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Algorithms for variable rate application of crop protection products

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Summary

Between 2006 and 2011 over 30 experiments were carried out with Variable Rate application of potato haulm killing herbicides and contact fungicides. Two systems were used to site-specifically dose on the basis of variation in crop biomass. The study shows that use of these pesticides can be reduced using variable rate application technology with 25–50% compared to standard practice, while efficacy remains good. In the case of potato haulm killing, % dead plant tissue and harvestability were measured, in the case of fungicides disease development was recorded. The need for standardisation and further R&D on development of dosing algorithms is discussed for different classes of pesticides.

Key words: Precision agriculture, herbicide, fungicide, site specific crop management

Introduction

Several innovations paved the way for introduction of variable rate application (VRA) and spot treatment of pesticides in agriculture. Global Navigation Satellite Systems (GNSS) allow accurate assessment of positions of machines in fields at any time. Several sensors is used on farms today to measure online specific crop and soil properties that (may) have an effect on efficacy of pesticides, and so, on minimum effective dosages. In ongoing R&D programmes, we see the development of camera systems for detection of individual weeds, diseases and pests. Modern field sprayers can adjust dosages or spray volume relatively fast within metres of distance over the whole width of a spray boom or per section of the spray boom (e.g. Oerke, 2010). And even dosing per nozzle is possible. So, most components for VRA are available.

VRA can be done at different scales, as described by Christensen *et al*. (2009). In this manuscript we focus on the scale of grid treatment in arable crops, which is about 10–50 m^2 and mainly determined by properties and settings of the sprayer. Each successful VRA concept/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. The aim of this manuscript is to present progress in VRA of potato haulm killing herbicides and fungicides in arable crops at Wageningen UR and various partners. Data on spatial variation of dose determining factors are presented together with agronomic performance of the VRA compared to standard practice. We shortly address VRA of soil herbicides too.

Materials and Methods

We carried out over 30 experiments with VRA of pesticides on commercial arable fields between 2006 and 2011, mainly in the province of Flevoland in the Netherlands. Soil type in Flevoland is a relatively young and fertile marine clay with modest spatial variation in soil properties. Typical crops on arable farms in Flevoland are potatoes, sugarbeets, cereals and onions, with now and then, flower bulbs, maize or grass in the rotation. Sprayers used in the experiments were conventional sprayers (e.g. Hardi, Agrifac, CHD) or an injection type sprayer (Hardi). Since 2009, experiments were also done in Germany (one test with Yara N-Sensor and potato haulm killing) and in the south of Netherlands near Eindhoven (sandy soil, potato haulm killing with Yara N-Sensor MLHD PHK VRA).

Each experiment was 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 application of the pesticide. Pesticide choice and timing was done by the owner of the field, supported by local advisors, a disease warning system and/or weather forecast. On each part of the field, efficacy was assessed after pesticide applications by observations of at least 10 randomly chosen positions on each part of the field. On these positions, if present, infections by pathogens were recorded and, for potato haulm killing, % dead plant tissue one and 3 weeks after treatment were determined. Yield assessments were not done.

Two VRA systems were tested. One system uses the Yara N-Sensor technology (Yara International ASA, Oslo, Norway). We worked with the passive sensor that uses ambient light, and the ALS sensor that contains a light source. An 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 × 15 m^2 area. The N-Sensor was combined with both conventional sprayers (27–48 m wide) and an injection sprayer (27 m wide). For details, see www.precisielandbouw.eu and Kempenaar & Struik (2008). The other VRA system tested is named SensiSpray (Homburg BV, Stiens, The Netherlands), which is a system that can adjust 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).

As a reference to compare densities of canopies at time of treatment, we measured WDVI values of crops with near-ground sensors radiometers (Cropscan Inc., Rochester MN, USA). The Cropscan sensors have both upward- and downward looking photo diodes so as to enable immediate measurement of reflectance. We calculated a WDVI from the reflectance data using a green and infrared band ((Bouman *et al*., 1992; Clevers, 1989):

$$\mathrm{WDVI} = R_{v,810} - (R_{s,810}/R_{s,560})\, R_{v,560} \qquad (1)$$

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.

Dosing algorithms for potato haulm killing herbicides were taken from R&D between 1999 and 2004 (Kempenaar & Struijck, 2008; Kempenaar *et al*., 2004). A typical example of such an algorithm is given for Reglone (200 g diquat-dibromide L^{-1}), the mostly used herbicide in the study:

$$D = min[\ 3.0,\ 0.38 * exp(\ 4.9 * \mathrm{WDVI}\ )\ ] \qquad (2)$$

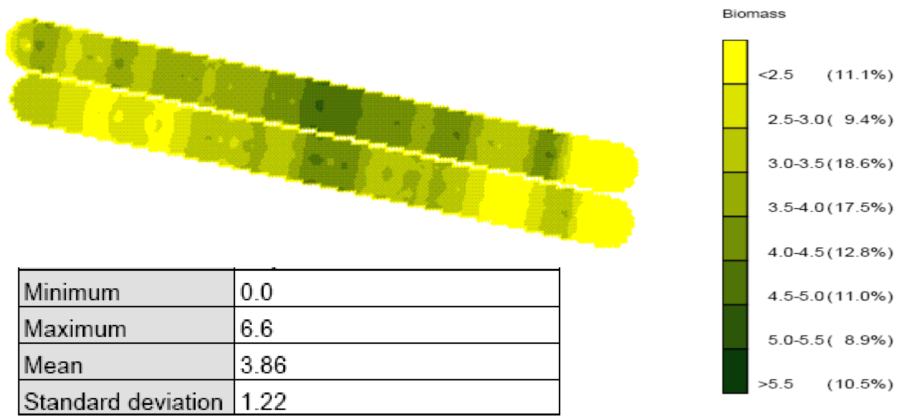
where D = application rate (L ha^{-1}) of the haulm killing herbicide, *min()* is a function which returns the smallest of its arguments, *exp()* indicates exponentiation with base e, and WDVI (Weighted Difference Vegetation Index, $0 \leq WDVI \leq 1$) is the vegetation index. In this case 3.0 is the maximum recommended dosage of Reglone at high WDVI > 0.4. Parameters 0.38 and 4.9 are pesticide specific parameters. The dosing algorithms used in this study are all programmed in the software of the decision making unit (sensor or board computer) of the two VRA systems. All algorithms have in common that they have a sigmoidal shape, having:

1. a minimum dosage larger than 0 L or kg product ha^{-1} 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.

Results

VRA potato haulm killing herbicides

Fig. 1 shows a typical result of Yara N-Sensor biomass measurements on a ware potato field at the time potato haulm killing is done. The variation in measured biomass (N-Sensor output are S_1 and S_N values, the latter is presented) is shown for two spray bands on this field. Highest dosages are applied on the positions with dark green colours. WDVI values on this field were between 0.05 to 0.3.



Minimum	0.0
Maximum	6.6
Mean	3.86
Standard deviation	1.22

Fig. 1. Biomass map (top left) of two bands in a ware potato field mede with Yara ALS N-Sensor (Biddinghuizen, 2008). The legend relates colours to biomass-parameter (S_N value). The Table contains minimum, maximum, mean and stdev of S_N.

The Yara N-Sensor VRA system has been tested on more than 20 commercial fields between 2006 and 2011 using the MLHD PHK dosing algorithms (Kempenaar *et al*., 2004, see also Eqn 2). In 90 % of the cases the a.i. diquat-dibromide was used, others were glufosinate-ammonium, carfentrazone-ethyl or metoxuron. WDVI values on these fields differed quite much, they ranged from 0.04 to 0.42 at the time of treatment. Table 1 contains a summary of the herbicide use data on these fields. The VRA system was compared with the dosages the farmer normally would apply on the field. The YARA N-Sensor VRA system gave on average a 40% reduction in herbicide use while efficacy remained good. One and three weeks after treatment, VRA plots did not differ significantly from the standard practice plots in terms of % dead plant tissue and harvestability. During the experimental period, farmers learnt about the system and already lowered their standard practice dosages during the period.

Table 1. *Data on herbicide reduction by VRA of potato haulm killing herbicides in different settings and years*

Sensors in VRA	Years (# of Expt)	Reduction in herbicide use	Herbicide use in reference (g a.i. ha^{-1})
Yara N-Sensor	2006 – 2008 (n = 11)	47 %	640
Yara N-Sensor	2009 – 2011 (n = 12)	36 %	440
SensiSpray	2007 – 2011 (n = 6)	33 %	463

The SensiSpray VRA system with GreenSeeker sensors and dosage optimization per section of the spray boom gave similar results as the Yara N-Sensor VRA system. In six experiments with diquat-dibromide herbicide the reduction in herbicide use was 33% on average compared to standard practice, while efficacy (% dead plant tissue and harvestability) remained good. A typical biomass map of one of the experiments is shown in Fig. 2. NDVI values (GreenSeeker output) on these field ranged from 0.2–0.7, comparable with WDVI values on these fields of 0.1–0.35.

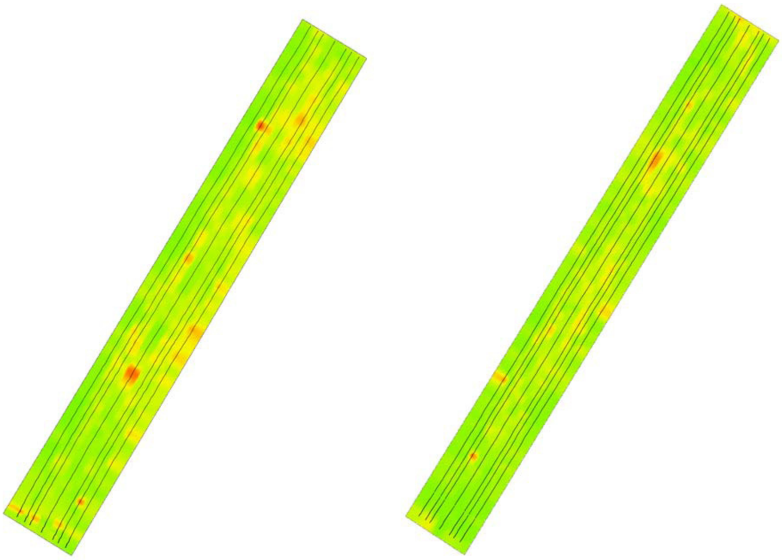


Fig. 2. Biomass maps of two bands in a ware potato field made with SensiSpray Greenseeker sensors (Lelystad, 2008). Each bands shows 7 lines, reflecting positions were GreenSeekers measured NDVI. The middle line is the tram line of the sprayer.

VRA fungicides

VRA fungicide use with SensiSpray was tested in potatoes and tulips between 2008 and 2011. In the case of potatoes, the system was applied only during first 3–5 sprays in the season, from crop emergence to closure of canopy. Crop NDVI values during application increased from *c*. 0.3 (first spray) to 0.9 (last spray). In the case of tulips, three sprays were done with the SensiSpray VRA system in one crop. Crop NDVI values during application increased from *c*. 0.3 (first spray) to 0.9 (last spray). Reference WDVI values are 0.15–0.45.

Fungicide use was reduced by *c*. 25% in both crops with VRA (see Table 2), while no differences were observed in *Phytophthora* (potato) or *Botrytis* (tulip) infestation of the crops between the VRA system and standard practice. The efficacy was good in both systems tested in potatoes and tulips. The fungicides used were Shirlan, Revus and Infinito. In 2011, an additional test was done to check if leaves treated with VRA still had sufficient protection at the end of spray intervals. No significant difference in protections was found in this test between leaves treated with VRA and standard practice (Kempenaar *et al*., 2011, in prep.).

Table 2. *Data on fungicide reduction by VRA of fungicides in potatoes and tulips*

Sensors in VRA	Years (# of expt)	Reduction in fungicide use
SensiSpray potato	2008 – 2011 (n = 4)	23%
SensiSpray tulips	2008 (n = 1)	25%

Discussion

Over 30 experiments with VRA based on differences in crop biomass (canopy density) show the potential of this technology in reducing pesticide use in arable crops. The sale of precision was between 10 and 50 m^2. The case of potato haulm killing is now that advanced that it can be applied in practice. Farmers still have to make a choice on which dosing algorithm for which herbicide to use, but this choice is supported by a menu on the board computer and manuals of the suppliers (see MLHD PHK description in N-Sensor manual on www.sensoroffice.com).

The case of VRA of contact fungicides early in the season is more complex. It is used in combination with an early warning system for pathogenic fungi as *Phytophthora infestans* in potato and *Botrytis* spp. in tulip, to determine the timing of treatment. Also the risk perception of this type of VRA is much larger; any mistake may lead to major crop loss. However, results so far show promising results. Further R&D is required to make VRA of contact fungicides ready for use in practice. Dosing algorithms are to be developed for all fungicides and fungicide combinations.

We see the need for standardisation of dosing algorithms. When VRA technologies become more available, the need for validated dosing algorithms increases. And they must be compatible with different technologies, either the two sensors mentioned in this manuscript or other crop reflection sensors, including satellite images (van Evert *et al*., 2011, in prep.).

VRA systems are not limited to dosing on the basis van variation in biomass. In the case of contact herbicides, we need to be able to discriminate between above ground crops and weed biomass. And in the case of soil herbicides, soil properties are a main determinant of efficacy. R&D for soil herbicides is ongoing at Wageningen UR. Concept dosing algorithms have been developed in Greenhouse experiments. They will be tested in 2012 on commercial farms using sprayers as mentioned in this manuscript. Dosing will then be done on the basis of spatial variation in lutum fraction or organic matter, as shown in Fig. 3.

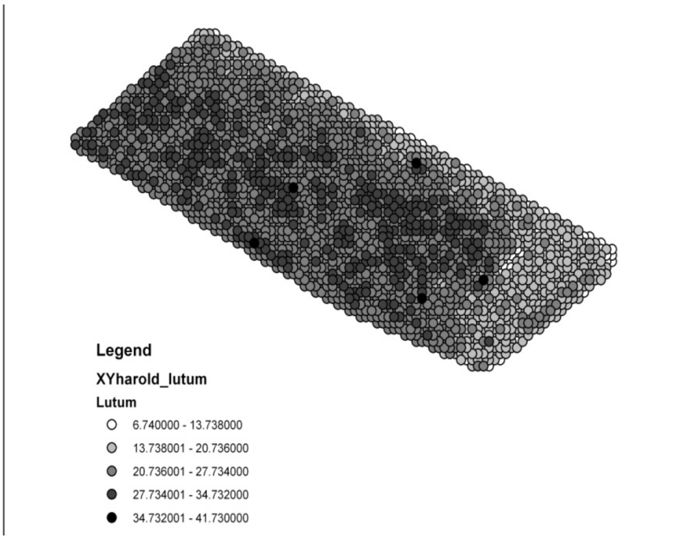


Fig. 3. Soil lutum map of an arable field (Biddinghuizen, 2011).In 2012, these data will be used for VRA of soil herbicides.

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