Technology Impact on Agricultural Productivity: A Review of Precision Agriculture Using Unmanned Aerial Vehicles

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Abstract. Technology application to agricultural productivity is thought to be the solution to meet food demand of the growing population. In a rapidly changing world, with the prospect of decreasing arable land due to urbanization and industrialization, agricultural output requires a 70 % increase in production levels and efficient growth in the harvesting, distribution and consumption of the resources, to meet demand. There are innovations in Information and Communications Technology that can be applied to the agricultural sector in areas of precision farming, use of farm management software, wireless sensors, and use of agricultural machinery. Remote sensing technology is playing a key role through precision agriculture. This paper highlights ways in which precision agriculture is impacting on agriculture with the use of unmanned aerial vehicles for image capturing, processing and analysis.

Keywords: Agricultural productivity · Geographical information system · Global Positioning System · Image capturing · Precision agriculture · Unmanned Aerial Vehicle

1 Introduction

The application of technology to agricultural development is fast increasing and widely practiced in many parts of the world, where agriculture serves as a major source of revenue and livelihood. Technology is referred to as the application of scientific knowledge for practical purposes or the use of machinery to better facilitate a process and reduce the intensive manual labour required in agricultural production [1].

Technological applications to the agricultural sector eliminates the stress and tedious manual labour involved in agriculture. It also increases yield and aids proper management of farm input translating into output. The advantages of applying modern technology to agricultural productivity are: more people would eat better, while eradicating hunger and reducing malnutrition from increased production; improved nutrients in food; reduction in the physical pressure on the environment; improved quality of life and living standards as food costs decline, and; increase in savings, as the majority of people spend most of what they earn on food [2]. This serves as an encouragement to young individuals, not interested in the sector due to

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the subsistence methods previously employed in farming, which were considered tedious and unrewarding. Technology is also playing an important role in marketing in recent times and it is very important to the agro-industry, either at the primary or production, secondary or processing, or tertiary, involving both marketing and packaging stages. Agricultural technology can also play a vital role in solving the problems and concerns relating to the conservation and management of rural resources. Mass production, being aided by new technology and intensive marketing, can only help the agriculturist in exploiting both the domestic market and the international market to all extent, with the volume of production depending on the capital investments, and marketing strategies with the technical capacity used in the production and processing stage [3].

Space technology is playing a key role in its use for agricultural productivity through precision farming and by taking aerial views of farms. Precision farming deals with obtaining the exact readings of some particular events, such as: weather forecasts, to help to prepare lands for farming; and Global Positioning System (GPS) monitoring, and the use of the Unmanned Aerial Vehicle (UAV) systems, which can provide farmers with GPS guidance to position the applicators (Variable rate technology) by applying specific amount of chemicals to specific locations. Precision agriculture is a viable solution to agricultural production due to: (i) the ongoing reduction in the amount of arable land; (ii) projected increase in global population, and; (iii) reduction in cost of agriculture by avoiding wastage in the application of chemicals or water.

Figure 1 shows the classification of agricultural technology.

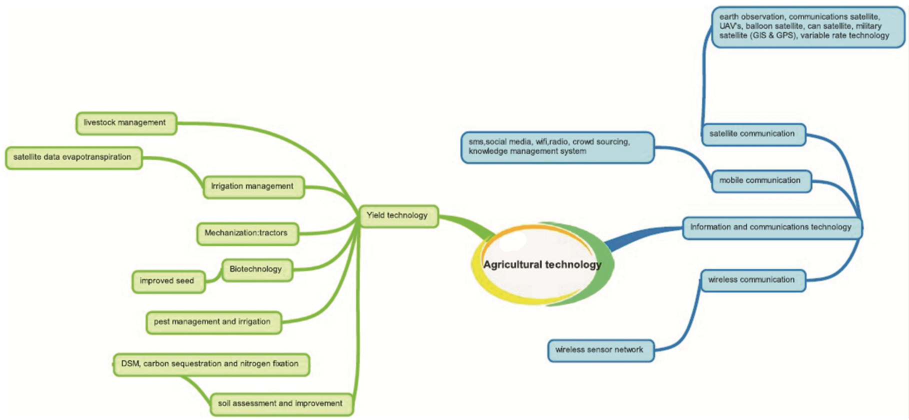

Fig. 1. Classification of agricultural technology

1.1 Precision Agriculture Using UAVs

If appropriately utilised, precision farming technology, which includes yield mapping, automatic steering and variable rate application, can greatly increase the efficiency of farm operations. Precision agriculture is majorly involved with two basic technologies, *viz.*: Geographical Information System (GIS) and GPS technology, which may eventually utilise sensors, monitors and controllers for controlling a farm's equipment, such as shaft monitors, servo motors etc.

Precision farming is a technology that affects the entire production process from extension services to management functions. It is mainly an information technology (IT) based farm management system and it involves a process of data collection, data mapping and analysis, and site specific treatment.

The components of precision agriculture are: spatial referring, crop and soil monitoring, decision support and differential action [4].

1.2 Cycle of Precision Agriculture

The cycle of precision farming involves obtaining images or data to generate map yields, weeds and topography, before application of the herbicides or fertilizer, water (irrigation) and finally to obtain results for implementation.

Before an agriculturist starts the process of precision farming, a good idea and understanding of the soil types, hydrology, micro-climates and aerial photography of the farm are required, as well as an understanding of the variable factors within the fields that effect a yield map. The yield map serves as a confirmation of data of what the farmers have, usually by simply taking an aerial photograph of the farm [4, 5].

Remote sensing used in implementing the technology include platforms such as satellites, aircraft, balloons and helicopters, and a variety of sensors such as optical and near-infrared and RADAR (Radio Detection and Ranging) installed on these platforms for its applications. Diagnostic information derived from images collected from these on-board sensors, such as biomass, Leaf Area Index (LAI), disease, water stress and lodging, can thus assist in crop management, yield forecasting, and environmental protection [6, 7].

The cycle of precision agriculture application is shown in Fig. 2:

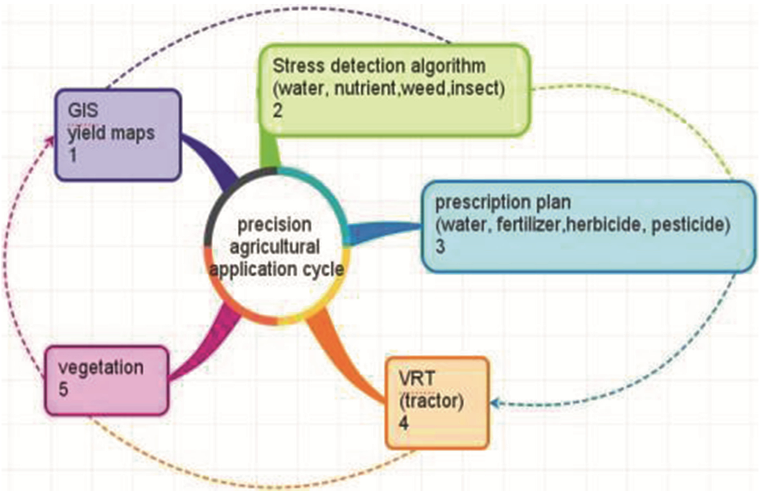

Fig. 2. The cycle of precision agriculture

The process of high resolution imagery collection involves the transmission of low cost multi hi-resolution imagery to a mobile ground station and processing centre, then via the Internet (GPS/WAAS (The Wide Area Augmentation System) based geo referencing) and to GIS (Geographical information system) processing.

Precision agriculture has effectively been in use since 2007, precisely when yield maps and target soil sampling came into use. The yield map and the target maps are used to create prescription take-off maps for phosphate and potash to apply to crops, while the Yara-N sensor is used to apply a variable rate of nitrogen.

The electromagnetic (EM) scans identify different soil types, and this layer of data is used to create variable rate seed maps with the aim to improve crop establishment. Tractors majorly use auto steer with the information provided and the sprayers have auto section control and auto boom height.

All of the different aspects of precision agriculture used have individual gains, but the auto steer used in machineries like tractors probably gives the most advantages due to production efficiency, allowing the operator to concentrate on the job being done rather than on driving the tractor. It also means that if the tramlines are established accurately, all subsequent passes will also be accurate. Variable rate application of fertilizer has allowed some savings on the farm, but more importantly the fertilizer is allocated to the correct areas of the field at the appropriate amount, which makes economic and environmental sense.

One major challenge with precision agriculture is managing and analyzing large data sets but in the future, cloud systems will be used to transfer data from machines or equipment to the office, or mobile devices and *vice-versa*. Another feature of precision agriculture that is being used is weed spotting and site specific in-crop treatments that have been effectively used for weeds, such as blackgrass and other grass weeds [5].

1.3 Benefits of Precision Agriculture/Farming

Precision agriculture helps to monitor the vegetation's physical and chemical parameters by placing electrical conductivity, temperature, nitrates, soil moisture, evapotranspiration and radiation sensors. These ensure that the optimal conditions for plant growth are achieved. This makes the field administration automated by consolidating a Decision Support System (DSS) in the precision agriculture environment in the best conditions for the particular soil and plant species and will be consequently advanced in view of the information acquired by the sensors. The Decision Support System will propose the best period for watering (or whether it is needed), the need to inundate to wash the salt substance because of an abundance in the radicular zone, the need to prepare, and so on. By presenting a precision agriculture framework in the everyday operation of an agrarian misuse, time is spared because of the up to date estimation systems. Information from the sensors is naturally transmitted to a central server and this can be consulted utilizing a Smartphone or Laptop. On the other hand, email or SMS alerts can be modified to tell the field holder when there is a need to flood, prepare or address any issue in their properties. Also, costs regarding water, pesticides and others are improved and can undoubtedly be decreased [9]. In summary, with precision agriculture, the benefits are greater sustainability, higher productivity, increases in economic benefits and environmental protection.

Precision agriculture revolves around data analysis and evaluation with its use in precision soil preparation, precision seeding, Precision crop management and precision harvesting.

1.4 Technologies Employed in Precision Agriculture

The technologies used in precision agriculture are remote sensing using satellites, UAVs, generally involving data capturing process, GIS, GPS and the Variable rate sensors. Geostatistics is an associated technology with precision agriculture, known as a branch of applied statistics that quantifies the spatial dependence and spatial structure of a measured property, and in turn uses that spatial structure to predict values of the property at unsampled locations on the field. Interpolation is a procedure generally used for predicting unknown values of neighboring location. Other technologies employed are spatial modelling, also known as variography, and spatial interpolation, otherwise called kriging [10].

2 UAV's in Precision Agriculture

The use of UAVs in agriculture is fast becoming widespread, while the implementation of aerospace engineering and sensor technology are reducing in cost. UAVs employ cameras to collect images and sensors to compile a set of data to help with monitoring and decision making on the farm.

UAVs collect data at high spatial resolutions enabling differences in crops to be compared by the centimetre rather than the metre, as in the case with satellites. They also provide immediate visual information about large areas of crops, which help farmers with fast decision making.

UAVs are small-sized electronically controlled devices launched from the side of a field or area of interest to the user. The size of UAVs usually affect the size of the payload, respectively. UAVs are guided by either a radio controller and drones generally have been made compatible with Android or Apple Smartphone applications that control the drones. Cameras attached to a UAV take pictures that can be two dimensional, with every pixel linked to a GPS location on the ground.

UAVs can also transmit live videos from flight to the receiving station on the ground. Depending on the type of camera employed, thermal images can be obtained from the UAV [11].

There are basically two types of UAVs available at the moment, as summarized in Table 1:

Table 2, below, highlights the differences between using a satellite and the UAV for obtaining images on the ground.

Figure 3 shows an example of the differences in image quality of an analyzed vegetation spot using both satellite and a UAV. The image on the left is from the satellite with the best resolution of 1 m and on the right is a UAV image highlighting the vegetation clearly with a resolution of 10 cm.

Table 1. Basic UAV Types [11, 12]

UAV	Rotary wings	Fixed wings
Flight duration	Fly duration shorter than fixed wings.	Fly up to an hour(s)
Wind pressure	Can be flown in winds gusting from 20 to 50 mph	Fly in and out of the wind rather than across the wind for satisfactory images
Flexibility in changing direction	Allow new direction during flight for re-direction	Allow new direction upload during flight for re-direction
Price range	\$500 to \$100,000	\$500 to \$100,000
Deployable option Resolution	highly deployable ± 1 cm RGB, 5 cm Multispectral	highly deployable ± 8 cm RGB and 15 cm Multispectral

Table 2. Differences between using a Satellite and a UAV for Obtaining Images on the Ground

Observation body	Satellites	UAVs
Area of coverage and usages	Global, covers large areas	Local, covers only a specific location
Air traffic restriction	Not affected by air traffic restrictions	Affected by air traffic
Operation costs, resolution	Costly, slow to task, low resolution (63 cm) and affected by cloud cover	Low operation costs, highly deployable and high resolution (4 to 10 cm), buy in costs are high but gradually falling
Regulations	No regulations	Regulations exist in certain locations like the United states.

UAV's are also useful for farmers, consultants or crop insurance agents for scouting for damages from weather events, harmful insects, diseases and chemical drift on the farm [11].

Images taken during flights are imported to GIS databases, which can be stitched together with special software to generate 3D reconstruction of fields. Normalized Differential Vegetation Index (NDVI) sees the health of crops or highlights stress areas in crops, water nutrients or weeds that they might have missed with eyes, alone. Multi-spectral cameras used on the UAVs allow farmers to identify crop health, perform risk mitigation and even identify soil health, while the more recent hyperspectral cameras will allow the identification of specific vegetation types in the future. Right after obtaining patterns from images, maps can be obtained from extracted GPS coordinates.

Fig. 3. Satellite image on the left with a UAV image analyzed on the right [13]

A recent approach of using UAVs that improves farmers' decision making is through mapping fields with 3D technology that provides detailed topographical images where soil changes may be present. This can also help in the future to fine tune hybrid detection for higher elevations with more water and higher organic matter [8, 9]. The general term for all flying objects used is unmanned aircraft systems, involving the use of drones, UAVs and aerial survey. It should be noted that using low cost balloons, kites and UAVs for taking aerial photography costs are low compared to the use of conventional satellites with respect to the respective requirements as seen from the table above.

Post processing of data obtained involves observation, crop type, soil moisture, biomass and irrigated land mapping, while imaging involves the use of the following sensors; visual sensor, light detector and ranging sensor, thermal infrared and multi-spectral sensors [15].

Precision technology is found to be certainly most useful in arable farming, where growers can observe fields on a square by square metre basis and apply nutrients to specific locations where required while treating disease problems. Livestock farming also profits in some ways, like the automated feeding systems used in adjusting the quantity and type of feed served to animals according to the need, weight and lactation period of the livestock [14].

The technology can be used on machineries with sensors attached, like a combine harvester spotting a bearing that is running too hot, and a field connect service that gathers information on weather, soil and crops to determine irrigation decisions.

Big data is a word that encompasses any mass of information obtained from the sensors or any recording equipment. The data/information on a farm can range from irrigation, slurry spreading, fungicide applications to dairy rations. Data have always been important in agriculture before precision agriculture, from the amount of nitrogen applied to fuel used and a tractor's last service date. Algorithms are what add real monetary value to data collection by transforming pages of machinery coding into clear, interpreted information that can be used to produce maps or yield prediction models [15].

2.1 Benefits of Using UAVs/Drones

Drones can provide farmers with detailed views making it possible to see crops from the air that can reveal patterns exposing everything from irrigation problems to soil variation and even pest and fungal infestations that are not apparent to the human eye. Airborne cameras can take multispectral images, capturing data from the infrared as well as the visual spectrum. These can be combined to provide details of healthy and distressed plants. Drones can be used anytime as desired by the farmer (weekly, monthly, hourly etc.) [16].

Most successes recorded using UAVs are crop scouting, weed management and livestock monitoring. Data implementation and analysis using broadband mobile communications are expected to provide live streaming and also have possibilities for robust images, such as weed mapping [17].

2.2 Limitations of UAVs

The low costs of UAVs (the cost of purchasing a drone is just a part and not inclusive of the cost of processing, collecting and producing images) limit the sensor payload, both in weight and dimension, and they are also not as stable as the high-end sensors resulting in reduced image quality. Since low cost UAVs are usually equipped with light weight engines, this limits their reachable altitude.

Also, the available commercial software packages applied for photogrammetric data processing are set up to support UAV images, as there are no standardized work flows and sensor models currently being implemented. UAV images do not also benefit from the sensing and intelligent human features that limits them from taking actions based on unexpected situations, like avoiding collisions with an oncoming flying object and also requires full understanding before it can be deployed with maximum interaction with its receiving station, usually a laptop.

The frequency of flying UAVs also has to be carefully selected and, finally, there are insufficient regulations on flying UAVs and they are restricted in certain regions as a security precaution [18]. Some other challenges are their inability to take readings during extreme weather conditions like rain.

2.3 Analyzing UAV Images

The processing of images involves starting with obtaining a small inexpensive UAV that maps the fields at high resolution with a multi spectral camera, then the images are geo-referenced and auto-rectified to provide an accurate representation of the field. Now the location of the weed patches is relayed to a larger helicopter type UAV that spot sprays the patches with herbicides, pesticides or even water for irrigation. An existing model for that purpose is the YAMAHA RMAX, which does not take over the conventional crop spraying method but helps to ease spraying on a spot application basis. Crop scouting can be said at this point to be the best or highest use of UAVs, while the aerial imagery is just to locate problem areas [19, 20].

The GPS/INS data onboard the UAV and the ground receiving stations are required to obtain images or predefined points for georeferencing or mosaicking [21, 22]. Other uses include monitoring crop progress before harvest, which cannot be easily done due to weather instability, but the UAV tracks plant growth with a high level of accuracy. In the near future, it is projected that UAVs will be able to observe, monitor and forecast the spread of fungus-like organisms that endanger crops [15]. The Normalized Difference Vegetation Index (NDVI), the Soil Adjusted Vegetation Index (SAVI), and the Green NDVI, which are all vegetation indices, are being used extensively to study various biological parameters quantifiably [22, 23].

NDVI shows the difference between regular red light reflected from plants and near infrared light. Healthy chlorophyll absorbs the red light and reflects near infra-red, while damaged chlorophyll reflects both [24]. One way to make a cheap consumer 3D camera with two lenses is by modifying one for near infra-red [25]. UAV images are usually processed using open source software like the digital terrain model processing tools. The images have to be rectified and merged to an ortho-mosaic for further analysis, while the best result is achieved by photogrammetric processing. Single image processing is used in place of photogrammetric processing when there is no regular image block alignment. The single image rectification involves correcting the optical distortion using a third degree polynomial approach and then rectifying using a nonparametric rectification approach and then to mosaic processing. Image blending is an effective way of producing high quality mosaics, while noting that radiometric variations of overlapping views occur often with UAV images. An improved scale invariant feature transform (SIFT) algorithm is mostly used for UAV imagery but has a disadvantage of memory consumption

Images can be completely processed by using a close range Vision Measurement Software (VMS) photogrammetry software and GOTCHA image matching. Open source GIS software used in UAV images are the Qgis and the open jump [26]. These images can then be compared to the aerial photograph taken on the ground with set GPS coordinates to map out areas of specific needs of herbicide, fertilizer, water and also identification of high yield producing vegetations on the ground depending on request. Figure 4 shows an analyzed image of an aerial farm using UAV.

The figure shows the result of an analyzed image from a UAV showing details on farm status and highlighting problem areas and areas due for harvest.

3 Discussion

This paper focuses on the stages involved in using UAVs to monitor crop growth/health status during growth seasons ensuring that the crops or plants obtain the required amount of treatment needed to avoid losses, while increasing production growth rate. It is concluded from the above that technological applications are the solution to an increased agricultural production required to feed the growing population with the limited available resources.

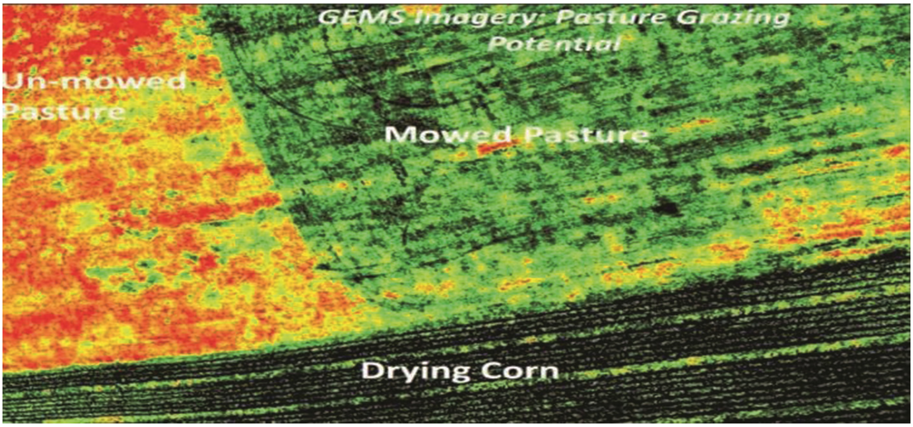

Fig. 4. An analyzed aerial image of an Agricultural Farm showing its status [27]

Ensuring that the specific quantity of required farm input resources like fertilizers, insecticides, herbicides, water to plants and the reduction in farm labour activities are the key areas where the technology has been effective. These technologies also ensure improved soil fertility before planting to post-harvest activities.

From research, it is observed that policies are the key playing factors in the agricultural sector from the land use act, price standardization in farm land inputs, stable market output prices, land ownership acts (laws on small lands and large farms), laws on maintaining the environment where farms are located, provision of credit facilities to farmers for machinery and farm input resource purchase, ensuring the basic standard of living for farmers, etc. All of these form standards making the application of technological services possible. Policy implementation has made remarkable differences in the United Kingdom and Brazil in their production rates, making their economies food sufficient and also exporters of their major food crops. These policies, however, differ from region to region depending on existing laws on agricultural practices.

However, a very clear understanding of these agricultural technologies is usually the first step in its implementation. The costs of applying these technologies are high and not affordable by the majority of farm land owners, especially small scale farmers, but from research, it is observed that the amount required for using the technology is less than losses accounted on harvested products. Also, nutrients in food crops are lower as compared to when technology was applied by ensuring the over usage of chemicals on farmlands and other input resources.

Precision agriculture on the other hand using UAVs is a relatively new technology and strict regulations are still enforced in certain regions about flying objects but the advantages offered surpasses its costs and disadvantages. Data implementation and analysis are areas of great importance, while the software for processing the UAV images are not readily available and difficult to utilise.

Future research work should focus on reducing the cost of UAVs and that of implementing the technology by using low cost components for obtaining high resolution images. Also, continued research is required in the software processing or UAV photogrammetry, which actually generates the result of the true health status of crops at every stage of germination.

With all of these facts, UAVs should be commercialized for agricultural purposes and laws should be enforced to permit its usage following its relevance to the sector.

4 Conclusion

UAV technology in precision agriculture is a robust, timely, cost effective way to obtain viable data on the farm to improve yields and overall profitability in sustainable farming systems. It saves time, increases yields and provides return on investment. The future of agricultural production with less human labour, increased productivity, reduced losses on harvest and planting, all depend largely on these technologies and should be given due consideration in every ramification. The control of the UAVs should be automated for both flying and landing purposes with less human intervention. Also, this technology should be very familiar to farmers and hence extension programmes should be arranged to teach them how to fully utilise and implement the technology.

5 Future Research Work

The future research work here involves the use of multiple sensors to monitor vegetation, ranging from thermal, multispectral, hyperspectral, optoelectronic, crop reflectance to photo electric. This produces results to measure soil nutrient content, detect water stress detection, leaf area index, and chlorophyll index.

These biophysical parameters are then estimated using NDVI, NGRDI (Normalized green red difference index), and ExG (excess green index) vegetation indices before validation. All of which is in an effort to avoid post-harvest loss, pestilence and diseases by monitoring yield, for a uniform soil fertility, which gives maximum production. Also for high profitability by employing low input costs, especially fertilizer N applied to crops, for sustainability and protecting the environment by greatly avoiding ground water contamination and delaying deterioration. The next phase of this research will involve obtaining results from a UAV in a particular field with the necessary simulations, computer model and the appropriate decision support system for real-time applications by variable rate applicators or manual applications, depending on the demand. This phase will be purely technical involving algorithms, processing and analyzing images, while presenting results to the field or field trials. Having performed all field trials for the different requirements such as estimation of nutrient availability, fertilizer N requirement, weed spotting, and irrigation requirements, appropriate seedling and timing, appropriate harvest period, and specific applications will be matched for each exact requirements on a field. This involves matching platforms with specific applications to suit its exact purpose. Also, an interface will be developed where results obtained from the images are input to simulate results as to how they will affect the farm in reality. This will be developed using matlab and special software. Also algorithms will be developed to fully analyze crop health and define specific amount requirements in the plots, which can finally be used in the application maps.

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