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PROSPECT OF A GIS BASED DIGITIZATION AND 3D MODEL FOR A BETTER MANAGEMENT AND LAND USE IN A SPECIFIC MICRO-AREAL FOR CROP TREES

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Abstract

There is a great need for an efficient geographic information system (GIS) implementation in interdisciplinary domains for providing useful information for scientific and managerial processes of further improving land-use planning and decision making in horticulture. The main goal of this study was the creation of a digital map and GIS application for the Fruit Research Station in Cluj-Napoca, North-Western Romania. The benefit of this implementation is a fully integrated land information system, where information is accessed omnipresent for processing, value adding and further analysis. The created model is as a modern solution for obsolete analogue maps, sketches, inventory and land records that are usually unreliable and poorly represented in agricultural productive units. Using the created GIS database and spatial analysis there were obtained a very useful orchard mappings that incorporate management and economical attributes essential in land planning. Future focus and development will be mainly on system maintenance, including system enhancement and upgrading rather than to create a new systems. Under the constant pressures of urban sprawl and land degradation in this area, the paper conducts towards a guideline and model for an effective use of land resources to the best advantage and capacity.

Key words: GIS database, land planning, management, orchard mapping, spatial analysis

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1. Introduction

Land is one of the most important resource without which humankind cannot survive (Brevik et al., 2015; Keesstra et al., 2016). Recently, the population growth and urbanization, effects of climate change, erosion, pollution etc. are increasingly affecting this resource (Berland et al., 2017; Carlson and Dierwechter, 2007; Martínez-Hernández et al., 2017; Nikolic et al., 2019; Rodrigo Comino et al., 2016). Land plays an essential component for the creation of economic growth in developing countries

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and countries with economies in transition such as Romania. The city of Cluj-Napoca is a prime example because the access to unoccupied terrain for agricultural production is becoming progressively difficult due to the expansion for industrial and terrestrial purposes.

In addition to economic growth, land with a correct administration and management of their resources can lead to optimum food security, energy supply, nature conservation and other objectives (Bilaşco et al., 2016; Harvey et al., 2014; Jaafari et al., 2017; Scherr et al., 2012). It is required to find more efficient and effective ways of managing this valuable resource and such a digital cartography implementation. Land use planning can help find a balance among these necessities and requirements (Burgi et al., 2001; Campos et al., 2012; Cerdà et al., 2017; Klauco et al., 2017).

Land management is the process in which the resources of land are allocated into efficient use and to the best advantage (Sestras et al., 2018). The most important components for the management of land and natural resources include land-use planning, land administration and land information infrastructure (Wu et al., 2011). Nowadays, Romania, because of unreliable land records, poor inventory and outdated topographical maps, geo-spatial information technologies turn out to be growingly significant in the land-use planning process, land management and administration (Bilaşco et al., 2016). Geographic Information Systems (GIS) and satellite data revolutionised the perception of landscape, which further improve land and resource managements (Cousins and Ihse, 1998; Čurović et al., 2019; Li and Zhao, 2006).

The present study aimed to complete the spatial analysis and attribute GIS database of a fruit crop unit, in order to: i) increase the efficiency of land use and management; ii) the technical material base for the buildings and related facilities; iii) the location of land areas intended for orchards based on the cultivated species. For this purpose, through the creation of the 3D model in which there are evidenced different areas occupied by temperate tree species (e.g. apple, pear, plum, cherry, sour cherry), each represented by certain cultivars (varieties), was taken into account the possibility of creating a spatial and attribute database needed for an efficient placement of species and varieties in certain areas of land (Umali et al., 2012), according to their suitability, including through the slope, exposure, microclimate conditions, etc.

In the past, in the Fruit Research Station in Cluj-Napoca (North-Western Romania) and in similar institutions, information, inventory and land records were processed in the form of analogue maps, sketches or account books. These methods are usually inadequate, poorly represented, unreliable and difficult to oversee and work with or modify for future land use management or land planning. Therefore, it is essential to establish an accurate database for land information. This will help further development, management and planning of the economic agents (Boschmanna and Cubbona, 2014; Garcia-Aguirre et al., 2007; Hupy et al., 2005).

Thanks to the technological progress of satellite remote sensing, GPS data and GIS, it is possible to create a innovative land information management system that will integrate land cover information, collected scientific data and technical surveys. Geospatial data has the advantage to increase the accuracy of data gathering and analysis and offer reliable management facilitation for land use, resources and environment (Graham et al., 2011, Roşca et al., 2015). In addition, once the geo-database is created, the personnel, scientists and researchers can conveniently and efficiently use the information, initiate analysis and further modify the base model for future land-use planning and changes (Carstensen and Campbell, 1991).

The main goal of this study was to observe this possible implementation after its creation using a GIS application for land-use planning, landscape and horticulture for providing useful data for scientific and informational use, and an easier land management and administration. The objective was to create a fully integrated land information system where information can be accessed omnipresent for processing, value adding, analysis and decision making.

2. Materials and methods

2.1. Study area location and socio-economic conditions

The case study refers to Fruit Research Station Cluj (FRS Cluj), a fruits crop unit situated in the city of Cluj-Napoca, in the North-Western part of Romania (Fig. 1), 46º46’ N, 23º36’ E, between Apuseni Mountains, the Someşan Plateau and Transylvania Plain. Cluj-Napoca is located in the historical province of Transylvania, has an area of over 179.5 km², altitudes ranging from 330 to 430 m a.s.l. and is surrounded on three sides by hills ranging between 500 and 825 m a.s.l. The position at the confluence of three important water streams and the presence of hills in the northern and southern part of the city confer Cluj-Napoca a great morphological and landscape diversity. With a population of over 420,000 inhabitants (including the metropolitan area), the unprecedented expansion of the city, population and a general move towards urbanization, land is becoming an increasingly difficult resource to manage and preserve. From its foundation in the communist regime (1953), FRS Cluj was intended to provide fresh fruits for the Cluj-Napoca market (Fig. 2). After Romanian Revolution in 1989 and the restitution of land to former owners, the surface was reduced from over 1200 hectares to 168.5 hectares. It was as certain that the local market is abundant in fruits, but overall fruits imported from different countries prevail over the fruits produced in Romania (Dan et al., 2015). The local production is mostly sold in the local markets (approx. 35%) than retailed in specialised shops or fruit displays in hypermarkets.

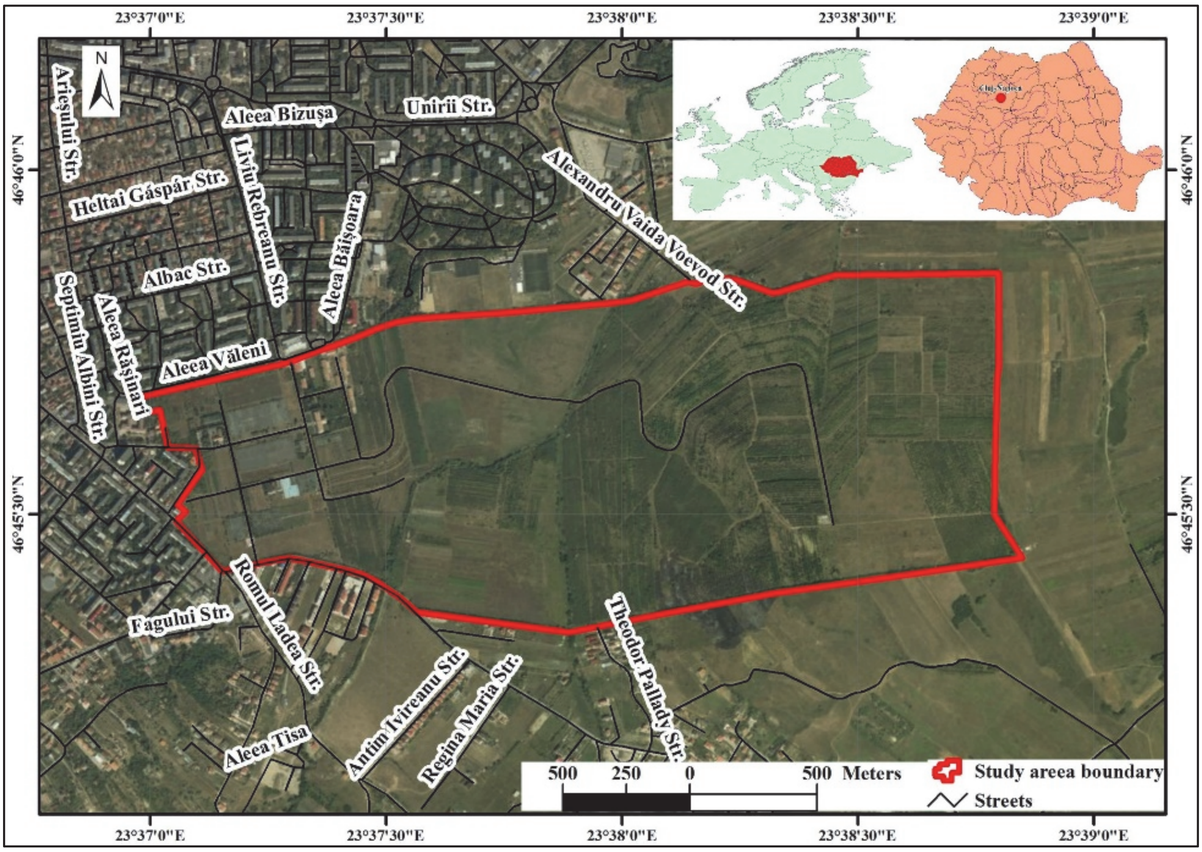


Fig. 1. Cluj-Napoca, Romania localization; FRS Cluj position in the city

Fig. 2. FRS Cluj localization; aerial view; picture of the main building

Inside the large hypermarket chains, over 90% of the apples come from European Union (EU), not from Romanian orchards (Popescu, 2012; Pirvutoiu and Popescu, 2014).

2.2. Database and methods

The spatial modelling of the cultivated parcels within FRS Cluj required the use of spatial analysis which rely on specialised software and the manipulation of thematic layers by means of mathematical equations transformed into GIS equations and functions of spatial analysis used to generate new attributes stored in various databases, as was described by Petrea et al. (2014). Along with spatial analysis, the present paper integrates digital cartography and 3D modelling to further complete the GIS implementation of the studied area.

Local map development began with land-based peculiarities, such as land-use intensification or diversification in the search for topographic features of land, slope, exposure and cultivated species. The science-based approach used was built around compiling topographic data, respectively combining them with species and cultivars (varieties), trees growth requirement information and characteristics in a GIS (orchard mapping) environment.

Digitization in ArcGIS software (version 10.1) was the process of converting information into a digital format, where the drawn objects (plans or maps) are transmuted in a series of Cartesian coordinates (x, y) and stored. For GIS it is essential that the graphic information is vector data. The basic vector data representations are the point, line (polyline) and polygon. To define these elements, it is necessary a number of coordinates and a number of specific geometric features (Bonham-Carter, 2014; Di Lisio and Russo, 2010).

The present case study vectorization (digitization) process of maps and plans improved over time with the development of computer technology and software. The development of computing, storage capacity and image applications encouraged the evolution of on-screen digitization. Raster (digital image) became the basic component of GIS (along with vectors and their associated databases). Today it is very common to obtain vector information by digitizing directly on the orthophoto (Krygier and Wood, 2011). Data used in the study was obtained from the offices and specialized departments (technical-administrative department, fruit growing and improvement laboratories) of the FRS Cluj, a renowned research facility in Romania in the field of horticulture.

3. Results and discussion

3.1. Digital cartography and 3D model of FRS Cluj

Based on presented methods, there were created maps in GIS, so that they can be easily read and comprehended by the personnel, researchers and engineers (Fig. 3). This was obtained by using explicit and simple legend and the overlay of layers.

The DEM (Digital Elevation Model) used as raster composed of a matrix of cells, assured 3D visualisation with each cell possessing quantitative values for the elevation (Fig. 4). The area of interest of the orthophoto and DEM was used by giving the orthophotography layer the function “Floating on a custom surface” from the “Base Heights” layer properties (Fig. 5a). A suitability map can further be established which delineate land where there is high or low potential for growing certain crops and fruit tree species (Tait, 2010). Such maps can be used to focus more detailed site-specific investigations.

With the reconstruction of the buildings in architectural software (Fig. 5b) and the model replacement, the 3D design of FSR Cluj was practically improved. The “Extrusion” function was used to add height to the buildings and from the 3D Editor was selected “Replace with model” function for each previously build and exported 3D model (Fig. 6).

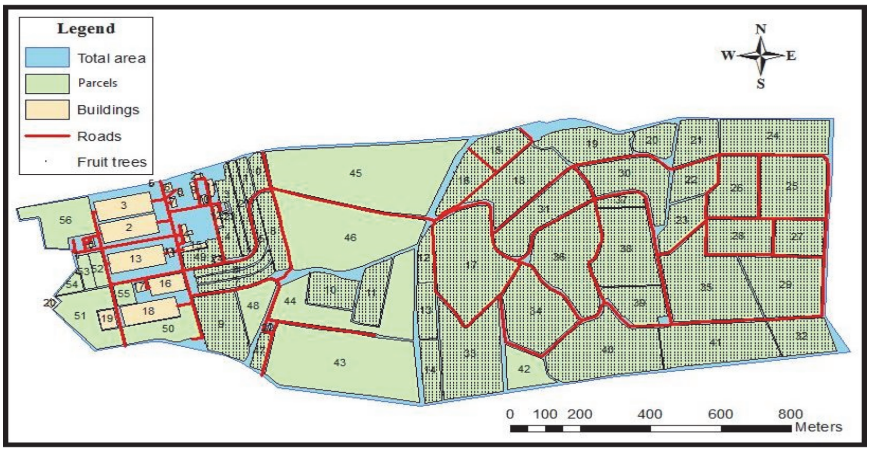


Fig. 3. Digital map of FRS Cluj

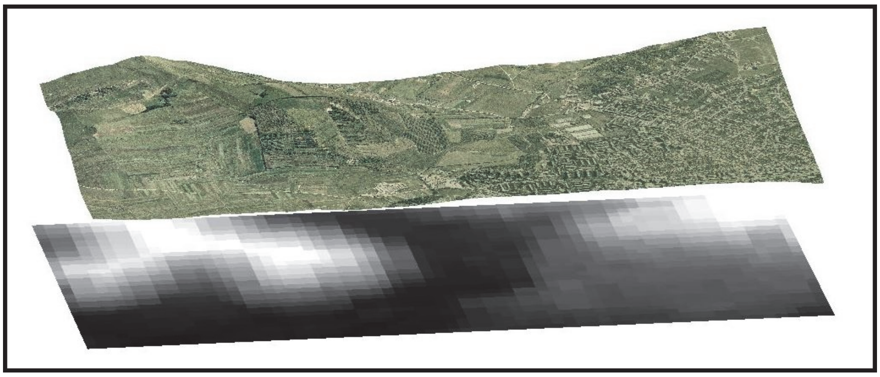
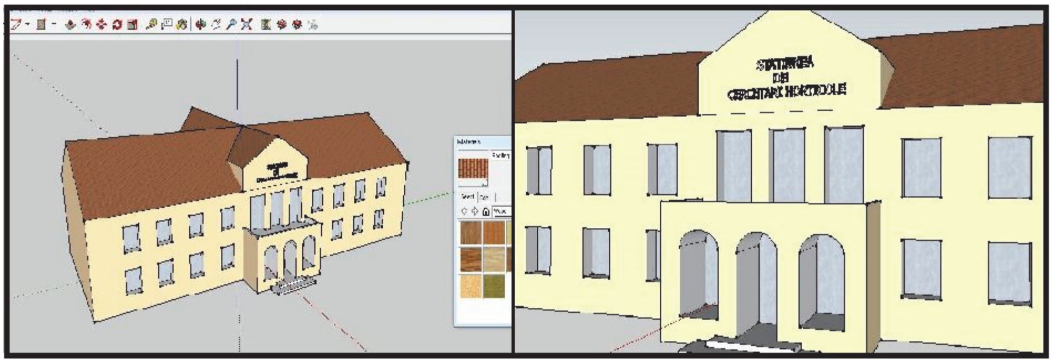
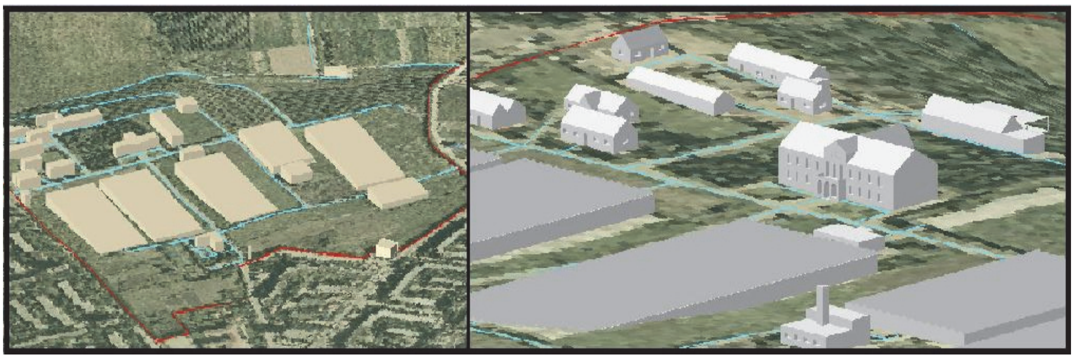


Fig. 4. Elevation for the area of interest



(a)



(b)

Fig. 5. (a) Main building of FRS Cluj reconstructed in a 3D model; (**b)** Replacement of the constructed 3D models of buildings and greenhouses

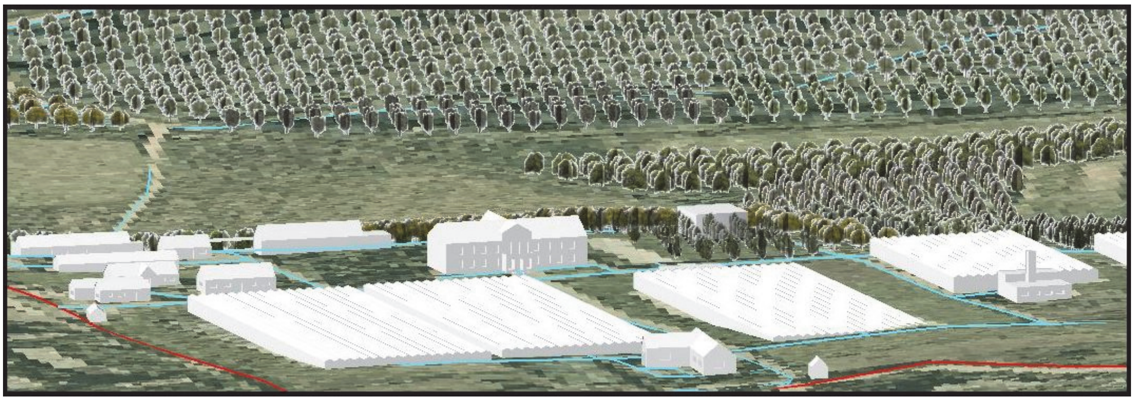


Fig. 6. 3D model of FRS Cluj

The constructed 3D model of the FRS Cluj offers a better administration, management and land-use for each parcel, buildings, greenhouses and other facilities (Fig. 7). Each parcel is evidenced differently according to the tree species (eg. apple, pear, plum, cherry, sour cherry etc.) each represented by certain cultivars (varieties).

The created database offers the possibility to effectively place species and varieties in certain areas of land according to their suitability, including through the slope, exposure, microclimate conditions etc. The 3D model will help the viewing of the facility and future land planning.

3.2. Spatial analysis and a case study to determine the most profitable land parcel

The basic features of land parcels and their boundaries are recorded and values and information were added in the attribute table (Fig. 7), which forms the core data for land management and land administration to create a geospatial database.

The results presented in the synthetic attribute table comprise the collected data from FRS Cluj and help identify the parcels depending on the cultivar and variety. Each polygon represents a parcel in the field and the area is generated in square meters using the

"Calculate Geometry" function. Based on the data collected from offices and specialized departments and laboratories, in another column of the attribute table is introduced the fruit tree productivity in tonnes per hectare (t/ha). Introducing in a new column the approximate fruit price per kilogram (producer price), was calculated the profit of each individual parcel in "lei" (Romanian currency) using the harvest in kilograms and cost per kilogram of fruit.

To find the most profitable orchard, the profit can be calculated depending on the productivity offered by the cultivar and variety. In the column of 'rentability', the profit was obtained using a standard surface of one hectare (1 ha) and taking into account the price of the fruits per kilogram. Using the data contained in the attribute work tables, the detailed values of each parcel were highlighted: productivity (Fig. 7a), harvest (Fig. 7b), fruit price (Fig. 7c), profit (Fig. 7d) and rentability (Fig. 7e).

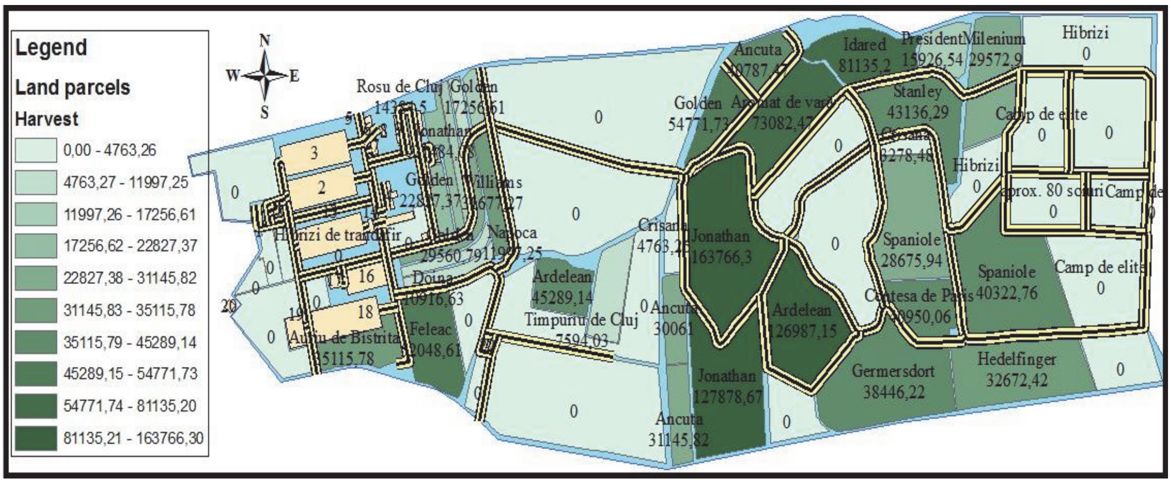
Figs. 7(a-b) illustrate the productivity, respectively the harvest for each parcel represented as a polygon. Fig. 7a shows that the apple varieties 'Golden Delicious', 'Idared' and 'Ardelean' have the most significant productivity based on the added values. Fig. 7b represents the harvest and is based on the productivity and surface of each parcel. The highest values are found in three parcels of apple with the cultivars 'Jonathan' (two fields) and 'Ardelean'.

Figs. 7(c-d) illustrate the parcels with the highest fruit price, respectively profit. The sour cherry varieties have the highest price, followed by the cherry varieties 'Hedelfinger' and 'Germersdorf'. The parcel with the largest profit is the one with the sour cherry variety 'Spaniole'.

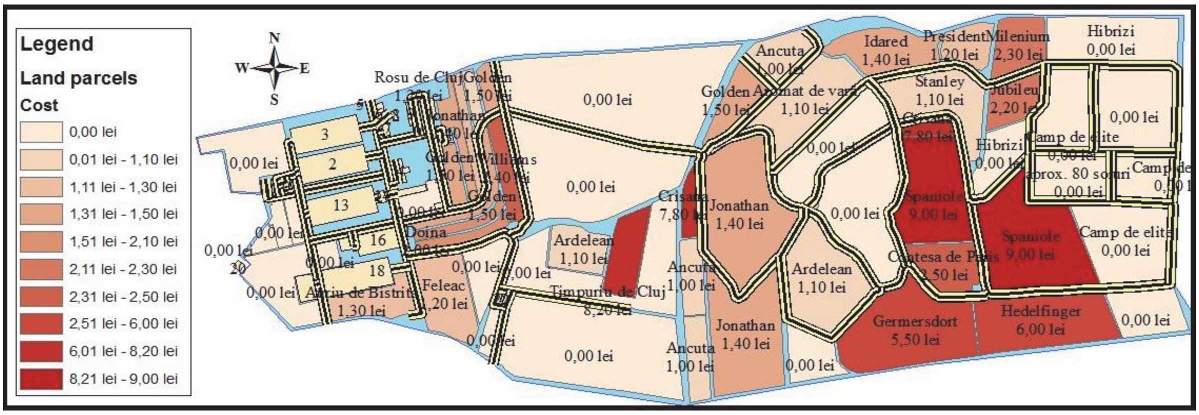
Fig. 7e illustrates the rentability of the parcels based on the cultivar, variety, productivity and cost, on a standard surface of 1 hectare. The top place is the pear variety 'Williams', which although has a smaller price than the cherry or sour cherry varieties, it has a greater productivity.

Because the purpose of this research was to have a long-term management plan and to integrate wider range of data, all information can be correlated with the other known details: soil type, slope exposure, heat and humidity, etc. All information and knowledge will be merged and integrated into the land information system to avoid environmental risk, create anaesthetic landscape and assure a healthy medium close to the city. Future focus and development will be mainly on system maintenance, including system enhancement and upgrading rather than to create a new system.

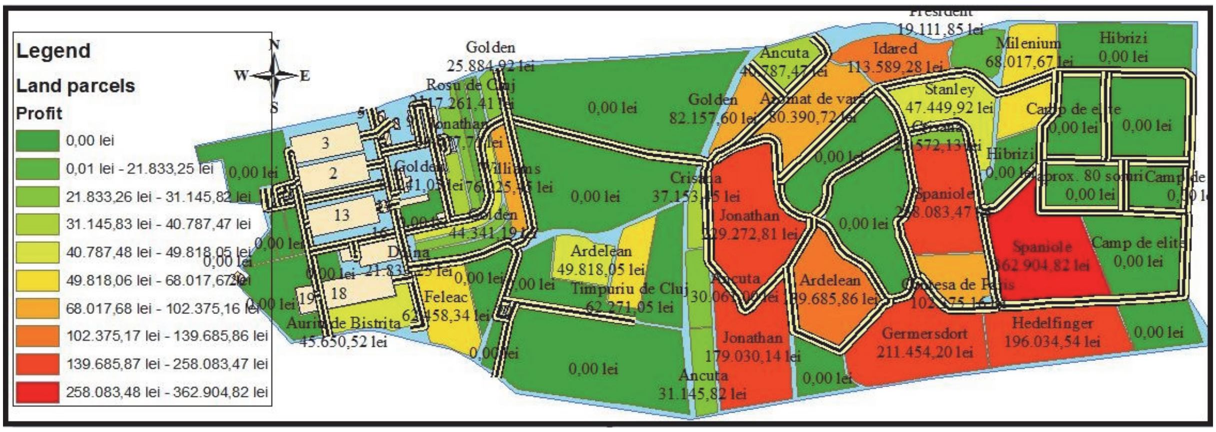
(a)



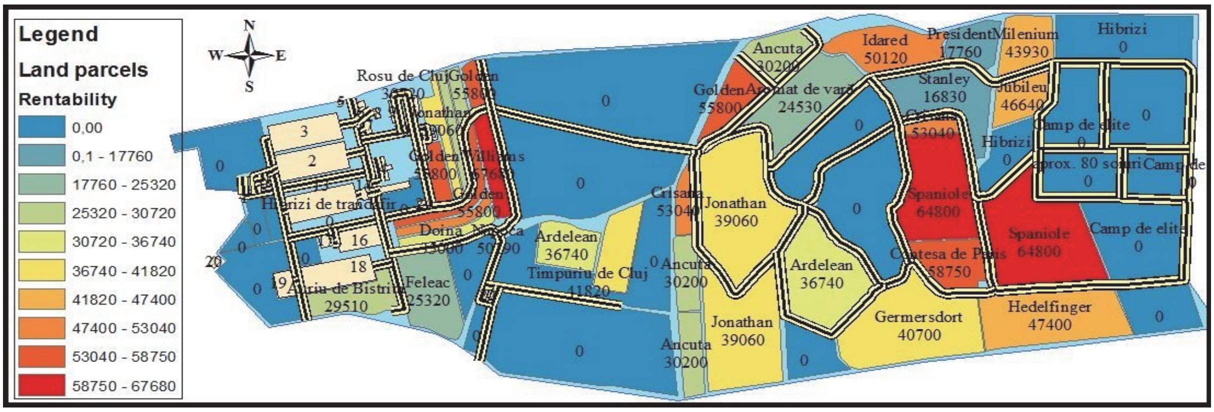
(b)



(c)



(d)



(e)

Fig. 7.(a) Productivity highlight, (b) Harvest highlight; (c). Price highlight; (d) Profit highlight (e|) Rentability highlight

3.4. Discussions

GIS provided digital information about FRS Cluj, identified by its geographical location. It was used to process data about objects defined by geographic location and having a set of associated attributes (descriptive data) grouped in databases as different orchards fields, parcels, buildings, facilities etc. The main approach of this research was the digitization and 3D modelling of the Fruit Research Station Cluj (FRS Cluj) and the implementation of collected data in a GIS database for a better management and land-use for each parcel. The 3D model will help the viewing of the facility and future land planning.

With the help of GIS the fundamental modelling process and digitization was created by editing parcels, buildings, roads and the fruit trees from the orchards. For a more accurate 3D model, additional software programs were used to construct and reproduce the buildings and greenhouses from the facility.

The created GIS could contribute to the economic rehabilitation of the FRS Cluj, which in the last years suffered a decline, as well as the Romanian agricultural research (Roger, 2014). Because of technological progress in satellite remote sensing and GIS software, the advantage of increased accuracy and spatial analysis establish the GIS applications the perfect solution for reliable resources and land administration (Merem and Twumasi, 2008).

Additionally, GIS model is capable of supporting an integrative management and increase of economically efficiency of the orchards, towards with adequate planning resources of soils, terrace, sustainability, environmental protection, landscape etc. (Lwin et al., 2012; Marceau et al., 2001; Sestras et al., 2019). It is such a revolutionary tool that GIS changed the way of reading and interpreting the landscape, integrate public and scientific information, and conduct research (Li et al., 2006).

4. Conclusions

This geospatial information system is the optimal solution to provide valuable and timely information about natural resources and is the key to planning, management and administration of land. It makes the job of facility personnel, researchers and manager much easier and radically improves the ways in which land information is collected, managed and used.

The tools and methods used in this paper conduct towards a guideline and model for the development of the much needed geographic information databases and the effective administration of land areas to further improve economic development, food quality, production and effective use of land resources to the best advantage and capacity.

The presented maps can efficiently be used in agricultural, respectively horticultural productive units to further increase the efficient administrative management and economic potential by incorporating both spatial and inventory data.

Under the constant pressures of urbanization and the extent of environmental change, a GIS is an important administrative system to define the dimensions, location and use of land parcels and the basis for planning, land management and decision making.

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