USE OF VEGETATION INDICES IN VARIABLE RATE APPLICATION OF POTATO HAULM KILLING HERBICIDES

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Abstract

Variable rate application (VRA) of pesticides based on measured spatial variation in crop biomass is possible with currently available crop reflection sensors (remote and proximal), GNSS technology and modern field sprayers. VRA has the potential to contribute to a more sustainable use of pesticide. Dose rates are optimized based on local needs at a scale of about 5-50 m^2, leading to less adverse side effects, less costs and higher yields. In the long run, individual plant treatment (optimization at a scale < $1m^2$) will become practical too.

WUR-PRI has developed with some partners VRA systems for leaf desiccants (potato haulm killing herbicides) in potato. The basis of the system is a decision support system (DSS) that relates biomass parameters ($WDVI_g$, or derived parameter) to minimum effective doses of the desiccants, such as the a.i. diquat-dibromide, glufosinate, carfentrazone-ethyl. Proximal and remote sensors were used. A first prototype of a proximal sensor (N-Sensor) and injection type sprayer in combination with the DSS was successfully tested in ware potatoes in 2006. In next years, other types of sprayers in combination with other types of proximal (e.g. Greenseeker) and remote (satellite and UAS mounted) sensors systems were tested. This R&D yielded several options for farmers to acquire data on spatial variation of crop biomass on their fields. With the Dutch satellite images database, which became available in 2012, farmers have access to spatial biomass data on a scale of less than 10 m^2. If data are obtained from UAS mounted cameras, the resolution is even higher up to less than 1 m^2.

The different sensor – sprayer VRA systems have been tested in practice in commercially grown potato crops over eight years in The Netherlands, Germany, UK and Denmark. These validation studies showed good efficacy while potato haulm killing herbicide use was 30 to 40 % less compared to farmers' practices. The actual reduction was determined by e.g. resolution of sensor, patchyness of the field and width of (the section) of the spray boom. Following up on the success of the VRA potato haulm killing system, new biomass dependent VRA systems for fungicides in e.g. potatoes, strawberries and orchards are being developed.

Introduction

Current global Navigation Satellite Systems (GNSS) allow accurate assessment of positions of machines in fields. Several sensors have become available to measure crop and soil properties that affect efficacy of pesticides and so, minimum effective dosages. Modern field sprayers can adjust dosages or spray volume within meters of distance over the whole width of a spray boom or per section of the spray boom (e.g. Oerke, 2010). So, most components for VRA of pesticides are available.

VRA can be done at different scales: at the level of patches, grids or individual plants (Christensen et al., 2009). In this manuscript, we describe results of the development of a VRA system for potato haulm killing herbicides at grids of 10-50 m^2. A successful VRA system consists of (1) a sensing unit for detection of site-specific variation in weeds, pests, diseases, soil and/or crop conditions, (2) a decision making unit that translates sensor readings into need and intensity of treatment, and (3) an actuator or implement unit that carries out the control method. In this case, we tested several proximal and remote crop biomass sensors in combination with different sprayers and a decision support system that recommends minimum effective dosages on the basis of biomass parameters. The perspective of this technology is discussed.

Materials & Methods

Sensors and sprayers

Spectral crop reflection data in the first phase of the project were measured with a handheld Cropscan spectroradiometer (Cropscan Inc., Rochester MN, USA). This sensor has both upward- and downward looking photo diodes so as to enable immediate measurement of reflectance. Spectral data were used to calculate specific vegetation indices (Table 1), such as $WDVI_g$:

$$WDVI_g = R_{v,810} - (R_{s,810}/R_{s,560})\, R_{v,560}$$

where $R_{v,810}$ = reflectance centered at 810 nm from the vegetated scene, $R_{v,560}$ = reflectance at 560 nm from the vegetated scene, $R_{s,810}$ = reflectance at 810 nm from bare soil, and $R_{s,560}$ = reflectance at 560 nm from bare soil.

Other proximal sensors used later on in the project were commercial sensors integrated in the different VRA systems tested. Most experiments were done with N-Sensors (www.sensoroffice.com, in cooperation withYara Benelux and Agricon GmbH, Germany), both the passive and active light sensors. In the SensiSpray system, we use Greenseeker sensors (www.trimble.com, in cooperation with Homburg Holland, Stiens, The Netherlands).

Remote sensors used were either mounted on Unmanned Aerial Systems (UAS) or satellites. A tetracam multi-spectral camera was mounted on an UAS (Van Valkengoed et al., 2011). Specifications on the satellite mounted sensors, see e.g. Van der Wal (2014).

Two types of variable rate application (VRA) were studied: ‘on the go’ sensing and VRA dosing with proximal sensors, and VRA task map spraying using biomass maps from remote sensing and DSS.

Two ‘on the go’ VRA systems were tested. The one system used the N-Sensor for crop biomass sensing. The N-Sensor is typically mounted on the roof of a tractor and has an oblique view of the crop in four directions: to the left-front, left-rear, right-front and right-rear. In each direction, a roughly circular patch is viewed. The patches fall within a 15 x 15 m^2 area. The N-Sensor was combined with both conventional sprayers (boom width varying between 27 m to 48 m wide) and an injection sprayer (27 m wide). For details, see www.precisielandbouw.eu and Kempenaar and Struik (2008). Other sprayers used in the experiments were conventional sprayers (e.g. Hardi, Agrifac, Johne Deere, CHD).The other 'on the go' VRA system tested was named SensiSpray (Homburg B.V., Stiens, The Netherlands), which is a system that adjusts dosages per section of the spray boom. Greenseekers sensors are mounted on each section of a 27 m wide Hardi Commander sprayer. Lechler VarioSelect nozzles are mounted on the spray boom, which can be switched on and off in a fraction of a second to allow VRA over a wide range of dosages. Spray boom sections are 3 to 4 m wide. The sensors are mounted on the boom in the middle of each section and straight above the middle of a crop row or planting bed. The sensor typically scans a 60 cm wide strip when the spray boom is about 1 m above the canopy. For details, see www.precisielandbouw.eu and Michielsen et al. (2010).

Two types of remote sensing were tested; biomass maps were either obtained with sensors on UAS, with resolution of 0.5 - 1 m^2, or with sensors on satellites, with resolutions of 2-10 m^2.

Decision support system and ICT

Dosing algorithms (decision support rules (DSR)) for potato haulm killing herbicides were developed between 1999 and 2004 in more than 10 dose response experiments in potato crops, combination with $WDVI_g$ measurements of the individual plots. (Kempenaar & Struik, 2008; Kempenaar et al., 2004). A typical example of such an algorithm is given for Reglone (200 g diquat-dibromide per L), the mostly used herbicide in the study:

$$D = \mathit{min}[\, 3.0, 0.38 * \mathit{exp}(\, 4.9 * \mathrm{WDVI}\,)\,]$$

where D = application rate (L ha^{-1}) of the haulm killing herbicide, *min()* is a function which returns the smallest of its arguments, *exp()* indicates exponentiation with base e, and $WDVI_g$ (Weighted Difference Vegetation Index, $0 \leq \mathrm{WDVI} \leq 1$) is the vegetation index. In this case 3.0 is the maximum recommended dosage of Reglone.

For the 'on the go' VRA systems, the dosing algorithms were integrated in the software of the decision making unit (sensor or board computer). All algorithms had in common that they have a sigmoidal shape, having:

1. a minimum dosage larger than 0 L or kg product per ha at low canopy densities (WDVI $<$ 0.1);
2. a maximum dosage smaller or equal then the recommended or standard practice dosage at high canopy densities (WDVI $>$ 0.4);
3. a linearly or exponentially increasing dosage at intermediate canopy densities.

We used regression algorithms from spectral crop reflection studies, to relate $WDVI_g$ to the output parameters of the commercial sensors used (S_1 of N-Sensor, NDVI of Greenseeker).

In the VRA task map systems, the task maps were made with the Farmworks Farm Management System (www.farmworks.com) or with the software of the internet portal Akkerweb (v1t.akkerweb.nl). Task files were send to sprayers as shape or ISO-XML files.

The DSS was more than just a single dosing algorithms. The user can account for specific conditions, such as less sensitive varieties or weed in the crop. In those cases, min. and max. dosage and slope of algorithms change according to settings.

Validation experiments

We carried out over 30 validations experiments with VRA systems on commercially grown potato crops between 2006 and 2014, mainly in the province of Flevoland in the Netherlands (marine clay soil). Other Dutch study regions were the provinces of South Holland (clay soil), Noord Brabant (sandy soil) and Drenthe (peat and sandy soils). Also, experiments were done in Sachsen.

Experiments were done in a crop on a commercial field in the following way. Each field (normally 5- 20 ha) was split into two parts. On one part, the VRA system was applied while on the other part standard practice, fixed rate of the potato haulm killing herbicides was applied. Pesticide choice and timing was done by the owner of the field, supported by his local advisors if any. On each part of the field, efficacy was assessed after treatment by observations of at least 10 randomly chosen positions on each part of the field. On these position, % dead plant tissue one and three weeks after treatment were determined. Farmers were asked if they noted any difference in harvestability of the potatoes on the standard practice part and VRA part of the field. Herbicide use on both parts of the fields were recorded.

Results & Discussion

Spectral reflection data as measured with optical sensors can be used to non-destructively assess aboveground vegetation properties, such as amount of biomass, or nitrogen content of the biomass. To this purpose, a large number of vegetation indices have been published to assess vegetation properties (Table 1). Bouwman et al. (1992) concluded that the $WDVI_g$ index was probably the best index to assess the aboveground biomass of potato, wheat and sugar beet crops. Recently Duisterwinkel (2013) confirmed with regression analysis that, compared to the $WDVI_r$, NDVI and TCARI/OSAVI indices, the $WDVI_g$ index correlated the best with aboveground amount of biomass and N-content, with correlation coefficients (R^2) greater than 0.8. He analysed data sets on spectral crop reflection and potato canopy properties from three seasons (1997, 1998 and 1999) (Van Evert et al., 2012). Also in the development of the MLHD PHK, $WDVI_g$ proved to be a good index to work with, and has become the basis in the VRA decision support system (Kempenaar et al., 2004). It is a benefit that the $WDVI_g$ index can also be used very well for VRA side-dressing advices on nitrogen in potato crops.

The two types of VRA (on the go versus task map spraying) we tested both proved to be useful. Figures 2 and 3 shows a typical results of variable rates applied on potato crops with task map spraying. For a typical result with on the go dosing, see Figure 3. The starting situation of the crop mid-September 2013 is shown in Figure 1. The canopy started to die back, with a gradient over the field. Standard practice potato haulm killing was a fixed rate of 3 L Reglone per ha.

In all validation experiments we saw that the efficacy of VRA system was good. The canopy die back was slowed down only one to two days compared to the higher standard practice fixed rates. But at time of harvest, both the canopy of the VRA treated part of the crop and the standard practice fixed rate part of the crop had died that much that mechanical harvest could be done in a desired way, with no differences between VRA and standard practice. Table 2 summarizes all validation experiments. Most of the 37 validation experiments on commercial fields were doe with Reglone. The DSS allows the farmer to choose for split application of herbicides and to correct for weed development in the crop or for less sensitive potato cultivars. The proximal sensors with on the go VRA dosing yielded on average 38 % reduction in herbicide use. For the remote sensors in combination with task map spraying, the reduction was on average 31 %. We cannot conclude on the basis of this study that proximal sensor are better suited for reduction of herbicide use than remote sensors, because of unpaired experiments and relative low numbers of tests with remote sensors. In general, we can conclude that both types of VRA are useful in potato production. Both systems have pro's and con's. Costs of sensing, accuracy, resolution, easiness of use and timely delivery are key factors determining adoption rate of the technology presented.

Table 1. Vegetation being used to quantify aboveground biomass properties (Van der Wal, 2014).

Index	Name	Formula	Authors (year)
NDVI	Normalized Difference Vegetation Index	$(R_{nir}-R_{red})/(R_{nir}+R_{red})$	(Rouse et al. (1974)
RVI	Ratio Vegetation Index	R_{nir}/R_{red}	Jordan (1969)
$WDVI_r$	$WDVI_r$, with red light reflection in formula	$R_{810}-(R_{810}-R_{560})xR_{560}$	Clevers (1989)
$WDVI_g$	$WDVI_g$, with green light reflection in formula	$R_{810}-(R_{810}-R_{660})xR_{660}$	Bouwman (1992)
REP-LI	Red Edge Position: Linear Interpolation method	$700+40x(Rre-R_{700})/(R_{740}-R_{700})$; and $Rre = (R_{670}+R_{780})/2$	Guyot et al. (1988)
MTCI	Meris Terrestrial Chlorophyll Index	$(R_{754}-R_{708})/(R_{708}-R_{680})$	Dash, Curran (2008)
TCARI	Transformed Chlorophyll Absorption in Reflectance Index	$3x((R_{700}-R_{670})-0.2x(R_{700}-R_{550})x(R_{700}/R_{670}))$	Haboudane et al. (2002)
TCARI/ OSAVI	TCARI with Optimized Soil-Adjusted Vegetation Index	$1.16x(R_{800}-R_{670})/(R_{800}+R_{670}+0.16)$	Haboudane et al. (2002)
MCARI	Modified Chlorophyll Absorption Index	$(R_{700}-R_{670})-(0.2x(R_{700}-R_{550})x(R_{700}/R_{670}))$	Daughtry et al. (2000)
DCNI	Double-peak Canopy Nitrogen Index	$((R_{720}-R_{700})/(R_{700}-R_{670})/ (R_{720}-R_{670}+0.03))$	Chen et al. (2010)
NDRE	Normalized Difference Red Edge index	$(R_{780}-R_{720})/(R_{780}+R_{720})$	Eitel et al. (2010)

R_{nir} = reflection at near-infrared wavelengths, R_{red} at red light wavelengths, other reflections at specified wavelengths.

Table 2. Summary of 37 observations of VRA of PHK herbicides with the MLHD PHK decision support system in combination with different sensors and sprayer types, compared to standard practice on the same fields in commercially grown potato crops between 2006 and 2013 in The Netherlands and Germany. N-Sensors and Greenseekers were near sensors, while the others remote sensors (Unmanned Aerial Systems or Satellites).

Sensor type – sprayer type	Growth seasons (number of crops in the comparison)	Reduction in PHK herbicide use compared to reference	Herbicide use in standard practice reference (a.i. per ha)
N-Sensors – conv. sprayers	2006 – 2008 (n = 11)	47 %	640
N-Sensors – conv. sprayers	2009 – 2011 (n = 12)	36 %	440
N-Sensors – conv. sprayers	2012 and 2013 (n = 4)	38 %	575
Greenseeker - SensiSpray	2007 – 2011 (n = 6)	33 %	463
UAS M.Sp.camera – conv. spr.	2011 and 2012 (n = 2)	38 %	450
Sat. Worldview2 – conv. sprayer	2011 (n = 1)	20 %	600
Sat. Formosat-2 – conv. sprayer	2013 (n = 1)	27 %	600

Figure 1. Biomass NDVI map of potato crop, 16 September 2013.

Figure 2. Reglone dose map based on NDVI map of potato crop.

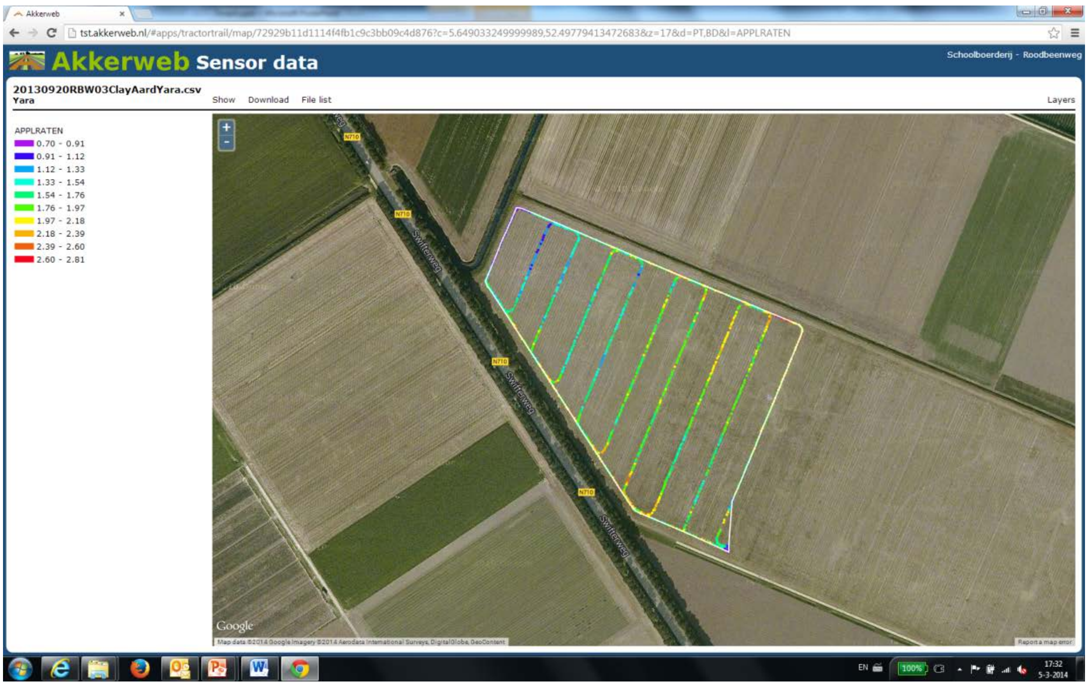

Figure 3. Reglone as applied map based on Yara N-Sensor biomass scan.

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