Chapter 23
Providing Precision Crop and Range Protection in the US Northern Great Plains

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Abstract Faculty, students, and staff from eight universities in the U.S. Northern Great Plains formed the Upper Midwest Aerospace Consortium (UMAC) to lead a regional transition to sustainability. One major focus was on agriculture, an important part of the region's economy and social structure. By forming a learning community in concert with farmers and ranchers, UMAC has made information an asset as valuable as land, labor, and capital. One primary source of information combined with traditional sources is remotely sensed imagery. UMAC has created an end-to-end operation, starting with data acquisition by airborne and orbiting sensors customized to acquire data needed to meet producer demands, proceeding to development of value-added products, and finally making them readily accessible on the WWW to non-expert users whom we also train. A specific example of the operation in action illustrates the economic and environmental benefits that result.

1 Introduction

Humanity has arrived at a moment of historic change. The number of people in the world and their collective ability to modify the planet and its living inhabitants have introduced the Anthropocene (Crutzen 2002), a geologic epoch dominated by the single species, *Homo sapiens*. Decisions we make now at the onset of this epoch will have consequences for many generations beyond ours. The historic transition the times demand is one to sustainable practices. Since food is a basic human need, agriculture is and will continue to be a foundation of civilization. It follows, therefore,

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that agriculture, too, must change, and that decisions about how to transition it toward sustainability cannot be delayed (Brown 2009).

With that in mind, researchers and educators at eight universities in the northern Great Plains of the United States organized a collaboration called the Upper Midwest Aerospace Consortium (UMAC). The member institutions are the Universities of North Dakota, Montana, Idaho, and Wyoming; South Dakota and Montana State Universities; Sinte Gleska University; and the South Dakota School of Mines and Technology. A driving purpose for the consortium was to assemble both the depth in numbers and breadth in expertise needed for the multi-disciplinary cause of sustainability. A second purpose was to have the capability to customize products and services to specific locations within the wider region. Finally, by forming a distributed organization, UMAC offers access nodes throughout the region so that residents can interact with familiar, local institutions.

Interaction with residents is crucial to the consortium's core mission of sustainability. The challenge is to foster actions that deliver economic benefits now to people who undertake them, while simultaneously delivering benefits to generations not born by sustaining a healthy environment. The method was to create a learning community in which people were encouraged to share their expertise without regard to whether it was acquired through formal education or practical experience (Seelan et al. 2003). A major difference, then, is that agricultural producers are treated as research partners, not as clients. The actual applications that emerge from this inclusive partnership are carried out on farms and ranches in for-profit production. That entails working with agroecosystems, with all their complexity but also with none of the artificiality of controlled experiments. The weakness of the latter is that knowing how components of a system behave when examined individually does not necessarily indicate how the full system will behave when all components are unconstrained. In essence this philosophy accepts crops or livestock as the true biophysical integrator of their environment.

Building a learning community focused on initiating sustainable practices in agriculture was a four-step process. First, UMAC had to create an Environmental Information Bridge. The analogy with a bridge indicates that information flows both ways between producers and researchers. Crucial is to work on challenges or opportunities that producers identify. Knowing the needs of producers leads to a second step, research and development of a kind that is benefits-driven, not purely curiosity-driven. Research relies on use of data, so the consortium's third step was to design, build, and operate data acquisition and data dissemination technologies. Finally, training has to be provided so that consumers of the research and its developments know how to turn them into profitable and environmentally benign actions (Seelan et al. 2007).

The following sections describe how information was incorporated into farm and ranch management strategies, which is to say they describe how precision agriculture was encouraged. A report by the U.S. National Research Council (Sonka 1997) "defines precision agriculture as a management strategy that uses information technologies to bring data from multiple sources to bear on decisions associated with crop production." This became UMAC's working definition.

A significant thrust of UMAC was to synthesize remotely sensed information with that from many other sources to enable wiser decision-making by farmers and ranchers. ZoneMAP (Section 2) automatically characterizes farms' and ranches' heterogeneity. Heterogeneity in evapotranspiration on a farm exemplifies site-specific management of corn yield (Section 3). Methods to assist ranchers to make informed decisions about livestock carrying capacity are described in Section 4. Critical to all UMAC's decisions is Digital Northern Great Plains (Section 5), a system for providing convenient access to the information generated. Since an ultimate goal is to customize products and services to each individual producer's needs, UMAC developed and operates sensors designed specifically to meet the agricultural needs of our region (Section 6). A farm that may be a harbinger of precision crop protection (Section 7) illustrates how all the consortium's activities are brought together. Lessons Learned (Section 8) concludes the chapter.

2 ZoneMAP: Defining Heterogeneity in Crop and Range Lands

Precision agriculture has been made possible by modern technologies on farm implements that permit treatments applied to farms or ranches to be varied. The Global Positioning Satellites (GPS) system allows specification of precise location within a field, and onboard computers can regulate the flow of the treatment being applied. In addition, combines and other harvesting implements can record yields as a function of location. Farming has become, to a large extent, management of variations rather than management of average properties.

The power of the new technologies can only be utilized if a producer knows what the appropriate rate at which an input – of seeds, fertilizer, herbicide, pesticide, irrigated water, or other – should be applied at every location. Zone Mapping Application for Precision Farming (http://zonemap.umac.org) is a web-based decision-support tool developed to meet this need. ZoneMAP can automatically determine the optimal number of management zones and delineate them using satellite imagery and field survey data provided by users. ZoneMAP is linked to a rich archive of satellite imagery called Digital Northern Great Plains (see Section 5).

Remote sensing for precision agriculture is based on the relationships between surface spectral reflectance and various soil properties and crop characteristics (Moran et al. 1997). Satellite observations provide measurements of surface reflectance with ∼15–60 m spatial resolution (e.g. SPOT, Landsat or ASTER) at least a few cloud-free times during a growing season. Objectives of ZoneMAP for using satellite imagery to delineate zones included: (I) streamlining format conversion, reprojection, and gridding of data obtained from a variety of sources, (II) providing straightforward access to satellite images, (III) allowing selection of a specific area of interest within the much larger image, (IV) creating an output map that could be directly ported into farm machinery, and (V) running computing algorithms on a UMAC server to free users from the need to buy expensive, complicated software for which they would need powerful computers.

2.1 ZoneMAP's Classification System

Fuzzy c-means (FCM) (Burrough 1989, Burrough et al. 1992, Fridgen et al. 2004) was the clustering algorithm selected for ZoneMAP. The algorithm determines the degree of similarity between an observed value (say, a surface reflectance point) and a cluster center. The first step was to determine the optimal number of zones into which a field should be divided. To determine this, within-cluster variability for a number n of clusters was compared with that for n–1 clusters. Figure 23.1 illustrates that generally the percentage of total within-cluster variability with respect to the total initial variability decreases as the number of clusters increases. A similar trend was found by Brock et al. (2005). After an initial rapid decrease the total within-cluster variance typically approaches an asymptotic value as the number of clusters increases. The optimal number of zones is therefore the number of clusters that reduces the variance significantly as compared to the initial variability, yet changes little when the number of zones is further increased. Two criteria capture this turning point in a relatively consistent manner: (1) overall reduction of variance >50%; and (2) consecutive reduction of variance <20% or a break at which within-cluster variability begins increasing instead of decreasing.

Such vegetation indices as Normalized Difference Vegetation Index (NDVI) and Green NDVI (GNDVI) have been widely used for developing management zones (Metternicht 2003, Moran et al. 1997). ZoneMAP automatically calculates NDVI and GNDVI on-the-fly. Since a canopy's reflectance changes during a growing season as vegetation goes through stages of emergence, maturity, reproduction, and senescence, zone classifications are improved if more than a single image is used.

A remote sensing image covers a much bigger area than a single farm or ranch field. Instead of processing the entire image, ZoneMAP automatically crops the

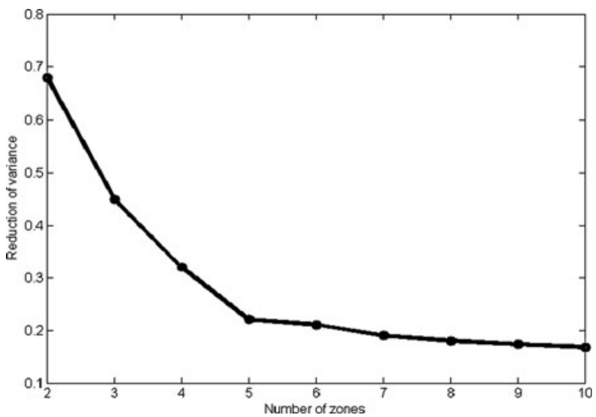

Fig. 23.1 Total within-cluster variability as a percentage of initial variance. For case shown, optimum number of zones is five

image to an area of interest defined by the user. ZoneMAP also automatically reprojects and resamples different images to a common projection plane with an equal ground sampling distance determined by the user.

Properties other than surface reflectance can assist classification into management zones. These include electrical conductivity, soil samples, yield maps, often for multiple years and crops, and other parameters. Usually, though, various data sources come in different formats, projections, and spatial resolutions. ZoneMAP invokes subsetting, reprojecting, and resampling procedures to project them onto the same grid as the one for images.

All users' data are saved in a secure online database so that within-season or multi-year comparisons of management zones can be performed. For each creation of a set of management zones, metadata is generated describing the procedure and datasets used. Users can download their results in three formats, raster image, grid text, and shape file. For each format, one can choose from multiple projections. In addition, users can input application rates for each zone to generate a variable rate application map.

2.2 Sample Map for Production Field

Figure 23.2a shows management zones determined by ZoneMAP from two NDVI images of a 97-ha field in Minnesota, acquired in successive years at the time of

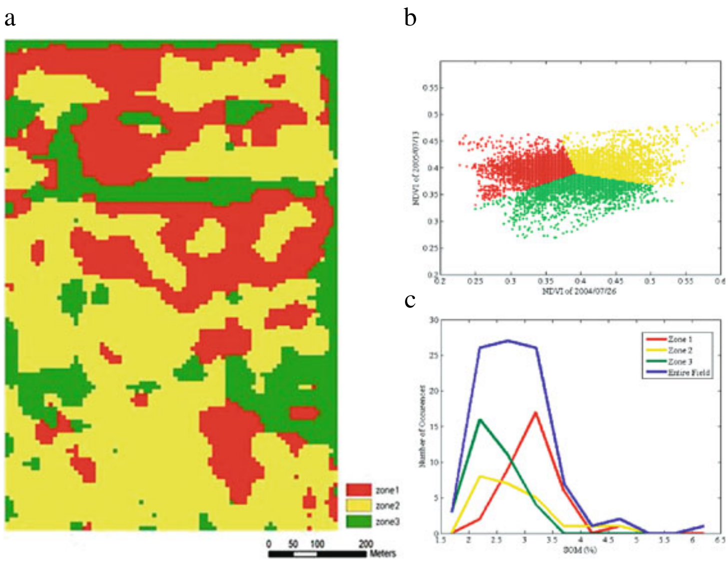

Fig. 23.2 Management zones (**a**) and corresponding scatter plot (**b**) created using reflectance measurements at NIR by Landsat on 26 July 2004 and 13 July 2005. Histograms of SOM within each zone and for the entire field are plotted in (**c**)

maximum canopy cover. The 2004 crop was soybeans and the 2005 crop, wheat. The optimal number of zones was determined to be three. Each zone was clearly defined into distinctive domains defined by NDVI values of 2004/07/26 versus 2005/07/13 (Fig. 23.2b). Histograms of soil organic matter (SOM) within each zone (Fig. 23.2c) show clear separations, with means for each class of 3.15, 2.95, and 2.42. The means of pH values for each zone were 8.42, 8.19, and 8.36, respectively.

These results confirm that remote sensing can be effectively incorporated into delineation of management zones (Zhang et al. 2010a). However, field surveys of soil attributes and nutrient conditions are important and cannot always be replaced by current remote observations. At a minimum, though, a preliminary mapping of subfield zones using remote sensing helps to design a cost-effective survey plan.

3 Mapping Evapotranspiration for Site-Specific Farm Management

Since the global demand for food is projected to double by 2030–2050 (Bruinsma 2003), pressure to increase yields from the Northern Great Plains will mount. The existing delicate balance among crop and livestock production, wildlife, soil sustainability and other goods and services provided by natural resources will be challenged. UMAC is confronting this challenge by integrating spatial technologies fully into production systems. The ability to develop appropriate site-specific algorithms has been limited by the difficulty of quantifying the yield-limiting factors over landscapes and watersheds. Three young technologies, remote sensing, yield monitors, and molecular biology, can provide the information needed to better refine weed, nutrient, and pest management decisions.

Although many factors influence yields, much of the current precision crop protection research has concentrated on evaluating the impact of water and nutrient availability on yields (Clay et al. 2001, Clay et al. 2003). This work has shown that water is scarcer, and therefore yields lower, in summit/shoulder areas. These areas can be defined using a combination of simulation models, remote sensing, and ground-collected data. For example, Mishra et al. (2008) used a Landsat scene acquired on 4 August 2001, ground-based weather station data, and the METRIC (Mapping Evapotranspiration at High Resolution and with Internalized Calibration) model (Allen et al. 2005) to estimate evapotranspiration (ET) over a 65 ha corn (*Zea mays* L.) field in South Dakota. The year 2001 was drier and slightly warmer than average in July and August compared with the 30-year average (1971–2000) of precipitation and temperature for May through August. No precipitation was recorded during the week before the satellite overpass, which suggests soils were not at field capacity when ET was estimated. Soil samples, collected (0–15 and 15–60 cm) periodically during the growing season, were analyzed for gravimetric soil water.

Evapotranspiration values calculated with a spatial resolution of 30 m correlated strongly with corn yield ($r = 0.85^{**}$), and with apparent electrical conductivity, EC_a

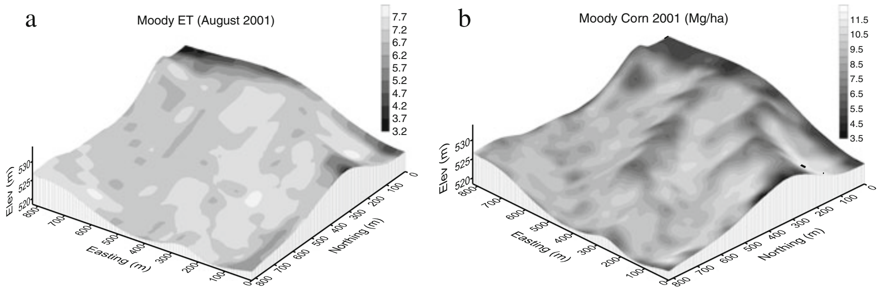

Fig. 23.3 Evapotranspiration based on the METRIC model (**a**). Yield maps draped over the digital elevation map (**b**; Mishra et al. 2008)

($r = 0.71^{**}$). In the footslope positions, high ET values were associated with high corn yields, while in the summit/shoulder areas low ET values were associated with low yields. The strong relationship between evapotranspiration and productivity shown in Fig. 23.3 was attributed to landscape processes that influenced plant-available water. Remote sensing-based ET data were most successful in identifying areas where water stress reduced corn yields, while EC_a was most successful in identifying high-yielding management zones.

4 Uses of Satellite Imagery in Range Protection

The arid Northern Great Plains of the United States have a sizable west-to-east precipitation gradient, from approximately 30 cm year^{-1} in the rain shadow of the Rocky Mountains in the west to twice that amount in its extreme east. The region's ranchers must accordingly make critical decisions at the beginning of the cattle-grazing season (Holechek 1988, Sankey et al. 2008). First is the decision about livestock grazing intensity permissible in each pasture based on the best estimates of forage available during the upcoming season. Next is a decision whether certain pastures require differential treatment or can withstand more intensive grazing. These decisions have historically been based on a rancher's sometimes unreliable personal knowledge of the grazing lands. Remotely sensed data provide more reliable information upon which to base grazing decisions, as shown in the following two examples.

4.1 Soil Water Estimation

Remote sensing has been shown to be powerful for estimating forage quantity (see e.g. Maynard et al. 2007a), but most approaches require individual parameterization for each scene. Gathering ground reference data for such parameterization is not practical. An alternative is to focus on water availability, because it is directly correlated to forage amount (Sankey et al. 2008). Rainfall during the season is inherently unpredictable, but it has proved possible to model the amount of water stored in the soil at the beginning of a growing season.

The procedure for modeling soil water was carried out at two ranches, the Decker/Bales Ranch in southeast Montana and the BBar Ranch in south central Montana. To make a practical system that ranchers would use, collection of field data had to be limited to a single day. One hundred samples were collected on the Decker/Bales Ranch and 82 on the BBar Ranch, both with the use of a hand auger. Complementing the field data were Landsat 5 Thematic Mapper images from the previous growing season to represent the potential for evapotranspiration occurring the previous year. Remote sensing successfully quantifies vegetation leaf area (Qi et al. 1994), which is highly correlated with evapotranspiration (Obrist et al. 2003). Other spatial variables important for modeling soil water include topographic slope and aspect, which can be derived from digital elevation models (DEMs), and soil characteristics, which can be derived from soil surveys (Landon 1995). Analysis consisted of least squares regressions with the response variable of water content and the potential predictor variables of spectral, topographic, and soils data.

For both ranches the models predicted soil moisture within 0.04 gravimetric water content, within the predicted margin of error for our sample sizes of 7.6 cm of moist soil (Fig. 23.4). The variables included in the models had both similarities and differences, indicating the method is *ad hoc*. However, it requires only a reasonable level of parameterization. Red and near infrared bands were important as expected, given the established relationship between these two bands and vegetation amount. One might expect that, where vegetation was abundant, evapotranspiration would be correspondingly greater and soil moisture therefore less. Instead, the correlation of the red and near infrared bands to soil water indicated that where biomass was most abundant in one year is where soil water content would be greatest the following spring. Evidently areas were producing more vegetation because there was more water, and this water was either not exhausted or was recharged in the ensuing season.

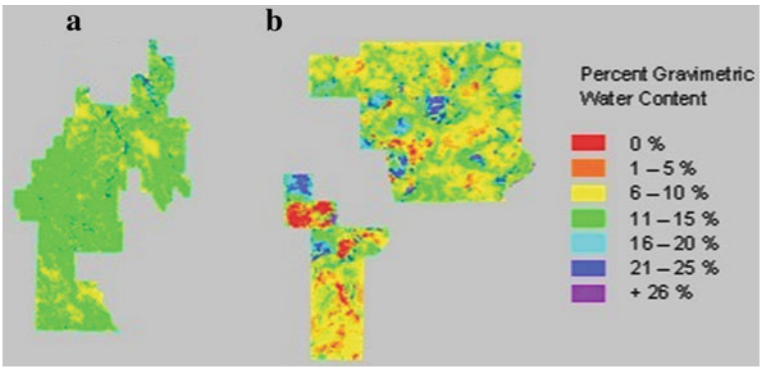

Fig. 23.4 Soil water content on BBar (**a**) and Decker/Bales (**b**) ranches

Slope and percent clay content were also important model variables at the BBar Ranch. Aspect, percent clay content, and the thermal band were important model variables at the Decker/Bales Ranch. The conclusion, though, is that with a minimum level of parameterization on an annual basis, remotely sensed data combined with other spatial data can model soil water within predicted levels of precision. Knowledge of pastures' available soil water can be used to decide upon livestock grazing intensity.

4.2 Rangeland Condition Evaluation

U.S. ranchers can obtain permits allowing their cattle to graze on public lands. Federal government managers, though, are responsible for stewardship of these lands. Remote sensing is almost the only tool for gathering information over large territories with limited personnel (Maynard et al. 2007b, Hunt et al. 2003). Medium resolution satellite imagery provides large fields of view, but at the expense of inadequate spatial detail to quantify factors such as biomass, percent bare soil, species and community types, and soil condition. Consequently, a hybrid method was developed, combining remotely sensed imagery with traditional field-based evaluations.

Remote sensing allowed categorization of rangelands according to their general condition. Then field sampling was conducted in subsets of the various categories. The approach added statistical power to a field-based sampling design. Land managers could either greatly reduce the extent of rangeland they visited on the ground to obtain the same information content, or for the same effort could gather much more information from field sampling.

Stratification was according to ecological site description (ESD) polygons. ESDs are map units of similar soil and climate characteristics. Using them allowed distinction between inherent variability in productivity among differing ecosystems from that caused by management practices. Spectral anomalies in images were not attributed solely to anomalies in rangeland management (Maynard et al. 2007b).

Data were collected from 263 sites on five Montana ranches with respect to two critical measures of rangeland condition, productivity and exposed bare soil. These were then compared to overall measures within each of 24 distinct ESDs to determine whether the site was within or outside the norm for that particular type. Thirteen Landsat ETM+ scenes were acquired to evaluate all 263 sampled sites. Each scene was converted to tasseled cap components, which are standard spectral indices that relate to each pixel's brightness, greenness in terms of vegetation quantity, and wetness in terms of leaf or surface water content. The means and standard deviations were computed for each of these components within each ESD, and the sample sites were evaluated to determine whether they were within or outside the norm for the particular ESD with respect to any of the three components. Only one of the 263 sites was evaluated as not anomalous in the field data but anomalous in the spectral data, and only three sites were evaluated as anomalous in the field data but not in the spectral data (overall accuracy 98.4%).

Remote sensing greatly increases the efficiency of field-based evaluations of rangeland condition. If 75% of an ESD is considered within the norm for its type, it would be grossly inefficient to spend 75% of an evaluator's time in fields that were essentially alike, which is what a random sampling would dictate. If instead only 33% of the field evaluation time were spent on "normal" sites, with no change in the time spent on anomalous sites, then the total effort would be reduced by 42%.

5 Digital Northern Great Plains: A Decision-Support System

Information in both spatial and temporal dimensions is what makes management by precision agriculture possible. Of course, information is valuable only to the extent it is timely, accurate, and can be (I) easily accessed, (II) straightforwardly integrated with multiple sources, (III) analyzed with software and hardware a typical information-seeker possesses, and (IV) used with a minimum of training. These challenges are amplified in the case of precision agriculture by the digital dimensions of satellite scenes and the limited bandwidths available to producers in many rural areas.

A single Landsat scene covers ~300,000 ha and contains about 500 MB of data. For a 56 k dialup connection to the Internet, still used by some rural residents in the U.S., downloading one scene would take 20 h. A typical farm field of 1,200 ha only occupies 1/250th of a scene. Obviously, if an image can be partitioned, even a slow connection can provide enough bandwidth. A second difficulty associated with sophisticated information technologies and complex scientific datasets can be overcome by providing value-added products that can be easily interpreted. Finally, to be truly useful, the data and products derived from it have to be compatible with other data and products regardless of format.

Digital Northern Great Plains (DNGP, Zhang et al. 2010b) is designed to overcome all these challenges. Its major functions are to subset images, add value to them, and present them in a format compatible with data systems farmers and ranchers already use.

UMAC has collected a rich archive spanning more than 30 years of remote sensing imagery over the northern Great Plains, including the states of North and South Dakota, Minnesota, Montana, Wyoming, and Idaho. Data include high resolution (20–250 m) multispectral images from Landsat MSS, TM and ETM+, ASTER, medium resolution MODIS, surface relief from SRTM, and very high resolution (1–2 m) images from AEROCam (see Section 6.1). To ensure consistency in temporal and spatial comparisons, all images have been atmospherically corrected. The final product is reflectance at the surface. All images are managed through a database system with capability in spatial operation.

Raster and vector data are processed using an Open Source Geospatial Data Abstraction Library (GDAL). Another open source package, MapServer, is the presentation platform. A "thin-client" design ensures the minimum footprint on a client computer; all computing and analyzing are carried out on the server side, with results presented through a web interface accessible via a web browser. The computing power needed by a typical individual can therefore be minimized.

Features that make the Digital Northern Great Plains system (http://dngp.umac.org) attractive include the following:

- Searches can be conducted via spatial coordinates through an intuitive user interface.
- Remote sensing images can be subset either spatially or spectrally.
- Products (e.g., sugar beet yield) are generated on the fly, both simplifying the database design and providing dynamic update capability.
- Images or products can be downloaded in a variety of formats to ensure compatibility with other application software.
- A multitude of identifying vector layers is incorporated into the system.
- "One interface" design ensures a smooth user experience and simplifies the learning curve.

To promote use of the DNGP system by end users UMAC followed the model of Rogers (2003) on adoption and diffusion of innovation. A cadre of early adopters provided feedback that improved the system iteratively. Endorsement of the technology by these early adopters accelerated its widespread adoption.

Two peaks in usage occur annually. The first occurs in March or April, when the growing season begins. The second occurs in late August and early September, the time for harvest. This suggests the system is particularly useful for planning and production.

6 Sensors Customized to Precision Agriculture's Needs

Landsat's value for analysis of vegetation derives from its sun-synchronous orbit and fixed pattern of paths and rows. The result is well-controlled imagery, repeating on a 16-day revisit time, well-suited for scientific investigations over inter-annual and multi-decadal time scales. However, analysis of rapidly changing phenomena on crop and range lands is equally valuable for in-season production management decisions. For critical times or geographic locations prone to frequent cloudy days, typically only a few Landsat scenes can be captured during a growing season, often not when optimal; short northern growing seasons exacerbate this problem. In addition, Landsat's spatial resolution is fine for many agricultural applications, but higher resolution imagery is needed for others.

To meet farmers' and ranchers' requests for higher spatial resolution, more frequent images, and shortened latency, UMAC designed and built two sensors, one operated on an aircraft and the other soon to be operating on the International Space Station.

6.1 Airborne Environmental Research Observational Camera (AEROCam)

AEROCam is flown on one of the University of North Dakota's light aircraft. The sensor consists of a Redlake MS4100 multi-spectral (B, G, R, NIR) area-scan camera. Images can either be RGB (red, green, blue), offering true color, or CIR (near-infrared, red, green), false color. Spatial resolution depends on altitude: 1 m is typical for production agriculture applications, but 0.5 and 2 m are also frequently requested, as is 0.25 m for special purposes. Available products include both individual scenes and mosaics, georeferenced and radiometrically corrected. In addition to superb resolution, AEROCam images can be acquired at the time they are most valuable, not just when a satellite orbit dictates.

The majority of AEROCam requests are from farmers and ranchers directly engaged in production agriculture. Their uses include establishing fine-scale zonal mapping of highly variable soils, assessing effectiveness of variable rate fertility and crop treatments, improving drainage, and identifying areas of soil compaction and salinity. The immediate, in-season decision support made possible with AEROCam often is served by analyzing relative variations within a single scene or mosaic captured at the appropriate time. An example of the degree of detail available in AEROCam images is illustrated in Fig. 23.5. Much of the heterogeneity evident in this image would have been lost in a satellite image with resolution ~30 m.

6.2 International Space Station Agricultural Camera (ISSAC)

AEROCam's successes led to a desire for sensor capabilities in low Earth orbit. A sensor called International Space Station Agricultural Camera, or ISSAC (Hulst et al. 2004), soon to be launched to the International Space Station (ISS) is the result. The sensor will collect two bands, red (630–690 nm) and near-infrared (780–890 nm), such that the Normalized Difference Vegetation Index can be produced. A pointing system allowing off-nadir look angles of up to 30° will enable

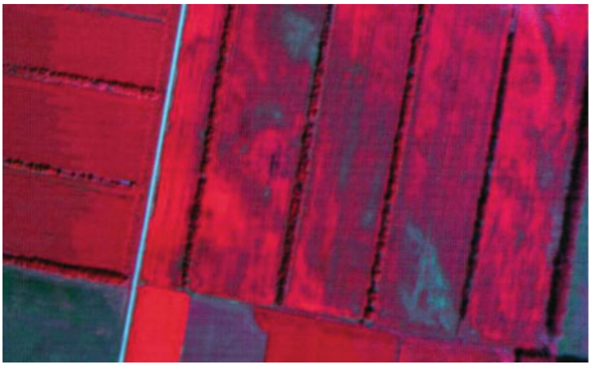

Fig. 23.5 AEROCam image collected in northeast North Dakota, August 2008. The image, a false color composite (G, R, NIR), is approximately 1 km wide with 1 m resolution. Heterogeneity effects are due to management practices (red shading differences on left) and natural variability (*blue*/*red* mottling on right)

images of particular areas to be acquired frequently. ISSAC will be installed on the ISS in 2011 and testing, validating, and verifying its output will occupy much of the 2011 growing season.

ISS's altitude varies between 350 and 420 km; when at a nominal 400 km the size of a scene will be about 57 × 57 km, with a ground spatial resolution comparable to Landsat's. Radiometric calibration will significantly reduce noise and imaging artifacts. Since long-ray paths due to variable sun and look angles will make atmospheric effects more apparent, we will apply correction techniques that will utilize concurrent measurements made by other orbiting NASA sensors of ozone and water vapor. Primary science target area is the UMAC region; secondary science targets could be imaged anywhere under the ISS orbit (inclined 51.6°).

During the growing season, primary targets will have occasional 3–4 week 'blackout' periods when ISS overflights of the northern Great Plains occur either at night or in low-light conditions. Between blackout periods ISSAC imaging opportunities will occur several times per week. A Science Operations Center at the University of North Dakota will convert end user's tasking requests into camera commands; after acquisition, the same operations team will process received telemetry into imagery for distribution via Digital Northern Great Plains (Section 5). The goal is to disseminate corrected, calibrated, geo-located imagery within 24 h of acquisition. For the first time, agricultural producers will have information about crop and range health frequently and in near-realtime throughout the evolution of their fields, from emergence through maturation to senescence.

7 Precision Crop Protection: Its Promise Demonstrated

The Cronin Farms near Gettysburg, South Dakota serves as an example of how the Upper Midwest Aerospace Consortium is bringing about positive changes in agricultural practices. The example verifies the approach of conducting "experiments" in actual producing fields under prevailing conditions.

The first step was to create management zones, the very basis for any differential treatments. The collaborating farmer did this by combining Landsat images, yield maps, and soil surveys into an ArcView Geographic Information System. This took advantage of UMAC's Digital Northern Great Plains data dissemination system and its ZoneMAP product. The resulting zone map for a single 44.5-ha field classified into three zones is shown in Fig. 23.6. By knowing the characteristics of each zone, specific goals for yields of spring wheat could be set. To meet the goals the rate of application of synthetic fertilizer needed in each zone to supplement the nutrients known to be present from soil samples was calculated. The result of this careful management was that actual yields exceeded the goal by 9%.

The enhanced yields, of course, increased income. Using 2008 spring wheat prices, the incremental income from boosting yield in this 44.5 ha field was US$1,870. At the same time, costs were significantly reduced. In the absence of site-specific information, neighboring farms applied as much as 250 kg more urea

Fig. 23.6 Corn field of 44.5-ha classified into three zones on the basis of previous years 'Landsat' images, yield maps, and soil surveys

fertilizer per hectare. By comparison, the Cronin Farms saved US$1,750. The third benefit was environmental: 2,840 kg less fertilizer entered the environment.

One major reason why the fertilizer applications could be less than a standard (i.e., non-precision) prescription was use of no-till practices on Cronin Farms, not just on a single 44.5-ha field but instead on the full 3,620 ha of the farm. A disadvantage of tilling soil is that organic matter contained within it is oxygenated when exposed to air. By not overturning soil, no-till prevents oxygenation and instead increases soil's concentration of organic matter – from 2.1% in 1991 to 3.2% in 2007 on the Cronin Farms. Each increase of 1% in SOM reduces the necessary application of nitrogen by 22–34 kg/ha, of phosphorus by 5–7 kg/ha, and of sulfur by 2–3.5 kg/ha.

Benefits accrue if these practices are followed for several years. Table 23.1 compares yields obtained in 1991, before either precision, variable rate treatments or no-till were being practiced, with those in 2007. The increases are exceptional.

Wise crop-protection strategies offer additional benefits. At the same time one crop is harvested, another is planted atop the residue. Such cover-cropping protects soil against wind and water erosion. It also helps cycle nutrients and retain water. If the rotation of crops includes legumes or other nitrogen-fixing plants, fertilizer requirements can be reduced even more, in one specific case by 90 kg ha^{-1}. At the close of the crop-growing season, one final cover crop is planted. It could be oats, or turnips, radishes, or lentils. This crop and the other residues on the field serve as fodder for cattle that are allowed to graze until the onset of winter. Manure thereby is fed back into the nutrient supply.

Table 23.1 Productivity increases from no-till precision agriculture, Cronin Farms, South Dakota USA

Crop	1991 Yield	2007 Yield
Winter wheat	50 bushels/acre	70 bushels/acre
Spring wheat	40 bushels/acre	60 bushels/acre
Corn	60 bushels/acre	145 bushels/acre
Sunflowers	2,250 kg/ha	2,915 kg/ha

A UMAC-partnering farmer has conducted a crop-protection program that improves soil fertility, prevents its erosion, fixes atmospheric nitrogen, recycles nutrients, retains water and facilitates its infiltration, reduces compaction by minimizing passages of farm machinery over the soil, and does all this while cutting costs and increasing yields or equivalently income – in addition to significantly improving stewardship of the environment (D. Forgey, private communication 2008). Table 23.2 compares how much progress has been made, progress that is strikingly evident in the satellite image (Fig. 23.7), showing fields farmed with precision and no-till for 0, 3, 6, and 13 years.

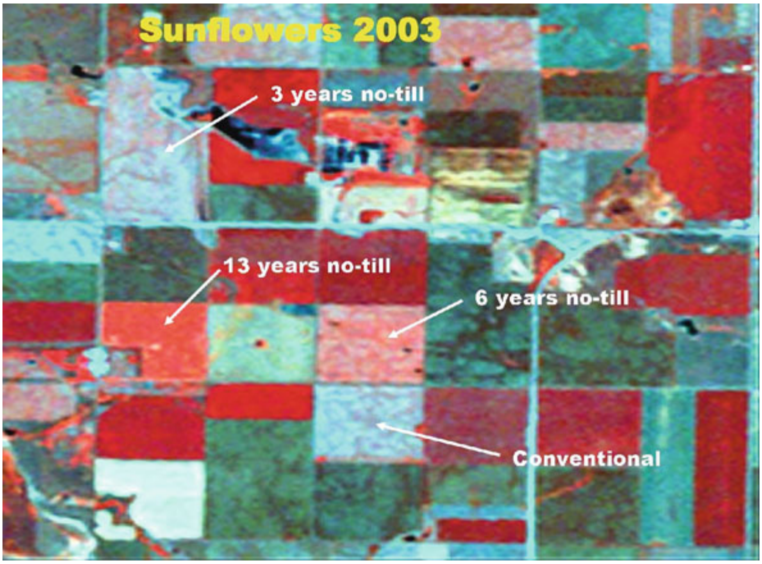

Fig. 23.7 2003 Landsat false-color image identifying sunflower crops grown traditionally and with 3, 6, and 13 years of variable-rate treatments and no soil tillage. The deeper the red, the greater the productivity

Table 23.2 Crop protection progress, Cronin Farms, South Dakota, USA

	1991	2007
Area farmed	2,085 ha	3,620 ha
Number of farmers	4	2
Tractors	3 (525 hp)	1 (255 hp)
Crops raised	6	12

8 Lessons Learned

Producers have made many management decisions in addition to the few we have described. They have been able to delineate acreage damage caused by hail and windstorms, quantify the effectiveness of chemical applications, identify and rectify drainage problems, spot damage caused by drift of applications sprayed on adjacent fields, locate invasive species, detect plant diseases, and many more uses.

From these experiences those in the Upper Midwest Aerospace Consortium have learned several lessons.

- Techniques that work in one region may not be applicable in all others. Agroecosystems are complex and intimately connected to their local environment. In the northern Great Plains they are subjected to short growing seasons, potentially extreme variations in temperature and precipitation, competition between crops for food or for fuel, and limited use of irrigation. Other regions could make similar lists of peculiarities. Nevertheless, the principles of precision crop protection described do have general applicability.
- Imagery from sensors on satellites or aircraft is extremely valuable. But images are not magical solutions that replace all other sources of information. When they are combined with other sources – e.g., electrical conductivity measurements, yield maps, weather data, soil ecology, topography, etc. – their value is greatly amplified.
- Precision crop protection requires a commitment. The rewards come only after a few to several seasons. Knowledge about agroecosystems accumulates over each crop grown each season. Comparisons of geospatial information at various times within a season, between seasons, and between the current season and the average of several give a context upon which to base sound decisions.
- An organization that sets out to empower farmers and ranchers to make informed decisions also must be committed for a long term. With so much income at stake, producers are slow to change practices, and initially new technologies are bewildering to many of them. Unless support has the prospect of continuing, producers are unlikely to begin relying on it.
- UMAC has demonstrated the value of breaking down boundaries: between academia's traditional disciplines, between various academic institutions, and between academia and the public. The world of tomorrow cannot be created by perpetuating the world of yesterday.

Economics, the environment, and depletion of natural resources such as the oil on which industrial agriculture is based, are all converging on a pressing need for change in agriculture. Social pressures also bear heavily. More people are continually added to the planet and among them are many whose improving circumstances allow them to demand richer diets. The consequence is immense pressure to grow more food, even though the best arable lands are already in production. Along with humanity's desire for more food is one for different energy sources. Among the potential new sources are biofuels, the growth of which is a competing use for the same arable land. There is no doubt that agricultural practices will be different in the near future. Precision management is almost certain to be one of the new strategies.

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