Focus Group Fertiliser efficiency in horticulture

Mini-paper - Nitrogen and water need based on a model

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Introduction

In the European region, horticultural crops are produced under intensive management practices with high consumption of inputs to produce high yields but with consequent environmental problems in soil, groundwater and atmosphere. The horticultural crops managed with high inputs use large quantities of mineral fertilisers to maintain high production levels in quantity and quality. Generally, the nitrogen use efficiency (NUE) of these crops is low (< 50%) (Carranca, 2012). NUE depends on several factors including climatic conditions, soil type, crop genotype, rootstock, root development, fertiliser N source, placement, rate and timing of fertiliser application, irrigation system, and type of associated crops. The N not used by the crop is thereafter immobilised in the soil in the microbial biomass or "fixed" in the expanding clay minerals, or lost from the ecosystem by leaching/runoff, volatilisation or denitrification emissions. Besides the environmental impact, the overuse of fertilisers represents a substantial cost for farmers.

Simulation models can be used to design strategies of irrigation and N fertilisation based on estimated crop water and N requirements throughout the season (Figure 1). Once models have been calibrated and validated they can be used before and during the cropping season considering the crop type, management practices and environmental conditions for a better fertilisation and irrigation strategy. The combined use of prediction models and monitoring sensors allows the design of precision irrigation and N management practices. The combination of these techniques with crop rotation and intercropping systems improve the NUE of horticulture crops.

Objective

The objective of this paper is to make a general review of previous developed prediction models for horticultural crops, to discuss the main bottlenecks of the use of simulation models developed for vegetable crops and, to identify additional needs for research and dissemination activities that should be promoted.

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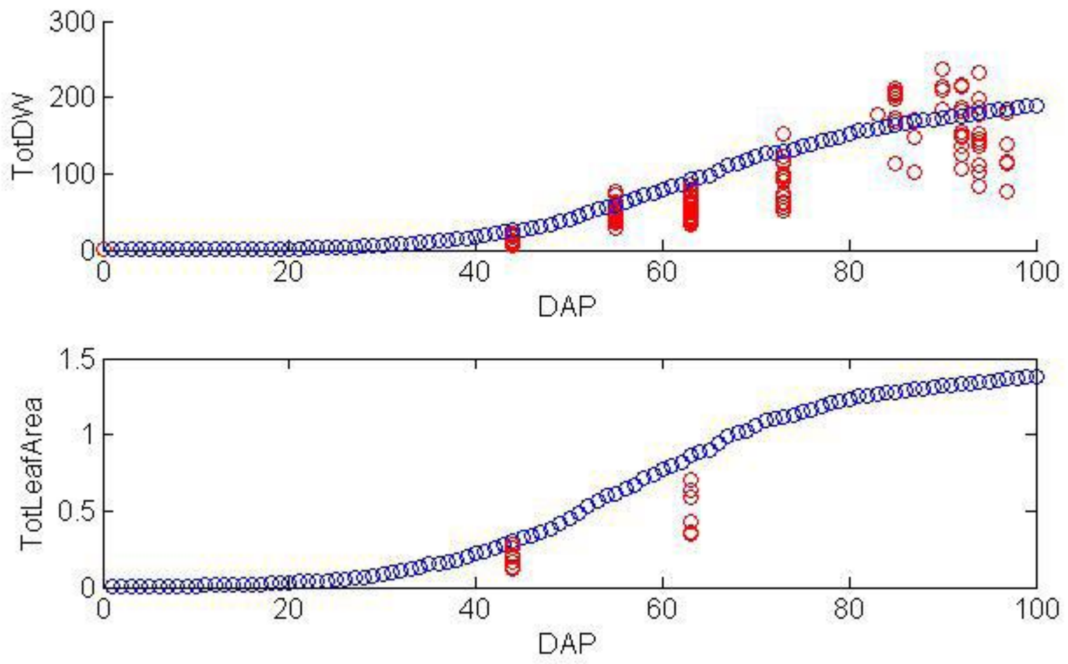

Figure 1 Measured (red dots) and simulated values (blue dotted line) of total crop dry weight (TotDW) and total leaf area during the growing season of cauliflower of 2009 (DAP, days after planting), for one example of broadcast N (after van Loon *et al.*, 2011)

Revision and discussion

The use of simulation models has changed during the last years to present. The first simulation models were developed to make yield estimations of cereal crops and to simulate soil erosion processes, such as EPIC (Williams *et al.*, 1984), STICS (Brisson *et al.*, 1998), CropSyst (Stöckle *et al.*, 2003), CERES (Ritchie *et al.*, 1998) and the DSSAT group of models (Jones *et al.*, 1998). These models are complex and require detailed and large amount of data. For that reason, these models have been used during the last years by researchers and policymakers, but they have not been used by farmers and technical advisors as a Decision Support System (DDS) to design irrigation and fertilisation strategies. Additional models have been developed to simulate N dynamics of crops grown in open field conditions, such as APSIM (McCown *et al.*, 1996), CENTURY (Parton *et al.*, 1994), SOILN (Johnsson *et al.*, 1987), WELL-N (Rahn *et al.*, 1996) and N_ABLE (Greenwood *et al.*, 1996). These models are mostly complex, mechanistic, are data hungry, and have been calibrated and validated in different areas and under different management conditions. Detailed physiological simulation models have been developed for scientific applications such as the mechanistic photosynthesis-based model developed by Marcelis *et al.* (2005). These kinds of models are too complex and not suitable for practical on-farm management.

Some worldwide known complex models (CropSyst, N_ABLE) (Stöckle *et al.*, 2003; Greenwood *et al.*, 1996) have been used to develop new simplified models, useful to simulate the N use by horticulture crops. VegSyst (Gallardo *et al.*, 2011) can simulate daily dry matter production, evapotranspiration and N uptake. It has been calibrated for horticulture crops grown under greenhouse conditions, and now it is being calibrated for different vegetable crops grown in open field conditions. The EU-Rotate_N model (Greenwood *et al.*, 1996) is able to simulate accurately the N dynamics in the soil-plant system of many horticulture crops under no N limiting conditions.

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Simulation models need a preliminary calibration and validation work before being used with different crops. This preparatory work is rather expensive and time consuming. In addition, most of the prediction models that are useful to estimate N and water requirements need a high amount of input data, and these data are not always available. Some models are too complex to be used and /or understood by farmers or are still in the state of research at the moment. In most cases, advisors should support farmers when they want to use prediction models. Farmers should be involved in the demonstration of models. A practical way to support farmers using models could be the use of models in commercial farms by advisors and the feedback of this knowledge to farmers later.

Conclusions

Most of the simulation models that have been developed to simulate the N dynamics in the soil-plant system are too complex, require a large amount of input data and, in some cases, research is necessary to obtain calibration factors for specific horticulture crops. The more complex models are useful to test new strategies at a regional level and for legislation purposes. Some models have been simplified to make them easier to be used by farmers and consultants, reducing the number of required inputs and assuming the possible risk of loss of accuracy. These simplified models work well and provide simple and useful information for farmers to design appropriate and to compare different fertilisation and irrigation strategies. Additional studies are still necessary to create complete reference databases (climatic data, physical and chemical soil parameters and crop calibration factors) for different European areas to promote the use of prediction models. Some simple and useful software and applications for smartphones can be developed based on these simplified models to assist farmers with the estimations of N requirements of different horticulture crops. Training and dissemination activities must be promoted and organised to transfer the knowledge about simulation models, their estimation routines and their potential use. The combined use of soil and plant monitoring sensors and simulation models is a useful group of tools to design optimal irrigation and N management practices.

References

Brisson, N.; Mary, B.; Ripoche, D.; Jeuffroy, M.H.; Ruget, F.; Nicoullaud, B.; Gate, P.; Devienne-Barret, F.; Antonioletti, R.; Durr, C.; Richard, G.; Beaudoin, N.; Recous, S.; Taylor, X.; Plenet, D.; Cellier, P.; Machet, J.M.; Meynard, J.M.; Delecolle, R., 1998. STICS: a generic model for the simulation of crops and their water and nitrogen balances. I. Theory and parameterization applied to wheat and corn. Agronomie, 18: 311- 346.

Carranca, C.2012. Nitrogen use efficiency by annual and perennial crops. In: Lichtfouse, E. (ed.). Farming for Food and Water Security. Series: Sustainable Agriculture Reviews, 10: 57- 82. Springer Science+Business Media Dordrecht. ISSN 2210-4410, ISBN 978-94-007-4499-8 (doi 10.1007/978-94-007-4500-1_3).

Gallardo, M.; Giménez, C.; Martínez-Gaitán, C.; Stöckle, C.O.; Thompson, R.B. 2011. Evaluation of the VegSyst model with muskmelon to simulate crop growth, nitrogen uptake and evapotranspiration. Agricultural Water Management, 101: 107 – 117.

Greenwood, D.J.; Rahn, C.R.; Praycott, A.; Vaidyanathan, L.V.; Paterson, C.D., 1996. Modelling and measurement of the effects of fertilizer-N and crop residue incorporation on N-dynamics in vegetable cropping. Soil Use and Management, 12: 13 - 24.

Greenwood, D.J.; Mcktee, J.M.T.; Fuller, D.P.; Burns, I.G.; Mulholland, B.J. 2007. A novel method of supplying nutrients permits predictable shoot growth and root : shoot ratios of pre - transplant bedding plants. Annals of Botany, 99: 171-182. (doi:10.1093/aob/mcl240)

Jones, J.W.; Tsuji, G.Y.; Hoogenboom, G.; Hunt, L.A.; Thornton, P.K.; Wilkens, P.W.; Imamura, D.T.; Bowen, W.T.; Singh, U., 1998. Decision support systems for agrotechnology transfer DSSAT v3. In: Tsuji, G.Y.;

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Hoogenboom, G.; Thornton, P.K. (Eds.). Understanding Options for Agricultural Production. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 157-177.

Johnsson, H.; Bergstrom, L.; Jonsson, P.E.; Paustrian, K., 1987.Simulation of nitrogen dynamics and losses in a layered agricultural soil. Agricult. Ecosys. Environ., 18: 333-356.

Marcelis, L.F.M. ; Brajeul, E.; Elings, A. ; Garate, A. ; Heuvelink, E. ; de Visser, P.H.B., 2005. Modelling nutrient uptake of sweet pepper. Acta Hort., 691: 285-292.

McCown, R.L.; Hammer, G.L.; Hargreaves, J.N.G.; Holzworth, D.P.; Freebairn, D.M., 1996. APSIM: a novel software system for model development, model testing, and simulation in agricultural systems research. Agric. Syst., 50: 255-271.

Parton, W.J.; Rasmussen, P.E.; 1994. Long-term effects of crop management in wheat-fallow: II CENTURY model simulations. Soil Sci. Soc. Am. J., 58: 530-536.

Rahn, C.R.; Greenwood, D.J.; Draycott, A., 1996.Prediction of nitrogen fertilizer requirement with the HRI WELL-N computer model. In: Progress in Nitrogen Cycling Studie*s*. Springer Netherlands, pp. 255-258.

Ritchie, J.T.; Singh, U.; Godwin, D.C.; Bowen, W.T., 1998.Cereal growth, development, and yield. In: Tsuji, G.Y., Hoogenboom, G., Thornton, P.K. (Eds.). Understanding Options for Agricultural Production. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 79-98.

Stöckle, C.O.; Donatelli, M.; Nelson, R., 2003.CropSyst, a cropping systems simulation model. European Journal of Agronomy, 18: 289-307.

van Loon, J.; Vansteenkiste, J.; Diels, J.; Schrevens, E., 2011. Developing and testing a model for open field horticultural crops to enable use of a "just-in-time" fertilization management. 19th Int. Cong. On Modelling and Simulation, Perth, Australia, 12-16 December 2011.

Williams, J.R.; Jones, C.A.; Dyke, P.T., 1984. A modelling approach to determining the relationship between erosion and soil productivity. Transactions of the ASAE, 27 (1): 129-144.

Yang, L.; Wadsworth, G.A.; Rowell, D.L.; Burns, I.G., 1999.Evaluating a crop nitrogen simulation model, N_ABLE, using a field experiment with lettuce. Nutrient Cycling in Agroecosystems, 55: 221–230.

APPENDIX Simulation models

1. The N_ABLE model

The N_ABLE is a deterministic dynamic N model designed by Greenwood *et al.* (1996) to simulate the growth of vegetables and arable crops in England and Western Europe. The model incorporates the relationships between the daily dry weight (W), growth rate and soil mineral N during the growing period. The measured growth curve (W) was described as a J - shaped or an S - shaped curve depending on the date of period of growth. However the N_ABLE model only described accurately the exponential part of the growth curve (J - shaped curve). This model underestimates the daily dry weight at low N inputs. For longer periods of growth, a modified growth equation was developed and was based on an asymmetrical S - shaped curve (Yang *et al.*, 1999):

$dW/dT = k_2 * W * Gf * Gk^{/ (1+W)}$

where W = growth (g m^{-2}), T = time (day, d), k_2 is the growth rate coefficient (g m^{-2} d^{-1}), Gf ($\leq$ 1) is the correction coefficient for any restriction in growth rate caused by sub - optimal N concentration in the plant and is estimated by the ratio of N concentration in the plant to critical N concentration, and Gk= $(2.58 / W)^2$. Using this modified equation, predicted yield becomes more accurate at all stages of growth but the model still requires a further validation.

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2. The EU – ROTATE _N model

The EU - Rotate_N model is based on the N - ABLE model (Greenwood *et al.*, 1996). It has been evaluated with different vegetable crops in different climatic conditions to simulate the dry matter production, the crop N uptake, the marketable fresh yield, the evapotranspiration crop coefficient, the drainage, the nitrate leaching, and the soil water and mineral N dynamics, with very good results. The EU – Rotate _N prediction model provides a general accurate simulation for a large amount of field vegetables and soil N dynamics. Additional studies are necessary to calibrate the mineralisation factor of this model for Mediterranean conditions.

3. The VegSyst model

The VegSyst simulation model was developed to assist with N and irrigation management of vegetable crops grown under greenhouse conditions, but it can be used with vegetable crops grown in open field conditions. One of the most useful practical features of the VegSyst model is that it is a relatively simple model intended for on-farm use as a Decision Support System to provide an effective simulation of daily dry matter production, N uptake and evapotranspiration for vegetable crops with different planting dates. Additional studies are necessary to calibrate this model for different vegetable crops.

4. A new model

A new model was proposed by Greenwood *et al.* (2007) based on published algorithms for the dependence of plant growth rate and optimal nutrient concentration on shoot dry weight (Ws, g m^{-2}), and on measuring evapotranspiration rate and shoot dry weight at weekly intervals. This model enables plant growth to be maintained for long periods at different values of the growth rate coefficient [K_2 (g m^{-2} d^{-1})] without the appearance of any nutrient (N) deficiency symptoms even when nutrients are severely limiting the growth. The value of K_2 for the optimum nutrient supply was well defined by a modification of a previously published equation in terms of average temperature and incoming radiation. The ratio of K_2 for a sub - optimum rate of supply relative to that with the optimum rate was logarithmically related to the nutrient supply as a fraction of the optimum N rate.

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