Application of Geospatial and GIS technologies used in Agricultural Management in Maricopa County

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Introduction (Bonifas, Lim, Singh)

Precision agriculture is the practice of incorporating geospatial technology into traditional farming approaches. Utilization of remote sensing, geographical information systems (GIS), and global positioning systems (GPS) technologies allow for comprehensive and precise methodologies for understanding the land. With this technology, farmers are able to have a better understanding of the land and its characteristics (slope, soil types, field shapes and locations, nutrients and microclimate conditions). Having a thorough understanding of the land allows for precise application of resources such as fertilizers, water and pesticides, reducing environmental impact and overall costs.

A growing issue that farmers are facing today is how to maximize crop yield and production while maintaining low operating costs and complying with environmental regulations. Overuse of fertilizer and pesticides have led to widespread instances of water pollution, pest resistance and crop and soil degradation, creating a need for improved application methods. Added agricultural issues include high water demand for irrigation in regions where water availability is a concern. These issues are both regional and global in scope; however, the focus of this paper will be within Maricopa County, Arizona (Fig. 1). Specifically, we will be examining how geospatial technologies can improve the efficiency of fertilizer application, irrigation management and pest control within Maricopa County, Arizona as the issues surrounding resource allocation persist and there is very little indicating how these technologies are being used in Maricopa County.

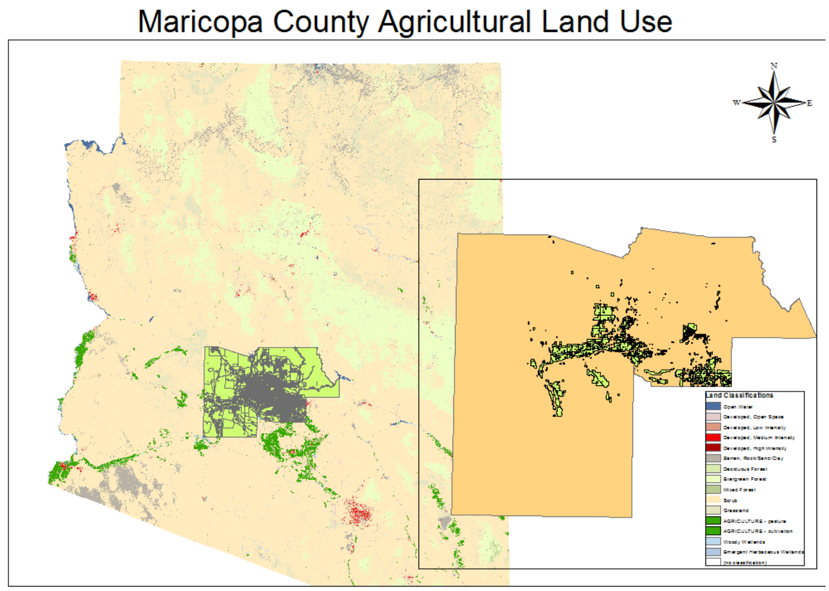


Fig. 1 The focus area of Maricopa County within Arizona. Areas highlighted detail the agricultural land within the state and focus area. John Bonifas 2014

Study Area (Bonifas, Lim, Singh)

This research was conducted within Maricopa County, Arizona, United State. It is located in the American Southwestern Desert. The total area of the county is 9, 203 square miles (City-Data, 2014) 297 acres of that area is agricultural farmlands. Approximately 78.1% of that acreage is family-owned or individually operated farms, who grow wheat, cotton, and vegetables.

Increasing use of fertilizers in Maricopa County for lawns and other landscaping plants has led to water pollution in the Colorado River, especially perchlorate salts derived from pechloric acid. The salts present in drinking water can affect people's thyroid glands, leading to cancer.

Maricopa County averages only 8.9" of rainfall annually, and thus farmers have a higher than average dependence on irrigated agriculture. Inefficient irrigation practices are of major concern, particularly relating to issues such as groundwater depletion, water loss due to evaporation and real time water management. Like Maricopa county, agricultural practices that take place in arid regions have similar water management challenges.

Literature Review

Fertilizer Management (Singh)

Fertilizer plays a significant role in agriculture, by supplying nutrients to plant life. Fertilizers are made easily available to farmers however, their use carries many environmental impacts, two of which are nutrient run-off (which is a major contributor to the eutrophication of lakes and rivers) and acidulated fertilizer (fertilizer that contains an abundance of acid and can lead to soil acidity which has been found to be very toxic to future crops). To help solve the fertilizing problems, scientists have developed and continued to develop GIS technologies to reduce negative impacts of soil fertilizer use in agriculture.

In Northeast China, research was conducted to help farmers improve fertilization and soil fertility and to protect soil from erosion. In particular, Xie, et al. (2010) developed a GIS-based Fertilizer Decision Support System (FDSS) to guide the farmers to aid in choosing rate of fertilizer application and amount of soil nutrients. The FDSS takes the soil sample data, using the spatial variability and geostatistical methods in ArcGIS to pinpoint which area of the land needs nutrients. This will help farmers maintain adequate nutrient levels in the soil to produce high crop yield while reducing the amount of fertilizer applied to agricultural land. It is reducing the environmental impact while being a cost effective solution for farmers.

In Yongji County, China, Zhang, et al. (2013) conducted a study on the spatial variability of soil and GIS nutrient management. They took approximately 511 soil samples using GPS receiver to record precise locations and then used descriptive statistical analysis to find the mean, maximum, minimum, standard deviation, and coefficient of variation to calculate the semi-variogram of each soil variable. They elevated the soil nutrients by using geostatistical analyses to see the increase of fertilizer regionally on ArcGIS (Fig. 2). This helped farmers identify soil deficiencies in Yongji County, by which they concluded that their focus should be on equalizing the amount of nitrogen and phosphates in the fertilizer.

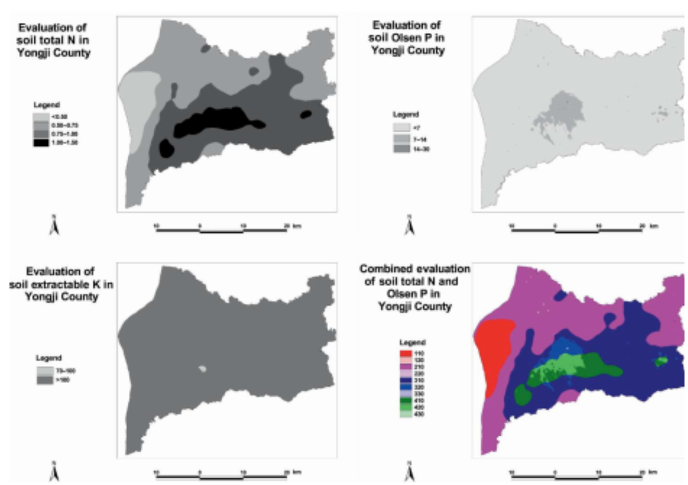


Fig. 2 Evaluation of soil nutrients in Yongji County, China. Zhang, Q., Yang, Z. P., Li, Y., Chen, D.L., Zhang, J.J., and Chen, M. C., 2010. Spatial Variability of soil nutrient and GIS-based nutrient management in Yongji County, China. *International Journal of Geographical Information Science* 20(7): 965 – 981.

In China, nitrogen has been used to increase the fertilization of soil, which has lead to groundwater contamination. Jianjun, et al. (2010) created a computer model called Denitrification- Decomposition (DNDC), which replicated nitrogen leaching and spatial distribution data for the crops grown. The model calculated soil moisture and tracked water flow similar to precipitation plant interception, transpiration, evaporation, bypass flow, and ponding water to determine the nitrogen availability in the water.

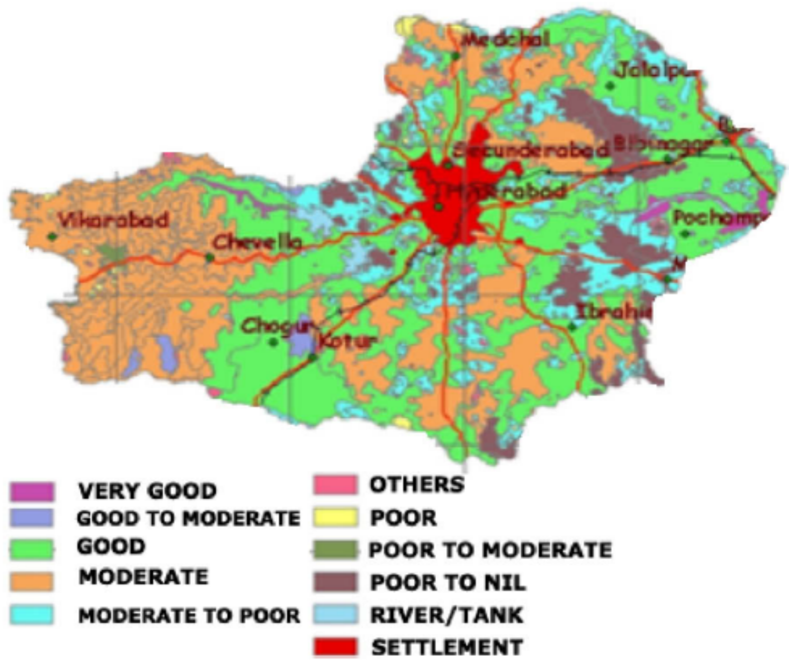
In summary, a variety of technologies are being used worldwide to help reduce fertilizer use in agriculture, such as GIS-based Fertilizer Decision Support systems, GPS receiving systems, geostatistical analysis software, and Denitrification-Decomposition systems. Reductions in fertilizer use can also reduce nutrient run-off and soil acidity.

Irrigation Management (Lim)

Studies using remote sensing, GIS, and GPS technologies have allowed researchers to better understand ground water levels in regions with arid climates. For example, Ganapuram, et al. (2009) focused on the Musi sub-basin of the Krishna Basin in India, utilizing Shuttle Radar Topographic Mission (SRTM) radar images from shuttle endeavor and Digital Elevation Model (DEM) data combined with the data present in ArcGIS software to create a series of maps. The maps generated provide a visual representation of the basin’s elevation, flow direction, flow accumulation, drainage, slope, land use/ land cover and geomorphic characteristics. With this data a hydrogeomorphological map was created, allowing areas of interest for further study and groundwater exploration. This technology will aid in the identification of potential groundwater zones which will contribute to the collection of data for thematic mapping of the basin, allowing for easier identification of those favorable groundwater zones (Fig. 3).

Fig. 3 A map of favorable groundwater prospect zones in the Musi sub-basin created using GIS.

Ganapuram, S., Kumar, G. T. V., Krishna, I. V. M., Kahya, E., and Demirel, M. C., 2009. Mapping of groundwater potential zones in the Musi basin using remote sensing data and GIS. *Advances in Engieering Software* 40 (1): 506 – 518.



Satellite-based remote sensing (RS) and GIS have been used for estimating seasonal crop evapotranspiration in the Kheda district of the Gujarat state in western-central India (Ray, et al. 2001).   A significant amount of water can be conserved by utilizing real-time monitoring for the crop's evapotranspiration rate and determining a more efficient irrigation schedule. The data used included temperature and wind speed for the specific crop location (since those variables can vary significantly within just a few miles) and the condition of the crop. Maps were generated using atmospheric, climate, and land cover data, with multiple maps made for three months of the crop-growing season. Data was then compared with nearby weather station data, rainfall amounts, and water delivery records of the farmers. With this information a "better estimate of crop water use was determined, resulting in a better estimate of crop water use and minimizing the impacts of over-irrigation as well as under irrigation". (Ray, et al. 2001).

The use of low resolution satellite data and radar imagery have been the traditional approaches to performing spatial analysis within GIS. Newer technology includes the use of small unmanned autonomous vehicles (UAVs) to perform agriculture mapping (Haiyang, 2008). These low-cost, unmanned air vehicles are equipped to take high resolution images form low altitudes and minimal interference from clouds. Haiyang, et al. (2008) is conducting research at Utah State University's Cache Junction farm, where UAVs are being used to capture images of vegetation type and soil moisture in real time for determining efficient irrigation schedules. Once the images are captured, they are then overlaid onto an aerial image taken from a manned aircraft. The outcome of this study determined that for optimal real-time monitoring of a crop or farm, multiple UAVs would need to be utilized, however with developing technology this is a viable and cost effective solution for efficient irrigation scheduling.

Effective irrigation management is being achieved by the utilization and implementation of GIS software (including ArcGIS), GPS sensors, satellite-based remote sensing and more recently the use of UAVs. By utilizing these technologies, irrigation managers are able to create and build mapping tools to allow for improved identification of favorable sites of potential groundwater sources, eliminating the guess-work from the process of scouting cropland locations. A reduction of overall water usage is achieved with the use of real-time crop monitoring through satellite-based remote sensing, which allows farmers to deliver water to isolated areas that are in need of irrigation (not just throughout the field as a whole). Developing technology will soon allow farmers to have real-time aerial images of their crops through the use of UAVs, which could potentially aid in an even more efficient irrigation schedule, reducing the amount of wasted water through evaporation.

Pest Management (Bonifas)

Another part of the overall issues of maximizing crop yield, maintaining low operating costs, and compliance with environmental regulations, is the management of crop damage caused by various pests. Certain insects, rodents, birds and the like can affect crop yields in a negative way.

The research team of Carrière et al. (2006) sought to understand the effects that different patterns of crop fields had on insect pest populations. Once insect pest behavior and population density changes in different cropping patterns was understood, cropping patterns could then be optimized to minimize insect pest population density, without the use of pesticides and other similar pest management methods. Data was gathered from a large agricultural community in Pinal County, Arizona containing a sample set of 50 fields of one of four pre-selected crop types, and was sampled weekly. Location and area of agricultural fields were determined with global positioning system (GPS) technology.

Fields that had been irrigated or sprayed with pesticides were not sampled for that week. Statistics of the weekly sampled data were generated, GIS maps of the selected fields were created, and then both were analyzed, the team looking for inherent patterns of pest density. The results showed that fields with lots of weeds increased insect pest density, as did certain cropping patterns. Other cropping patterns decreased insect pest density, and subsequently reduced cotton crop damage.

Recently, transgenic crops have been introduced as another way of combatting pests and diseases, while improving crop yields. Transgenic crops are Genetically Modified Organisms (GMOs) that have had genes from other plant and/or animal species inserted into their genomes, giving them special characteristics, such as the ability to develop toxins inside them that are non-toxic to humans but toxic to common insect pests. Unfortunately, it has been discovered that insects that feed on these plants have the potential to rapidly adapt to and become resistant to the plants' defenses. Accordingly, the EPA has launched several insect resistance management programs, the basis of which is that the speed of heritability of resistance (the resemblance between resistant parents and their offspring) can be substantially slowed down when special plots of a non-transgenic crop, called "refuges", are planted near the transgenic fields, thereby delaying the evolution of resistance. However, it has been a challenge for the EPA to determine if farmers are complying with refuge guidelines.

According to Carrière et al. (2005), a field crew has been mapping the position of cotton fields, and collecting information from producers on cotton type grown in these fields, since 1998. So far, about 85% of Arizona's cotton fields have been mapped to within 10 meters using

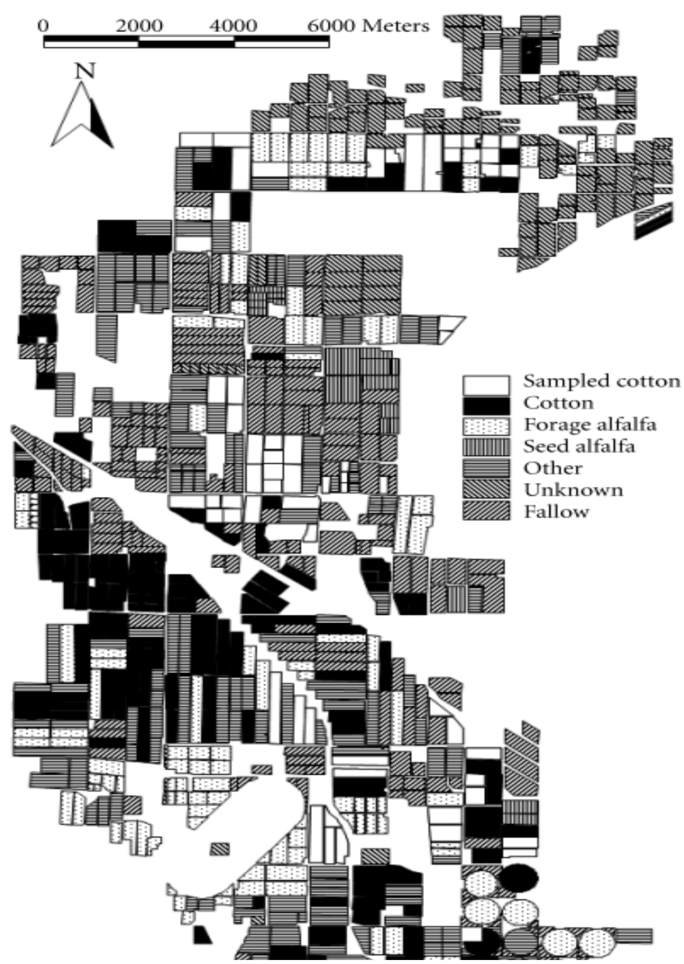
GIS technology, and 15% to within 100 meters using micro-surveyors. During the first year the field crew was in operation, refuges were categorized as external or in-field; starting in 1999, refuges were categorized as external, embedded, or in-field. Once a year the GIS data collected was validated by comparing it with paper maps created by ground measurements.

Carrières' team developed software that, using the field crews' GIS maps as input, calculates regional compliance to EPA refuge guidelines. The software focuses on each transgenic cotton field in a region. It then evaluates the region for EPA compliance.

Evaluation of the data generated by the software showed that transgenic cotton fields with embedded and in-field refuges were always within EPA compliance.

Fig. 4

GIS map of the region sampled for *Lygus hesperus* in central Arizona. Carrière, Y., P. Ellsworth, P. Dutilleul, C. Ellers-Kirk, V. Barkley, and L. Antilla 2006. A GIS-based approach for areawide pest management: the scales of Lygus hesperus movements to cotton from alfalfa, weeds, and cotton. Entomologia Experimentalis et Applicata 118 (3): 203-210.



Methods (Bonifas, Lim, Singh)

In order to determine geospatial technologies and other information used within Maricopa County, AZ regarding fertilizer, irrigation and pest management, Erica and Parul conducted phone interviews asking two-part questions to determine what technologies were in use and what technologies are being considered for future use. The questions used were:

- What types of geospatial and GIS technologies are currently being used by within Maricopa County agriculture, specifically for fertilizer, irrigation and pest management?
- Are there other technologies or types of data or information you use in your agency's planning and management activities related to agriculture?

The questions were directed at contacts within Agribusiness & Water Council of Arizona, Arizona State Association of Conservation Districts, Arizona Farm Bureau, Arizona Department of Agriculture, Arizona Department of Water Resources and professors at Arizona State University and University of Arizona. Information used was compiled from a phone interview Parul had with Julie Murphee, Director of Communication, Arizona Farm Bureau and email interview with Keith Larson, Arizona State GIS Specialist, USDA-Natural Resources Conservation and also through an email interview Erica conducted with Executive Director, Steve Barker of Arizona State Association of Conservation Districts and through phone interviews with Irrigation

Specialist, Eduardo Enriquez of Arizona Department of Water Resources, Assistant Director, Susan Chase of Arizona Department of Agriculture Service.

Erica also spoke with Chris Udall, Executive Director at Agribusiness & Water Council of Arizona (his field of expertise is primarily within policy management, specifically working with over 20 irrigation districts, Central Arizona Project and Salt River Project managers), Mr. Udall was able to direct Erica and Parul to the contacts who may have more information, (Table 1) in both private industry and public learning institutions.

Table 1 (Parul)

Contacts	Title	Agency	Notes
Chris Udall	Executive Director	Agribusiness & Water Council of Arizona	Comments incorporated in the body
Donald Slack	Professor of Agriculture and Biosystems Engineering and Watershed Management and Eco-Hydrology	The University of Arizona	Comments incorporated in the body
Eduardo Engurez	Irrigation Specialist	Arizona Department of Water resources	Comments incorporated in the body
George Cairo	CEO	George Cairo Enigneering	Unable to contribute information
George Jones	Program Director	U.S. Department of Agriculture	Unable to contribute information
Julie Murphree	Director of Communications	Arizona Farm Bureau	Comments incorporated in the body
Keith Larson	State GIS Specialist and Cartographer	Natural Resources Conservation Service	Comments incorporated in the body

Netra Chetri	Associate Professor at School of Geographical Sciences and Urban Planning	Arizona State University - School of Geographical Science & Urban Planning	Unable to contribute information
RimJhim Aggarwal	Associate Professor at School of Sustainability	Arizona State University - School of Sustainability	Unable to contribute information
Soe W. Myint	Associate Professor at School of Geographical Sciences and Urban Planning	Arizona State University - School of Geographical Science & Urban Planning	Unable to contribute information
Steve Barker	Executive Director	Arizona State Association of Conservation Disricts	Comments incorporated in the body
Susan Chase	Assistant Director	Arizona Department of Agriculture	Comments incorporated in the body

While conducting phone interviews, John examined state websites to obtain additional information pertaining to the practices of precision agriculture within Maricopa County. The method John used for his research are as follows. He used the specially crafted Google Scholar query below: +(gis OR " geographic information ") +agriculture +arizona + [pest | irrigation | fertilizer] where he used one of the three words - pest, irrigation, fertilizer – for each focus. He then used this query to find his most valuable sources, two of which were the articles by Carrière on the use of GIS technology to improve the shape and placement of cotton crop fields in Arizona, and the use of GIS technology to improve EPA refuge field compliance.

Results (Bonifas, Lim, Singh)

Geospatial and GIS technologies are currently being utilized in Maricopa County agricultural management. GPS is currently the most widely used technology, however the applications and methods vary. In an interview conducted by Parul, Julie Murphee, Director of Communications at Arizona Farm Bureau, indicated that GPS is utilized in the form of plant monitoring with the purpose of determining need for fertilizer or pesticides in a precise location or area of crop. This also corresponds with the information obtained from Erica's phone interview with Irrigation Specialist Eduardo Enriquez (AZDWR), who described how GPS is used in crops to calculate the slope of the field and better determine water flow, which allows for more accuracy in water application. Although Assistant Director Susan Chase (Arizona Dept. of Agriculture) wasn't able to comment directly regarding specific GPS practices in agriculture, she said that there was a long history of irrigation controllers similar to this technology being used on Arizona golf courses. In terms of irrigation, GPS technology has been utilized in Maricopa County for decades, just not in agriculture.

GPS is also being utilized by farmers in mobile applications and on board guided tractors. In an email from Steve Barker, Executive Director, Arizona State Association of Conservation Districts, wrote that:

> "GPS equipped tractors are being utilized by farmers to allow data to be gathered as the crop is being harvested (monitoring yield and capturing location of yield) for later mapping. This allows farmers to pinpoint areas that need

> fertilizer and then utilize the GPS tool to automatically apply the fertilizer when the tractor is in the location. GPS is also used when the crop is on drip irrigation, as it allows for precise planting of seeds without damaging existing irrigation lines. In the case of flood irrigation. Aircraft is equipped with GPS which is utilized during the application of pesticides to only treat targeted areas, avoiding unintentional spraying to wildlife areas, lakes and streams."

GIS technology is currently being utilized in Maricopa County agriculture. According to the email interview Parul conducted with Keith Larson (AZ GIS Specialist, USDA, NRCS):

> "We have 23 field offices that work with land owners and agricultural producers. These folks also use GIS with a front end in house developed software product. This software manages the producers conservation plans and maps."

Additionally, we found that raster and aerial images are being utilized to aid in irrigation and pesticide application by identifying areas in need. As indicated through the email interview, Steve Barker as he stated:

> "The imagery is overlaid with digitized soil maps to provide a base map for conservation and to better determining crop stress (lack of moisture, disease, insects). GIS is also used to identify patterns and amounts of vegetation on the ground."

In his website research, John found that GIS and GPS technologies have enabled the use of VR (Variable Rate) technology in the applications of fertilizers to major crop production systems, with significant success, according to the College of Agriculture, University of Arizona website. VR fertilizer input has produced average relative economic returns of $25 per hectare over traditional fertilizer application processes. VR fertilization processes also resulted in better phosphorous fertilizer management because they applied 12 to 41% less fertilizer than traditional methods. A decline in the amount of variability in soil test phosphorus was also observed.

GIS and GPS technology was used in the development and application of the AgIIS irrigation system, which, unlike satellite based sensor systems, gives the farmer better control over when and how much water to apply to crops.

According to the Department of Agricultural and Biosystems Engineering, University of Arizona website, John also found that pest density was significantly reduced in areas where GIS technology was used to place and shape crop fields. GIS software analysis showed that forage and seed fields, as well as fallow fields densely populated with weeds, acted as sources of pest density. Use of GIS technology to measure compliance with EPA refuge field guidelines increased compliance measurement accuracy over traditional measurement methods to 92% or higher.

Conclusion (Bonifas, Lim, Singh)

Precision agriculture in Maricopa County is made possible by the implementation of geospatial technologies and GIS. Through these new technologies, individuals and organizations will be able to make more informed decisions, allowing them to accurately determine the needs of their crops and pinpoint the focus of resources to maximize crop yield and benefit while reducing resource waste and land degradation. By utilizing GIS-based Fertilizer Decision Support System technology, easy identification of nutrient levels in soils or soil deficiencies will allow farmers to focus the application of fertilizer on crops. The use of software such as ArcGIS combined with satellite imagery allows for potential sites with groundwater availability to be identified, while UAV technology can provide real-time monitoring of crops, both technologies aiding in allocating appropriate water levels for irrigation. In Maricopa County GIS is also used in determining insect/pest level density to through aerial imagery identify areas of pesticide application. The utilization of geospatial technologies within agriculture is a rapidly growing trend, one which will allow those who use it to achieve much more efficient farming practices.

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