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DEVELOPMENT OF PLANT CULTIVATION USING PRECISION AGRICULTURE

ROZWÓJ UPRAW ROŚLIN Z ZASTOSOWANIEM ROLNICTWA PRECYZYJNEGO

Summary: *Processed aerial and satellite photographs, adjusted to the points of geodesy base in a specified coordinate system occur in a form of ortofotomaps. Satellite systems make possible to obtain information about soil structure and different types of crops including feed plants; owing to precision agriculture we may obtain not only obtain very high and good quality yields but also have an influence on limiting of natural environment pollution and reduction of production costs. Obtaining data by using teledetection methods are integrated with information concerning spatial variability of soil and plants, which comes from register units provided recording of changes of different parameters, heaving importance from the point of view application in precision agriculture. IACS computer system, contribute to the development of precise agriculture by steering of farm machinery during field work, doing monitoring of biomass and crop yields, soil sampling, dosing of mineral fertilizers and pesticides, field crops measurement, monitoring of animals, generation of field parcels ID, monitoring of farm machinery work. Besides that it can rationalize process of payments management concerning IACS computer system, contribute to the development of precise agriculture by steering of farm machinery during field work, doing monitoring of biomass and crop yields, taking soil samples, dosing of mineral fertilizers and pesticides, field crops measurement, monitoring of animals, generation of field parcels ID and monitoring of farm machinery work.*

Key words: *precision agriculture, agricultural engineering, ecology, cultivation, control, satellite systems, aerial photographs, GPS, monitoring, digital maps, fertilization, harvesting, progress*

Streszczenie: *Przetworzone zdjęcia lotnicze i satelitarne, dostosowane do punktów bazy geodezyjnej w określonym układzie współrzędnych występują w postaci ortofotomap. Systemy satelitarne umożliwiają uzyskiwanie informacji o strukturze gleby i różnych rodzajach upraw włącznie z roślinami paszowymi, a także dzięki rolnictwu precyzyjnemu nie tylko uzyskuje się bardzo wysokie i dobrej jakości plony, ale także wpływa się na ograniczenie zanieczyszczenia środowiska naturalnego i zmniejszenie kosztów produkcji. Uzyskanie danych za pomocą metod teledetekcyjnych jest zintegrowane z informacją o przestrzennej zmienności gleby i roślin, która pochodzi z jednostek monitorujących wykonujących rejestrację zmian w czasie, co ma znaczenie z punktu widzenia stosowania rolnictwa precyzyjnego. Poza tym może zracjonalizować proces zarządzania płatnościami w systemie komputerowym IACS, przyczynić się do rozwoju rolnictwa precyzyjnego na większą skalę poprzez sterowanie maszynami rolniczymi podczas prac polowych, monitorowanie biomasy i plonów, pobieranie próbek gleby, dozowanie nawozów mineralnych i pestycydów, pomiary upraw polowych, monitorowanie ilości zwierząt w gospodarstwie i monitorowanie pracy maszyn rolniczych.*

Słowa kluczowe: *rolnictwo precyzyjne, inżynieria rolnicza, ekologia, uprawa, kontrola, systemy satelitarne, zdjęcia lotnicze, GPS, monitoring, mapy cyfrowe, nawożenie, zbiory, postęp*

Introduction

Precision agriculture is the title given to a method of crop management owing to which areas of crop within a field may be managed with different levels of input depending upon the yield potential of the crop in that particular area of land. The benefits of so doing are as follows: cost of producing the crop in the discussed area can be reduced and the risk of environmental pollution from agrochemicals applied at levels higher than those required by the crop can be reduced as well (Earl et al, 1996). Precision agriculture is an integrated agricultural management system incorporating several technologies. The technological tools often include the global positioning system, geographical information system, yield monitor, variable rate technology and remote sensing. Literature review shows that there are quite a lot of problems to be solved by utilization of precision agriculture.

The global positioning system GPS is a network of satellites developed by the U.S. Defense Department shown on figure 1. The GPS constellation of 24 satellites, orbiting the earth, transmits precise satellite time and location information to the ground receivers. The ground receiving units are able to receive this location information from several satellites at a time for use in calculating a triangulation fix thus determining the exact location of the receiver.

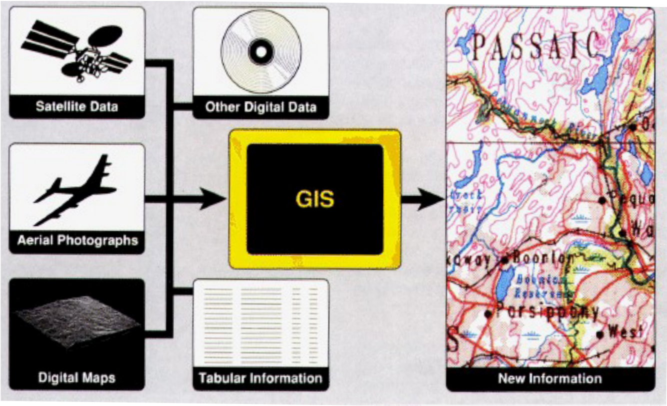
Fig. 1 Global Positioning System (GPS)

Source: United States Department of Agriculture (USDA), 2010

Formerly, agronomic practices and management recommendations have been developed for implementation on a field basis. This generally results in the uniform application of tillage, fertilizer, sowing and pest control treatments at a field scale. Farm fields, however, display considerable spatial variation in crop yield, at the field scale. Such uniform treatment of a field ignores the natural and induced variation in soil properties, and may result in areas being under- or over-treated, giving rise to economic and environmental problems.

The more substantial of these problems include: economically significant yield losses, excessive chemical costs, gaseous or percolator release of chemical components, unacceptable long-term retention of chemical components and a less than optimal crop growing environment. A geographical information system GIS consists of a computer software data base system used to input, store, retrieve, analyze, and display, in map-like form, spatially referenced geographical information in figure 2.

Fig. 2. Data integrated through a geographical information system (GIS)



Source: [United States Department of Agriculture (USDA), 2010]

Precision agriculture offers a remedy to many of these concerns. The philosophy involves matching resource application and agronomic practices with soil properties and crop requirements as they vary across a site. Precision agriculture involves the observation, impact assessment and timely strategic response to fine-scale variation in causative components of an agricultural production process.

Therefore, precision agriculture may cover a range of agricultural enterprises, from dairy herd management through horticulture to field crop production. The philosophy can be also applied to pre- and post-production aspects of agricultural enterprises. With this definition in mind, the present attention is focused on applying precision agriculture in field crop production systems. The term 'site-specific management' describes precision agriculture.

Collectively, these actions are referred to as the "differential" treatment of field variation as opposed to the "uniform" treatment underlying traditional management systems. The result is an improvement in the efficiency and environmental impact of crop production systems. Elaboration of precision digital maps concerns fertilization (mineral fertilizer, liquid fertilizer, manure spreading), sowing, spraying, on the basis of field soil tests. In a similar way, the elaboration of digital maps of yield concerns different crops. Also it is important to collect yield models from different farm machinery such as corn and fodder harvesters of different models and companies.

It is important to have data concerning plots' area, exclusion of fields' area, dividing on cultivation groups, plot localization regarding to registries' plots. As an example of measurement unit, we may mention DGPS Crescent with accuracy of position evaluation to better than 60 centimetres at 95 percent of working time of a measurement apparatus at frequency 10 Hz (10 measurement points per second). It is possible to obtain measurement accuracy lower than 2 percent, but in practice, it can be achieved in the range from 0.5 to 0.9 percent. Elaborated maps contain a few layers as it is shown in figure 3.

Besides that, it is a rationalized process of payment management concerning IACS computer system and also contributing to the development of precision agriculture by steering of farm machinery during field work, they doing monitoring of biomass and crop yields, soil sampling, dosing of mineral fertilizers and pesticides, field crops measurement, monitoring of animals, generation of field parcels ID and monitoring of farm machinery work.

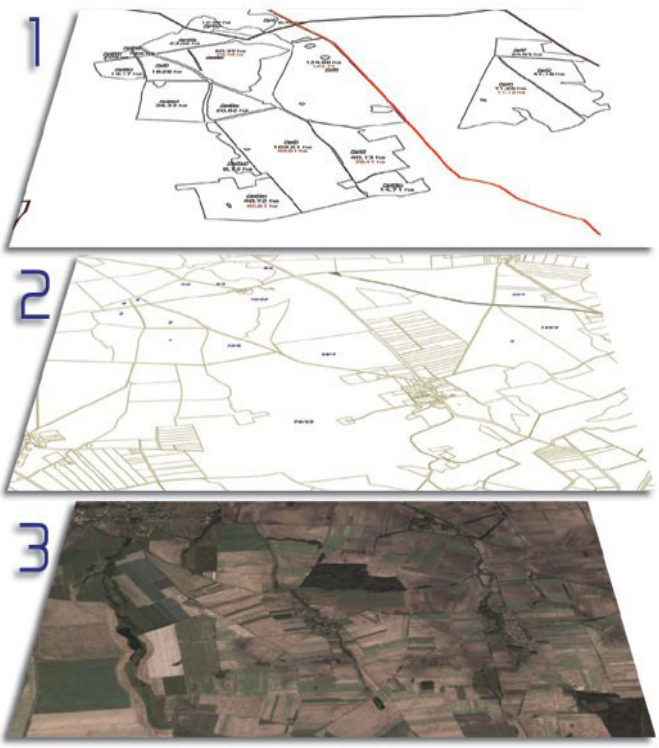
Processed aerial and satellite photographs, adjusted to the points of geodesy base in specified coordinate system occur in a form of ortofotomaps. Precision agriculture warrantees not only obtaining very high and good quality yields but also has an influence on limiting of natural environment pollution and reduction of production costs. Aerial photographs adapted to the form of ortofotomaps can be purchased in Geodesy and Cartography Centre in Warsaw at a price of 700 PLN for 500 hectares of the land concerned [Barwicki, 2011].

Precision agriculture depends on circumstances in which we want to introduce modern organization, technology and knowledge. First of all is to check resources. Digital maps of plots will be utilized for different field work, but their proper area can be used for direct payments from EU. [Barwicki, 2011] Soil tests on the farm are recommended by Good Agriculture Practice and it can be also utilized for both purposes.

The goal of precision agriculture

The goal of precision agriculture is to gather and analyze information about the variability of soil and crop conditions in order to maximize the efficiency of crop inputs within small areas of the farm field. To meet this efficiency goal the variability within the field must be controllable. Efficiency in the use of crop inputs means that fewer crop inputs such as fertilizer and chemicals will be used and placed where needed. The benefits from this efficiency will be both economical and environmental.

Fig. 3. Elaboration of digital layer maps for different plants cultivation purposes as: sowing, fertilization, harvesting and yield evaluation



Source: [TPI Agrisystem, 2011]

Development of environment protection

Environmental costs are difficult to quantify in monetary terms. The reduction of soil and groundwater pollution from farming activities has a desirable benefit to the farmer and to society. If maps of the spatial distribution of soil productivity potential (maps of the expected yield) and maps of the spatial distribution of plant nutrients available from the soil are developed for a field, fertilizers and organic wastes can be applied in amounts per acre that are directly proportional to the soil's expected yield and adjusted for the soil's fertility at any location in the field. Such a procedure would optimize the economic potential of a field, yet minimize the leaching of nutrients.

The above protocol depends on having a good map of the spatial variation of expected yields for crop fields. Maps of past crop yields for a field could be used for this purpose. However, multiple years of spatial yield data would be needed to overcome variations caused by year to year differences in weather, especially rainfall, and there are multiple factors which result in lack of year to year correlation. An alternative to mapping of actual crop yields would be to use remote sensing to determine spatial distribution of plant status (health or efficiency) and the subsequent expected yields.

A major advantage of this approach is that remote sensing can provide a current assessment of the overall plant health of the crop rather than relying on past history of yields. Several different approaches exist for using remote sensing data for this purpose. Most of the commonly recognized techniques depend on measuring the greenness of the field.

Typically, this involves some relationship comparing the reflectance of a visible band (such as red light) to the reflectance of a near-infrared band. Since green vegetation has a very sharp change in reflectivity across this range and other materials do not, virtually any technique will in fact detect it. The approach suffers from several defects.

Fig. 4. Aircraft NASA jet equipped in ATLAS scanner - left

Source: [NASA Stennis Space Center, 2010]

For example, it is a relative technique and can be significantly affected by soil conditions. It have been pursued a different path in this research. It have been examined the thermodynamic efficiency of the crop.

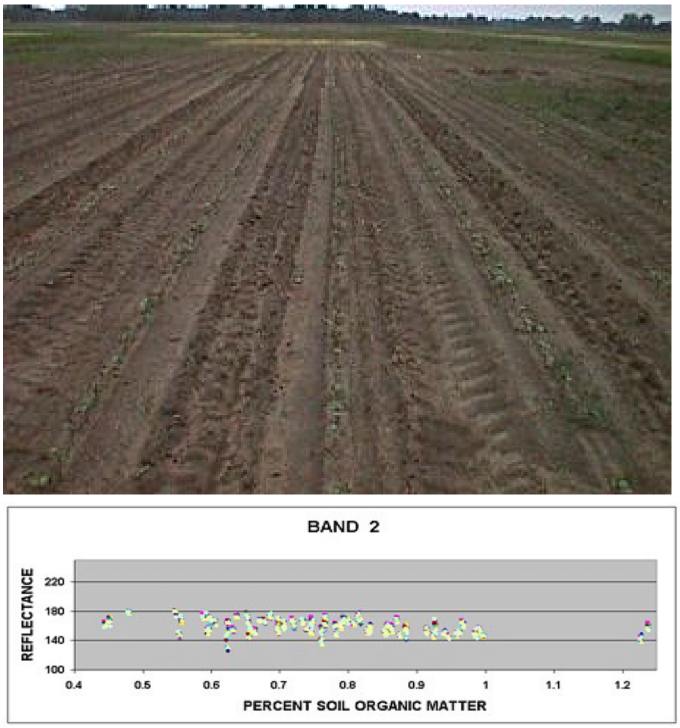
The core of this approach depends on energy in the thermal-IR. This experiment relied on the study of the energy budget of the crops and obtaining a relationship between multi-temporal thermal imagery and crop yield. The precision agriculture study utilizes the advanced thermal and land applications sensor ATLAS remote sensing instrument flown on the NASA Lear jet figure shown in figure 4.

ATLAS is able to sense 15 multispectral radiation channels across the thermal - near infrared - visible spectrums. The sensor also incorporates onboard, active calibration sources for all bands. Atlas is capable of approximately 2.0 meter resolution per pixel when flown in NASA's Lear jet and sees about a 30 degree swath width to each side of the aircraft.

The position of the aircraft, its orientation and the sensor orientation are all recorded at least once a second. The active calibration and record of position mean it is possible to accurately and reproducibly measure the field plots while flying in a jet aircraft.

A tremendous amount of data is collected on each flight, and must be processed by investigators prior to conducting research on the imagery. The data must be corrected for geometric abnormalities due to flight path variations, and must be radio metrically calibrated. These raw sensor scan lines are then reconstructed into a two dimensional image data set.

Fig. 5. Soil organic matter tests at Wiregrass Experiment Station



Source: [Auburn University, Headland, Alabama, USA, 2009]

Knowing that the data is an image, the scientist is able to begin data inquiries. This is typically done by creating false colour images based on 3 spectral channels from the sensor. Dependent on whether vegetation health or soil characteristics are of concern, differing channels of the data will be combined. Data from one channel is assigned to shades of red, another to those of green and a third to the blue ones.

The discussed pictures then visually reveal a tremendous amount of information to the investigator. Our remote sensing is driven by the biology and physics of the crop and the soil. We need visible and near infra red bands for several reasons. Vegetation has a very strong reflectance feature at 0.7 microns see the plot of typical reflectance curves in figure 5.

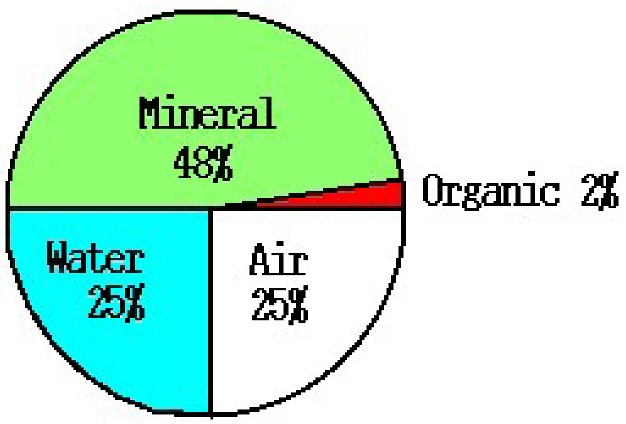
A pair of bands which bracket this can be used to determine the amount of green vegetation. Clay minerals have a strong absorption feature in the 2.2 micron region. Comparison of a 2.2 micron band with a 1.6 micron band is therefore sensitive to clay. Iron, as hydrated iron oxides, has a high reflectivity in the red portion near 0.7 microns of the spectrum and a reflectance depression near 0.8 microns. Bands which cover these features can measure iron content. Thermal bands are used for completely different reasons. Plants cool themselves by evaporating of water. Some of plants which are warm and the other ones, which are cool show up differently in thermal bands.

Crop stage, spatial resolution, seasonal and daily weather conditions must be controlled. For example spatial resolution in the 2-5 meter range was chosen, avoiding many complexities caused by aliasing crop row spacing at higher resolutions yet finer than the harvester's tightest recording rate. This dictates use of an airborne system.

Use of an airborne system also makes scheduling around weather much simpler than use of satellite data. Active video calibration was recognized as essential if quantitative measures were ever to be obtained or reproduced. The system would also have to have onboard geometry recorded during data acquisition.

There are a limited number of sensor/aircraft combinations that provide the needed features. There is presented a currently available system that meets all of these criteria and is called the Atlas scanner, flown out of NASA Stennis Space Centre.

Fig.6. Components of a loamy Alabama soil in ideal condition for plant growth. Source:



[Wiregrass Experiment Station, Auburn University, Headland, Alabama, USA, 2009]

Soil composition ang moisture

With remote sensing we can estimate many important properties of the soil. The organic carbon content can be estimated from albedo. Clay, iron and other mineral contents can also be estimated. While nutrients are important to plant growth, more critical to their vitality is plant available moisture. Water is essential for the transport of nutrients to and from the plant. This transport occurs laterally within the soil, and vertically within the plant.

Water therefore, is the lifeblood of the system. Without sufficient moisture, photosynthesis is impossible. Perhaps more importantly is a proper balance of available water. Root systems of plants also require air in order to survive, with too much water, plants will literally drown. Components of a loamy Alabama soil in ideal condition for plant growth are presented on figure 7.

Remote sensing in precision agriculture

Remote sensing refers to the process of gathering information about an object, at a distance, without touching the object itself. The most common remote sensing method that comes to most people's minds is the photographic image of an object taken with a camera. Remote sensing has evolved into much more than looking at objects with our eyes.

It now includes using instruments, which can measure attributes of the objects. Photogrammetric and remote sensing is the technology of obtaining reliable information about physical objects and the environment, through a process of recording, measuring and interpreting imagery and digital representations of energy patterns derived from noncontact sensor systems [Colwell, 1997]. Remote sensing may be broadly defined as the collection of information about an object without being in physical contact with the object. Aircraft and satellites are the common platforms from which remote sensing observations are carried out.

The term remote sensing is restricted to the methods that employ electromagnetic energy as the means of detecting and measuring target characteristics. Remote sensing is the information obtaining from a distance about the objects or phenomena without being in physical contact with them. The science of remote sensing provides the instruments and theory to understand how objects and phenomena can be detected. [Aronoff, 1995].

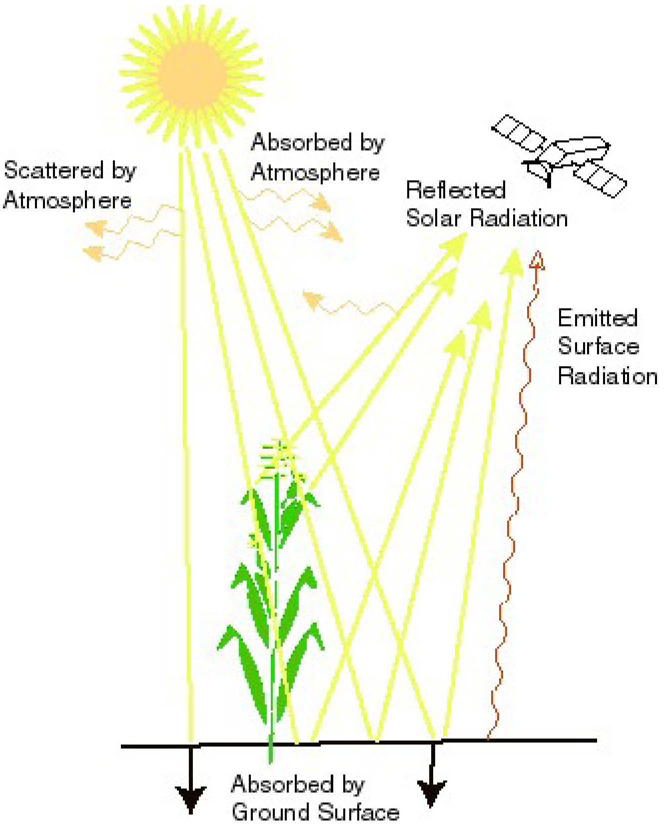
Satellite images have been used to monitor the degradation and pollution of the environment. These images also can be used to assess the damage of floods and natural disasters, assist in forecasting the weather, locate minerals and oil reserves, locate fish stocks, monitor ocean currents, assist in land use mapping and planning, produce geologic maps, and monitor range, forestry and agricultural resources.

Utylization of electromagnetic spectrum

All objects including plants and soil emit and/ or reflect energy in the form of electromagnetic radiation. Electromagnetic radiation travels in waves propagating through space similar to that shown in figure 9. Three major components of these waves are frequency, amplitude and wavelength. Frequency is the number of cycle crests passing a point during a given period of time. One cycle per second is referred to as one hertz. Amplitude is the energy level of each wave measuring the height of each wave peak. Wavelength is the distance from the top of one wave peak to the top of the following wave peak.

It is the sun that most often provides the energy to illuminate objects as we can see in figure 7. The sun's radiant energy strikes an object on the ground and some of this energy that is not scattered or absorbed is then reflected back to the remote sensor. A portion of the sun's energy is absorbed by objects on the earth's surface and is then emitted back into the atmosphere as thermal energy.

Fig. 7. Absorption and reflection of electromagnetic radiation concerning soil surface and plant



Source: [USDA, 2010]

The visible light portion of the electromagnetic spectrum ranges from 0.4 micrometers ("µm") (shorter wavelength, higher frequency) to 0.7 µm (longer wavelength, lower frequency). This is the frequency range of light that the human eye is sensitive to. Every object reflects, absorbs and transmits electromagnetic energy in the visible portion of the electromagnetic spectrum and also other non-visible frequencies.

Electromagnetic energy which completely passes through an object is referred to as transmittance. Our eyes receive the visible light reflected from an object. The non-visible infrared spectral region lies between the visible light and the microwave portion of the electromagnetic spectrum. The infrared region covers a wavelength range from .7 µm to 14 µm.

Disccusion and conclusions

- Remote sensing collect data on energy reflected from the surface of plants and soil. The physics used in remote sensing technology is very complicated. Farm operators will be dependent upon professional engineers and precision farming consultants to process the raw image data into useable information for making management decisions. There is an abundance of remote sensing technology available to measure variability in plants and soils. Also, there is a shortage of information about the causes of plant condition variability and the management solutions needed manage variability to improve crop production. The lack of knowledge needed to answer these variability questions is restricting the development of precision farming management decision support systems.
- The concept of precision agriculture has emerged over the past 15 years with the introduction of new electronic equipment which has allowed farmers to increase the efficiency of their operations and develop new farming practices. However, the investment in precision agriculture equipment represents a significant financial outlay and as with all 'high-tech' equipment it can become superseded relatively quickly and therefore does not tend to hold its capital value. When deciding what equipment to purchase farmers need to understand the capabilities of currently available equipment as well as the likely evolution of the technology in order to 'future proof' their investment. This presentation looks at a number of technologies that are being used on a commercial basis in agriculture today and some research that is being conducted by universities into the technology of tomorrow.
- Most precision agriculture equipment is based around the Global Navigation Satellite System (GNSS). The United States and Russia are planning updates to their systems, while the European Union and China are planning to launch their own systems. This will significantly improve the accuracy and robustness of satellite navigation but will require new receivers to be purchased, however, the timeframe of the upgrade is around 10 years so may not influence purchasing decisions in the short term.
- There is a major push from farmers and equipment manufacturers for standardisation between different precision agriculture equipment and the associated data. This has led to the development of the ISOBUS 11783 standard which outlines both the hardware requirements in terms of plugs and wiring as well as the communication protocols so that equipment from different manufacturers can interact. Manufacturers are well down the path of meeting the standard with a lot of commercially available equipment already compliant. It is recommended that farmers should now look to purchase only ISOBUS compatible equipment to ensure maximum functionality into the future.
- Electronic monitors and controllers have long been utilised with boom sprayers, from simple running totals to today's automatic boom section controllers. Research is being conducted into further advancing application control across the boom, driven by increasing boom widths and wider travel speeds. A lot of this work is centred on controlling the application rate and spray pattern of individual nozzles. Another line of research is based around further advancing the concept of weed identification and automatic spot spraying. Systems are being developed that can identify and even differentiate plant species. This research is also closely tied to 'Micro Spray' research whereby several different systems are being developed to target and control weeds on a finer scale or individual basis. Given that an increasing proportion of cropping system is converting to minimum and no-till with the associate heavy reliance on bigger boom sprayers, it should be considered actively contributing to this major research effort.
- Advances in digital technology and sensor systems over the past decade have resulted in a great deal of research and development of more intelligent agricultural vehicles capable of automation tasks with minimal operator input. The ultimate aim is to remove the human operator all together and have tasks completed autonomously. While most of the hardware and control systems are already a reality, issues of machine interaction with an essentially unpredictable environment still need to be addressed. It is generally accepted that autonomous operations will need to be conducted by a number of small machines which interact to

complete a task rather that one large machine. This not only improves the safety aspects but also offers greater flexibility in terms of scalability. It should also be a part of this research effort as there are many operations in our farming systems which could greatly benefit from this technology.

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