf 2012), fragmentation of homogeneous arable landscapes (Baum et al. 2012), increased biodiversity (Rowe et al. 2011; Sage et al. 2006), reduction of soil erosion, lower fertilizer requirement, and sequestration of soil organic carbon (Blanco-Canqui 2010; Don et al. 2012). Due to its positive effects on soil and water quality SRC can also be cultivated on former cropland which has been abandoned due to soil and water issues (Schmidt-Walter & Lammersdorf 2012) and is optimal for the transition of marginal land (Holland et al. 2015). However, there is a strong reluctance of landowners to establish SRC due to the initial investment, the long-term (~20 yrs.) and binding nature of the decision, missing supply chains, as well as a lack of information and experience although SRC is an interesting option for areas of lower site quality (Drittler & Theuvsen 2018; Verwijst et al. 2013; Faasch & Patenaude 2012; Schweier & Becker 2012; Dimitriou et al. 2011). Furthermore, the economically competitive of SRC to annual crops was already proven, when proper sites are selected (Kröber et al. 2015).

Achieving ambitious political goals for the increase in woody biomass supply for energetic usage requires involving various stakeholders in discussion and participation processes in order to implement regional strategies. Several constraints, including aspects of ecological sustainability and economic advantageousness, are restricting the increased usage of existing biomass sources. Furthermore, the replacement of annual energy crop production on arable land by ecological advantageous SRC could be a further goal.

As governmental authorities own only small shares of land, private sector land owners need to be motivated to increase biomass supply for energetic usage. The government could stimulate the production of ecological advantageous bioenergy production by, for example, the establishment of financial incentives for landowners to shift to SRC and include landowners and further stakeholders, e.g. from nature conservation, in political strategy planning processes. Typically, participation takes place on the regional scale, where the integration of stakeholders can be most successful (Butler Manning et al. 2015). Those political participation and group-decision processes can be improved by using participative modelling and corresponding tools for scenario definition, modelling, and visualization. However, there is a gap between already existing paper-and-pencil DSS frameworks, simple spreadsheet-based end-user DSS and highly complex scientific bioenergy simulation systems. Stakeholders should be enabled to define and adjust scenarios participative and directly quantify and visualize the results.

The purpose of this paper is to present a methodology, modelling concept, and reference software implementation of a tool tailored to fill the described gap to support regional participation and group-
Participative dendromass bioenergy modeling in regional dialogs with the open-source BEAST system

decision processes for dendromass production by software-based scenario definition, quantification and visualization. Furthermore, it announces the public availability of the resulting software product under an open-source license to foster its application and to provide the software’s source code as a starting point for further developments.

2. Methodology

To support regional discussion and participation processes, participatory modeling is a useful approach to assist stakeholders in visualizing the consequences of specific decisions scenarios and to help in collective decision-making (La Rosa et al. 2014; Voinov & Bousquet 2010). For this purpose, the development of “Bio-Energy Assessment and Simulation Tool” (BEAST) was started in the context of the joint research project “Strengthening Bioenergy Regions” (German: “BioEnergie-Regionen stärken”, BEST). The tool integrates ecological assessments (ecosystem functions and services) with economic calculations as a basis for regional participative dialogs and participatory modeling (Figure 1). It considers wood from forests, open landscapes and short rotations. However, the focus is on the spatial selection of preference areas for SRC under user-defined ecological and economic restrictions and selection criteria. The BEAST uses preprocessed input data of a study region, which makes it independent from specific growth-modeling approaches; the BEAST also provides easy-to-use graphical user interfaces to define goals, restrictions and parameters for creating and analyzing scenarios of wooden bioenergy utilization. The selection of preferred SRC areas is processed – in a multi-criteria evaluation – based on stakeholders’ perceptions with respect to ecosystem functions and services as well as economic returns compared to certain annual field crops. The scenario results are processed for two 20-year periods: 2011 to 2030 and 2031 to 2050. This creates the possibility of incorporating climate change effects into the scenario assessment via the input data.

The BEAST system ideally complements existing approaches in the field of bioenergy modeling and participation process support, as those approaches and the BEAST can be applied side-by-side or integrated into regional participation processes. Such existing approaches comprise the following (GBEP - Global Bioenergy Partnership 2011; for a list of tools; see, e.g., Milbrandt & Uriarte 2012):

- Specific simulation models, which can serve as producers of input data for the BEAST. Examples of such models are detailed forest wood supply models (e.g., Sacchelli et al. 2013) and SRC growth models (e.g., De Grote et al. 2015; Tallis et al. 2013).
- Participation framework models, which can serve as discussion guidelines in which the application of the BEAST can be embedded, as these frameworks do not include computer simulations for (spatial) scenario visualization (e.g., FAO & UNEP 2010; Lezberg et al. 2010).
- Related simulation approaches for identification of potential areas for production (e.g., Aust et al. 2014; Bauen et al. 2010; Wu et al. 2012), fitomass energy calculations (e.g., Bai et al. 2016), CO2 calculations for different biomass sources (e.g., Bai et al. 2017), holistic renewable energy calculations (e.g., Benedek et al. 2018), and impact assessments of land-use changes (e.g., Meehan et al. 2013; Schulze et al. 2016) with different application domains and, therefore, without an integration into a user-friendly open-source tool applicable for participatory modeling in regional participation processes. Nevertheless, those approaches can serve as a technical basis for input generation or as a methodological basis for the extension of BEAST.
Figure 1. Use case visualization of the “Bio-Energy Assessment and Simulation Tool” (BEAST). The flow chart depicts the processes of input data preprocessing, iterative software usage in the stakeholder participation process by adjusting scenario settings, and the production of simulation results. Scenario adjustments are discussed in the stakeholder workshops on the basis of the simulation results and can be immediately entered into the forms of the BEAST software to request a new scenario simulation.

A first version of the BEAST tool was applied to the Göttingen district in Central Germany. This version was far away from being applicable independently from the system developers although the backend model system was equivalent. The results of that case study can be found in Busch & Thiele (2015). The paper presents a methodology to generate the necessary input data and parameter values for the tool, including advice on data sources, which can be adapted for system application to other study areas. In the meantime, the software has been further developed to be applicable in participative process independently from the system developers, e.g. by adding Saaty’s Analytic Hierarchy Process (AHP) (Saaty 1990; Saaty 1987) to support the group-decision making process.

The application software development cycle followed the spiral model by developing prototypes in several iterations. The prototypes were presented in stakeholder groups of regional actors of the Göttingen district for feedbacks which have been incorporated in the next version.

The development of the upstream backend model concept followed also the spiral model. The simulation model concept was developed by interviewing domain experts, transforming the interview results into algorithmic simulation model descriptions and requesting feedback on the descriptions by the domain experts.
3. Simulation Model Concept

The simulation model concept delivers an impression of the internal processes of the BEAST software, i.e., which inputs are used and how results are processed. The description follows the ODD (Overview, Design concepts, Details) protocol for simulation models (Grimm et al. 2006; Grimm et al. 2010).

3.1. Overview

3.1.1. Purpose

BEAST is designed to define and evaluate scenarios of woody biomass on a regional scale. It supports stakeholder participation regarding ecological and economic aspects via participatory modeling. The system considers different sources of woody biomass and delivers biomass and energy potentials. It also discloses preference areas suitable for establishment of SRC on arable land based on multiple criteria. It enables users to compare scenario-based biomass availability to a politically targeted amount. Thus, the system identifies, for example, the necessity of political actions to foster the attractiveness of woody biomass production.

3.1.2. Entities, state variables and scales

BEAST handles three sources of biomass: wood from forests, wood from outside of forests and SRC on arable land. For comparative purposes, field crops are also processed. Whereas wood from forests as well as from outside of forests is taken into account only as aggregated biomass pools in the system, SRC and field crops are modeled spatially explicitly on arable field geometries.

The basic state variables of the different sources are the biomass potentials.

The minimum time scale of internal processing is one year. The output is presented in two periods with lengths of 20 years each. The spatial scale of calculations for wood from forests and wood from outside of forests is the study region, determined by the input data. The scale for the processing of SRC and reference field crops is the single field, determined by the input data as well. Thus, the system itself is virtually scale-independent.

3.1.3. Process overview and scheduling

The simulation begins by loading the inputs and parameters from a selected input file and updating the parameter values using user inputs from the Graphical User Interface (GUI). Then, the simulation runs separately for the two simulation periods of 20 years each. Within a simulation period, the different biomass sources are simulated independently from each other. The biomass and energy potential from forest wood and wood from outside of forests is calculated distinctly for different compartments (forest: stem, industrial/fire wood, residues; outside of forest: stock, yield) but is spatially aggregated for the study area. In contrast, the calculations for arable reference crops and Short Rotation Coppices are performed spatially explicitly. Therefore, yield and resulting economic return are calculated for all fields. The economic return of a reference field crop rotation is calculated and compared to the economic return of SRC as an annuity difference value. This value serves as an area selection criterion in addition to other criteria or objectives, mostly ecological ones: susceptibility to (water) erosion, landscape diversity, rate of water percolation, potential nitrate leaching, area complexity, slope, soil quality index, and soil moisture index. A check of each field area against the selected restrictions and objectives is performed, as well as a calculation of the criteria sum based on criteria values, scaling and weightings is done. Then, the list of potential SRC areas is reduced to those that conform to the selected restrictions and objectives. This subset is sorted by decreasing value of the scaled criteria sum, which serves as a proxy for selection preference. Next, areas are selected as preference areas based on their criteria sums and by checking restrictions regarding the max. area of SRC within administrative and ecological units simultaneously. If the minimum distance option is selected, the minimum distance between two SRC fields is also checked by buffering and subsequent intersection test against all fields selected so far. If an intersection is found, the candidate area is
rejected and not put on the list of preference areas. At the end of the SRC calculations, the areas on the preference list are further classified. The inputs, parameters and results for all wood sources and the reference crops are aggregated and stored. If another simulation period is pending, parameters with annual change factors, i.e., yields, prices and costs, are prolonged to the next period and the next iteration is started. If the last simulation period is reached, there is an option of writing the results to a file and loading the results into the ResultsExplorer tool, which visualizes the results in tables, plots and maps.

A visualization of the process schedule is attached in Digital Supplement A.

3.2. Model design concepts

Basic principles. The data- and model-driven system serves as a shell for scenario analysis and decision support. High flexibility and fast processing are guaranteed by using as many input data as possible from pre-processed import files. Even changing the study area by loading a different input file is a simple task. Simultaneously, the system itself is independent from yield and growth models and corresponding modeling approaches. Its rapid response to changed parameters encourages users to play with values and learn how they affect the results.

Emergence. Scenario results, especially the pattern of spatial distribution of potential SRC fields, emerge from user-defined scenario settings, such as restrictions, objectives, criteria scaling and weighting.

Objectives. The system captures and visualizes the stakeholder’s perceptions of regional renewable energy goals for woody biomass.

Stochasticity. The system includes no random effects.

Observation. Figures of biomass demand and supply, primary energy equivalents and annuities are stored during the simulation for all sources of wood supply. Annuities for all field crops and crop rotation composition are also captured. Moreover, scaled criteria values, scaled criteria sums and flags reflecting (a) the fulfillment of restrictions and objectives, (b) the selection of potential SRC fields and (c) the SRC classification are stored for further analysis.

3.3. Details

Detailed descriptions of initialization, inputs, and processes are beyond the scope of this paper and can be found in the documentation accompanying the software bundle and in the online repository (https://beast.sourceforge.io/).

4. Software Design Principles

The following five principles guide the software design and implementation.

1. Easy to install and use: The target audience of the software is stakeholders in regional energy policy participation processes as well as consultants in such discussion processes. Therefore, the software needs to be easy to install and should come with a generally self-explanatory and easy-to-use GUI. The level of detail has to be selectable.

2. Integration of ecological, political and economic aspects: To mediate the interests of different stakeholders, the system has to integrate perceptions about different ecological, political and economic aspects of woody biomass production for energy usage.

3. Fast output generation: To support participation processes, the software should not only be useable in back-offices after discussion processes but also should be applicable simultaneously with the meetings. The scenario settings should be definable via the GUI and should guide the discussion. Testing and analyzing different variants of parameter adjustments should be possible during the meetings. Therefore, the processing of intensive calculations needs to be either avoided or optional in order to keep the software’s response-time as short as possible so as not to interrupt discussions for too long. Instead of using equation-based modeling on
demand in every scenario simulation, base data could be pre-processed, but they need to be modifiable during scenario processing.

4. **Visual result presentation and export**: To be usable in participation processes, the results should be presented visually. Because it focuses on the discussion of locations for Short Rotation Coppice, the system should present preference areas on a spatial map. Export functions could create the possibility of further analysis of results in external software, such as statistical analysis programs and Geographical Information Systems (GIS).

5. **Foster re-usage and further development**: To increase its reliability, the system should not appear as a black box, and it should come without costs and without usage of proprietary libraries in order to increase its distribution and re-usage. Furthermore, the source code should be available to allow community development and improvement of the software.

5. **Implementation**

The first design goal is addressed by providing ready-to-use Windows executables and by implementing a navigation tree separating and structuring the different input forms. Several supporting visualizations of input data help in finding reasonable parameter settings. Weights of criteria for multi-criteria analysis are derived from pairwise importance comparisons using Saaty's Analytic Hierarchy Process (AHP) (Saaty 1990; Saaty 1987). The resulting weights are visualized in a spider diagram, and user-defined criteria scaling are given by defining support points, which are visualized in a line graph. Where possible, form entries are validated for plausibility.

The second design goal is fulfilled by implementing the described simulation model concept, which ensures that ecological and economic aspects are integrated into the assessment, thus reflecting different political goals and stakeholder perceptions.

The requirement of short response times of the scenario simulation (3rd design goal) is addressed by shifting time-consuming operations as much as possible into preprocessing, as well as by loading and changing the input data from lightweight files packaged in a single archive file with the .beast extension. Furthermore, the tool is implemented as Desktop software instead of as a Web application to ensure usability everywhere, even without Internet access.

The 4th design principle is addressed with the ResultsExplorer tool, which provides functionality to load results stored in a .beast file or immediately processed with the ScenarioGenerator tool. The ResultsExplorer produces interactive bar charts and boxplots of all ecological and economic criteria for all biomass sources. A MapViewer application is integrated into the ResultsExplorer, which provides the possibility of analyzing the inputs and results of the SRC/field crop scenario simulations spatially and of combining them with external maps from local files and/or WebMapping Services.

The software is built upon established open-source libraries and comes under an open-source license to meet the 5th design goal. As a program written in the Java language (Gosling et al. 2015), it is implemented platform-independent and executable on various platforms. Table 1 gives an overview of the libraries used for implementing the software. BEAST is developed using the Eclipse IDE (The Eclipse Foundation 2017) with Maven build tool (The Apache Software Foundation 2017a) support. In conjunction with the launch4j plugin (Kowal 2015), a full-fledged automatic production ecosystem for executables is realized. Directions for setting up the project with Maven in Eclipse IDE, as well as the source code itself, are documented in a development guide, which accompanies the usage guide and documentation.

<table>
<thead>
<tr>
<th>Library</th>
<th>Domain</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swing</td>
<td>Basic GUI components</td>
<td>Oracle (2015)</td>
</tr>
<tr>
<td>JGoodies</td>
<td>Advanced look and feel as well as form layout for Swing panels</td>
<td>Lentzsclh (2016)</td>
</tr>
<tr>
<td>JFreeChart</td>
<td>Interactive and non-interactive charts including bar charts, spider web as</td>
<td>Gilbert (2014)</td>
</tr>
</tbody>
</table>
Participative dendromass bioenergy modeling in regional dialogs with the open-source BEAST system

As well as box and whisker plots

<table>
<thead>
<tr>
<th>Tool</th>
<th>Feature</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apache Commons Lang</td>
<td>Multi-language GUI support</td>
<td>The Apache Software Foundation (2017b)</td>
</tr>
<tr>
<td>EclipseLink MOXy</td>
<td>XML-file mapping</td>
<td>The Eclipse Foundation (2015)</td>
</tr>
<tr>
<td>Opencsv</td>
<td>.csv file parser</td>
<td>Smith et al. (2017)</td>
</tr>
<tr>
<td>GeoTools</td>
<td>Geoprocessing and map viewing</td>
<td>GeoTools (2016)</td>
</tr>
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<td></td>
<td>functions</td>
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So far, the tool and its foundations were briefly introduced by describing the simulation model concept, the software design principles, and the implementation. The software product is available as open-source software, which is an important step towards more open and reproducible science and towards lowering the boundary between science and government by means of transparency (Pfenninger et al. 2017).

To foster re-usability, a comprehensive usage guide, documentation and development guide were added, and the software as well as its source code can be downloaded from a publically available repository (https://beast.sourceforge.io/). Being freely available, it can be applied to any region after input data preprocessing. Furthermore, as an open-source software, the source code can be modified, thus, the software can be extended to additional use-cases, or parts of the code can serve as starting points for different tasks with similar functional requirements.

Next, a brief impression of the software’s GUIs is given (Figure 2). A comprehensive overview can be found in the usage guide. When starting the software the ScenarioGenerator opens and the user can select a study region. The delivered software package comes with a dummy input dataset of an imaginary example region as well as with a tool to create input files from pre-processed data. The ScenarioGenerator opens the possibility to modify the default model parameters and delivers manifold options to adjust the input values, e.g. the field specific growth rates of the different field crops. Several plots visualize the input data to support such customizations of the input data. Furthermore, the constraints for the potential SRC fields as well as the selection criteria based on the AHP are defined in the ScenarioGenerator. The settings can be stored in the same or a new scenario input file.
Figure 2. Two example views of the ScenarioGenerator of BEAST tool. On top of the figure: SRC objectives selection. Here, only field with a low soil quality (index < 50) should be selected. The plot on the right shows the distribution of the soil quality index in the study area, which is given as orientation of meaningful values. As the soil quality index of a field is assumed to be invariable over time, the value distributions are identical for both simulation periods (could be changed via the input data). On bottom of figure: The summary view of criteria weightings based on AHP. The spider graph on the right delivers a visual representation of the importance ranking of the different selection criteria. In this example, pot. nitrate leaching has the highest importance, i.e. areas which get out most of SRC regarding nitrate leaching will be prioritized.

Once the scenario is defined the simulation can be requested. Depending on the number of polygons and the settings the processing takes some seconds till some minutes. When the simulation is finished the results can be stored in the same or a new scenario file and the scenario results can be opened in the ResultsExplorer (Figure 3). There are many fold options for analyzing the results. The interactive demand vs. supply plot shows, if the predefined demand of dendromass can be delivered under the defined scenario settings and, if so, which dendromass sources are required. The results are presented in several tables, barcharts and boxplots and can be analyzed by manifold criteria. Furthermore, they can be explored spatially with the MapViewer component (Figure 4) and it is possible to export the data in tables and maps to be further analyzed in external software.
Figure 3. Two example screenshots of the ResultsExplorer for the example given in Figure 2. On top the woody biomass demand is compared to the biomass potential for the selected scenario. In the figure on the right, the different sources can be switched on and off and the necessary mix of sources to meet the demand can be explored. On bottom the distribution of the pot. nitrate leaching of the potential SRC fields are given – as total over the whole study region as well as total over all SRC preference locations and for each preference class. The effect of the high weight of this criteria is indicated by the strong decrease over the different preference classes.
Figure 4. Screenshot of MapViewer to analyze the scenario results of potential SRC fields spatially. Red colored polygons indicate selected potential SRC fields. The different colors represent the different preference classes. A minimum distance between two SRC field of 100 meters was specified in the ScenarioGenerator, which explains the scattered spatial pattern.

6. Conclusion

The BEAST system presented here allows users to integrate economic returns with ecological assessments of the utilization of woody biomass on local and regional levels. It was developed to facilitate participatory scenario generation and analysis in stakeholder dialogues. During the tool’s development, the concept and prototypes were presented to stakeholders, and their feedback has been incorporated into the development of the system.

The system was applied to the Göttingen district in Central Germany (Busch & Thiele 2015); however, the system has been implemented as a scenario simulation shell and is, therefore, generic enough to be applied to other study regions. It is possible to replace criteria sets without rebuilding the system architecture. Therefore, Hübner et al. (2016) adapted the BEAST to a second study area with a focus on landscape metrics, and a report about the general methodology is currently under review by the International Energy Agency (Busch 2017).

Furthermore, the range of applications could be extended. For example, Bredemeier et al. (2015) and Busch (2017) used the BEAST methodology for purely scientific purposes instead of for stakeholder dialogs by running multiple scenario simulations – with cost and price values drawn from statistical distributions – as Monte Carlo simulations manually. The BEAST software could be extended to run and analyze those Monte Carlo simulations automatically.

However, key factors for the long-term success of any such simulation system are continuous adaptation, improvement and support. Therefore, the system is now released under an open-source license and placed into the hands of the scientific community for usage and further development. It comes with a usage guide, documentation, and a development guide.

If governments want to foster the production and use of wooden bioenergy as one key part of a renewable energy mix, first, a realistic estimation of available biomass potentials is needed, and
second, governmental energy planning needs to reflect the interests of various stakeholders, such as land owners and nature conservators, which usually results in regional participation processes. Tools such as the one presented can support such political participation processes with participative modeling techniques using scenario quantifications and visualizations and, therefore, should become an integral part of such participation processes. However, even if such tools are developed in a scientific framework, as is the case with the BEAST software, they can only be successful if they do not appear as black boxes. Thus, they should always be available as open source software.

Digital Supplement

A. Process Map of BEAST

Acknowledgements

The author would like to thank two anonymous reviewers for their helpful and constructive comments that greatly contributed to improving the manuscript.

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Busch, G 2017, ‘A spatial explicit scenario method to support participative regional land-use decisions regarding economic and ecological options of short rotation coppice (SRC) for renewable energy production on arable

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Jan C. Thiele: Participative dendromass bioenergy modeling in regional dialogs with the open-source BEAST system


La Rosa, D, Lorz, C, König, HJ, & Fürst, C 2014, ‘Spatial information and participation in socio-ecological systems: experiences, tools and lessons learned for land-use planning’, *iForest - Biogeosciences and Forestry*, vol. 7, no. 6, p. 349.


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Appendix A – Process map of BEAST

The figure sketches the process flow implemented in the BEAST software with five main blocks for the three wooden biomass sources and the reference crop rotation. Processing of Short Rotation Coppices is distinguished into three consecutive sub-blocks: the first one runs independently for each single field separately, the second one takes the results of the reference crop rotation into account, and the last one selects the preferable sites according to the distance of the other geometries.

Note: The document is in DIN A4 format. Printing it on DIN A4 paper scales the figure down to 32%, which makes it extremely small.
Geospatial agro-climatic characterization for assessment of potential agricultural areas in Somalia, Africa

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Geographic Information Systems, Hydrological Model, Land Use / Land Cover, Soil Erodibility.

ABSTRACT
Somalia nation has been in the past classified as a volatile and of low economic value since 1990s when the government was deemed to have collapsed. Currently the independent Somalia is turning out to be one economic back bone of the Northern and Eastern parts of Africa in trade and agriculture. This paper focuses on the agricultural potential of Somalia using geospatial techniques through characterization. Climate is characterized and described, terrain models are derived, Soil analysis and hydrological assessment are also analyzed. Agroclimatic maps are developed to show suitable and unsuitable areas for agricultural production. The terrain of Somalia is more of a flat plain coupled with river basins that can be used as arable lands for agriculture. The ground water points can sustainably irrigate large number of parcels for crop production. Through GIS technology adopted for this particular work, two basins were mapped out to be possible agricultural potential areas: Juba and Shabelle. The assessment indicates that crop production can be achieved through irrigating of the arable plains and not relying so much on rain-fed agricultural systems. Agro-climatic zones of Somalia are delineated mainly due the amount of rainfall, temperature ranges and terrain patterns. With this study, farmers can be advised on which area to focus for crop production. The agricultural potential that lies in Somalia is so huge it could be named the future food basket of Africa, who knows?

1. Introduction

Somalia is on the horn of Africa and is bordered by Kenya to the southwest, Ethiopia to the west and Djibouti to the far northwest in the Gulf of Aden. Somalia is officially divided into 6 proposed regional states; Somaliland, Puntland, Galmudug, Jubaland, South West State and Hir-Shabelle. It lies between latitudes 2°S and 12°N, and longitudes 41° and 52°E. Strategically located at the mouth of the Bab el Mandeb gateway to the Red Sea and the Suez Canal, the country occupies the tip of a region that, due to its resemblance on the map to a rhinoceros' horn, is commonly referred to as the Horn of Africa.

Somalia's total land area is 637,540 km², of which 30% is classified as desert land unsuitable for agricultural production, 45% is covered by rangelands suitable for livestock grazing, 14% is covered by forest or woodland, and the remaining 11% is classified as arable land (Food and Agriculture Organization,1995). Livestock production was a major industry until the 1990s, accounting for over 60% of exports. Arable farming was also an important industry, though the Ministry of Agriculture (Yearbook of agricultural statistics 1989/1990, Mogadishu, Somalia) statistics indicate that only 22% of the designated arable land was viable for cultivation, and only 12% was cultivated, predominantly

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with maize and sorghum. The under-utilization of potential arable land was due to the predominantly arid climate that limits rain-fed agriculture and causes a heavy reliance on irrigation.

Groundwater is used throughout Somalia, obtained mainly from shallow hand-dug wells, though a few strategic boreholes are used to reach deeper aquifers, which act as an important reserve during the dry season. However, the groundwater quality is generally regarded as poor. In the downstream reaches of rivers, small freshwater lenses located mainly along the river banks are recharged during periods of high flow, and partially drained during the dry season. Therefore, the water resources of the Juba-Shabelle basin are particularly important for irrigation, as well as for Somalia’s general development (e.g. domestic and industrial water supply). The river flows also provide the safety-net required to sustain livestock herds during periods of serious drought. Several large-scale irrigation schemes used to exist on both rivers, and small-scale irrigation schemes were common on the flood plains throughout the Somali reaches. The rivers are prone to seasonal flooding, with flood recession farming being practiced in natural depressions adjacent to the river banks.

With a growing population, demands for water for irrigation and domestic supply are increasing sharply. Effective water and land management are both essential to ongoing relief and rehabilitation efforts which require good quality information on the country’s water and land resources, primarily the Juba and Shabelle rivers.

1.1. Agriculture and livestock

Somalia contains a variety of mammals due to its geographical and climatic diversity. Wild fauna is found throughout the territory, including the cheetah, lion, giraffe, baboon, civet, serval, elephant, bush pig, gazelle, ibex, kudu, dik-dik, oribi, Somali wild ass, reedbuck and zebra, shrew, rock hyrax, golden mole and antelope. It also has a large population of the dromedary camel. Somalia is currently home to around 727 species of birds. Of these, eight are endemic, one has been introduced by humans, and one is rare or accidental. Birds’ species are found exclusively in the country. Somalia’s territorial waters are prime fishing grounds for highly migratory marine species, such as tuna. A narrow but productive continental shelf contains several demersal fish and crustacean species.

Agriculture is an important economic activity in Somalia not only in terms of meeting the food needs of the population but also in terms of generating income through crop sales and agricultural labour opportunities. With roughly 50% of population’s cereal requirements are met through domestic production, Agriculture is a major component particularly for two of the main rural livelihood systems in the Horn of Africa country: Agro-pastoralist, mix of agriculture and livestock production-based livelihood and agriculturalist, agriculture-based livelihood. Crop production performance and its potential is determined by the bi-modal rainfall. The two main agricultural seasons are: Gu-crop production, from April to June and Deyr crop production is from October to December.

Two areas are considered high potential for crop production with rainfall ranging from 400mm to 600mm: a small area in the Northwest (west of Hargeisa) and a much larger inter-riverine area between the Shabelle and Juba river valleys.

1.2. Pastoralism

Pastoralism is a means of livelihood for the majority of people living in the drylands of northern Kenya, southern Ethiopia, and southern and central Somalia. Pastoralist communities in the Horn of Africa are very diverse and differ in religion, culture, and in the form of pastoralism practiced. Some keep cattle, others keep camels, and a few communities keep both, often combined with keeping small stock such as goats and sheep (Lewis, I.M). In Somalia and the Somali region of Ethiopia, the Boran and Somali are the main pastoralist groups, whereas overall Somali pastoralists can be further divided into numerous other clans and sub clans.

Somalis are predominantly nomads, and to many nomads, the camel hold a special importance to their livelihoods, and has thus become an important figure in their lives. Nomads, by definition, constantly travel, and the Somali nomads depend on camels for this travel. Camels provide food (with their milk) on long trips, can carry heavy cargo, and do not require frequent water. To Somalis the
camel is almost like a religious totem (Farah, Z, M Mollet, M Younan, and R Dahi. 2007). The lack of data on these nomadic cultures challenges access to health care in some cases. Throughout Africa, the nomadic populations have the least access to health services.

2. Materials and Methods

2.1 Study area

The area of study is Somalia and its administrative regions as shown in Figure 1.

![Figure 1. Somalia showing its administrative regions and Somalia coastline.](image)

The study was done using various raster and vector datasets to show land use/land cover, hydrological components, land characterization and agro-climate changes. Data collected from desired sources were analysed using the applications of GIS techniques. This was achieved by using the following methods: Data collection, data integration, data processing, overlay analysis, multi-clustering algorithms and results analysed. The datasets used are shown in the table below.

**Table 1.** Data types and their sources.

<table>
<thead>
<tr>
<th>DATA</th>
<th>TYPE</th>
<th>SOURCE</th>
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<tbody>
<tr>
<td>Digital elevation model (DEM)</td>
<td>Raster</td>
<td>DIVA GIS</td>
</tr>
<tr>
<td>Climate estimates (5m)</td>
<td>Raster</td>
<td>Global climate data (ESRI grids)</td>
</tr>
<tr>
<td>Land use and Landcover</td>
<td>Raster</td>
<td>FEWSNET Data Portal</td>
</tr>
<tr>
<td>Roads</td>
<td>shapefile</td>
<td>FAOSWALIM</td>
</tr>
<tr>
<td>Administrative regions</td>
<td>shapefile</td>
<td>Humanitarian Data Exchange</td>
</tr>
</tbody>
</table>
Water point sources | shapefile | FAOSWALIM
Major rivers | shapefile | ILRI
Manual and automatic weather stations | shapefile | FAOSWALIM

| Land cover | shapefile | FAOSWALIM
Irrigation schemes | shapefile | FAOSWALIM
Drainage basins | shapefile | FAOSWALIM
soils | shapefile | FAOSWALIM

2.2. Geographic information system (GIS)

GIS is a collection of computer hardware and software, data and skilled personnel for managing and analysing geographic data. At present, GIS technology is widely applied in several fields such as natural resource management, agriculture management, commercial, urban and regional management to address complex and multidisciplinary planning and management problems at regional and global scales. GIS has gained widespread acceptance as an important versatile tool because of its ability to carry out complex spatial operations and capability to link spatial and non-spatial data.

GIS has the capability to manage many layers, integrate and analyse spatial data from different sources, with diverse formats, structures, projections and helps in spatial modelling. GIS is a collectively broad term that contains a number of technologies, processes, and methods. It is attached to many operations and has wider applications related to engineering, planning, management, transport/logistics, insurance, telecommunications, and business.

The study developed the use of a GIS land and climate assessment criteria to assess the agricultural potential areas. It utilized the land use/cover, climate analysis of temperature and rainfall, slopes derived from elevation model, surface and ground water hydrology and the understanding of soil erodibility of the area. Workflow in Figure 2 shows the graphical procedure adopted.

![Figure 2. Workflow for land assessment for agricultural potential areas.](image-url)
3. Results and Discussions

3.1. Landuse/landcover types

Vegetation in Somalia consists chiefly of coarse grass and stunted thorn and acacia trees. Aromatic flora, producing frankincense and myrrh, are indigenous to the mountain slopes. In southern Somalia, eucalyptus, euphorbia, and mahogany trees are found.

The region encompassing the Shabelle and Jubba rivers is relatively well watered and constitutes the country's most arable zone. The lowland between the rivers supports rich pasturage. It features arid to sub arid savanna, open woodland, and thickets that include frequently abundant underlying grasses. There are areas of grassland, and in the far southwest, near the Kenyan border, some dry evergreen forests are found.

Other vegetation includes plants and grasses found in the swamps into which the Shabelle River empties most of the year and in other large swamps in the course of the lower Jubba River. Mangrove forests are found at points along the coast, particularly from Chisimayu to near the Kenyan border. Uncontrolled exploitation appears to have caused some damage to forests in that area. Other mangrove forests are located near Mogadishu and at a number of places along the north-eastern and northern coasts.

Moreover, other types of land uses include rain-fed agriculture, irrigated agriculture and forestry. Most of the northern part of Somalia is dry and cannot support rain-fed agriculture except for small pockets of land in the areas around Hargeisa, Gebiley and Borama. In the rest of the region, sparse rainfall means that agriculture is only possible where there are alternative groundwater sources to support irrigation. This is common within the alluvial plains where shallow wells and permanent springs provide supplementary water for irrigated agriculture.

In the South, rain-fed agriculture is practiced in the Shabelle and Juba river basin. There are two crop growing seasons, coinciding with the Gu and Deyr rain seasons. The crops grown include sorghum, millet, maize, groundnuts, cowpeas, mung beans, sesame, cassava and vegetables. These crops are produced for both human consumption and animal fodder. Crop production is limited by factors such as shallow and stony soil, low soil moisture, rainfall variability, soil erosion and low soil fertility. A number of soil and water conservation measures such as soil bunding, terracing, and water storage (in dams and other reservoirs) are used to conserve soils and water and extend the growing season.
Figure 3. Map showing different types of land use in Somalia.
3.2. Climate

Climatic conditions in Somalia range from arid in the north-eastern and central regions to semi-arid in the northwest and south. Due to Somalia’s proximity to the equator, there is not much seasonal variation in its climate. Hot conditions prevail year-round along with periodic monsoon winds and irregular rainfall (Conway 200).

3.2.1. Rainfall

Somalia has two rainy seasons: the Gu (April to June) and the Dayr (October to November). Droughts usually occur every two to three years in the Dayr and every eight to ten years in both the Dayr and the Gu. The coastal region in the south around Mogadishu and Kismaayo has an additional rainy season, the Xagaaye (July to August), in which isolated rain showers occur. In the northeast, annual rainfall is less than 100 mm; in the central plateaus, it is about 200 to 300 mm. The north-western and south-western parts of the nation, however, receive considerably more rain, with an average of 510 to 610 mm falling per year (Kammer 1989). Although the coastal regions are hot and humid throughout the year, the hinterland is typically dry and hot.

![Figure 4. Mean annual rainfall received between 1960-1990 in mm.](image-url)
3.2.2. Temperature

Mean daily maximum temperatures range from 30 to 40 °C except at higher elevations along the eastern seaboard, where the effects of a cold offshor current can be felt. In Mogadishu, for instance, average afternoon highs range from 28 to 32 °C in April. Berbera on the north-western coast has an afternoon high that averages more than 38 °C from June through September. Nationally, mean daily minimums usually vary from about 15 to 30 °C. The greatest range in climate occurs in northern Somalia, where temperatures sometimes surpass 45 °C in July on the littoral plains and drop below the freezing point during December in the highlands.

Figure 5. Annual average temperature recorded in degrees Celsius.
3.3. Digital Elevation Model

Somalia's terrain consists mainly of plateaus, plains, and highlands. In the far north, the rugged east-west ranges of the Karkaar Mountains extend from the north-western border with Ethiopia eastward to the tip of the Horn of Africa, where they end in sheer cliffs. The general elevation along the crest of these mountains averages about 1,800 meters above sea level south of the port town of Berbera, and eastward from that area it continues at 1,800 to 2,100 meters. The country's highest point, Shimber Berris, which rises to 2,407 meters, is located near the town of Erigavo.

Southwestern Somalia is dominated by the country's only two permanent rivers, the Jubba and the Shabelle. With their sources in the Ethiopian highlands, these rivers flow in a generally southerly direction, cutting wide valleys in the Somali Plateau as it descends toward the sea; the plateau's elevation falls off rapidly in this area. The western part of the Ogo plateau region is crossed by numerous shallow valleys and dry watercourses. Annual rainfall is greater than in the east, and there are flat areas of arable land that provide a home for dryland cultivators. Most important, the western area has permanent wells to which the predominantly nomadic population returns during the dry seasons. Enhancing the value of the Haud are the natural depressions that during periods of rain become temporary lakes and ponds. The adjacent coastal zone, which includes the lower reaches of the rivers and extends from the Mudug Plain to the Kenyan border, averages 180 meters above sea level.

![Digital Elevation Model](image)

**Figure 6.** Digital elevation model.
3.4. Hydrology of Somalia

The Juba and Shabelle rivers originate in the Ethiopian Highlands, where the main streams and their tributaries are deeply incised into the steep slopes of the upper reaches. However, in Somalia, in the middle and lower reaches, there is a virtual absence of tributaries and other drainage channels; there are some spring-fed streams and some local runoff, but these contribute to river flow only in times of heavy rainfall. Over long reaches, particularly on the Shabelle, the riverbanks lie above the level of the surrounding land, so that any spillages are lost permanently from the river and no return flow occurs.

The areas of the Juba and Shabelle basins are 218,114 km² (to Jamaame, excluding Shabelle basin) and 296,972 km² (to the Juba confluence). The two basins share many common characteristics. Around two-thirds of the area of both basins lies in Ethiopia, and 5% of the Juba basin also lies in Kenya. Both basins range in altitude from just above sea level in the south to more than 3000 m in their headwaters in the Ethiopian Highlands.

The Juba River has three main tributaries which all flow south-eastwards, joining near the Ethiopia–Somalia border and the Somali town of Luuq. There the Juba turns south to the coast. The total length of the Juba River is about 1100 km (measured on the longest tributary), of which half lies in Ethiopia and half in Somalia.

The Shabelle River flows south-eastwards to the Ethiopia–Somalia border. There it turns south towards Mogadishu, but then turns southwest before it reaches the capital city and continues roughly parallel to the coast from which it is separated by a range of sand dunes. Halfway along the coastal stretch, it runs into a series of swamps. Downstream of the swamps the river resumes a defined channel, but flows are very much reduced and the Shabelle discharges into the Juba only in times of exceptional flood. The total length of the Shabelle River is about 1700 km, again approximately half lying in Ethiopia and half in Somalia (Conway, 2000).

Figure 7. Hydrology of Juba and Shabelle rivers.
3.5. Surface water situational analysis

The surface water situation for Somaliland and Puntland has been comprehensively described by SWALIM (2009) in their “Inventory of Drainage Basins of Northern Somalia”. The major drainage basins in the region are: The Gulf of Aden Basin, Dharoor Basin, Togdheer/Nugaal Basin and Ogaden Basin (Figure 6). In addition to these, the narrow strip of land along the Indian Ocean has short drainage networks and there is not much flow in these drainage channels that reaches the Indian Ocean.

![Diagram of Somalia major drainage basins]

Figure 8. Somalia major drainage basins.
3.6. Groundwater situational analysis

While locally varying, the general hydrogeological conditions in Somaliland and Puntland can be described as challenging with regards to water availability and water quality (Johnson, 1987). Climatic conditions range from semi-arid to arid and surface water availability as well as shallow groundwater levels fluctuate with the rainfall intensities in the different seasons. High salt concentrations in the groundwater of many wells render them marginally suitable or unsuitable for humans and/or livestock. Groundwater, being the primary source of water supply, is generally obtained from boreholes, dams, dugwells and springs. An overview of the distribution of these water sources is shown below;

![Figure 9. Distribution of various water sources in Somalia.](image-url)

3.7. Soil erodibility analysis

The quality of the soil is an essential and determinant component of Somalia’s agricultural productivity and natural ecosystems. But soil is a fragile and non-renewable resource. It is easily degraded and difficult, slow, and expensive to regenerate. Soil depletion and degradation is directly related to Somalia’s and the world’s hunger crisis. Somalia has various soil types, primarily according to climate and the parent rock. The northern part of the country (Somaliland and Puntland) has shallow
sandy and/or stony soils and some deeper lime-rich soils. In the highlands around Hargeisa, relatively high rainfall has raised the organic content in the sandy calcareous soils characteristic of the northern plains. This soil supports some rain-fed farming. South of Hargeisa begins the “Haud” region whose red calcareous soils continue into the Ethiopian Ogaden and support vegetation which is ideal for camel grazing. Deep clay soils are found south of Gebiley in Somaliland. The central part of the country is dominated by sandy soils along the coast and moderately deep loamy soils with a high content of calcium carbonate and/or gypsum further inland. Prominent in southern Somalia are low-lying alluvial plains, associated with the Juba and Shebelle Rivers. These plains mainly have clayey soils, some of which have poor drainage and/or high content of salts. Some of the riverine areas are also liable to flooding. The inter-riverine areas have both shallow soils (particularly towards the border with Ethiopia) and deep loamy and clayey soils. Figure 10 shows the soil unit characterization.

Figure 10. Soil units’ map analysis.

The soil erodibility analysis for Somalia was modelled from harmonized soil database with three main combination that largely characterize its erodibility. The soil gravel content, the depth or available water content and the texture was analysed in this category and classified according to the ease with which soil can easily be washed if the available cover is weak. The classification criteria classified gravel content that is above 10% as slightly erodible, 1 to 10% as moderately erodible and those less than 1% to be highly erodible, whereas the available water content of between 0 to 15mm/m as highly erodible, 50 to 100mm/m as slightly erodible and above 100mm/m to be of low erodibility.

11. Characterized soil erodibility map.

The soil texture in this combination was classified based on the particle size and type where the Loam (L), Silty loam (SiL), sandy loam (SL) and silt was classified as highly erodible due to their particle sizes. The moderately erodible soil was sandy clay (SCL), Clay (CL), Silty clay (SiCL), Loamy Sand (LS) and Sand(S) with low erodible soil contains; sandy Clay (SC), Clay and silty clay (SiCL).

3.8. Multivariate Geographical Clustering for Agro-climatic zoning

Multivariate clustering analysis represents a relatively recent development, characterizing discontinuities into subsets according to multiple parameters, such as orientation, spacing, and roughness, where rather than considering one variable at a time, a number of parameters can be treated simultaneously, so that the interactions between parameters are taken into account. Several investigators have recognized the potential of geographic multivariate clustering for delineating homogeneous regions objectively within small maps. Multiple geographic areas can be classified into a single common set of quantitative eco-regions to provide a basis for comparison, or maps of a single
area through time, can be classified to portray climatic or environmental changes geographically in terms of current conditions. This tool in ArcGIS software (geoprocessing tool) was used to delineate the agro-climatic zones of Somalia using the climate data (temperature and rainfall), hydrology, land use, soil erodibility and terrain. It requires the geographical geolocation of all raster data components and uses a statistical clustering in a multivariate layering approach. The results obtained indicated suitability zones / areas for agricultural development. (Figure 12).

Figure 12. Characterized Agro-climatic map of Somalia.

3.9. Assessment of Potential Areas for Agriculture in Somalia

Irrigated agriculture is practiced in the floodplains along the permanent rivers in south Somalia (the Juba and the Shabelle) and along the seasonal streams and springs. In northern Somalia, water is available within pockets of deep soil for irrigated orchards, or from shallow wells and springs, which are the major sources of water for crop irrigation, with water pumped to the fields. These fields in their respective locations shows that the land is productive for agricultural development with no much need for additional nutrients. Irrigated crops grown on a small scale include maize, sesame, fruit trees and vegetables, while crops such as bananas, guava, lemon, mango and papaya are grown on a large-scale for domestic consumption.

Considering the hydrology of Somalia, it is seen that the Ethiopian headwaters of the Juba and Shabelle, surface water resources are abundant. In the middle reaches, where runoff is highly localized...
and seasonal, the rivers themselves still carry considerable volumes of water during most of the year. Downstream of the Ethiopia-Somalia border, discharges reduce progressively with the Shabelle often ceasing to flow in its lower reach in the early part (January–March) of the year. It is therefore prudent to say that Shabelle has a substantially greater catchment area than the Juba, even though the flow in the Juba is about three times as large as the Shabelle flow. This is partly due to higher average annual rainfall, but also due to a much better developed drainage network in the upper part of its basin, with three tributaries producing high runoff volumes indicating agricultural potential.

In terms of soil variables as indicated in (Figure 10) brings a clear soil erodibility indication. The map indicates that the south-central parts of Somalia especially the convergence zones of river Juba and Shabelle which is moderately to highly erodible among other parts in the country can be productive. The erodibility serves as indicator of areas or regions with fragile fertile soils that are productive with fine top soil that is rich and can support food production. Vegetation cover in this areas or zones coupled with conservation measures is highly desirable to contain the top fine and productive soil for sustained agriculture. Figure 12 demarcates the zone areas that are deemed suitable for cropping.

The agricultural potential that lies in Somalia is so huge that one can imagine of one day being the main agricultural producing country in the Northern part of Africa. The climate, the hydrology, the soil erodibility and the land cover through a multivariate geographical clustering of a GIS presents an idea of where to target for agriculture. The existing ground water sources (boreholes) and surface water basins (juba and Shabelle basins) coupled with gentle sloppy terrain indicates a promising availability of water, which is a major requirement to food crops especially for the irrigate landscapes.

**Conclusion and recommendation**

GIS is one of the easiest ways of providing management tool for mapping all the land use, climatic change and other human activities. Remote Sensing integration with GIS is a versatile and user-friendly application that can be employed to provide an appropriate framework through the manipulating, visualizing and spatial analysis to support planning and decision-making process relevant to irrigation management. The integration of GIS with the available data management tools is more powerful and effective when dealing with large area and complex temporal data.

Higher temperatures and less rainfall will reduce the flow of rivers and streams, slow the rate at which aquifers recharge, and make the entire region more arid. These changes will have a series of effects, particularly on agriculture, energy and food security, and contribute to malnutrition, famine and starvation. Agriculture yields, especially in rain-fed areas, are expected to fluctuate more over time, and to stabilize at largely lower averages over the long-term.

**Acknowledgement and future research**

The authors acknowledge the support by department of Geomatic Engineering and GIS of Jomo Kenyatta University of Agriculture and Technology and also the capacity development provided by the department of research and development of Mapinfotek Geomatics Ltd in seeing this work was accomplished. Further research is to understand the impacts of climate change or climate variability on the agricultural potential areas and to develop a national agro–ecological zone chart for the country. Much thanks goes to FAO and KITE (University of York) for providing access portal to the datasets used.

**References**


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Geospatial information system land evaluation analysis for rainfed farming using multi-criteria decision analysis approach

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Geospatial information, MCDA, GIS, land suitability.

ABSTRACT
This paper aims to develop a geospatial information system based land evaluation method for rainfed farming. To produce geospatial information of potential areas for sorghum using Multi-Criteria Decision Analysis (MCDA) approach. The land suitability is based on the biophysical and soil factors. The analysis aimed at the production of geospatial information displayed in maps and a graph showing potential areas that are suitable for rainfed farming. A fuzzy modeling decision analysis tool integrated with map algebra expression ADD (+) Geographical Information System (GIS) analysis operation was used to combine the information from several criteria to form a single suitability map. The results showed the land parcels that are suitable, marginal suitable and non-suitable for sorghum. The suitability map was overlaid with the existing land use to identify areas that are plowed for sorghum that are on suitable areas.

1. Introduction

In this study, the focus was on the development of geospatial information system land evaluation analysis for sorghum crops. The study produced geospatial information of potential areas in maps that are suitable for sorghum crops under rainfed farming conditions using the Geographical Information System (GIS) tools and Multi-Criteria Decision Analysis (MCDA) approach. A wide range of geospatial information on maps is needed for planning, management, and operational decision making. Geospatial information is one of the important kinds of information that can be used for land suitability analysis and land use planning. This study focused on the land suitability of sorghum under rainfed farming in Botswana. The research investigated both areas of cultivated and uncultivated areas based on the current suitability which is the suitability based on the present climatic condition.

Geographical Information System (GIS) is a computer-based system of storage and manipulation of data which is organized by area or location (FAO 1996); (Prakash 2003). Research by (Leingsakul, Mekpaiboonwatana, Pramojane, Bronsveld & Huizing 1993) had shown that the integration of GIS and Remote Sensing technology could locate land for a new location to plant crops (Prakash 2003). GIS has the power to integrate a large number of complex data in maps, graphs, charts or in statistical format, to make decisions. In the multi-criteria evaluation of many factors, GIS has the power to analyze and produce results for decision making.

2. General Background

Research has been carried out on spatial information using GIS and Multi-Criteria Decision Analysis, and it has been used to assess the suitability of different crops for different areas and

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agricultural land resources. GIS, Remote Sensing, and Multi-Criteria Evaluation were integrated to provide decision of evaluation suitability of rice (Perveen, Nagasawa, Uddin & Delowar 2003). The biophysical and topography of the soils were considered for suitability analysis. Multi-Criteria Evaluation: Analytic Hierarchy Process (MCE: AHP) Analysis was used for decision making. The research provided suitability areas for rice.

In the western part of the Nile Delta in Egypt research was done to decide on the best agricultural use of uncultivated land (El-Kawy, Ismail, Rod & Sulumana 2010). The developed as a result Agricultural Land Evaluation System for Arid and Semi-arid Regions (ALESarid) used a GIS-based Multi-Criteria Decision Analysis (MCDA) to assess the agricultural land capability and suitability.

In 2012 a GIS Multi-Criteria Evaluation was used in modeling future land use for resources planning and management using physical parameters to find the best spatial allocation of land for future agriculture and forest development in the lower Aswa basin of Uganda (Nyeko 2012). GIS Multi-Criteria Evaluation Analysis based on land characteristics physical parameters were used. The results showed high potential areas to be used. Similarly, the land suitability evaluation for sorghum based on Boolean and fuzzy Multi-Criteria Decision Analysis method was also carried out in Libya (Elaaalem 2012). The study was based only on four biophysical criteria.

In Kenya, (Kihoro, Bosco & Murage 2013) carried research on suitability analysis for rice growing sites using Multi-Criteria Evaluation and GIS approach. The research was based on physical soil characteristics, climatic and topography consisting of six criteria. Similarly to previous research, in Libya, (Abushnafa, Spenceb & Rotherhama 2013) developed a Land Evaluation Model using a Geographic Information System and Multi-Criteria Analysis. The soil characteristics factors were used as input factors.

In Ethiopia, GIS-based Multi-Criteria Decision Analysis was applied and focused on land suitability analysis to identify permissible areas suitable for rice crop production in west-central highlands of Amhara Region (Ayehu & Besufekad 2015). This research was based on topography, physical and chemical properties of soil and climate.

This research used the Multi-Criteria Decision Analysis (MCDA) approach, Remote Sensing and Global Positioning systems (GPS) geospatial information tools and systems to improve the methods that were used in past studies. Multi-Criteria Decision Analysis (MCDA) approach was used to evaluate the factors. This research produced digital geospatial information and databases for potential agricultural crop production under rainfed farming that could be used by the farmers.

3. General and Specific Objectives

The general objective of this study was to develop a geospatial information system based land evaluation analysis for crops under rainfed agriculture using Multi-Criteria Decision Analysis approach.

The specific objectives of the study were as follows;

1. To identify advanced geospatial information system tools that can be used in the development of geospatial information system land evaluation analysis.
2. To develop methods of assessment and evaluation of land that is suitable for agricultural crop using Multi-Criteria Decision Analysis.
3. To collect spatial data and information on soil and land use.
4. To analyze the data and transform it into geospatial information using GIS tools.
5. To produce agricultural land suitability geospatial information and databases of the study area.

4. Methodology

Multi-Criteria Evaluation Decision Analysis was used for the suitability decision. Global Positioning System (GPS) was used for positioning locations and picking the reference points. Remote sensing
orthophoto-photos were used mapping the land use of the study area. The research used land and crop suitability indicators designed for the specific sorghum crop. The methodology is led by specific objectives (see Section 3).

4.1 Advanced Geospatial Information System Tools for Land Evaluation Analysis

This part describes new technologies and tools that can be used to develop geospatial information system land evaluation and analysis methods for land suitability for crops under rainfed farming. The tools that were used to develop geospatial information system methods for land evaluation and analysis were identified as follows:

- Remote sensing for providing land covers images
- Global Positioning System (GPS) for positioning the locations
- Multi-Criteria Decision Analysis for land assessment
- Geographical Information system for analysis, producing geospatial information, geospatial databases, and for producing maps for visualization and decision making.

4.2 Methods for Development of Methods for Assessment and Evaluation of Land Suitability for Agricultural Crops

The land is assessed and evaluated to match land use with land (FAO 1996). In this study agricultural land was assessed based on the requirements of crops under rainfed farming. The procedures were as follows; Firstly, it was the selection of study area to be evaluated and the agricultural land use that area, secondly, it was the description and identification of the requirements of the selected crop, and thirdly, it was the description of land units and their quality within the areas selected.

In this study agricultural land was evaluated for easy agro-climatological and ecologically zoning to match the land with its use to increase production as well as the management and conservation of agricultural land. The evaluation process was the next to be operated after the land assessment. Multi-Criteria Decision Making (MCDM) was used in the evaluation.

4.2.1 Multi-Criteria Decision Making (MCDM)

Land suitability is a multi-decision approach that involves the selection of major land use using many factors. All the factors (criteria) are not equally important and have different results. Multi-Criteria Evaluation (MCE) is primarily concerned with how to combine information from several criteria to form a single index of evaluation. It provides a collection of techniques and procedures for structuring decision problems, designing, evaluating and prioritizing alternative decisions. Multi-Criteria Decision Making (MCDM) is defined as a process that combines and transforms some geographic data inputs into a resultant decision output (Ayehu & Besufekad 2015). It involves input data, decision makers and the manipulation of data and information using specified decision rules. Evaluation is divided into steps. Step one is the decision on input datasets/criteria, step two is the creation of new data from the input, the third step is a reclassification of suitability, and the fourth step is to apply multi-criteria decision analysis method.

This study used the MCDM based on the spatial geographic data of land characteristics with large numbers of factors identified and considered to come out with the final suitability map of sorghum, five factors were used namely; soil Potential Hydrogen (PH), soil depth, slope, salinity and water holding capacity. These were used based on the crop requirements to match land with its use to increase sorghum production. Map algebra expression ADD (+), a GIS analysis operation was used. This operation was used to integrate, calculate and analyze the raster maps to produce a single suitability map using fuzzy overlay analysis.

The land evaluators and experts can define the ideal requirements of land use but are often unsure about the boundaries between classes; this has given the fuzzy operation a chance. Fuzzy operation method is the decision-making method to address the imprecision and uncertainty. The fuzzy logic
operation makes it possible to improve analysis and simplification of the soil characteristics that are characterized by vague conception (Prakash 2003).

4.3 Methods for Collection of Spatial Data and Information on Soil and Land use

The data was collected from different data types sources. The spatial and non-spatial data was collected in different formats such as digital data, analog and fieldwork data, and reports. The secondary land digital data on soil characteristics in the form of Geographical Information System files were used. The aerial ortho-photographs of the 1m resolution was digitized to produce existing land use maps. The data were combined with the data collected from the field. A survey was carried out to collect, survey, assess, groundtruthing and map the environment. The data was collected using a GPS device taking the x and y coordinates of locations that were used to reference the data and transform it into real-world geospatial information, including the attributes data for the study area.

4.4 Methods for Data Analysis and Transformation

This study used a Computer Assisted Overlay mapping techniques integrated with Multi-Criteria Decision Analysis (MCDA) methods. It allowed the evaluation criteria map layers to be combined in order to determine the composite map layer. The map overlay approach was used in the form of Map algebra and raster calculator operation. Different maps were overlaid for suitability. GIS Statistical and mathematical operations such as Map algebra operations were used for analysis. The data was analyzed using GIS and other supporting software.

In this study, GIS Computer Aided Overlay (CAO) analysis was used for analyzing the data for land suitability using soil physiological characteristics parameters of sorghum. Overlay analysis is a tool for applying weights to many inputs that can then be combined into a single output map (Abushnafa, Spenceb & Rotherhama 2013).

4.5 Methods for Producing Agricultural Land Suitability Geospatial Information and Databases

The process of land suitability classification is the evaluation and grouping of specific areas of land in terms of their suitability for a defined use (Prakash 2003). There are four categories of generalization of the land suitability classes. These are orders, classes, sub-classes, and units. This study used two orders being suitable (S) and non-suitable (N). The suitable order S was a combination of S1 (highly suitable), S2 (moderately suitable) and S3 (marginally suitable). The order categorized as non-suitable was a combination of N1 (currently unsuitable) and N2 (permanently unsuitable land). This was done because, from the economic point of view, growing crops on very marginally suitable lands is very risky. Even if farmers managed to grow these crops, the production would be very low and expensive. There are lands in Botswana where currently are not in use where the crops would be much easier to grow. It differs Botswana from European countries where ministries of agriculture and individual farmers could consider using very marginally suitable (S4) and even currently unsuitable lands (N1). The reason for that is that in Europe there might exist agricultural technologies not available currently in Botswana, and governments could afford investments into improving land quality and melioration for other use such as fruit tree production. European countries are small and densely populated (Olesen & Bindi 2008), so almost all agricultural land is in use.

Suitable classes on the maps were coded as (1), marginally suitable (2), non-suitable areas (3) while areas without any data were coded (4). The maps were then integrated together to produce a single map showing agricultural potential areas for a sorghum crop.

5. Results

The major problem today is to produce and provide accurate agricultural information to increase food production on scarce agricultural land and on difficult, unreliable climate change conditions. Global Positioning System (GPS) and Geographical Information System (GIS) are two examples of advanced Information and Communications Technologies able to increase production through land evaluation.
This research used GIS approach to identify areas suitable for sorghum crop based on the following five parameters: (1) slope, (2) soil depth, (3) soil PH, (4) salinity and (5) water holding capacity. The outputs were transformed into different maps of suitability for all factors used. The potential suitable areas for sorghum crops were based on five factors; (1) soil depth (50 cm - 200 cm), (2) slope (0 - 8%), (3) available water holding capacity (70 mm/m - 161 mm/m), (4) soil PH (5.2 - 8.5) and (5) salinity (0 - 10%). These factors were integrated using a Geographical Information System (GIS) Multi-Criteria Analysis to produce a single suitability map. A GIS analyst tool, Raster Calculator was used to overlying all the five factors together and produced unclassified maps with nine classes that were reclassified into two orders classified into four classes (coded 1,2,3,4 respectively) including Class 4 with no data.

![Figure 1: Unclassified potential areas of sorghum maps](image)

The maps on Figure 1 show the results of unclassified land suitable areas and non-suitable areas of sorghum.

The classes displayed on the maps are as follows;

1) Class 5 (dark green): all five suitable factors;
2) Class 6 (light green): four suitable factors and one marginally suitable factor;
3) Class 7 (red): three suitable factors and two marginally suitable factors;
4) Class 8 (yellow): two suitable factors and three marginally suitable factors;
5) Class 9 (light brown): three suitable factors and two non-suitable factors;
6) Class 10 (light grey): two suitable factors, two non-suitable factors and one marginally suitable factor;
7) Class 11 (purple): three non-suitable factors, two suitable factors;
8) Class 13 (brown): four non-suitable factors and one suitable factor;
9) Class 20 (blue): no data.

The results of unclassified calculated raster layers of all the five factors used to produce a single layer of suitability map are summarized in Table 1.
Table 1. Unclassified potentially suitable for sorghum areas.

<table>
<thead>
<tr>
<th>Class</th>
<th>Slope</th>
<th>Soil PH</th>
<th>Salinity (ESP)</th>
<th>Soil Depth</th>
<th>Water Holding Capacity</th>
<th>Summary of Class</th>
<th>Reclassification</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>All 5 (S)</td>
<td>Suitable</td>
</tr>
<tr>
<td>6</td>
<td>S</td>
<td>S</td>
<td>MG</td>
<td>S</td>
<td>4S + 1MG</td>
<td>4S + 1MG</td>
<td>Suitable</td>
</tr>
<tr>
<td>7</td>
<td>MG</td>
<td>S</td>
<td>MG</td>
<td>S</td>
<td>3S + 2MG</td>
<td>Marginal</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>S</td>
<td>S</td>
<td>MG</td>
<td>MG</td>
<td>2S + 3MG</td>
<td>Marginal</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>NS</td>
<td>S</td>
<td>S</td>
<td>NS</td>
<td>MG</td>
<td>3S + 2NS</td>
<td>Non-suitable</td>
</tr>
<tr>
<td>10</td>
<td>NS</td>
<td>S</td>
<td>NS</td>
<td>MG</td>
<td>2S + 2N + 1MG</td>
<td>Non-suitable</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>NS</td>
<td>NS</td>
<td>S</td>
<td>NS</td>
<td>3NS + 1S</td>
<td>Non-suitable</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>NS</td>
<td>NS</td>
<td>S</td>
<td>NS</td>
<td>4NS + 1S</td>
<td>Non-suitable</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>All ND</td>
<td>No data</td>
<td></td>
</tr>
</tbody>
</table>

S = suitable, MG = Marginal suitable, NS = Non-suitable, ND = No data

Classes 5 and 6 were reclassified as suitable, Classes 7 and 8 as marginally suitable, Classes 9, 10, 11, and 13 as non-suitable and Class 20 as a class with no data. The reclassification is representing the final map of potential suitability map classified into four classes (“suitable”, “marginal suitable”, “non-suitable” and “no data”).

The land suitability analysis results were overlaid with the existing areas of plowed sorghum to match and observe similarities. The comparison of existing land use and suitability indicated the land suitable for sorghum but not used for its production.

The map in Figure 2 shows the potential suitability of sorghum after the reclassification of unclassified result map generated after the integration of all five factors. The results showed that suitable areas were distributed over the study area. The marginally suitable areas were found on the lower areas and non-suitable on hilly or high areas referring to the slope map (Figure 1).

Figure 2: Land suitability for sorghum map
The potential land suitability map for the sorghum crop was overlaid with the maps of the existing arable lands to compare the differences and similarities of the distribution of the existing arable land with the distribution of suitability. The land suitability and arable lands maps were also overlaid to identify potentially suitable areas which were not in use. The maps were overlaid to identify the arable lands that were on the suitable, marginally suitable and non-suitable areas. The map in Figure 3 shows the distribution of the existing areas plowed for sorghum in all classes.

![Land suitable or marginal suitable for sorghum but not used Map](image)

**Figure 3**: Overlaid maps of land suitable for sorghum and existing arable lands where sorghum was grown.

The results showed that there was no correlation between the existing sorghum areas and the land suitability areas as some areas of plowed sorghum were marginally suitable, non-suitable or those with no data.

According to Figure 4, the existing areas of sorghum located on suitable land comprised 64 704 hectares (18%) of the total suitable land that was estimated to be 368 366 hectares. The sorghum plowed areas on marginal suitable comprised 42 530 hectares (11%) of the total area of the marginal land estimated to be (388 035 hectares).

![Land suitability and the existing areas for sorghum (hectares)](image)

**Figure 4**: Land suitable for sorghum and existing arable lands.
The sorghum plowed areas on non-suitable land comprised 16 262 hectares (5%) of the total non-suitable land (2 99 831 hectares). The sorghum plowed areas located on the land with no data comprised 14 423 (54%) of the total land with no data (26 398 hectares).

6. Discussion and Conclusion

This study achieved the objectives. The study improved the existing methods of land evaluation by developing a geospatial information system based land evaluation method. The existing methods that were improved are; methods for integration of complex dataset and information using GIS and GPS; methods for evaluation of land suitability Multi-Criteria Evaluation Analysis; and Spatial Multi-Criteria Decision Making Analysis methods integrated with fuzzy overlay. The method was improved using advanced GIS, MCEA, GPS, and Remote Sensing tools. These methods were used to process and transform data into land suitability information that was presented in maps of potential areas of sorghum.

The study proved the ability of GIS to integrate complex datasets and information using a variety of geographic technologies such as GPS to produce spatial information, spatial databases, and maps. The Multi-Criteria Evaluation Analysis methods based on geospatial information have the power to evaluate land suitability for rainfed farming. Spatial Multi-Criteria Decision Making Analysis methods, integrated with fuzzy overlay, have been proven to be the best methods that can be used to evaluate land use suitability.

This study concentrated only on sorghum, but the suitability of land for other crops, vegetables, and fruits could be evaluated using the same methods and techniques of GIS. The results of potentially suitable areas for sorghum showed that the suitable areas of rainfed farming (34%) could be easily doubled by improving the marginal land (36%). Thus there were substantial reserves for increasing the farming industry and reducing imports of food from other countries. Non-suitable lands are currently used for sorghum while suitable lands are not. This study was done for sorghum, but any other crop in other countries there might be a mismatch of land use, even in Europe.

This research helps to increase the area of crop production of sorghum as well as other crops in Botswana and other countries without waste resources on the non-suitable areas, or before plowing to improve the land. Even non-suitable lands can be improved. This helps reducing expenses, of waste resources on non-suitable lands. The land that is non-suitable can be converted for other suitability use. The marginally suitable and non-suitable lands can still be improved to be suitable for other crops in countries with a high population density. The spatial suitability information of the study area could improve the development of agro-climatological and ecological zoning. Land that is suitable for sorghum should be zoned for sorghum only same as other crops.

This research will act as a benchmark for future researchers and land use planners, monitors, and managers. Furthermore, the research can be used by other researchers as a reference to evaluate and identify the land quality for other land uses. Geospatial information system based land quality suitability analysis should be viewed as a process of converting geographic data into geospatial information that can be shared digital and online. The sharing of agricultural spatial information can be used by the farmers. Farmers need updated information about their farms for planning purposes. The spatial database created of the study area will contribute to the existing spatial information. It will help the decision makers to develop and implement policies, standards on digitized spatial data and information on land evaluation.

References


Overview of the decision support system and fruit growth stages to predict the action threshold in order to control the apple scab in Kosovo

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ABSTRACT

The apple scab caused by the fungal pathogen Venturia inaequalis (Cooke) G. Winter is a continuous problem for apple farmers in Kosovo. From this disease, the fruits become scabby brown or black spotty, losing their value. The fruit infection from A. scab requires immediate and multi time treatment. In the agricultural market, there are several plant protection products integrated in to various treatment variants provided by chemical manufacturers to control the apple scab infections. The purpose of this study was to identify the best action threshold based on the prediction of the infection risk provided by one decision support system (DSS RIMpro) and based on the empirical point of view by selecting few fruit growth stages from BBCH scale to control this disease in the research zone. Therefore, two different treatment intervals were used and eight treatment variants consisting of several fungicides were created. The research is carried out in one experimental orchard in cultivation with Starking apple cultivar. Based on analysed disease index on infected fruits, the treatment intervals were compared with each other to conclude the best action threshold for Kosovo conditions.

1. Introduction

In the commercial orchards throughout country of Kosovo, one of the major cultivated fruit species is the apple (Malus domestica Borkh.). The structure of main cultivars is created from ‘Golden delicious’, ‘Starking’, ‘Gala’ and ‘Granny Smith’. Other cultivars such as ‘Fuji’, ‘Jonagold’ and ‘Braeburn’ continue to be planted. In terms of susceptibility to the diseases and pests, the apple ‘Starking’ cultivar is known as very sensitive among the other cultivars. Taking in to consideration that ‘Starking’ cultivar is being cultivated mostly in the country, the apple scab disease remains the challenge and threat for local growers, especially in wet seasons when the disease can develop faster. This problem causes the fruit cultivation reduction which directly affects the export of the fruit, increases the import to the country which then effects the local growers to remain in solid position in the market.

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Therefore, the disease needs to be controlled with fungicides. Depending on the risk of disease, 10 to 15 or even more fungicidal applications are usually needed for efficient control (Meszka, 2015). The number of treatments depends on cultivar susceptibility, the amount of source infection and weather conditions, mainly air temperature, leaf wetness, relative humidity and rainfall (Mills, 1946; MacHardy and Gadoury, 1989; Stensvand et al., 1998). Important losses occur also due to the development of scab in storage (R. Tomerlin, 1983).

The overall goal of this study was to develop one action threshold with optimal time interval to realize the fungicide treatments to control the apple scab in Kosovo. If the primary infections are not managed successfully on adequate timeframe in the spring, then the secondary infections should remain in high level resulting in the fruit drop during the summer and overall fruit loss in the harvest time. In wet seasons and with temperature increment, the secondary scab infections from conidia will require few fungicidal applications. This study had three main objectives: a) the 1st objective was to start utilizing the DSS in Kosovo plant protection sector; b) the 2nd objective was to analyse the nowadays best decision support system in the market with some selected apple growth stages for predicting the best action threshold to start the treatments to prevent and control the scab disease; c) the 3rd objective was to compare a few treatment variants composed with different fungicides that would perfectly fit in the best action threshold derived from analysis of the treatment intervals. Actual trends in disease management intend to skip the excessive high number of treatments, which involve risks to human health and the environment, and motivate the use of decision support systems (DSSs) (Rossi et al., 2012).

2. Materials and methods

2.1. Location and duration

This research was accomplished in region of Gjilan, country of Kosovo, during three years 2015-2017. The experimental orchard is in ‘Starking’ cultivation.

2.2. Experimental design

The experimental design is set up in two factorial randomized block with four replications and is formed, as shown in table 1; with Factor A for treatment time interval in two levels: A₁. Phenological phases’ threshold; and A₂. RIMpro threshold (relative infection measure program-RIMpro). A₁ - the phenological phases’ threshold, consists from apple growth stages from the BBCH Scale (Meier, 2001), as shown in table 2.

A₂ - the RIMpro cloud service is developed by Bio-Fruit-Advies in Netherlands as decision support system (DSS) that provides predictions in forms of warnings for infection periods to the subscribed farmers and researchers all over the Europe and Northern America that are connected and interact with this online platform (figure 1).

![Figure 1. DSS RIMpro: a) platform view; b) infection process](image-url)
The second effect factor (B) is the treatment variant in eight levels (B₁ - B₈). The levels consist of different fungicides as shown in table 3.

The third effect factor (C) is the treatment year also in three levels: C₁: 2015, C₂: 2016 and C₃: 2017. In this factor the effects of weather conditions dominance were considered for each research year.

### Table 1. Treatment intervals and treatment variants for A. scab

<table>
<thead>
<tr>
<th>YEAR (Factor C)</th>
<th>TREATMENT INTERVAL (Factor A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1. 2015</td>
<td><strong>A1</strong> Phenological phases</td>
</tr>
<tr>
<td>C2. 2016</td>
<td><strong>A2</strong> DSS RIMpro</td>
</tr>
<tr>
<td>C3. 2017</td>
<td><strong>B1</strong> Copper hydroxide followed by Dodine</td>
</tr>
<tr>
<td></td>
<td><strong>B2</strong> Copper hydroxide followed by Captan</td>
</tr>
<tr>
<td></td>
<td><strong>B3</strong> Copper hydroxide followed by Mancozeb</td>
</tr>
<tr>
<td></td>
<td><strong>B4</strong> Copper hydroxide than Tebuconazole followed by Captan</td>
</tr>
<tr>
<td></td>
<td><strong>B5</strong> Copper hydroxide followed by Propineb than Difenconazole</td>
</tr>
<tr>
<td></td>
<td><strong>B6</strong> Copper hydroxide than Trifloxystrobin followed by Chlorothalonil</td>
</tr>
<tr>
<td></td>
<td><strong>B7</strong> Copper hydroxide followed by Cyprodinil than Dithianon</td>
</tr>
<tr>
<td></td>
<td><strong>B8</strong> Control (no treatment)</td>
</tr>
</tbody>
</table>

### Table 2. Phenological growth stages and identification keys of pome fruit. *Malus domestica Borkh* (Meier, 2001)

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Mouse-ear stage: Green leaf tips 10 mm above the bud scales. First leaves separating.</td>
</tr>
<tr>
<td>71</td>
<td>Fruit diameter size up to 10mm; fruit fall after flowering.</td>
</tr>
<tr>
<td>72</td>
<td>Fruit diameter size up to 20mm.</td>
</tr>
<tr>
<td>74</td>
<td>Fruit diameter up to 40mm; fruit erect.</td>
</tr>
<tr>
<td>85-87</td>
<td>Advanced ripening: increase in intensity of cultivar-specific colour. Fruit ripe for picking.</td>
</tr>
</tbody>
</table>

#### 2.3. Sampling

On the 23rd of September in each research year, 10 apple fruits from the randomized block trees were randomly picked for assessment. In the laboratory, 960 fruits were analysed for the disease index which were taken from total of 98 apple trees. For every treatment program, the disease infection level was checked based on the fruit surface area infected by the fungal pathogen *V. inaequalis*.

#### 2.4. Disease assessment

The disease severity was determined by rating the proportion of scabbed surface of the fruit. Disease severity is a measure of the amount of disease per sampling unit (Nutter et al., 2006). Croxall et al. (1952) reported a standard diagram method for rating the scab severity. Lateur and Blazek (2002) reported standard area diagram (SAD) from 1 to 9 scab intensity scale levels. This scale is modified from 9 to 6 SAD categories and is presented in percentage from 0% to 75% of the fruit surface infected area as shown in table 3 (Hasani, 2005).

The disease index was calculated with McKinney’s index (McKinney, 1925) which is modified by B.M Cooke (Cooke et al., 2006):

\[
I = \frac{\sum (n_i \times k_i)}{N \times K} \times 100
\]
I = disease index; ni = number of fruits in respective category; ki = number of each category; N = total number of fruits analysed; K = total number of categories.

Table 3. The Standard Area Diagram (SAD) field key for scab infection assessment on apple fruits

<table>
<thead>
<tr>
<th>Fruit Category</th>
<th>0% fruit surface infected</th>
<th>0.1 - 10% fruit surface infected</th>
<th>10.1 - 25% fruit surface infected</th>
<th>25.1 - 50% fruit surface infected</th>
<th>50.1 - 75% fruit surface infected</th>
<th>&gt;75% fruit surface infected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity level</td>
<td>Nothing noticed</td>
<td>Light intensity</td>
<td>Medium intensity</td>
<td>Strong intensity</td>
<td>Very strong intensity</td>
<td>Destructive intensity</td>
</tr>
<tr>
<td>Infection level</td>
<td>0% fruit surface infected</td>
<td>0.1 - 10% fruit surface infected</td>
<td>10.1 - 25% fruit surface infected</td>
<td>25.1 - 50% fruit surface infected</td>
<td>50.1 - 75% fruit surface infected</td>
<td>&gt;75% fruit surface infected</td>
</tr>
</tbody>
</table>

2.5. Plant Protection Products

The fungicides that were used are shown in table 4. The product volumes were prepared and mixed as per manufacturers’ recommendation on the product label. The trees in randomized block and other trees in the orchard were treated also with other plant protection products for preventive measures against other fungal diseases or pests besides the above fungicides which were used especially to control the Apple scab. Other regular agro technical actions were performed for orchard management as well.

2.6. Instruments and software

The weather conditions in the orchard and the leaf moisture were monitored and collected by weather station model i-Metos 2 (figure 2). This weather station was set up 2m above the ground in the orchard centre. The leaf moisture data’s are gathered by two specific sensors: one sensor was set up inside the apple tree wreath and other sensor was positioned outside the tree wreath. This station is produced and configured by Pessl Instruments GmbH from Austria. The collected data were sent out by the station every 15 minutes to the field-climate platform which is managed by the same inventor/company and after processing in the system, the information or warnings were provided in real time to the researcher/farmer through the same platform. The information was accessible with login in to the field-climate webpage through personal computer and smart phone application.

Figure 2. i-Metos 2, wetness sensor and FieldClimate platform view

The fungicide application was performed with Villager® spraying pump, model VBS with volume capacity of 16 litters and with spraying pressure: 2.6 - 4.0atm.
Table 4. Composition of treatment variants with fungicides

<table>
<thead>
<tr>
<th>Treatment variant Nr.</th>
<th>Fungicide</th>
<th>Activity</th>
<th>Producer</th>
<th>Treatment variant Nr.</th>
<th>Fungicide</th>
<th>Activity</th>
<th>Producer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Champion 50WG</td>
<td>Contact</td>
<td>Nufarm</td>
<td>5</td>
<td>Champion 50WG</td>
<td>Contact</td>
<td>Nufarm</td>
</tr>
<tr>
<td>2</td>
<td>Champion 50WG</td>
<td>Contact</td>
<td>Nufarm</td>
<td>5</td>
<td>Antracol 70WP</td>
<td>Contact</td>
<td>Bayer</td>
</tr>
<tr>
<td>3</td>
<td>Champion 50WG</td>
<td>Contact</td>
<td>Nufarm</td>
<td>6</td>
<td>Champion 50WG</td>
<td>Contact</td>
<td>Nufarm</td>
</tr>
<tr>
<td>4</td>
<td>Captain 80WG</td>
<td>Contact</td>
<td>Arysta</td>
<td>6</td>
<td>Zato 50WG</td>
<td>Systemic</td>
<td>Bayer</td>
</tr>
<tr>
<td>5</td>
<td>Mancosav 80WP</td>
<td>Contact</td>
<td>Agrosava</td>
<td>7</td>
<td>Dakonil 720SC</td>
<td>Contact</td>
<td>Syngenta</td>
</tr>
<tr>
<td>6</td>
<td>Champion 50WG</td>
<td>Contact</td>
<td>Nufarm</td>
<td>7</td>
<td>Champion 50WG</td>
<td>Contact</td>
<td>Nufarm</td>
</tr>
<tr>
<td>7</td>
<td>Folicur 250EW</td>
<td>Systemic</td>
<td>Bayer</td>
<td>7</td>
<td>Chorus 50WG</td>
<td>Systemic</td>
<td>Syngenta</td>
</tr>
<tr>
<td>8</td>
<td>Captain 80WG</td>
<td>Contact</td>
<td>Arysta</td>
<td>7</td>
<td>Daneel 700WG</td>
<td>Systemic</td>
<td>BASF</td>
</tr>
</tbody>
</table>

2.7. Statistical analysis

For statistical data analysis are used two applications: 1. Assistat® version 7.7 for mean values and standard deviation for treatment variants; 2. JMP® 14.0 is used for Dunnet’s and Tukey-Kramer HSD test for comparison of mean values for disease index and diamond/circles plots.

3. Results and Discussion

The assessment results for disease index on apple fruits of Starking cultivar, during three research years are presented on the table 5. The average disease index evaluated on phenological phases’ threshold begins with 9.3% in 1st treatment variant which is classified with letter C, then followed by letters BC in 2nd treatment variant with disease index value of 13.0% and up to 21.4% in control variant followed by letter A. The average disease index for DSS RIMpro threshold begins with 7.5% in 1st treatment variant followed by letter C than increases to 11.3% in 2nd variant followed by letter B and slightly increases in other variants but without any significant difference since it is followed by same letter and ends up to 20.4% in control group classified by letter A, as per Tukey-Kramer HSD test. The comparison of three-annual disease index averages from two treatment intervals, shows that RIMpro threshold has average disease index of 12.67% which is lower than phenological phases’ threshold with disease index 14.33%.

Table 5. Disease Index (1 %) data analysed on ‘Starking’ fruits for eight treatment variants realized in two treatment intervals during three years.

<table>
<thead>
<tr>
<th>Treatment variants</th>
<th>Phenological phases threshold DI% per variant/year Average</th>
<th>DSS RIMpro threshold DI% per variant/year Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.53</td>
<td>10.78</td>
</tr>
<tr>
<td>2</td>
<td>13.15</td>
<td>14.30</td>
</tr>
<tr>
<td>3</td>
<td>15.40</td>
<td>16.50</td>
</tr>
<tr>
<td>4</td>
<td>14.03</td>
<td>15.28</td>
</tr>
<tr>
<td>5</td>
<td>13.30</td>
<td>14.93</td>
</tr>
<tr>
<td>6</td>
<td>13.95</td>
<td>15.75</td>
</tr>
<tr>
<td>7</td>
<td>13.60</td>
<td>15.13</td>
</tr>
<tr>
<td>Control</td>
<td>21.75</td>
<td>23.28</td>
</tr>
<tr>
<td>Average</td>
<td>14.34</td>
<td>15.74</td>
</tr>
</tbody>
</table>

Tukey-Kramer HSD test at a level of 5% of probability was applied. The averages not connected by the same letter are significantly different.

The One-Way Analysis of Variance (ANOVA) for assessment of the scab disease index (1 %) on fruits for three years that is presented in table 6, shows statistically proven differences between the fungicide treatment variants in both treatment intervals. The fungicide treatment variants performed in the phenological phases’ action threshold period resulted with factual F value of 281.782** which
statistically proves the significance comparing to theoretical values from Fisher’s table for both levels of probability, for P=0.05 is 2.76 and for P=0.01 is 4.27. The statistical significance is also verified for repetitions factual value with theoretical values for both levels of probability.

The fungicide treatment variants conducted as per DSS RIMpro action threshold resulted with factual F value of 185.94** which is again greater than theoretical values as per Fisher’s table for two levels of authenticity, respectively for P=0.05 is 2.76 and for P=0.01 is 4.27. By comparing the repetitions value of this treatment interval with those from Fisher’s table, it results with significant difference for both levels of probability.

**Table 6. One-Way Analysis of Variance (ANOVA) of disease index (DI %) evaluated on fruits for eight treatment variants performed in two treatment intervals during three years.**

<table>
<thead>
<tr>
<th>Interval</th>
<th>Sources of variation</th>
<th>D.F</th>
<th>S.S</th>
<th>M.S</th>
<th>F Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Factual</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>95%</td>
<td>99%</td>
<td></td>
</tr>
<tr>
<td>Phenological phases threshold</td>
<td>Treatments</td>
<td>7</td>
<td>233.5346</td>
<td>33.36208</td>
<td>281.782**</td>
</tr>
<tr>
<td></td>
<td>Repetitions</td>
<td>2</td>
<td>32.13578</td>
<td>16.06789</td>
<td>135.712**</td>
</tr>
<tr>
<td></td>
<td>Error</td>
<td>14</td>
<td>1.65752</td>
<td>0.118397</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Variation total</td>
<td>23</td>
<td>267.3279</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Repetitions</td>
<td>2</td>
<td>11.86</td>
<td>5.931838</td>
<td>28.416**</td>
</tr>
<tr>
<td></td>
<td>Error</td>
<td>14</td>
<td>2.9224</td>
<td>0.208747</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Variation total</td>
<td>23</td>
<td>286.501</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Notes:** **Significant at a level of 1% of probability (P < 0.01); *Significant at a level of 5% of probability (0.01 = < P < 0.05); ns: Non-significant (P > = 0.05).**

The Two-Way Analysis of Variance (ANOVA) of the apple scab disease index (I %) evaluation on scabby fruits for three years, presented on table 7, shows the statistical significance for treatment intervals and treatment variants. The effects of factor A (treatment interval) and factor B (treatment variant) are significantly different, based on factual F value of 27.7009** for factor A which is greater than both theoretical Fisher’s table values 5.07 for level of 1% of probability and 6.78 for level of 5% of probability. The factual F value for factor B is 58.9703** results to be greater than theoretical Fisher’s table values, for P=0.05 is 3.03 and for P=0.01 is 5.47. The effects of the interaction between both factors AxB, the factual F value is 0.1514ns and resulted to be lower than theoretical values as per Fisher’s table for both levels of authenticity. Therefore, the interaction of these two factors practically had no effect on apple fruits protection.

**Table 7. Two-Way Analysis of Variance (ANOVA) of disease index (DI %) evaluated on fruits, for eight treatment variants performed in two treatment intervals during three years.**

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th>D.F</th>
<th>S.S</th>
<th>M.S</th>
<th>F Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Factual</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95%</td>
<td>99%</td>
<td></td>
</tr>
<tr>
<td>Treatment Intervals (A)</td>
<td>2</td>
<td>95.82951</td>
<td>47.91475</td>
<td>27.7009**</td>
</tr>
<tr>
<td>Treatment Variants (B)</td>
<td>7</td>
<td>714.01443</td>
<td>102.00206</td>
<td>58.9703**</td>
</tr>
<tr>
<td>Interaction AxB</td>
<td>14</td>
<td>3.66611</td>
<td>0.26187</td>
<td>0.1514ns</td>
</tr>
<tr>
<td>Treatments</td>
<td>23</td>
<td>813.51005</td>
<td>35.37000</td>
<td>20.4484**</td>
</tr>
<tr>
<td>Error</td>
<td>48</td>
<td>83.02653</td>
<td>1.72972</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>71</td>
<td>896.53659</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Notes:** **Significant at a level of 1% of probability (P < 0.01); *Significant at a level of 5% of probability (0.01 = < P < 0.05); ns: Non-significant (P > = 0.05).**

The Multi-factorial Analysis of Variance (M-ANOVA) for A. scab disease index (I %), assessment on ‘Starking’ fruits for three years, that is presented on table 8, proved that this disease is influenced by a few factors. This analysis proves that all treatment factors are statistically different. The effects of
factor A, the treatment years (different weather conditions), resulted with empirical F value of 303.2630** which is greater than both theoretical values from Fisher’s table, such values as 3.04 for the level of 1% probability and 4.71 for the level of 5% probability. The effects of factor B, the treatment intervals (two different action thresholds), resulted with empirical value of 428.7011** which is also greater than both theoretical values from Fisher’s table.

The effects of factor C, the fungicide treatment variants (eight variants with different combination of plant protection products), resulted with empirical value that is greater than both theoretical F values for both levels of probability. The effects of interaction between two factors AxB = 19.9297** resulted to be greater than theoretical F values. The effects of interaction between the factors AxC = 1.8507* resulted to be greater than theoretical F value for only one level of probability. The effects of interaction between other two factors BxC = 2.3535** resulted to be higher than theoretical values from Fisher’s table for both levels of probability as well.

Lastly, the interaction between all treatment factors AxBxC resulted with empirical value of 0.8490ns which is lower than both theoretical Fisher’s table values.

Table 8. Multi-factorial Analysis of Variance (MANOVA) for disease index (DI%) evaluated on fruits, for eight treatment variants performed in two treatment intervals during three years.

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th>D.F</th>
<th>S.S</th>
<th>M.S</th>
<th>F Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Factual</td>
</tr>
<tr>
<td>Treatment Years (A)</td>
<td>2</td>
<td>272.31194</td>
<td>136.15597</td>
<td>303.2630**</td>
</tr>
<tr>
<td>Treatment Intervals (B)</td>
<td>2</td>
<td>384.94778</td>
<td>192.47389</td>
<td>428.7011**</td>
</tr>
<tr>
<td>Treatment Variants (C)</td>
<td>7</td>
<td>2858.19135</td>
<td>408.31305</td>
<td>909.4441**</td>
</tr>
<tr>
<td>Interaction AxB</td>
<td>4</td>
<td>35.79139</td>
<td>8.94785</td>
<td>19.9297**</td>
</tr>
<tr>
<td>Interaction AxC</td>
<td>14</td>
<td>11.63250</td>
<td>0.83089</td>
<td>1.8507*</td>
</tr>
<tr>
<td>Interaction BxC</td>
<td>14</td>
<td>14.79333</td>
<td>1.05667</td>
<td>2.3535**</td>
</tr>
<tr>
<td>Interaction AxBxC</td>
<td>28</td>
<td>10.67250</td>
<td>0.38116</td>
<td>0.8490ns</td>
</tr>
<tr>
<td>Total treatments</td>
<td>71</td>
<td>3588.34080</td>
<td>50.54001</td>
<td>112.5688**</td>
</tr>
<tr>
<td>Error</td>
<td>216</td>
<td>96.97750</td>
<td>0.44897</td>
<td>-</td>
</tr>
<tr>
<td>Variation total</td>
<td>287</td>
<td>3685.31830</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Significant at a level of 1% of probability (P < 0.01); *Significant at a level of 5% of probability (0.01 < P < 0.05); ns: Non-significant (P > 0.05).

The pairwise comparison between the fungicide treatment variants (programs of treatment) with the control group as per phenological phases’ action threshold, are presented by the diagram of diamonds plot in figure 3. The fungicide treatment variants with grey circles and italicized variable labels, respectively the programs from 1 to 7 are significantly different from the control group, for the level of probability P = 0.05, as per Dunnett’s test. The means of these treatment variants/programs, except the 3rd program, are below the overall average which in this treatment period is 14.33%. The Tukey-Kramer HSD test pairwise comparison between the treatment variants, shows the significant differences in phenological phases’ action threshold.

The diagram of means diamonds in figure 4, provides the pairwise comparison between the fungicide treatment variants/programs with the control group, for scab disease control on infected fruits, as per DSS RIMpro action threshold. The treatment variants with fungicides marked with grey circles and italicized variable labels, as from 1 to 7, are significantly different from the control program, P = 0.05, as per Dunnett’s test. The treatment variants from 1<sup>st</sup> to 7<sup>th</sup>, except the 3<sup>rd</sup> program, are below the overall disease index average which in this case for DSS RIMpro action threshold is 12.6%. The 1<sup>st</sup> fungicide treatment variant has the lowest disease index followed by 2<sup>nd</sup> and 5<sup>th</sup>. The pairwise comparisons performed with Tukey-Kramer HSD test shows that there is a significant difference between the treatment variants (programs of treatment).
Edmond Rexhepi, Harallamb Paçe, Hekuran Vrapi, Arbenita Hasani: Overview of the decision support system with fruit growth stages to predict the action threshold in order to control the apple scab in Kosovo

Figure 3. Diagram of means diamonds (diamond plot) and comparison circles plot for Phenological phase’s action threshold.

Figure 4. Diagram of means diamonds (diamond plot) and comparison circles plot for DSS RIMpro action threshold.

The top and the bottom points of green diamonds are the confidence intervals (CI), as a supplement to the p value with 95% confidence interval for each mean. The green centre line presents the mean. The width of the diamond is proportional to the size of the sample group. The red boxes represent the distribution and the three blue dots per diamond represent the disease index values for three treatment years. The lower/upper horizontal blue lines are for the standard deviation. The grey and red circles represent the means comparison between the treatment variants/programs. The grey circles with italicized variable labels are for the variants/programs that are significantly different from the control group. The black horizontal centre line of the diamond and circles plot, is the overall average of the disease index per treatment interval.

Depending on the weather conditions, the apple scab infections happens every season in Kosovo and other countries in region but with different severity level. The issues of A. scab disease are checked from the specialists in the region. The latest studies from the regional countries confirm the scab infections every year. In Serbia, Djordevic et al (2013) tested the tolerance and resistance in few apple cultivars to the scab disease. In Albania, the Skenderasi et al (2013) checked in a couple of times the viability of some fungicides to manage the apple scab based on the infection level. Marku et al (2014) in Albania has evaluated the effectiveness of bicarbonates used alone or combined with horticultural oils to fight the apple scab. The primary cultivar used was ‘Starking’ and ‘Golden delicious’ and the scab severity index resulted with close values with this research. Balaz et al., (2017) surveyed the responses of few apple cultivars to apple scab and other diseases under natural infection in Serbia. Rexhepi et al. (2018) in Kosovo has assessed the scab infection level only on apple leaves. No other similar researches of the apple scab control could be found lately for Macedonia and Montenegro. The comparison of findings from similar studies for A. scab severity from other west, central or northern European countries with this research were not performed, since the weather conditions in those sub-climatic zones are slightly different with the research zone in the south-east Europe.

The apple scab fungus behavior and disease severity varies a lot based on the climatic conditions between the climatic zones. In this research, the results showed that based on the comparison of three annual disease index averages presented on table 5, for DSS RIMpro action threshold, the year 2017 had the lowest annual disease index average comparing to the other two research years. This is also the same in other treatment interval, the year 2017 had the lowest annual disease index average. This
could be due to the strict regime of fungicide treatment that was performed on trial apple trees and overall in the orchard, continuously for three years. Based on the comparison of disease index averages, from all fungicide treatment variants, realized in both action thresholds and in three treatment years, as presented on table 5, it resulted that: 1st treatment program had the lowest disease index average than any other treatment variant. It seems that this outcome is due to the effects from the fungicide combination of Champion 50WG and Syllit 400SC, which has provided the best fruit protection from the scab infections. The One-Way Analysis of Variance (ANOVA) shows that RIMpro action threshold has the greatest statistical difference comparing to other action threshold. Based on mean comparison in both diamond plots, presented in Figures 3 and 4, it is evidently seen that the first treatment variant which is realized based on the predictions that were provided by DSS RIMpro, had the lowest mean in both treatment intervals.

Based on MANOVA analysis presented on table 8, the effect of interactions between all treatment factors is statistically non-significant. Practically, the small difference of climatic conditions in three treatment years, has not affected the other effects that were derived from treatment variants realized in two action thresholds, and therefore did not change anything significantly regarding the protection of apple fruits from scab infections.

4. Conclusion

Based on the disease index assessed on apple fruits for three years, the second action threshold, a treatment interval predicted by DSS RIMpro and realized through all treatment variants, proved to be the best action threshold. This protection became possible because of the predictions that were received from DSS RIMpro based on weather data collected and provided by weather station from orchard, processed by FieldClimate® platform and sent to RIMpro cloud service for further processing. These predictions from DSS RIMpro were impacted by the information that were provided by the researchers (e.g. green tip date, volumes of used fungicides, etc.). The realization of fungicide spraying on exact time made it possible to create optimal and accurate treatment threshold. Therefore, the DSS RIMpro provided the best treatment interval for all treatment variants execution.

The first treatment interval consisted by six phenological phases of the apple cultivar provided very good action threshold which must be seriously considered to be used by the apple growers in this area. Especially those that do not have the possibility to be connected and to interact with DSS RIMpro or any other decision support system to control the apple scab.

Among the treatment variants, from all treatment intervals, in all three years, it appeared that the first treatment variant, which was composed with fungicides, such as Champion 50WG and Syllit 400SC, had the lowest disease index and provided the best fruit protection from scab infection.

References


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https://doi.org/10.1094/PHYTO.1998.88.9.902


Mobile device applications usability assessment: The example of an agricultural management application

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ABSTRACT
This paper examines the issue of mobile application usability assessment and is primarily intended to evaluate a “proposal” concerning the systematic recording of the technical and economic data of an agricultural holding with the aid of a rural management system (agroFarm). This application is an electronic calendar where farmers and breeders can store all the agricultural activities about crops, farms and agricultural machineries. Simultaneously agroFarm calculates the revenues and expenses of every rural activity.

The use of mobile applications requires solving problems in use so that access to information and services can be done without difficulty. This is achieved by assessing the use with methods that can measure the usability of mobile applications.

The application was evaluated with, the Questionnaire for User Interaction Satisfaction questionnaire. Ten users aged 20 to 45, at least high school graduates, holding different farms and different familiarity with digital applications participated in the evaluation process. In addition, a Heuristic evaluation was performed by experts who were asked to evaluate ten “heuristics criteria” and whether they were observed in the evaluated application.

The results of the evaluation showed that the users consider that most important feature of mobile applications is the ease of use and utility.

Keywords:
Mobile Applications, Usability assessment, Agricultural holding, agroFarm

1. Introduction

The complexity and the large amount of information used or required to solve problems of rural economy coupled with the need for quick decision-making have resulted in the interference of modern and often multifunctional computing units (portable devices computers) and individual devices which take place in different natural environments and can be used in rural economy almost immediately after their introduction.

Agricultural businesses seem to have much to gain from the use of internet technology, given their spatial dispersion and generally their small scale (in terms of employment and turnover), but the available statistics show a lower rate of adoption by small to medium-sized enterprises (Beley et al. 2013).

The adoption of new technologies in agriculture is rarely immediate. Even though much effort is placed into in persuading users to adopt new information and communication technologies (ICT) tools. Adoption ITC is a complex activity and many factors influence these decision-making processes (Pierpaoli et al. 2013).

From various surveys that have taken place at times, it appears that the proportion of the younger Internet-based producers for work purposes is higher than that of the “oldest” producers. Salampasis et al. (2006) report that the penetration of the internet in the Greek rural sector is limited mainly to young ages while it is extremely limited in the middle and older ages, a major obstacle to the use of ICT by Greek farms. In addition, with regard to the reasons why they do not use the Internet, those that come first are the non possession of a computer and the lack of knowledge of its use, as well as the educational

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Pliakoura, A., Beligiannis, G., Kontogeorgos, A.: Mobile Device Applications Usability Assessment: The example of an Agricultural Management Application

55
level, age and marital status which are also key determinants for the use or not of the Internet (Samathrakis et al. 2005). Another factor in the slow adoption of ICT technologies in the agriculture sector is related to the fact that existing market solutions (e.g., farm management information systems, logistics services) have been developed as closed proprietary ones, and their capabilities are directly proportional to their cost (Kaloxyllos et al. 2013).

Indeed, there is no better example of smart farming than the mobile application. It has become a change game for on-the-go growers and retailers, allowing them to perform critical tasks whenever and wherever they need it.

The purpose of the paper is to examine whether a portable agricultural management application can be evaluated in terms of its usability and the system efficiency in agricultural holdings.

In addition, to presenting the results of the evaluation, the presentation of the use of each method and the methodological framework used to make the results as reliable and valid as possible is also attempted.

The contribution of this work is that for the first time an agricultural mobile application appraisal is attempted in terms of ease of use and utility. Of importance is the large volume of agricultural applications coupled with exponential growth, which confirms that it is virtually impossible to evaluate every agricultural application available at online stores.

2. The use of mobile applications in agriculture and rural activities

This part presents the literature on portable applications usability assessment studies especially for the agricultural sector. Internet has been recognized as a tool that can be used to improve the efficiency of the agricultural sector (Gloy & Akridge 2000) and multiple factors influence farmers’ decisions to adopt agricultural technologies (Birthal et al. 2015, Asif et al. 2017). Farmers obtain information about the technologies and farming practices from different sources such as other farmers, government extension services, information through mobile phones and ITC (Aryal et al. 2018). According to Csótó (2015) the use of smartphone is basically determined by the personal characteristics and previous ICT experience of Hungarian farmers and used as an extension of the current information management system.

Arihippainen & Tahti (2003) in order to evaluate the use of a mobile application, factors related to the user and application characteristics as well as the space where it is used must be recorded. The Human-Computer Interaction (Cairns & Cox 2008) is based on the fields of computer science, psychology, cognitive science and organizational and social sciences, to understand how people use and test the interactive technology. Jacob Nielsen (1993) in his book Usability Engineering, devotes a whole chapter to explain the concept of usability. Shneiderman & Pleasant (2009) have extensively argued for the concept of universal usability, which also includes factors related to accessibility of products and systems.

Lockner & Bonnardel (2015) in addition to the traditional approach of usability and efficiency, introduce the concepts of empathy and emotional design for user interfaces. According to Hassenzahl et al. (2011) User Experience (UX) is the emotional effect of human-computer interaction, in other words, how a person feels when using a product or service. Mounane et al. (2016) present an empirical assessment of the framework developed for the use of ISO 9126 software quality standard in mobile telephony environments, in particular as regards the impact of mobile telephony restrictions (limited user interface, frequent disconnection, lower bandwidth, etc.) in accordance with ISO 25062 and ISO 9241. Certain representative applications of the agro-industry on the Internet and certain conclusions have led to the successful adoption of e-commerce in agriculture (Ferentinos 2006). According to Adamides et al. (2013) gender, age and education level of the principle farm owner, the annual income, the farm type (crop or livestock farming), the employment type (full-time or part-time), the participation in a Producers’ Organization and the district, are factors that significantly influence the usage of Internet by farmers.

Pongnumkul et al. (2015) conducted a research to examine smartphone applications that are referred to in bibliography and use built-in smartphone sensors to provide agricultural solutions. Jennex et al. 10.17700/jai.2018.9.3.460 Pliakoura, A., Beligiannis, G., Kontogeorgos, A.: Mobile Device Applications Usability Assessment: The example of an Agricultural Management Application
(2004) study the adoption of the Internet in small companies in developing countries. Studies have explored the use of e-commerce in agricultural enterprises (Liu et al. 2013) and small rural businesses (Beley et al. 2013). Stoyanov et al. (2015) developed a mobile application appraisal scale to evaluate the usability of mobile health applications. According to Stenberg et al. (2009) there has been a rapid increase in the use of the Internet and applications in almost all sectors of economy. From 1995 to 2008, worldwide Internet access increased from 16 million to 1.5 billion including internet access at home for the two-thirds of US adults. While other sectors use internet services to a large extent, the agricultural sector is slightly behind its urban counterpart. Porter (2001) argues that business survival without being connected to the Internet will become almost impossible in the future. Bohmer et al. (2011) evaluated the data collected through Appazaar. The authors concluded that the use of news apps dominated in the morning, games were widespread at night, and that communication applications were used throughout the day. While the application created very rich data, it did not collect demographic information; therefore, the conclusions are generally valid.

Hegarty & Wusteman (2011) to determine the usability of the services provided by EBSCO host Mobile, utilized the methodology that includes pre and post-use test questionnaires and "think out-loud" usability tests. Bidit et al. (2011) found that mobile phone use by Bangladesh farmers is hampered by language barriers, lack of literacy, unknown English terminology, incorrect Bengali language translation and financial constraints. The findings suggest that the current understanding of usability should be intertwined with technology appropriation to develop a better understanding of the use and the consequent incorporation of the technology in everyday life. They present an initial conceptual diagram that combines the concept of usability and appropriation.

Hansen & Hansen (2009) approach the theoretical exploration of the application of mobile learning (m-learning) in fields with practical orientation such as agriculture. In the agricultural sector (agriculture, livestock farming, fishing, etc.) during the last decade the applications of mobile learning (m-learning) increase more and more in rural education internationally (Denmark, Iran, USA, South America etc.).

Ballantyne et al. (2009) examined some trends and opportunities related to the use of ICT in agricultural science and development. Through investments in infrastructure and collaboration between e-sciences and rapid developments in digital devices and the interconnection in rural areas, the ways in which scientists, academics and development workers create, share and apply agricultural knowledge are transformed through the use of Information and Communication Technologies (ICT). Chang & Just (2009) used a multi-stage econometric analysis to assess the impact of internet access by farm households in Taiwan. A study by Sarban et al. (2015) discussed that people who have higher computer skills their use of ICT services in rural area has been in more rates. Kjeldskov & Graham (2003) conducting an extensive review of studies involving mobile applications from real users which were published from 2000 to 2002, conclude that 71% of these studies were performed in laboratory conditions and only 19% in the real environment for which applications were intended.

According to Beck et al. 2003 there is also reference to cases in which studies take place in laboratories designed in such a way as to simulate the characteristics of the area in which the tested application is to be used. Zhang & Adipat (2005) present an innovative framework that incorporates four major perspectives. That is, the presentation of information, the data input methods, the user and the mobile interface. Thomas (2012) recognizes the capabilities of smart phones as a tool for libraries, both public and academic.

3. Research methodology

This study presents a combination of evaluation methods. The methodology includes two basic methods. (a) the analytical method in the laboratory (without user participation) of the Heuristic Evaluation; and (b) the non-laboratory inquiry method (involving users) and the use of a questionnaire.

Initially, agroFarm (available at goggle play) was evaluated using the heuristic evaluation method. In the assessment process involved three experts, who have experience not only in designing software but in the application of the method and generally in the usability assessment of applications. The review
was conducted at the laboratory of the School of Electrical and Computer Engineering of the Aristotle University of Thessaloniki and the experts used a simulation of the application in a desktop environment. The simulation environment was developed to meet the needs of the assessment experiment. Experts were asked to evaluate the 10-heuristics criterion of Nielsen (1993) based on a numerical scale to indicate the degree of acceptance or rejection of the application's usability in the data being considered. Based on commonly accepted and well-established authorities, they examine whether they are implemented, the design rules and principles are respected. A Likert type scale ranging from 1 to 7 is chosen which is the simplest to create and the most widespread.

For the evaluation of the application usability, a questionnaire for User Interaction Satisfaction (QUIS) questionnaire was used.

Ten (10) users (9 men and 1 woman), aged 20 to 45, with different agricultural holdings, having different familiarity with digital applications and were at least high school graduates, participated in the usability evaluation process.

These users have been using agroFarm for six (6) months in their farm. Given this, they were asked to evaluate their usefulness by responding to a user interface questionnaire.

The QUIS questionnaire consists of 26 questions, divided into five parts, and the answers are given on a Likert type scale of one (1) to seven (7) which corresponds to the extent to which they disagree or agree with each of the questionnaire proposals. The graded answers start with one (1 = Absolutely disagree) and end up in seven (7 = Absolutely agree). Do not know / do not answer = NA.

The five parts of the QUIS questionnaire are; 1) General impression of the user, 2) Screen 3) Terminology and communication with the system, 4) Learning of use 5) System capabilities.

4. Results

The experts who participated in the heuristic evaluation were asked to evaluate the application using the 10 heuristics criteria of Nielsen (Nielsen, 1993) based on a numerical scale to indicate the degree of acceptance or rejection of the application usability on the data being considered. For the process, a Likert type scale from 1 to 7 was chosen which is the simples to create and most widespread. The results are shown in Table 1.

Table 1. Heuristic evaluation of the "agroFarm" application

<table>
<thead>
<tr>
<th>Questions</th>
<th>Expert 1</th>
<th>Expert 2</th>
<th>Expert 3</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1] Is the user aware of the changes that occur in the system constantly through his feedback?</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>Positive result: Data storage and deletion information is provided to the user.</td>
</tr>
<tr>
<td>[2] Do simple and understandable language be used and are the conventions of the real world followed?</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>Positive result: the user is given the content in a clear design</td>
</tr>
<tr>
<td>[3] Is the user able to cancel actions and revoke or repeat operations?</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>Positive result: User can navigate and control with device keys.</td>
</tr>
<tr>
<td>[4] There is consistency in the use of terminology, symbol semantics, etc. throughout the range of use?</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>Positive result: consistency in the use of terminology is sufficient and the system follows common contracts with similar systems</td>
</tr>
<tr>
<td>[5] Does the system protect the user from possible errors?</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>Negative result: no restrictions</td>
</tr>
</tbody>
</table>
An attempt is made to minimize the user’s memory load, is it possible to list information from previous screens? Negative result: usage and execution information is not sufficient to navigate the user.

Is it possible to distinguish between experienced and inexperienced users? Negative result: Does not provide navigation shortcuts.

From a design point of view, the system is characterized by elegance and proper flow of information to avoid confusion of the user. Positive result: the same design is provided on all screens, but any additional information is burdened by the user.

Are error messages clear and understandable and suggest a way out of the error? Negative result: there are no error messages.

Is the help provided and user manuals adequate and comprehensive and focused on user work? Positive result: There is user guidance at points defined as necessary.

The ten (10) users- owners of agricultural holdings evaluated the features for five individual dimensions of the application. They evaluated the 1) General impression of the user, 2) Screen content, 3) Terminology and communication with the System, 4) Learning of use, 5) System capabilities.

<table>
<thead>
<tr>
<th>Table 2.</th>
<th>General impression of the user</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Min</td>
<td>Max</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Std. Deviation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The overall reaction of the system was great</td>
<td>10</td>
<td>4.00</td>
<td>5.100</td>
<td>.567</td>
</tr>
<tr>
<td>The general reaction of the system satisfies</td>
<td>10</td>
<td>2.00</td>
<td>4.00</td>
<td>.942</td>
</tr>
<tr>
<td>The overall reaction of the system was pleasant</td>
<td>10</td>
<td>4.00</td>
<td>5.600</td>
<td>.699</td>
</tr>
<tr>
<td>The general reaction of the system was easy</td>
<td>10</td>
<td>2.00</td>
<td>3.900</td>
<td>1.100</td>
</tr>
<tr>
<td>The general reaction of the system was flexible</td>
<td>10</td>
<td>3.00</td>
<td>4.300</td>
<td>.948</td>
</tr>
</tbody>
</table>

By examining the user responses one can conclude that the users of the application were partially satisfied with the general impression of the application. The users felt that the application is quite pleasant and flexible, but less easy and with the general reaction of the system being confusing.

<table>
<thead>
<tr>
<th>Table 3.</th>
<th>Screen content</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Min</td>
<td>Max</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Std. Deviation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screen design has always helped</td>
<td>10</td>
<td>3.00</td>
<td>6.00</td>
<td>5.000</td>
</tr>
<tr>
<td>The amount of information displayed on the screen was sufficient</td>
<td>10</td>
<td>5.00</td>
<td>6.00</td>
<td>.816</td>
</tr>
<tr>
<td>The structure of information on the screen was organized</td>
<td>10</td>
<td>2.00</td>
<td>4.500</td>
<td>1.433</td>
</tr>
<tr>
<td>The sequence of screens was clear</td>
<td>10</td>
<td>3.00</td>
<td>4.600</td>
<td>.966</td>
</tr>
</tbody>
</table>
The user responses showed satisfaction with elements such as ‘screen design’, ‘the amount of on-screen information’, ‘return to the previous screen’, and ‘next screen in the predictable order’, while they showed that they expected more from the ‘building information’ and ‘the sequence of screens’.

**Table 4. Terminology and communication with the System**

<table>
<thead>
<tr>
<th>Message Description</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Messages appear consistently on the screen</td>
<td>10</td>
<td>5.00</td>
<td>6.00</td>
<td>5.600</td>
<td>.516</td>
</tr>
<tr>
<td>Messages that appear on the screen are clear</td>
<td>10</td>
<td>3.00</td>
<td>7.00</td>
<td>5.100</td>
<td>1.286</td>
</tr>
<tr>
<td>Your computer tells you what it's always doing</td>
<td>10</td>
<td>1.00</td>
<td>7.00</td>
<td>3.700</td>
<td>2.110</td>
</tr>
<tr>
<td>Performing a move leads to a predictable result</td>
<td>10</td>
<td>4.00</td>
<td>7.00</td>
<td>5.400</td>
<td>1.074</td>
</tr>
<tr>
<td>Delays were admissible</td>
<td>10</td>
<td>4.00</td>
<td>7.00</td>
<td>5.700</td>
<td>1.159</td>
</tr>
<tr>
<td>The error messages were very helpful</td>
<td>10</td>
<td>3.00</td>
<td>5.00</td>
<td>3.700</td>
<td>.675</td>
</tr>
</tbody>
</table>

Generally, the users liked the way the app communicated and scored high in questions about the messages that appeared on the screen. High scores were also given to questions like ‘if we conduct a move, we are led to a predictable outcome’ and users were pleased with the possible ‘delays’ in the application response.

**Table 5. Learning of use**

<table>
<thead>
<tr>
<th>Learning Description</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning to use the system is easy</td>
<td>10</td>
<td>2.00</td>
<td>7.00</td>
<td>4.200</td>
<td>1.549</td>
</tr>
<tr>
<td>User learning time is a few</td>
<td>10</td>
<td>2.00</td>
<td>7.00</td>
<td>3.900</td>
<td>1.595</td>
</tr>
<tr>
<td>Work is done in a logical sequence always</td>
<td>10</td>
<td>3.00</td>
<td>6.00</td>
<td>4.300</td>
<td>.948</td>
</tr>
<tr>
<td>The steps to complete always follow a logical sequence</td>
<td>10</td>
<td>4.00</td>
<td>600</td>
<td>5.100</td>
<td>.875</td>
</tr>
<tr>
<td>Feedback when the job is completed is clear</td>
<td>10</td>
<td>4.00</td>
<td>7.00</td>
<td>5.400</td>
<td>.966</td>
</tr>
</tbody>
</table>

The users argued that ‘learning how to use the system’ was not easy and the ‘time to learn’ was enough. Positive were their judgments about whether ‘steps to complete the job follow a logical sequence’ and about ‘feedback’ when a job is completed, while they were negative about whether ‘work is done in a logical sequence’.
Finally, the users believe that the ‘speed of the system’ is satisfactory and the application ‘stable’ and that ‘operations-functions’ take place quite reliably. The user responses to whether ‘user-friendliness depends on user experience’ reached almost Maximum with an average of 6.4.

Generally according to the users’ replies and their comments, they consider usability being the most important feature of mobile applications. The users want to get the information they are looking for following simple steps, and in the case of agroFarm, the relatively low rating on the question of organizing information on the screen clearly shows that almost everybody’s attention was focused on this point. In general, the second and third sections, which were concerned with the presentation of the data on the screen and the communication with the System, had the lowest score from all other sections. This indicates that users require of such an application (or generally a mobile app) to give more importance to presentation and usability rather than anything else.

### 5. Conclusions

Electronic applications are an easy, economical and dynamic way of organizing and managing farm and livestock units, whereby producers can monitor the operation of their farms or their businesses and the development of their economics.

Nowadays, a Smartphone or a tablet coupled with a data ‘packet’ is a valuable tool for the new farmer who saves time and money for the development of his farm.

The farm management application named “agroFarm” is an innovative proposal to Greek farmer as well as to the agronomist researcher, a simple system of keeping records and accounts that allows producers to monitor the smooth operation of their holdings or businesses, and indeed online. It can offer a different approach to accurate keeping of farm records and accounts, and to be a helper in the difficult journey of future agriculture.

With regard to the purpose set in the introductory chapter, it has been found that the use of portable computers can contribute to the integration of the two information spaces (physical and digital), creating a new type of experience. It was also found that for this purpose the main factors influencing the acceptance and intent to use the new technology are the users’ predisposition to mobile devices, the perceived performance improvement expectation, the perceived ease of use and utility, the expected personal benefits (e.g. less effort) and the suitability of the specific technology for the purpose for which it is used.

The analysis of the evaluation data revealed the primacy of expert judgment and their ability to identify problems related to system consistency and navigation so that they can be corrected at early stages of application development in general. However, in the future extension of the methodology, the integration of evaluation methods taking place in laboratories that simulate genuine conditions of use could be explored.

The overall conclusion that results from the use, study, and appraisal of the application at this stage is the creator's apparent effort for an application that is user friendly through simple, comprehensive language, symbolism, images and certain choices. In addition, the user is adequately updated to perform
his / her actions (storage, creation / deletion). As far as errors are concerned, they are possible to be corrected by the user himself. Yet, the correction is absent from the system itself, which is usually the main form of correction.

A desirable outcome of the usability evaluation is to identify the low usability and draw conclusions that will produce solutions for redesigning the application.

Nevertheless, further study is necessary to provide a wider understanding of the evaluation usability of mobile rural management applications.

The available applications are a raw good material for creating and developing more user-friendly, responsive and customized to the existing needs and requirements.

The results of this assessment case confirm that the application of different methods can give different type of conclusions of complementary character. Therefore all the methods used seem to be equally useful.

Finally, the assessment of rural management applications seems at present to be a difficult task. Initially, too many available apps in e-shops make it impossible to evaluate them, in combination with the rapid growth rate of new applications and the fact that evaluating a single application - according to the existing rating models - requires at least a few weeks to a few months to be carried out adequately, an important time constraint is introduced which contributes to the failure to evaluate all the Agricultural Management Applications available at webs hops.

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A fuzzy-based decision support system for soil selection in olericulture

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ABSTRACT
With the advent of modern computer technology, the field of Artificial Intelligence is playing a significant role in improving almost every spectrum of human life. In the field of agriculture, there is always need for optimality with improved crop yield. This paper dwells majorly on the application of fuzzy logic to predict crop type with optimal crop yield based on available soil nutrients. Some soil data samples were collected from the department of soil science, Federal University of Agriculture, Abeokuta and used as input into the system. The proposed system was simulated using MatLab Fuzzy inference System with a triangular member function. The range of nutrients was later deployed as input into a visual basic developed application to predict the best crop to be planted. A dual method (static and dynamic) was used in testing and validating the result of research which showed a significant improvement on the crop type selection than the conventional prediction mode.

1. Introduction
In recent time, research in computer science has been geared towards soft computing which deals with approximate models and gives solutions to complex real-life problems. Soft computing includes fuzzy logic, neural networks, probabilistic reasoning, and genetic algorithms (Efraim et al., 2008).

Today, techniques or a combination of techniques from these areas are used in artificial intelligence to design intelligent systems (Corne et al, 1999). However, these intelligent systems are capable of exhibiting the characteristics associated with intelligence in human behavior-understanding, language learning, reasoning, solving problems and so on (Kalogirou,2003).

The current trend is to computerize farming operations by using specially designed software and assigning various tasks to a computer (Diasio and AgeIl,2009), which include choosing the best soil for planting, determining soil moisture content, diagnosing animal health etc.

Nowadays, farmers are not only better educated but also informed of the current trends of computer applications that can help to improve operations in order to meet their ever increasing demands which are more preferable to the conventional or traditional methods used in early years (Regan, 2005). The soil is a fundamental natural resource on which civilization depends (Hudleston, 1984). Agricultural production is directly related to the quality of soil, and as soil nutrients diminish so does crop yield (Larson and Pierce, 1994). Maintaining soil quality is essential, not only for agricultural sustainability, but also for environmental protection. Mechanisms to measure changes in soil quality (nutrients) are important if soil scientists and farmers are to develop better methods (which will provide understanding) to manage the soil system and improve crop yield.

Many methods have been deployed by researchers for monitoring soil quality for improved crop yield. A major method for monitoring is the utilization of soil quality indicators. Bremer et al., (2004)

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Adebukola Onashoga, Olusegun Ojesanmi, Femi Johnson, Femi Emmanuel Ayo: A fuzzy-based decision support system for soil selection in olericulture
also provided examples of the development and use of soil quality indices. These and many more ongoing types of research are evidence that soil nutrients are a major determinant for a successful and blossom crop yield. The main objective of this paper is to develop a decision making tool built with a fuzzy logic model to enhance soil selection in the planting of vegetables.

2. Meaning of Olericulture

Olericulture is the science of vegetable crops or the cultivation of vegetable crops e.g. pumpkin, water leaf, tomato, potato, radish, carrot, chilli, bottle gourd. All societies and ethnic groups eat vegetables because they are essential for maintaining human health.

The importance of vegetables is quite numerous that the demand will increase as the population continues to grow. Most vegetables are good sources of proteins, vitamins and minerals required for the proper functioning and development of the human body. Nutrients resident in vegetables vary considerably but with sufficient proportions of their required minerals, pro-vitamins, vitamins (A, B6 and K) and carbohydrates respectively. The availability of nutrients can also be influenced by a list of factors such as topography, soil structure, climate etc.

2.1. Soil composition and nutrients

The soil is a mixture of organic matters, minerals, gases, liquids, and organisms that together support life. It is the source of moisture, plant nutrients, support, and some air needed for plant growth. The composition of soil is an important aspect of nutrient management. While soil minerals and organic matter hold and store nutrients, soil water readily provides nutrients for plant uptake. Soil air plays an integral role since many of the micro-organisms that live in the soil need air to undergo the biological processes that release additional nutrients into the soil.

The basic components of soil are minerals, organic matter, water and air. A typical soil consists of approximately 45% mineral, 5% organic matter, 20-30% water and 20-30% air. (See Figure 1)

In reality, the soil is very complex and dynamic. Soil’s composition can fluctuate on a daily basis, depending on numerous factors such as water supply, cultivation practices and soil type.

![Figure 1](https://example.com/figure1.png)

**Figure 1.** The composition of the soil sample

Plants, like all other living things, need food for their growth and development (Badifu and Gabriel, 1993). Plants require some essential nutrients for proper growth. These nutrients are basically grouped into two categories namely:

- **Macro plant nutrients:** These nutrients are required by plants in large quantities. Examples are nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, carbon, hydrogen and oxygen.

- **Micro plant nutrients:** These are also known as trace nutrients. They are needed by plants in minute quantities. Examples are iron, zinc, manganese, copper, boron, molybdenum, and chlorine. These nutrients are supplied either from soil minerals, organic matter or by fertilizer application.
2.2. Fuzzy Logic in Decision Support Systems

Decision Support Systems, which employ the concept of fuzzy logic for making a decision, are generally termed as fuzzy logic based systems. Fuzzy logic is an approach to computing based on "degrees of truth" rather than the usual "true or false" (1 or 0) boolean logic on which the modern computer is based (Satzger, 2012).

The Fuzzy logic tool introduced in 1965 by Lotfi Zadeh, is a mathematical tool for dealing with uncertainties. Zadeh proposed a set membership idea to make suitable decisions when uncertainty occurs unlike the classical set with crisp values.

\[
\begin{align*}
\text{Classical set} & \quad A(x) = \begin{cases} 1 & \text{if } x \in A \\ 0 & \text{if } x \notin A \end{cases} \\
\text{Fuzzy set} & \quad a(x) = \text{Degree } (x \in A), \\
& \quad A = \{(x,a(x))\}, x \in X
\end{align*}
\]

It can be generally seen in classical sets that there is no uncertainty, hence they have crisp boundaries, but in the case of a fuzzy set, since uncertainty occurs, the boundaries may be ambiguously specified.

Fuzzy Logic provides a simple way to arrive at a definite conclusion based upon input information that is the experience of experts. Fuzzy logic helps to arrive at a distinct conclusion, depending upon the input sensor information that is the experience knowledge of experts (Sprague, 1993).

The most common operators applied to fuzzy sets are ‘AND’ (minimum), ‘OR’ (maximum) and negation (complementation), where ‘AND’ and ‘OR’ have binary arguments, while negation has a unary argument (Konar et al., 1998). Fuzzy logic is used mainly in control engineering. It is based on fuzzy logic reasoning which employs linguistic rules in the form of “IF-THEN” statement (Whinston, 1996).

2.2.1. Fuzzy-based Decision Support System’s Design procedures

A well-designed decision support system aids decision makers in compiling a variety of data from many sources: raw data, documents, personal knowledge from employees, management, executives and business model (Liang, 2008). The following are the main phases of fuzzy system design:

i. Identifying the problem and choosing the type of fuzzy system which best suits the problem requirements. A fuzzy based decision system can be designed consisting of several fuzzy modules linked together.

ii. Defining the input and output variables, their fuzzy values, and their membership functions.

iii. Articulating the set of fuzzy heuristic rules.

iv. Choosing the fuzzy inference method, fuzzification and defuzzification methods if necessary; some experiments may be necessary until a proper inference method is chosen.

v. Experimenting with the fuzzy system prototype; drawing the goal function between input and fuzzy output variables; changing membership functions and fuzzy rules if necessary; tuning the fuzzy system validation of the results (Luis and Andreas, 2007).

2.2.2. Review of Related Work

Wei et al., (2017) developed an Urban Plants Decision Support System (UP-DSS) for assisting plant selection in urban areas with diversified solar radiation. The objective was to maintain the diversity of plant species and to ensure their ecological adaptability (solar radiation) in the context of sustainable development. UP-DSS consists of the solar radiation model and calibration, the urban plant database, and information retrieval model. It was UP-DSS implemented on a platform of Geographic Information Systems (GIS) and Microsoft Excel, The results showed that UP-DSS could provide a very scientific and stable tool for the adaptive planning of shade-tolerant plants and photoperiod-sensitive plants, and also provided user decision-making according to different sunshine radiation conditions and the designer’s preferences.
In a bid to manage agricultural production, (Azaza et al., 2016) developed a Smart Greenhouse Control System (SGCS) based on fuzzy logic. This fuzzy logic controlled system integrates all the greenhouse key climate parameters through specific measures to the temperature and humidity correlation. To further enhance the system, a wireless data monitoring platform which allows data routing and logging was incorporated to provide real time data access. Research findings revealed a significant improvement in the application of the SGCS towards managing energy and water saving level for optimal agricultural production.

The process of site selection for the installation of a Managed Aquifer Recharge (MAR) facility is of paramount importance for the feasibility and effectiveness of the project itself, especially when the facility includes the use of waters of impaired quality as a recharge source, as in the case of Soil-Aquifer-Treatment systems. Tsangaratos et al, (2017) developed a multi-criteria Decision Support System (DSS) framework that integrates within a dynamic platform the main groundwater engineering parameters associated with MAR applications together with the general geographical features which determine the effectiveness of such a project. As reported, the proposed system is meant to provide an advanced coupled DSS-GIS tool capable of handling local MAR-related issues such as hydrogeology, topography, soil, climate etc., and spatially distributed variables -such as societal, economic, administrative, legislative etc., with special reference to Soil-Aquifer-Treatment technologies.

Vishwajith et al., (2014) designed a Decision Support System (DSS) for fertilizer application recommendation in different crops. The DSS application was developed using Visual Basic 6.0 as a platform taking help of the information from Soil Test and Crop Response (STCR) research. The study revealed that the developed DSS is useful in augmenting economic agricultural production maintaining soil and environmental health, avoiding unnecessary wastage of resources, even in the absence of experts by the farmers themselves.

3. Data sources and methodology

3.1. Scope of the collected data set.

It has been discovered from the literature that soil selection and crop prediction is full of uncertainties hence the reason for the use of fuzzy logic to provide a solution for dealing with uncertainties. The proposed fuzzy-based decision support system for soil selection and predicting crop type is based on the ranges of soil nutrients. Inputs of dataset collected from research conducted on the FUNAAB farm with fuzzy inference system whose membership functions parameters were tuned to provide an appropriate prediction of crop type.

3.2. Fuzzy Logic Paradigm

3.2.1. Fuzzy set

A fuzzy set is any set, which provides different grades of the membership function for its elements usually in the interval of (0-1). A fuzzy set is an extension of a crisp set. Crisp sets allow only full membership or no membership at all, whereas fuzzy sets allow partial membership. The list of soil nutrients formed the fuzzy set

\[ A = \{ \text{Nitrogen, Phosphorus, Potassium, Calcium,} \ldots \} \]  

3.2.2. Membership Function

A membership function is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The membership function maps each element of X to a membership value between 0 and 1 represented by the equation:

\[ \mu(x) = \{\text{High, Moderate, Low}\} \]
3.2.3. Fuzzification

This is the process of turning a crisp input into a linguistic variable using the membership function provided by the fuzzy knowledge base. The triangular membership function is also used in this work since the linguistic variables are modeled into three sets: (High, Moderate and Low).

3.2.4. Defuzzification

Defuzzification involves turning fuzzy values to crisp values for better understanding. The defuzzification method applied in this research is the centroid model. This method determines the centre of gravity (centroid) and uses that value as the output of the fuzzy logic system. It is represented as shown below:

$$\text{CoG}(Y^*) = \frac{\sum \mu_y(x_i)x_i}{\sum \mu_y(x_i)}$$  \hspace{1cm} (3)

3.3. Input linguistic variables and values

The fuzzy based inference decision system needs to get input supplied by the user. The compositional ranges of these nutrients are great determinants for the prediction of selected crop. These nutrients range have been grouped into three linguistic variables as shown in Table 1.

<table>
<thead>
<tr>
<th>S/N</th>
<th>NUTRIENTS</th>
<th>LOW</th>
<th>MODERATE</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Nitrogen</td>
<td>1.0 - 2.0</td>
<td>2.01 - 4.00</td>
<td>4.01 - 6.0</td>
</tr>
<tr>
<td>2.</td>
<td>Phosphorus</td>
<td>0.2 - 0.4</td>
<td>0.41 - 0.60</td>
<td>0.61 - 0.80</td>
</tr>
<tr>
<td>3.</td>
<td>Potassium</td>
<td>0.1 – 2.5</td>
<td>2.51 - 4.50</td>
<td>4.51 - 8.50</td>
</tr>
<tr>
<td>4.</td>
<td>Calcium</td>
<td>0.1-0.20</td>
<td>0.21 - 0.30</td>
<td>0.31 - 0.40</td>
</tr>
<tr>
<td>5.</td>
<td>Magnesium</td>
<td>0.1-0.3</td>
<td>0.31 - 0.50</td>
<td>0.51 - 0.90</td>
</tr>
<tr>
<td>6.</td>
<td>Sulphur</td>
<td>0.0 – 0.4</td>
<td>0.41 -0.80</td>
<td>0.81 – 1.5</td>
</tr>
<tr>
<td>7.</td>
<td>Iron</td>
<td>30-100</td>
<td>100 – 200</td>
<td>200- 350</td>
</tr>
<tr>
<td>8.</td>
<td>Boron</td>
<td>0 – 40</td>
<td>40 – 70</td>
<td>70 – 100</td>
</tr>
<tr>
<td>9.</td>
<td>Copper</td>
<td>0 - 20</td>
<td>20 – 45</td>
<td>45 – 70</td>
</tr>
<tr>
<td>10.</td>
<td>Manganese</td>
<td>0 – 80</td>
<td>80 – 150</td>
<td>150 – 300</td>
</tr>
<tr>
<td>11.</td>
<td>Zinc</td>
<td>0 – 80</td>
<td>85- 165</td>
<td>165 – 250</td>
</tr>
<tr>
<td>12.</td>
<td>Molybdenum</td>
<td>0 – 0.4</td>
<td>0.4 – 0.8</td>
<td>0.8 -1.5</td>
</tr>
</tbody>
</table>

3.4. Fuzzy rule Knowledge Base

The knowledge base is a component where knowledge is developed, stored, organized, processed and disseminated. It consists of a database and a rule base. The database provides the necessary elements for defining the linguistic variables and rules using IF - THEN control constructs. The database includes a set of facts used to match against the IF (condition) parts of rules stored in the knowledge base. The rule knowledgebase for this paper follows the Mamdani rule formation. Table 2 shows some of the rules derived from the adoption of Mamdani rule.

<table>
<thead>
<tr>
<th>S/N</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>S</th>
<th>Mg</th>
<th>Fe</th>
<th>B</th>
<th>C</th>
<th>Mn</th>
<th>Zn</th>
<th>Mo</th>
<th>Crop type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>Pumpkin leaf</td>
</tr>
<tr>
<td>2</td>
<td>H</td>
<td>H</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>M</td>
<td>Pumpkin</td>
</tr>
<tr>
<td>3</td>
<td>H</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>M</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>Water leaf</td>
</tr>
</tbody>
</table>
4. Implementation and Discussion

The Fuzzy-based decision support system was built on MATLAB because it integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notations.

MATLAB is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick and dirty throw-away programs, and "programming in the large" to create complete large and complex application programs.

In this paper, the various soil nutrient ranges as shown in Table 1 above were converted to their equivalent fuzzy sets to which individual membership function was assigned as depicted in figure 2 and figure 3 respectively below.

<table>
<thead>
<tr>
<th>Soil Nutrient</th>
<th>Equivalent Fuzzy Set</th>
</tr>
</thead>
</table>
| Nitrogen (N)  | \[1, (N) \geq 0.67 \]
|               | \[0.25 \leq (N) \leq 0.67 \] |
|               | \[0, (N) < 0.25 \] |
| Iron (Fe)     | \[1, (Fe) \geq 0.71 \]
|               | \[0.4 \leq (Fe) \leq 0.71 \]
|               | \[0, (Fe) < 0.4 \] |
| Phosphorus (P)| \[1, (P) \geq 0.60 \]
|               | \[0.4 \leq (P) \leq 0.60 \] |
|               | \[0, (P) < 0.40 \] |
| Boron (B)     | \[1, (B) \geq 0.7 \]
|               | \[0.4 \leq (B) \leq 0.7 \] |
|               | \[0, (B) < 0.4 \] |
Adebukola Onashoga, Olusegun Ojesanmi, Femi Johnson, Femi Emmanuel Ayo: A fuzzy-based decision support system for soil selection in olericulture

Figure 2. Fuzzy set representation of Input variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fuzzy Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N)</td>
<td></td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td></td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td></td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td></td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td></td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td></td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td></td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td></td>
</tr>
<tr>
<td>Potassium (K)</td>
<td></td>
</tr>
</tbody>
</table>
Adebukola Onashoga, Olusegun Ojesanmi, Femi Johnson, Femi Emmanuel Ayo: A fuzzy-based decision support system for soil selection in olericulture
Adebukola Onashoga, Olusegun Ojesanmi, Femi Johnson, Femi Emmanuel Ayo: A fuzzy-based decision support system for soil selection in olericulture

Figure 3. Input variable membership function plots

4.1. Fuzzy Logic Rule Editor and Viewer

Figure 4a and 4b depict a fuzzy rule editor and viewer. A fuzzy rule editor is an interface in fuzzy logic for creating, editing and modifying rules, which are used by the fuzzy inference system for result prediction. The inference system generates the output using the membership levels assigned to each variable and the provided rules. These rules comprising of “IF-THEN” statements provide the knowledge required by the system to function appropriately.
Adebukola Onashoga, Olusegun Ojesanmi, Femi Johnson, Femi Emmanuel Ayo: A fuzzy-based decision support system for soil selection in olericulture

In addition, the output of a fuzzy system is a fuzzy set with an assigned membership function. This output may not be easily understood until it has been interpreted. In a bid to avoid difficulty in the interpretation of result and complexity in the determination of the vegetables to be planted a system was developed.

The system was sectioned into modules which creates room for easy documentation, upgrade and debugging when the need arises.
4.2. Discussion

The performance of the developed system was evaluated repeatedly to determine its correctness and accuracy. Soil samples data ranges used by the system were those shown in figure 2. The ranges and membership functions are also depicted in Figure 3 depicted.

Figure 5 shows a screenshot of the “user login interface” for the system. The user will log into the system by providing login details which include a username and password. In the case of the user entering a wrong username or password, the system will authenticate the details supplied by the user and if otherwise, requests the user to register on the system.

![Figure 5. User login interface for the developed system](image)

For the authenticated user, a soil nutrients data interface, where the user selects linguistic variables of soil nutrient ranges is displayed as shown in Figure 6.

![Figure 6. Decision support system with linguistic variables interface](image)

The user selects fuzzy linguistic options as responses from the interface provided by the system. These selected options are fuzzified by the system to predict the best vegetable suited for propagation on the chosen soil sample as output displayed in Figure 7.
Adebukola Onashoga, Olusegun Ojesanmi, Femi Johnson, Femi Emmanuel Ayo: A fuzzy-based decision support system for soil selection in olericulture

Conclusion

As useful and important the computer is in this present age, its application in the area of agriculture must not be underestimated such as prediction of the best crop to be planted on farm land with specific soil samples that will result in optimum crop yield leading to the improved economic and financial status of farmers. Farmers should also be aware of the various ways soil nutrients can be lost and thus seek ways and methods to reduce nutrient lost. The inference derived from the result of tested soil samples also attest to the fact that the fuzzy based decision support developed is capable of accurately performing its intended function.

This paper reduces the challenges faced by farmers in the selection of soil by proposing a scientific method for selecting the best suitable soil for planting selected vegetables through an interactive fuzzy based decision support system and thus improves the economic status of farmers.

Furthermore, the system can be implemented as many times as possible thus overcoming the stressful challenge faced by human experts with other forms of shortcoming associated with traditional systems.

References


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Adebukola Onashoga, Olusegun Ojesanmi, Femi Johnson, Femi Emmanuel Ayo: A fuzzy-based decision support system for soil selection in olericulture