Using Site-specific Approaches to Advance Potato Management in Irrigated Systems

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SUMMARY. Potatoes (*Solanum tuberosum* L.) are grown extensively throughout the Pacific northwestern United States as a high value crop in irrigated rotations with other row crops such as wheat (*Triticum aestivum* L.) and both field and sweet corn (*Zea mays* L.). Center pivots are the predominant irrigation systems. Soil texture ranges from coarse sands to finer textured silt loams and silts and can vary within one field, particularly in fields with hilly topography. Site specific management is being evaluated as an approach to help to optimize inputs (water, seed, agricultural chemicals) to maintain or enhance yield and reduce potential negative environmental impacts from these farming systems. Currently, variable rate fertilizer application technology and harvest yield monitoring equipment are commercially available for potato. Variable rate seeding and variable rate irrigation water application technologies are developed but not fully commercialized and variable rate pesticide application equipment is in development. At the Irrigated Agricultural Research and Extension Center in Prosser, Wash., we have a team of research scientists, interested individuals from local industry, and other key organizations (e.g. local conservation districts) who are working together to evaluate different site specific technologies, improve the ability to use available tools, and to improve decision-making ability by conducting research both on farm and in research plots.

The concept of precision farming, or site-specific crop management (SSCM) is to manage inputs for agricultural production systems to meet both spatial and temporal variability in production. Early work on this concept focused on agronomic crops grown on large acreage in the midwestern United States. However, as tools and technologies have become more advanced, there has been a shift to looking at SSCM approaches for horticultural crops.

In the irrigated production areas of the Pacific northwestern U.S., potato (*Solanum tuberosum*) is grown on large fields [55 ha (120 acres)], predominantly under center pivot irrigation. These large fields have a high degree of spatial variability in soil factors and crop yield (Han et al., 1996) and are known to have temporal variability in water and nutrient demand (Evans et al., 1996).

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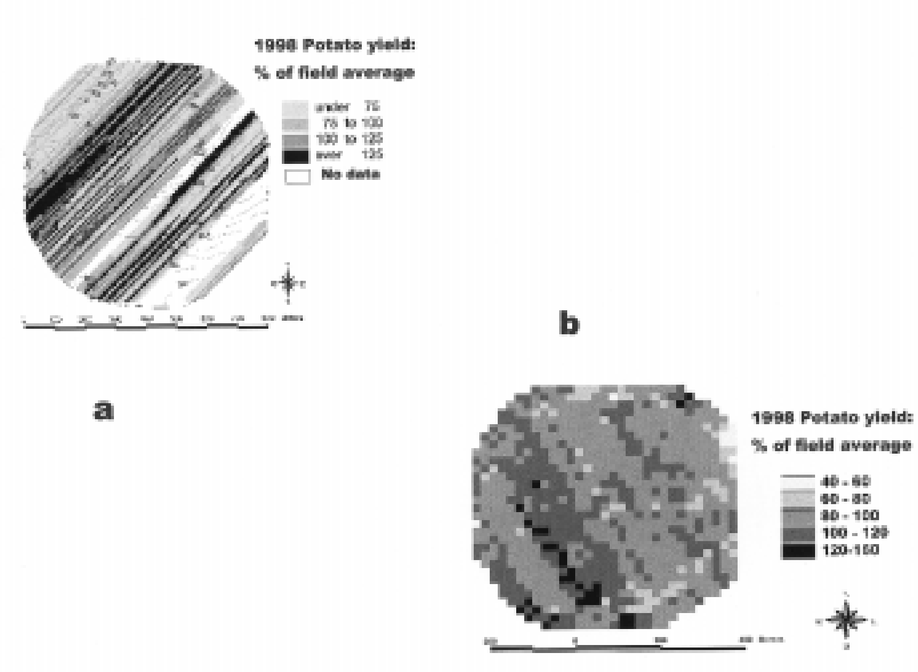


Fig. 1. Yield map of potato in 1996 (A) and 1998 (B) showing progression in ability to monitor the entire field without data gaps; 1.0 m = 3.3 ft.

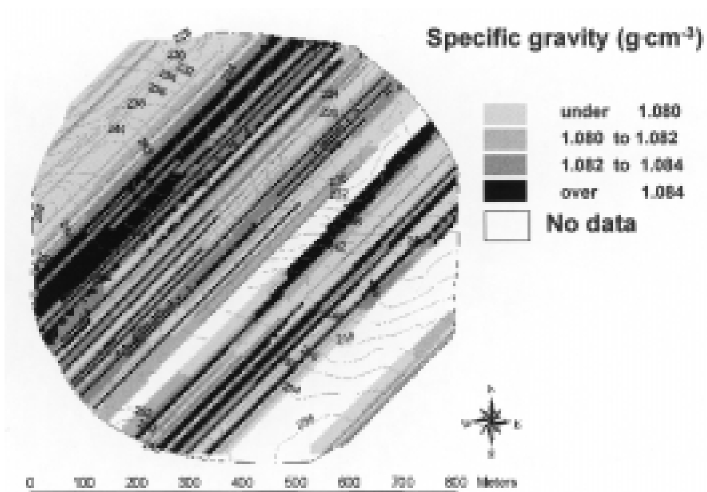


Fig. 2. Map of potato specific gravity (sg) from 1996 where sg measurements were taken as a bulk measurement from a truckload of potatoes and integrated across the harvested row(s); 1.0 m = 3.3 ft.

Additionally, recently published water quality survey information indicates that there are problems with nitrate contamination in wells in the area associated with potato production (Williamson et al., 1998). Thus, the potato production system offers an ideal situation for developing SSCM approaches for improved production economics and reduced potential negative environmental impacts.

To develop SSCM approaches for irrigated potato rotation systems in the Pacific northwestern United States, a team effort was initiated at the Irrigated Agricultural Research and Extension Center (IAREC) in Prosser, Wash. The initial team was made up of both federal (USDA–ARS) and state (Washington State University) scientists at IAREC. Within one year of the team's inception, partners from a number of industries were asked to join. The team now has involvement from a number of partners ranging from irrigation equipment companies to a large multinational electronics firm, county conservation districts, and local farmers. Efforts have been underway to develop an understanding of the potato system and to begin implementing SSCM practices. This paper discusses accomplishments and what the future may hold for potato production should these technologies be fully adapted and adopted.

Advances in precision potato management

YIELD AND QUALITY MONITORING. Understanding variability in potato yield and quality is important for developing an understanding of the factors that can be modified to reduce variability. Thus, the development of yield monitoring equipment was amongst the first efforts towards developing SSCM approaches in potato. This work was conducted collaboratively with an industry partner. Yield monitoring equipment for potato involves using load cells on the belt of a commercial potato harvest equipment in combination with a global positioning system (GPS) monitoring device to collect potato weight and location during harvest (Schneider et al., 1996). Early efforts during the equipment development phase resulted in yield maps

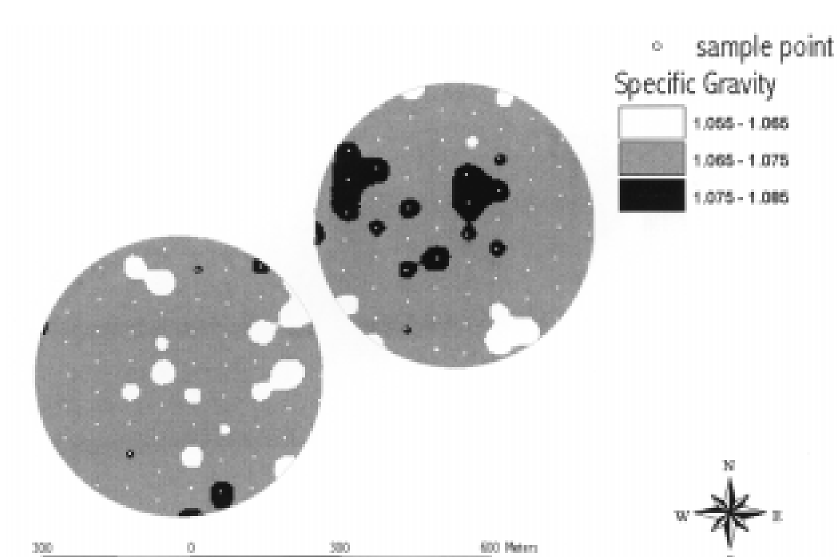


Fig. 3. Potato specific gravity taken as point data samples and integrated across the field; 1.0 m = 3.3 ft.

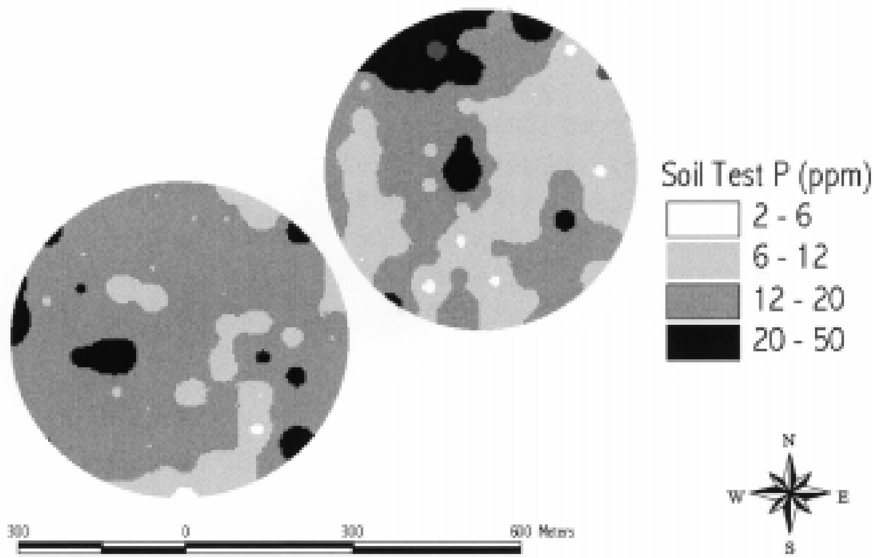


Fig. 4. Spatial variability in soil test P in two adjacent potato fields; 1.0 m = 3.3 ft.

with numerous data gaps. However, by 1998 our team successfully harvested whole fields with few to no data gaps (Fig. 1).

Monitoring potato quality has been more difficult. Although yield is an important component of potato production and marketing, process potato pricing is influenced by both size distribution and specific gravity. Early approaches for monitoring variability in potato quality involved collecting subsamples of potato tubers from individual trucks, evaluating them for quality, and georeferencing the data to the harvested strip (Fig. 2). To develop more specific data, sampling is now being conducted by collecting samples from specific georeferenced points in a monitored field (Schneider et al., 1997) by harvesting a 10-ft (3.07-m) row length before commercial harvest, and evaluating these samples for quality (Fig. 3). Although this approach is well suited to a research situation, it is not feasible for commercial operations. Efforts are currently underway to modify the current yield monitoring device that would allow real-time measurement of potato quality during harvest (S. Rawlins, personal communication).

These advances have resulted in equipment for real-time potato yield monitoring that is commercially available. However, its operation is still sophisticated enough that it is not widely commercially adapted. Continued refinements of the technology plus the addition of quality monitoring show promise for yield monitoring to become more than a research tool.

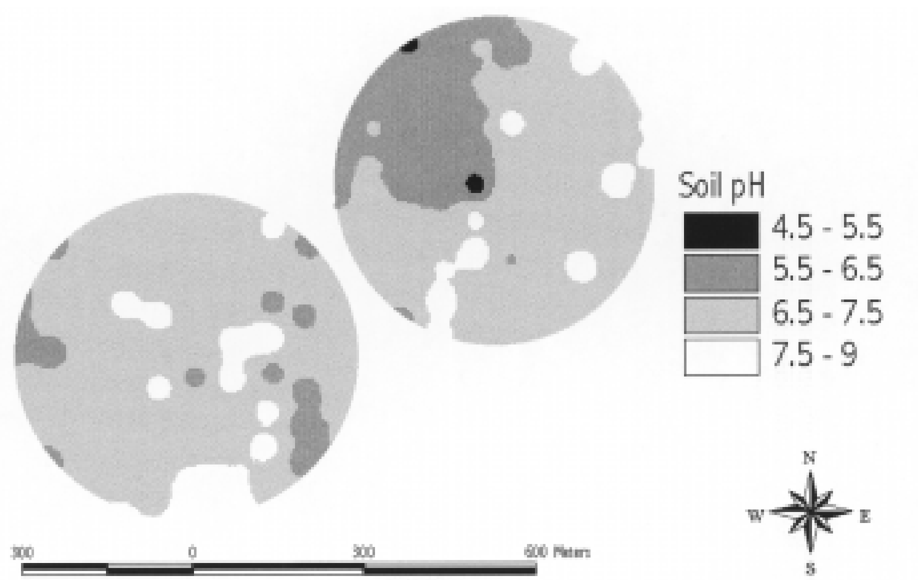
VARIABLE RATE FERTILIZER APPLICATION. Perhaps the greatest technological advances in SSCM and variable rate technology (VRT) are those which have been made for granular fertilizer application. Commercial equipment is available to make VRT applications for row crops as well as orchard and vineyard crops. However, the ability of the equipment to apply fertilizers at variable rates may exceed our ability to predict variability in fertilizer requirement as finely as it can be applied.

In potato, VRT fertilizer application is predominantly for P, K, and S, although some preplant N is variably applied. Advanced systems that provide VRT water application can also provide VRT fertigation (King et al., 1996) for in-season N application.

Perhaps one of the biggest questions in VRT fertilizer application is soil sampling to determine spatial variability. It is generally agreed that smaller sampling densities provide better guidance in predicting variability in fertilizer needs (Wollenhaupt et al., 1994). However, there needs to be a balance between a sampling density that provides a good predictor and high sampling densities that exceed the economic gains from spatially variable fertilizer application. Research with potato has suggested that a 1-acre (61 × 61-m) grid size for soil sampling is appropriate (M. Hammond, personal communication). An alternative strategy for multiple soil sampling in a single field is to use a directed or smart sampling approach (Pocknee et al., 1996). In the smart sampling approach, soil is sampled at densities that are both finer and coarser than a 1 acre grid suggests. Sampling densities are established using field history (e.g., yield, management practices) to direct the sample density for increased economic gain from each sample (i.e., finer density in areas of greater variability, coarser in more uniform areas). Currently efforts are underway in Washington to compare efficacy of VRT fertilizer decisions based on conventional (single soil test), grid sampling, and smart sampling in potato.

Another aspect of soil sampling that affects decision making for VRT fertilizer application is the actual soil

Fig. 5. Spatial variability in soil pH in two adjacent potato fields. Sample points represent points where soil samples were collected on a 1 acre grid; 1.0 m = 3.3 ft.



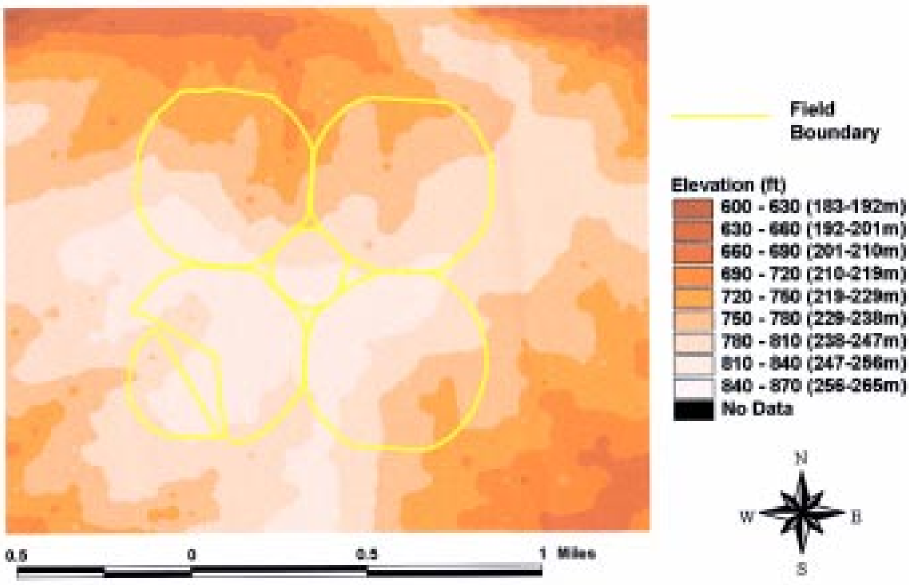


Fig. 6. Field elevation across a landscape containing five fields of irrigated row crops in central Washington; 1.0 km = 0.62 miles.

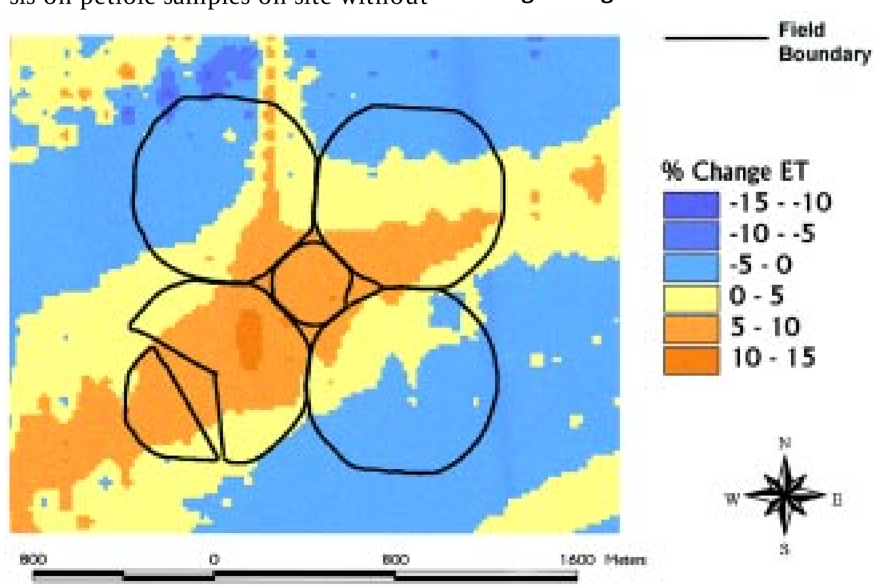
test procedure and the interpretation of results. Method development for soil testing was conducted on soils that came from very small, controlled plots, historically at land grant universities and research stations. The goal of these programs was to develop a single number that most closely related to the amount of a given nutrient (generally P and K) that a plant could effectively extract from the soil during a single growing season. It has long been understood that chemical extraction methods developed for soil test are predictions, not absolutes. There are several aspects of nutrient management for precision farming that challenge the applicability of using single element soil test values as the basis of predicting variable rate fertilizer needs across the large fields (Hergert et al., 1997) used for potato farming. One is that large fields have a great deal more variability than the small plots which were used to develop soil test values. A second is that the availability of sophisticated information handling systems (computers with spreadsheets and / or geographic information system (GIS) programs) now makes it relatively easy to use more than a single value to predict fertilizer need. Figures 4 and 5 show variability of both soil test P and soil pH in two potato fields. Two years of research on this farm indicated that there was a stronger correlation between P fertilizer response and soil pH than with soil test P (Davenport et al., 1999). This suggests that multifactorial models for variably applying fertilizers to potato will result in greater nutrient use efficiency and improved economic returns.

Although much of the work on VRT fertilizers has focused on preplant granular fertilizer applications, the ability to apply nutrients, especially nitrogen, variably through the irrigation system during the season increases the need for large scale nondestructive monitoring of potato nutrient demand. There are several approaches that can be used. Historically in-season nitrogen need in potato is determined through monitoring petiole soluble nitrogen content. Hand held ion-selective electrodes offer an opportunity to conduct nitrate analysis on petiole samples on site without waiting for test lab results (Errebhi et al., 1998). However, such devices still require destructive sampling and are time-consuming. Ion exchange resin technology has advanced to the point where devices can be inserted into the field, removed at various intervals (e.g., 24 h, 2 weeks), extracted, and used to determine nutrient flux through the root zone (Qian and Schoenau, 1995). Although nondestructive, this technique does not provide the instantaneous, spatially integrated information that is desired for monitoring large fields for crop nutrient demand (Frazier et al., 1997).

Currently we are working on evaluating canopy reflectance and photosynthetic kinetic measurements as possible technologies for nondestructive nutrient and water stress response in potato. This work is very preliminary, but the data suggest that the different stresses have distinct and separate signals that can be identified by both technologies. Prototype equipment for monitoring is being field tested this (1999) crop year. Success in developing this type of equipment and integrating the information transfer into a GIS program would provide real-time feedback for applying in-season variable rate nitrogen to potato through a center pivot irrigation system.

VRT WATER APPLICATION AND PLANT DEMAND. As researchers have collected data on spatial variability in potato yield in the Pacific northwestern U.S.,

Fig. 7. Variation in evapotransipration (ET) demand across whole fields for a single day of the growing season.



an interesting finding has emerged. Consistently, the single factor correlated with yield is elevation. Data from Washington State has shown yield to be positively correlated with elevation, which researchers concluded was actually a correlation with soil moisture (Han et al., 1996). Research in Idaho has shown a negative correlation between yield and elevation (Ojala and Chiappini, 1998) which likely supports the Washington findings and could indicate a difference in irrigation management strategies in the two growing areas.

In potato, crop water demand varies both spatially and temporally (Hattendorf, 1991). An irrigation system that provides water variably across a management area could increase crop yield and quality, decrease the area in a field susceptible to the fungal rot organism late blight (*Phytopthora infestans* L.), and reduce potential nutrient leaching. Two different approaches have been used to develop prototype VRT water application systems through center pivot for potato production. One technology uses individual solenoid controllers on each nozzle to control the duration of the water application, allowing the water to be pulsed on or off for a specific length of time (Evans et al., 1996). The second technology uses a double nozzle approach. At the end of each water line hanging from the pivot (the drop line), the line is split and two nozzles are attached. The nozzles are differentially sized to allow a configuration where each drop emitter can provide 0, 33% 67%, or 100% of the drop line capacity (King et al., 1995). Both systems are controlled to meet spatially variable demand through GIS programing for variability in soil texture and landscape position. Currently a large corporate farm is adapting and adopting the first of these two technologies for irrigated potato. A commercial firm is investigating the feasibility of the second technology.

Irrigation scheduling using VRT combines knowledge of spatially variable soil water-holding capacity, spatial and temporal variability of applied water, system delivery specifications, and weather-driven crop evapotranspiration (ET) calculations. In non-VRT applications, a single value of crop evapotranspiration is typically used for entire fields or areas for use in irrigation scheduling software. Breaking a field into smaller management zones with separate estimates of ET for each zone requires more data from infield sensors, or reliable methods to model weather data at grid points in the field. Two methods of modeling weather data at grid locations could be used, depending on the variable. One method is to estimate scalar variables (e.g., temperature, relative humidity, and solar radiation) by geostatistics, providing that enough data are available for the procedure. Estimation using process-driven models is another method, which is better suited for modeling wind speed and direction. Several models for high-resolution, small area wind modeling are available that have accessible data requirements. Often only one data site is required for model initiation.

As part of our SSCM efforts in potato, the WADOCT model (wind and diffusion over complex terrain) model (Kunkle and Izumi, 1990) was chosen to illustrate the concept of field-scale, spatially variable ET calculations. Data inputs for this modeling were taken from a weather station at a commercial potato farm in Eltopia, Wash. The data inputs into WADOCT included air temperature at 1.6 m (5.2 ft) and 10 m (32.8 ft), wind speed and direction at 10 m, digital elevation model (DEM) data thinned to 90 m (295.3 ft) (Fig. 6), 13 cm (5.1 inches) vegetative roughness, corner grid coordinates, coordinates of the weather station, and the grid interval. Additional available data included relative humidity and solar radiation at 1.5 m (4.9 ft), and wind speed at 2 m (6.6 ft). Evapotranspiration was calculated at each grid point (Fig. 6) at 15 min intervals by $LE = (RN - G) - \rho C_p(Tc - Ta)/r_a$, where LE is latent energy or evapotranspiration in $W \cdot m^{-2}$ (langleys / min), RN is net radiation in $W \cdot m^{-2}$ (langleys / min), G is soil heat flux in $W \cdot m^{-2}$, ρC_p is heat capacity at constant pressure, Tc is canopy temperature (°C or °F), and Ta is air temperature (°C or °F) at 1.5 m. Soil heat flux was estimated as 5% of RN. Net radiation was estimated following Dong et al. (1992). All variables except wind speed and direction were the same at each grid point. Calculated ET at a given time varied spatially with gridded output from the wind model.

A framework for ET calculations based on remotely sensed Tc was developed using the arbitrarily constructed relationship $Tc - Ta = 1.0 - 1.8 \times$ vapor pressure deficit in kPa (bars). ET values were then averaged over the entire grid and percent change from the mean field ET was calculated (Fig. 7).

Results showed that wind speeds varied from 0.8 to 2.6 $m \cdot s^{-1}$ (1.8 to 5.8 miles / h) at 1200 HR on day 228. Wind direction across the 2 km^2 (1.2 $miles^2$) varied from south southeast to west northwest, with highest wind speeds associated with southerly winds and the ridge top. Lowest wind speeds were associated with lower elevation (draws in the study area). Mean wind direction was from the south. Flows counter to that direction in the northwest portion of the study area were associated with deep draws. Wind run (total distance traveled from 0800 to 1900 HR, day 228) was greatest across the higher elevations of the study area. Based on wind travel, expected ET would be higher on hilltops and ridge tops.

Calculated total daily ET ranged from 7 to 9 mm (0.28 to 0.35 inches) on day 228, which are reasonable values for the region and season. Percent change in calculated ET from the field mean ranged from –15% to –10% in the deepest draw to +10% to 15% on the ridge top (Fig. 7).

Conclusions drawn from this study are

- the model can help identify areas with high or low wind speed with the implications that
- areas with decreased wind run (ventilation) could be more at risk for disease incidence. A windflow model could help identify such areas.
- areas of increased ventilation could more readily transport disease spores.
- areas of deviant wind direction could be identified and information used in feedback for irrigation nozzle control.
- potential new areas of disease outbreak could be identified by knowing wind vectors in infected areas
- much of the ET change occurred in the –5% to 5% range, but in the central ridge top zone, ET ranged from 5% to 15% of the study mean.
- Wind speed variation contributed to changes in ET of up to 10% to 15% and should be considered in complex terrain.

Ongoing work includes the validation of WADOCT and other appropriate models for local conditions.

VRT SEEDING. Technology for VRT seeding was initially developed for agronomic crops like corn and wheat, using the technology to vary planting rate or variety (Anderson and Humburg, 1997). Adapting the technology to the large seed piece used for potato planting has required changes in the planter design but not in the other equipment for operation. Research in Idaho has indicated that both yield and quality gains can be made through varying potato planting density with spatial variability in soil texture and compaction, topography, and water deposition patterns (Hess et al., 1998). In addition to yield and quality gains, variable seed piece spacing in potato could be used with newly developed pest resistant varieties where the resistant varieties could be planted in high risk area for pathogen or insect populations. This selective planting of genetically altered seed offers the possibility of improving economics and decreasing resistance development.

VRT PEST CONTROL. Probably one of the more difficult aspects in VRT technology is developing systems for variable rate application of pest control chemicals. Differential seeding with resistant varieties is one possible approach but, currently, commercially available potatoes with pest resistance are limited, although more are certainly in development (Corsini et al., 1999). Weed activated spot sprayers are commercially available but must be set up with sensors that allow spectral differentiation of leaf reflectance between the crop plant and weed species (Anderson and Humburg, 1997; Sudduth et al., 1997).

Center pivot irrigated potato systems offer a unique opportunity to attach a separate boom to the pivot to apply variable rate sprays where needed. As with the weed activated spot sprayers, technology to determine where pest problems are needed to effectively develop these sprayers (Sudduth et al, 1997). Advances in pattern recognition software, high resolution satellite or aerial imagery, and / or other nondestructive means of monitoring pest pressure are needed before VRT pest control in potato can be implemented.

Summary and conclusions

Using SSCM for management in potato has promise to help advance potato production from both economic and environmental aspects. The tools currently commercially available to potato growers are yield monitoring and VRT fertilizer application equipment. Better understanding of the information needed to make fertilizer use management decisions is needed plus modification of the yield monitoring equipment to include information on quality will enhance the use of these devices. Other equipment in various stages of commercial development has the potential to greatly enhance both economic and environmental benefits of SSCM in potato—particularly in arid irrigated systems. Advancements in nondestructive crop monitoring will also greatly enhance the commercial adaptation of SSCM in potato. In the future it is highly likely that potato management will be largely through very integrated, automated, computer driven packages that can be adjusted across large field expanses to optimize inputs and returns.

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