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An Overview of Potential Applications of GIS in Horticultural Crops: Special reference to Fruit Yielding Trees

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ABSTRACT

Among horticultural crops, fruit crops play an important role in nutritional value and income security of the world. With increasing population, there is tremendous pressure on establishment of new orchards with the introduction of non-traditional fruit crops to meet the ever rising demand. However, the successful performance of orchard depends on the application of advance technology. Therefore, it is critical that a potential fruit grower makes correction decisions based upon sound information on agro-ecology, management of fruit orchard and marketing chain. One potential solution in making appropriate decision in orchard development and post-harvest management is the automated Geographic Information System (GIS), a computer-assisted system for the capture, storage, retrieval, analysis, manipulate geographic data in various formats and display of spatial data. GIS is a kind of precision agriculture which is helping in increase productivity with minimal input which inturn increases the cost-benefit economics of agricultural crops including fruit orchards. In the paper, potential use of GIS techniques in land suitability, climatic, ecological suitability, nutrients management, yield monitoring, germplasm management and pest and diseases management and marketing of various fruit crops are reviewed. Few constrains of GIS technique are discussed.

INTRODUCTION

Fruit trees have been cultivated since time immemorial in India. Today, India is the second largest producer of fruit in the world after China and almost all kind of fruit crops can be favourably grown in India due to its diverse agro-climatic zones. The area under fruit crops in 2011-12 was 6.58 million ha with a production of 77.52 million tonnes, which contributes to a 32 percent share in total horticultural production (Anon 2012). Area under fruit trees and total production in 2011-12 was more than doubled over the figures for 1991-92. An investment in fruit culture is made even more alluring given that productive orchards have an average life span of 20 to 30 years, and include on-going fiscal return with routine maintenance. An important issue relating to the fruit industry today is to locate a potential new orchard with new non-traditional crops in order to meet the ever rising demand. The establishment and maintenance costs of orchards are high. The successful cultivation of fruit trees for producing high yielding and quality crops requires knowledge of the physical and environmental conditions characterizing the local landscape. Therefore, it is critical that a potential fruit grower makes correct decisions based upon sound information on site / climatic and management of orchard and marketing chain.

PROSPECTS AND SCOPE

The modern population are more conscious about nutrition and health, leading to an increasing demand for fruits; therefore there is a need to expand area under fruit cultivation to meet out the existing demand. However, land availability for agriculture/ horticulture decreasing day by day that leads to high pressure on agricultural land. Similarly, orchard planning, establishment, and maintenance and post-harvest chain management is also equally importance in order to increase productive and reduce post-harvest wastage. One potential solution in making appropriate decision in orchard development and post-harvest management is the automated Geographic Information System (GIS), a computer-assisted system for the capture, storage, retrieval, analysis, manipulate geographic data in various formats and display of spatial data (Fletcher 2009). This is not only capable of overcoming the limitations of the paper map, but it also allows for sophisticated forms of spatial analysis (Chen 2011). GIS is a kind of precision agriculture which helps to increase production with minimal input and enhanced the cost-benefit scenario in crop production (Panda et al. 2010). GIS techniques help in integration of data from a variety of spatial, non spatial and temporal parameters to be analyzed simultaneously in an efficient fashion. This may provide prospective fruit growers with necessary information on many parameters required for decision on planning and managing fruit orchard (Chen 2011). GIS tools are becoming increasingly user-friendly, especially those applications designed to be used on the web and on-line access to those tools, and the ever increasing amount of online environmental data will support researchers developing new model and concept on cropping (Greene 2007). The future will bring even more user-friendly and flexible online crop suitability consultation system in combination of GIS tools with Map Server and Web Server component. The web-GIS tools, would provides the information on the crop suitability rank, suitability category, suitable land area for that crop, current vegetation and statistics data (Jayasinghe et al. 2009). In order to work GIS efficiently, comprehensive plant related databases need to be established. The main factors involved in growth and production of fruit culture are the different soil characteristics, climatic conditions, and land-use type. Soil characteristics contribute toward fruit production are the soil pH, nutritional status, proper drainage, texture, permeability and water holding capacity. Climatic factors involved are temperature, solar radiation, rainfall, chilling hours, growing degree days, *etc*. All these physical factors must be part of a geospatial database and correlate to the corresponding spatial-based yield for fruit and nut crops for the development of a GIS model (Panda et al. 2010). Similarly, delineation of study area, ground truth of orchard boundary by digitization, and preparation of other spatial data in addition to remotely sensed imagery are some of the tasks that could be accomplished with GIS.

GIS is one of the most widely used techniques for mapping fruit trees. The GIS-map is an important aid for the fruit scientist and extension personnel; but it can also be linked to economic development initiatives related to the processing industry and markets. Besides, the map can also be used to compare and validate the GIS model (Chen 2011). The determination of spatial distribution of slope exposure and slope inclination in fruit growing areas will help in determining the ecological suitability of an area for fruit growing and their influence to a large extent in both directions of fruit production and fruit quality. The availability of information in their share and variation in fruit growing areas, allows to establish the proper varieties, to place each variety in the optimum location (micro-zoning), to choose the optimal training system and the appropriate maintenance techniques for the orchard area (Irimia and Patriche 2011). Therefore, it is necessary to have advanced and accurate database for systematic planning in orchard which including area expansion, increase in productivity and setting up facilities for post harvest handling (Sharma and Panigraphy 2007).

Although, GIS has widely been used in

agricultural crops like corn, wheat, rice, soybean, *etc*., but has very little application in fruit trees (Panda et al. 2010). Among fruit crops, the GIS have been mostly used in viticulture research and GIS has been reported to be applied in grapes for more than a decade (Ryerson et al. 2008). The use of GIS for fruit culture has potential for optimizing resource use and increasing net returns (Panda et al. 2009). The delineation of orchards and spatial analysis using geospatial technology can provide additional information for management decision making, such as the prediction of fruit yield, the quantification and scheduling of precise and proper fertilizer, irrigation needs, and the application of pesticides for pest and disease management. Ultimately, it will improve profits for producers (Panda et al. 2009). Therefore, today, the use of Remote Sensing (RS) has becoming importance for the general detection of the growth and health of orchards on a larger scale. Similarly, digital imaging technology is increasingly being used for intensive site-specific management of orchards (Panda et al. 2010). With an adequate database, GIS can serve as a powerful analytic and decision making tool for fruit culture development (Hem 1992; Reid and Wood 1976) particularly in big country like India, where agro-ecological zones is so diverse.

APPLICATIONS

Land suitability

Land suitability evaluation and mapping are an importance tools for planning and decision making in reclamation and management of problematic soils. In India, Mandal and Sharma (2006) showed the use of GIS to develop maps for salt-affected soils at the regional and state level. Similarly, in Thailand, GIS-based analysis was employed to identify suitable land suitable for establishment of banana plantations (Boonyanuphap et al. 2004). Wu et al. (2001) further demonstrated the use of soil survey geographic data (SSURGO), integrated with RS and other GIS layers for planning and managing natural resources in Finney County Kansas, US. The use of SSURGO data was also observed to be an excellent source for determining erodible areas and for developing conservation practices (Wu et al. 1997). Fletcher (2009) also found in citrus orchard that SSURGO, U.S. census spatial and tabular data integrated with GIS technology can be a powerful tool for citri-culture in identifying orchards that may be affected by urban expansion, and selecting potential sites for establishing new citrus orchards.

Climatic / ecological suitability

Climatic variation is known to be a major factors that affecting fruit yield and quality (Giomo et al. 1996). To determine the suitability of a geographic area for establishing of an orchard, there is a need of defining climatic factors and its indicators including solar radiation, solar insolation, annual average temperature, the hottest month average temperature, for generating database (Irimia et al. 2011). Vaudour and Shaw (2005) employed GIS based approaches for grape growing, where a large variety of physical, cultural, and economic factors, which determine the suitability of environment, are used. Irimia et al. (2011) assessed the vineyard suitability in temperate continental climate areas using multifactorial GIS-based analysis. Their GIS evaluation design is strictly applied to vineyard areas, this allows finding and delimiting of most favourable micro-zones for wine varieties, generically known as "*terroir*". Irimia et al. (2011) also used GIS inputs that includes fifteen climatic, pedological and topographic factors, for the ecological suitability of a geographic area. The values of these ecological factors were assessed according to their influence on grapes quality for wine varieties, the least suitable showing the possibility to produce white table wines and the most suitable produced red qualitative wines (Irimia and Rotaru 2009). Smith and Whigham (1999) demonstrated that the spatial and temporal variables associated with the growth of grape vines and management of vineyards were ideally suited to the application of spatial information systems. Similar GIS based studies on garpes are also reported by Boyer and Wolf (2000), Jones et al. (2004) and Wu and Day (2009). The GIS tool could also be employed for developing and identification of cultivar-specific climatologically in the country.

Nutrient management

The site specific management can be

developed to map nutrient spatial variability within individual fields and to correlate this nutrient variability with yield variability. Based on this correlation, a variable rate fertilizer scheme could be designed to minimize the variability and make the fields uniform in terms of nutrient content and yields. Mapping nutrient variability requires intensive soil sampling across the field which makes this approach expensive in tropical fruit crops (Espinosa et al. 2006). In many cases, GIS based site specific management is the only way to determine the actual size and distribution of the fields in the farm. The demarcation and area determination of the orchards is the first step to improve management. The GIS normalized data allows a better management of nutrients in the field. Correlation between yield and nutrient utilization information can be estimated to known a soil critical level for nutrients. This will help soil testing to be a reliable diagnostic tool and differences in soil nutrients content can be adequately interpreted (Espinosa et al. 2006). Furthermore, Srivastava et al. (2010) developed GIS-based maps nutrient constraints distribution maps for Khasi' mandarin which showed that most of the Khasi mandarin orchards were optimum in N nutrition, low to deficient in P and optimum to high in K. Whereas, Ca and Mg nutrition were mostly severely deficient due to the poor supply of Ca and Mg in soil. On the other hand, Fe content was mostly high to excess. Copper nutrition showed deficiency levels, while Mn was mostly optimum to high with majority being at sub-optimum level. GIS based nutrient distribution maps helped in identifying potential sites for harnessing sustainability in quality production (Srivastava et al. 2010).

Yield monitoring

Yield monitoring and mapping are most valuable sources of spatial data for precision agriculture. Sitompul et al. (2012) studied the spatial relationship of air temperature with the productivity of apple trees using GIS PCRaster. They found that the semi-variance of fruit yield was closely related to the distance of orchard sites, and it increased linearly with an increase in the distance, suggested a spatial dependence between orchard sites. Further, the altitude does not responsible for the variation in fruit yield among different sites, however, air temperature is closely related to the altitude. The distribution map of fruit yield generated with the Geostatistical interpolation (ordinary kriging) was then used to regenerate the average of fruit yield at a particular range of altitude (Sitompul et al. 2012). Therefore, based on the spatial analyses, the air temperature had a marked negative effect on the fruit yield. Yield monitoring using GIS in citrus orchard gave 90.6 percent average prediction accuracy (Zaman et al. 2006). This information is valuable for yield forecasting and to plan harvest schedules.

Germplasm management

GIS can be used to assess distribution and diversity level of plant genetic resources in the country on the basis of field data gathered during survey, which may help in managing plant biodiversity in sustainably way. SuperGeo Technologies, the leading global provider of complete GIS software and solutions, developed a GIS platform for sharing and managing the data of horticultural crops, especially wild relatives and the system is used in internet map server (Anon 2013). Further, it contains the database of species list and survey data as well, which provides the related staff with the integrated data of species characteristics and distribution space as a reference for conservation.

Pest management

Fruit trees are sensitive to stress factors associated with changes in moisture, temperature, as well as anthropogenic factors, such as air pollution, pests and disease. GIS together with the field of geostatistics / RS offer the means to identify, monitor the magnitude, and anticipate the spread of infestations (Rock and Vogelmann 1989). The GIS when combined with RS, is a powerful tool that can be used in integrated pest management programs to assist the better understanding of ecological relationships of pest arthropods and their surrounding landscape (Johnson 1989). The GIS database has been created as a tool for managing the codling moth in apple orchards in British Columbia (Vernon et al. 2006). The related web-based “pesticide sensitive crop locator” would serve the assist producers in avoiding the drift of damaging or destructive chemicals onto grape vines

(Chen 2011).

Disease management

Assessment of diseases in fruit crops using RS in combination with GIS has proven to be a useful tool for diseases management in the orchard (Ryerson et al. 2008). It is commonly used for identifying, monitoring and anticipated the spread of infestations. For instance, Johnson (1995) monitored and assessed a *Phylloxera* infected grape plots in California using aerial imagery and ground survey. He also produced a map each year to show the extent of damage, which over time can be used to support the understanding of the factors which lead to outbreaks and therefore their control. Similarly, GIS proved to be useful in management of monilla (*Monilla sp*) infection in *cv.* CCN-51 cocoa. The severity and dynamics of this fungal disease was easily monitored using GPS readings to locate the spread of the disease in the farm (Espinosa et al. 2006). In disease management, detection of infection to crops using GIS provides valuable information for management planning and decision making in orchard.

Horti-Marketing

GIS has an immense potential to transform the horticultural sector into a main resource for earning foreign exchange. GIS based Agro/horti-marketing is a decision-based support system specifically developed to plan marketing strategy and its application is developed on GIS software's like Archinfo and ArcView (Das 2008). Used of GIS tool in supply chain management will add more value to horti-market logistics and easier identification of markets on the targeted segment. Similarly, the number of route plan with desired options could be worked out automatically as well as manually with GIS application within a few minutes. This would help in radical cutback of the time between data processing, planning, implementation and marketing, they are the basic essence of effective supply-chain Management (Das 2008).

CONSTRAINS

GIS has been adopted in several agricultural crops over a wide range of land and ecological variability. However, it is still not been utilized much in fruit crops and also several constraints exists with the GIS applications to be technically feasible in fruit culture. Quantitative data allows comparisons from place to place. Further, it is difficult to extract quantitative radiometric information from an analogue data source. Therefore, such analogue data are not recommended for operational applications (Curran 1980). However, this problem is eventually solved today due to the availability of digital data from commercially airborne scanners. Similarly, using of RS permits comparisons over time. Other constraints are inadequate communication means between computer systems, data suppliers and users. Moreover, the insufficient training and experience among the local experts, networking functions and data updating among the government institutions, research agencies and academic organizations are still lacking. With the advancement made the way data processing, communication, and interaction occurring in the computing world today would definitely have an influence on GIS technology, the delivery of information to the mobile phone is well demonstrated (Venkatachalam and Moha 2012). Thus, it is evidence that the prospective routine application of GIS to orchard management has become a possibility due to the availability of advanced digital and fully calibrated systems.

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