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Precision Irrigation: New strategy irrigation water management

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Abstract

Agricultural cropping systems depend on the use of water resources for survival, and water needs vary spatially in fields because of spatial soil variability (texture, topography, water holding capacity and infiltration and drainage rate). Therefore, the need for irrigation may differ between different zones of a particular field. While moving irrigation systems apply water at constant rates, some areas of the field may receive too much water and others not enough. Precision irrigation, an existing aspect of precision agriculture just beginning to be explored, means applying water in the right place with the right amount. The use of precision agriculture for irrigation water management is still in the development stage and requires a lot of investigation and experimental work to determine its feasibility and applicability.

The availability of some low-cost data gathering methods, positioning systems and the development in computer programming will help in regulating the depth of water within a field. So the next generation in irrigation scheduling is not just when-how much but when, where and how much to irrigate. A precision irrigation system expected to have the ability to apply the right amount of water directly where it is needed, therefore is saving water through preventing excessive water runoff and leaching. So the suitable technology to control varying amounts of water in direction of travelling and crosswise has to be developed.

The Federal Agriculture Research Centre (FAL)/ Institute of Production Engineering and Building Research/ Braunschweig/Germany in co-operation with the Department of Agricultural Engineering/University of Kassel starts a research activity aimed to review the state of precision irrigation, to add necessary background information and to develop a strategy for its application. The future challenge is to build a rich database in order to formulate a complete decision support system for precision farming, including all field activities i.e. irrigation, fertilisation, tillage, plant protection and weed control. The presented project contributes to reduce the use of scarce water resources.

Keywords: Precision Agriculture, Precision Irrigation, Spatial variability, Water saving, Irrigation scheduling, Water holding capacity, EM38.

BACKGROUND

Since 1990's a new management concept for sustainable utilisation of agricultural resources, known as precision agriculture or site-specific management, starts to receive a great interest as a new experimental field in management space. Using conventional practices, farm managers tend to treat a field as a single unit and manage it to optimise the average production as a whole. The objective behind precision farming is, breaking the field into several sub-units and treating them independently, thereof, the production of each unit can be optimised, rather than treating the entire field as an average (Maohua, 2001). Up to now, the main efforts and applications have focussed on site-specific crop management and has being tested for fertilisers and chemical applications through variable-rate technology. Water need varies spatially in many fields because of soil spatial variability. Different soil types have different textures, topography, water holding capacities and infiltration and drainage rates, therefore, the need for irrigation may differ between different zones of a particular field. Irrigation systems have been developed, but still applying the same amount of water through

the field, without taking soil spatial variability into consideration, therefore, some areas may receive too much water and others not enough within one field. Excessive water application could contribute to surface water runoff and/or leaching of nutrients and chemicals to groundwater. Inefficient water application causes reductions in yield quantity and quality, inefficient use of fertiliser and other inputs, and lower overall water use efficiency. The use of precision farming for irrigation water management/scheduling, known as precision irrigation, in order to apply water in the right place with the right amount at the right time, is still in the development stages and requires a lot of experimental works to determine its feasibility and applicability.

It is believed that, improving irrigation system performance to applied water uniformly over the field had received, and still, a great attention in both hands, research and technology or industry, and reached a stage, in which, any further improvements will not significantly increase in profitability. It is important now to shift toward and concentrate on maximisation of the net profit from this water through applying it in the appropriate place and quantity. It is possible to take the advantages of some existing technologies to be adapted for precision irrigation, such as speed-control systems, which are still used for constant speed along the whole field, although it can be used for different speeds. Other option is to take advantage of pulse concept to control single sprinkler (Frassie et al., 1995), single span or small segments along each span (Omary et al., 1997; Camp et al., 1998), through solenoid valves, which are known in irrigation market, but this needs software to control its operation. Therefore, the next generation in irrigation scheduling should be re-defined to have the ability to apply the right amount of water directly where it is needed, therefore, saving water through preventing excessive runoff/leaching is expected.

A study was conducted during 2001/2002 in Federal Agriculture Research Center (FAL)/ Institute of Production Engineering and Building Research/Braunschweig/Germany in co-operation with Department of Agricultural Engineering/Uni. of Kassel. The main objectives for this work were to add new experiences to the state of precision irrigation at the turn of the millennium, test available speed control systems to change the applied water, test a computer control system for variable rate of water with a centre pivot irrigation machine developed in FAL and to offer some speculation as to its future.

MATERIAL AND METHOD

The structure for establishing a strategy for precision irrigation is shown in figure 1. The first information needed to delineation of in-field spatial variability is originated from the soil-yard maps, which can be found in agricultural planning offices. These information are not sufficient to be used for precision irrigation, since these maps provide information about *in-region* (Large scale) spatial variability. The next step is to obtain *in-field* information (small scale), which comes from taking the advantages of the fast, non-destructive real-time sensors, such as EM38, and the concept of surrogated properties, such as EC. This must be followed by soil sampling, based on the maps produced from this sensor, and correlate the surrogate

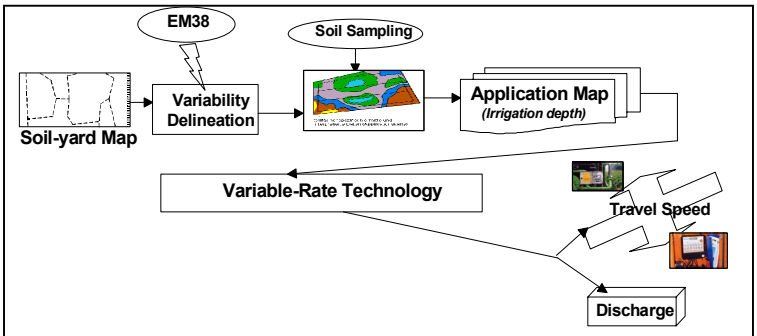

Figure 1: Established strategy for precision irrigation.

property with the property in question (EC vs. AWC). Map for the management zones within the field (application map) for the field activity, here irrigation, showing the different quantities (depths) and their location within the field is established. Then a decision must be taken concerning the technologies that must be integrated with the present field machinery or need to be introduced, here, variable-rate technologies. Evaluations for the parameters of this technology, here travel speed and discharge rate, should be done.

Soil Variability Delineation

Soil electrical conductivity (EC) could be determined without physical contact between the sensors and the soil by use of commercially available dual coil Electromagnetic Induction (EMI) systems (Rhoades, et al., 1989; Hendrickx et al., 1992; Sudduth et al., 1999; Dalgaard et al., 2001; Domsch and Giebel, 2001; Sudduth et al., 2001). An EMI meter, EM38, developed by *Geonics Limited, Mississauga, Ontario, Canada*, provides fast non-destructive measurements of apparent soil EC. Principle of measurement is described in the above literatures. For soil reconnaissance to quantify EC (mS/m), EM38 sensor, after calibration and in the vertical operation mode, mounted on a PVC-sledge together with a DGPS unit and pulled by a 4x4 motorbike and was pulled across the field along the tramlines 5 m apart. The DGPS data were integrated with EM38 data to provide the co-ordinates of each measurement point. Values for EC and position with sub-meter accuracy for each individual measurement was merged and stored at a rate of 1 sec^{-1}. The reading were logged to a data logger and interpolated using a spherical kriging model in Surfer (Golden Software, 1994) using Arcview to produce EMI-soil conductivity map. This procedure was carried out in 3-experimental sites/FAL. The resulted maps expect to show zones with different soil EC-ranges, and in each zone sample positions were selected depending on the co-ordinates using DGPS. The soil auger-samples to a depth 90 cm from those zones were collected to determine the water holding capacity in laboratory. The same sampling points were subjected to in-situ description for texture using feeling method.

Travel-Speed Adjustment

Two types of computerised electronic instruments, to control the speed of two linear irrigation systems, were tested from two different companies: IRRIGAMATIC 350 (*Matermacc/Italy*), and PROGRAM RAIN 9 (*Nortoft Electronic/Denmark*). Four speeds 40, 32, 24 and 16 m/hr were selected to be programmed (V_p). These were used to evaluate the change in irrigation depth with changing the speed of the irrigation system using these control systems. The performance of the controlled systems was evaluated by calculating the mean and standard deviation of the measured speeds (V_m). After the required information was stored in both controlling systems, the (V_m) was measured by measuring the time required to travel a pre-set's of 1 m on the moving main lateral using stopwatch.

Change in irrigation water depth

Irrigated water depth changes with adjustment of the system travel speed was conducted using IRRIGAMATIC 350. A 1x1 m grid of catch cans was established under a linear move system along the travel path (figure 2). Three speed switching, 32 to 16, 16 to 24 and 24 to 40 m/hr were conducted independently on the same transect of cans, the speed was checked using procedure described above. The system allowed movement of 10 m with the first speed to reach nearly constant speed and determine the depth of water for that speed then moved 20 m after switching from one speed to anther to determine the water depth for the second speed.

Figure 2: Water depth measurements.

Description of the Irrigation System and Control Unit

Three-spans commercial centre pivot system (figure 3), located at FAL research field, with a 117 m total length used to irrigate an area of 4.3 ha. The irrigation system could be operated forward or reverse, with and without applying water, that is pumped from underlying network, and the pressure at the pivot was 2 bar. Conventional nozzles package from Nelson, R3000 Pivot Rotator™ that had a wide range of flow rate and size, were selected to be installed in the 2nd and 3rd spans for evaluation of water distribution (figure 3). These sprinklers working at a pressure range of 15-50 psi (1-3.4 bar) and a relative throw distance of 50-70' (15.2-21.3 m). The sprinklers were placed at 3 m apart along the irrigation system at a height of 2 m above the ground to ensure good spray overlap and to reduce the effect of wind (Roth and Gardner, 1989). A small weather station was installed at the experimental site to record wind speed and direction (figure 3). Five field tests were conducted to evaluate the basic radial water distribution with this package, while the machine was travelling at constant speed of 9.3 and 17.9 m/hr for the 1st and 2nd towers, respectively (the system moved 20 sec and stopped 60 sec to obtain this speed setting). The water depth (mm) collected in 40 catch cans spaced 1 m apart along the system radius. The water depth measurements in these and the followed experiments were conducted according to DIN/EN/ ISO 11545 (Deutsche Norm, 2001). The first step that taken was, adjustment this present commercial system to a site-specific irrigation system by establishing some modifications, to evaluate the variable-rate application technology that developed in FAL for precision irrigation with centre pivot.

Figure 3: Modified centre pivot irrigation system in FAL.

The irrigation system had to be modified so that the desired water level could be applied to the management zones with different AWC, while it is moved, based on data stored in a database. The appropriate application depths were selected based on differences in AWC for different soils, therefore, four discrete depths were selected as a first approximation of true variable-rate application. Spatial location of each depth was to be determined by the system operating parameters: angle of rotation and location along the truss. Target application rates were to be determined from digitised maps stored in a computer files.

In order to control the depth of water applied along the system radius, 16 normally closed solenoid valves (Baureihe 40, GSR Co.) were installed at each sprinkler position starting from the 2nd span and forward (figure 3). Each solenoid valve was wired individually and connected to a switch at the main control system that opened/closed based on data base values and the location in the field to control the irrigation depth of each zone. The location in field was determined using position encoder by counting the no. of teeth, which gives a definite edge in reading the pivot's exact location relative to a 360° circle (figure 3). The application rate was determined by the duty cycle of the solenoid valves that supplied water to each sprinkler. The valves were pulsed by switching the solenoids on/off for varying portions of a duty cycle of 10 min. The base radial water distribution after the installation of the solenoid valves was also measured (averaged over five replicates) using 120 collection cups divided into three lines 1° between lines (65-87 cm) and 1 m between the cans in one line.

Programmable Logic Control (PLC)

All electrical output devices (solenoid valves, position encoder, etc.) were controlled using PLC developed in FAL and mounted on the mobile unit, about 3 m from pivot point (figure 3). The integrative PLC had on-board PC with software to read a saved data file and allows changes in the system information; convert the map of control to on/off setting in the directly-addressable solenoid control registers of the PLC. The position in polar co-ordinates was found using the angel and the segment position on the truss, which, in turn, interrogated from the on-board PC. When the location had been determined and a zone boundary was crossed, the program checked the expected application map, the appropriate table lookup was performed, and the solenoid registers set accordingly.

Field Test

The amounts of water to be applied ranged from 57% to 100% of the system design capacity when operate in the normal condition of speed at which the system can travel without potential runoff occurring, and divided into 4 levels: 100, 86, 71 and 57%. The irrigation depth normally used in FAL is equivalent to 24 mm, therefore, the amounts to be applied throughout the field are, 24, 20.6, 17 and 13.7 mm, respectively. The distribution of these amounts in the field is shown in figure 4. The differences in the amount of water to be applied, could be justified by the differences in AWC for the different soil types that found in FAL fields (personal communications and annual reports).

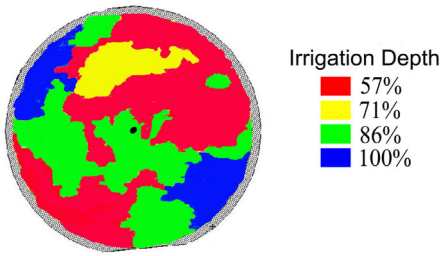

Figure 4: The Application map used to evaluate the PLC.

To examine and evaluate the validation the PLC and system modifications, test cases, each with five replicates, were conducted, in which different amounts of water should be added along the system radius. The water distributions were measured while machine was operating under normal field conditions, except that the test periods were chosen so that the wind was relatively light and was moving across the line of collection cups. The tests were conducted during early morning hours, and the wind speed during test time was less than 2 m/s and were assumed to have an insignificant effect on distribution. Radial water depth measurements were conducted with the above described procedure.

RESULTS AND DISCUSSION

On the basis of the EM38-sensor measurements figure 5 shows the EC of one field displaying different EC-range zones. According to the results, there are no significant EC differences between the zones, indicating little EC-variability in one area, agreed with Domsch and Giebel, 2000; Dalgaard et al., 2001 and Durlesser 1999. But, on the other hand, this could reflect the variability in texture, and this later affects the available water content (AWC) of the different zones.

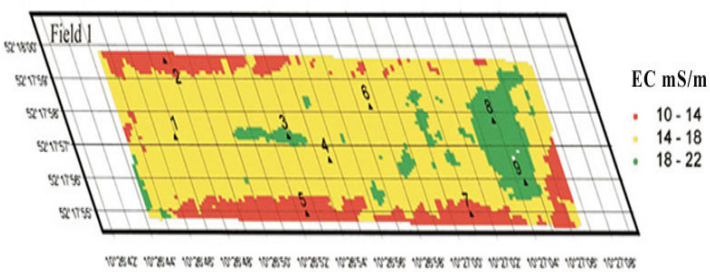

Figure 5: EC (mS/m) map resulted from EM38 and sampling sites

Laboratory results for the average PWP, FC, ρ_b. and AWC for the different EC zones in the 3 fields are shown in table (1). As shown in the table, there are small differences in AWC between the different EC-zones in one field, and the differences increased between fields. The differences between zones in one field reflect the little variations in texture and this was proved by feeling the texture at the sampling points. The increase differences in AWC between the fields is mainly due to the change in texture, especially sand percentage, as indicated above. This could be explain the lowest AWC in field 3, compared with the other fields, because the texture is dominated by sand for the whole 90 cm. The heavier the texture, relatively as in fields 2 and 1, the higher the AWC and the differences between fields are due to more sand in field 1 after 40-50 cm compared to field 2.

Table 1: Average PWP, FC, AWC and ρ_b for the three fields at different EC-zones

EC-zones (mS/m)	PWP	FC	AWC	ρ_b
	Mm			g/cm^3
Field 1				
10-14	31.5	135.1	103.6	1.60
14-18	30.3	136.4	106.1	
18-23	29.6	137.3	107.6	
Field 2				
10-16	32.9	149.3	116.4	1.53
16-22	35.8	156.3	120.5	
Field 3				
10-13	23.4	97.6	74.2	1.50
13-16	25.2	104.3	79.1	

Depth of water applied to the area covered by the sprinklers, d_n was changed due to the change in the travel speed of the irrigation system V_m. Figure 6 shows an example for the change in application depth by switching the system speed. As results indicated, with increasing the system speed, the depth of water applied to the entire area covered by the sprinklers was decreased (Roth et al., 1989). As shown in the figures, the system needs about 1 m, after the change in speed happened, to reach the programmed speed. The change in water depth needs about 16 m to reach the constant depth, due to the wetted diameter of sprinklers which is 16 m and the overlap in he travel direction.

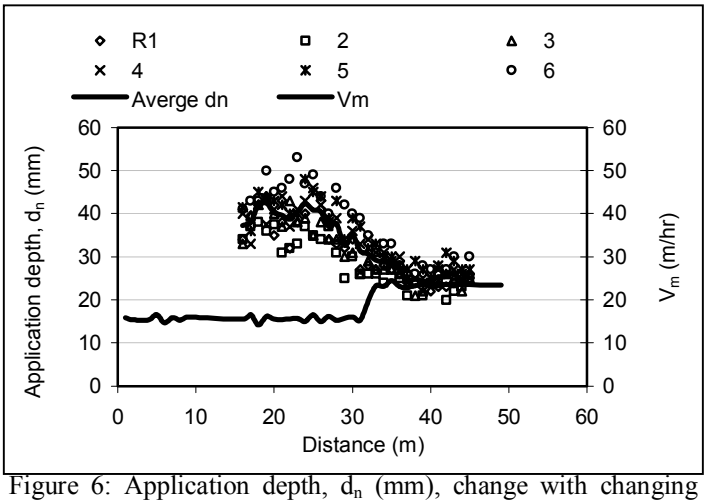

Figure 6: Application depth, d_n (mm), change with changing system speed, V_m from 16 to 24 m/hr.

The pattern of water distribution depths (average of five replicates), for selected settings as test cases, along the radius and under the segment installed with the solenoid valves are shown is in figure 7. Comparison of the averaged measured application depths with the target application map (figure 4) shows a good agreement, but with some deviations at the management zone's boarder.

As results showed, this variable water application system has operated successfully, and relatively, the water depth measured reached the target depths. These tests indicated, that the pulsed irrigation system will be provide a flexible means of applying variable water treatments (Fraisse et al., 1995; Duke et al., 1997). Although the measurements of water depths indicate acceptable control system performance, more extensive evaluation and improvements will be required before definitive conclusions can be reached.

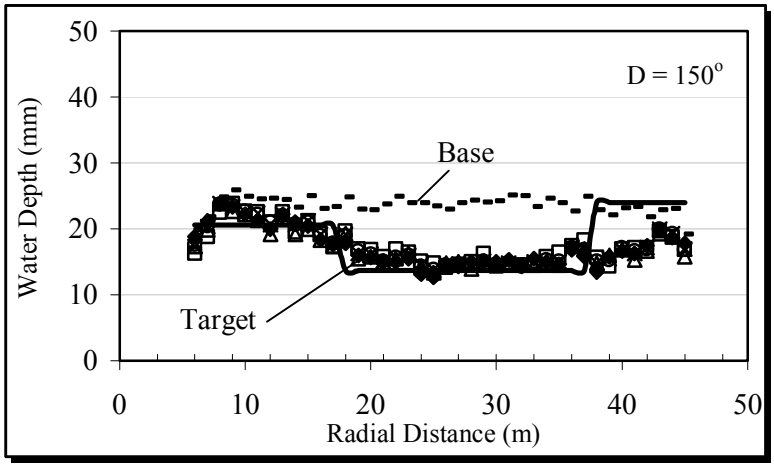

Figure 7: Base, target and measured water depth (mm).

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