Best Management Practices
Use Case: the Westland Region (NL)

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List of abbreviations

AGRINUPES	Integrated monitoring and control of water, nutrients and plant protection products towards a sustainable agricultural sector
GEM	Greenhouse Emission Model
PPPs	Plant Protection Products (pesticides)
WFD	Water Framework Directive
N	Nitrogen
P	Phosphorus
K	Potassium
ET	Evapotranspiration
ZLD	Zero Liquid Discharge
EC	Electrical Conductivity

Summary

The Greenhouse industry in The Netherlands is facing strict regulations to decrease the emission of nutrients (N. P) and plant protection products (PPPs). Growers work together to achieve the goals. According the Water Authorities the water quality is slowly improving. Collecting of rainwater, recirculation, collection of condensation water, emission norms for nitrogen leading to an almost zero emission for all greenhouse crops by 2027 and purification of discharge water to achieve 95% elimination of PPPs are the steering factors.

About a quarter (2500 ha) of the Dutch greenhouse area is located in the Westland Region of The Netherlands. It is a knowledge and capital-intensive area. Here, two third of the area is soilless grown and the drain water is collected and reused. Soil cultivation in the Westland must purify discharge water too, and as far as possible reuse the drainage water. Therefore, NPK-sensors could be used by the grower to have an immediate indication of the N, P and K levels in his circulating nutrient solution, whereas a biosensor for measuring Plant Protection Products is considered less attractive for the grower. However, water authorities in the Westland and other regions in The Netherlands would highly value to have a rapid indication of N, P and K as well as of a Plant Protection Products biosensor. Those sensors can give them a much shorter reaction time compared to a long-lasting laboratory analysis, resulting in reduced costs and a higher quality of surface water. Environmental accidents can be detected sooner with a smaller impact to aquatic organisms.

1. Introduction

The Netherlands is well known by its market in high-tech glasshouses for the production of vegetables, flowers and pot plants. Since the nineties, substrate-grown crops with recirculation of drain water is the common practice, but discharges and leaching occur regularly (on average 5-10% of the supply given to the plants; Van Der Salm et al, 2020). There is an urgent need of complying with emission restrictions (EU-WFD, 2000) and drastically reduce leaching of fertilisers and Plant Protection Products (PPP). To cope with this, growers need to optimally dose nutrients and clean their discharge water (remove PPPs). Water treatment technologies are available but are rather costly. Use of new sensors and controllers will help them to improve operational decisions in their water management to achieve a high-quality crop and cope as well with regulations.

With 3,500 companies, the total area of Dutch greenhouses is somewhat less than 10,000 ha (0.5-40 ha in size and on average 2.8 ha) with both soil-bound and soilless grown crops. Vegetables are grown by 1216 companies on 5,330 ha, while the rest are mainly ornamentals (cut flowers and pot plants, on 3837 ha). Nursery stock production and fruit form a minor part (5%) of the total area. Greenhouses are high-tech glass (Figure 2) with computer controlled climatization. The majority of the crops is grown on a soilless culture (90% of the area). Gutter systems with stone wool slabs or containers with different substrate types (peat, coir, stone wool) are being used (figure 3). Major vegetable crops, often grown in a high-wire cultivation system, are tomato (1690 ha), sweet pepper (1313 ha), cucumber (545 ha), strawberry (491 ha) and aubergine (128 ha). The major soilless-grown cut flowers are rose (250 ha), gerbera (163 ha), lilies (157 ha) and orchids (117 ha). Many kinds of potplants (on floors or on tables) have another 2000 ha soilless grown. (agrimatie.nl, 2020; Raaphorst, 2017). About 10% of the crops are grown in soil (Raaphorst, 2017), because an economically feasible soilless production system does not yet exist for those crops. This applies mainly for some cut-flowers (namely chrysanthemum - figure 4, freesia, alstroemeria, lisianthus), leafy vegetables (figure 5) (lettuce types) and radish and organically grown crops, which include mainly tomato, sweet pepper and cucumber (100 ha).

Figure 1. Westland region, the Netherlands (source Google Maps, Nov. 2020): all grey squares are greenhouses; brown spots are houses and villages.

The Westland area (Figure 1) had 2300 ha greenhouse production area in 2018 of which 1048 ha vegetables and 1102 ha cut flowers and pot plants, divided over 587 companies (3.9 ha per company), according the municipality Westland (Groentennieuws, 2019). It means that about 25% of the Dutch greenhouse area is located in the Westland region (Raaphorst, 2017). Compared to The Netherlands there is some more soil cultivation (radishes, freesia and chrysanthemums) in the Westland region and farms are somewhat bigger (more modern).

Figure 2. High-Tech greenhouse (Wageningen University and Research facility in Bleiswijk, NL), characterized as houses with diffuse glass, with a gutter height of 7 m, rainwater collection (left) and rainwater collection tanks and drainage pipes to the ditch (right).

Figure 3. Substrate grown tomatoes in a typical Dutch high-tech greenhouse (left), and a gerbera crop grown in containers on gutters (right).

Figure 4. A soil-grown and recently planted Chrysanthemum crop (left), and during cropping with artificial light (right).

Figure 5. A soil-grown radish crop (left), red oak leaf lettuce hydroponically grown in nutrient film technique (NFT) on movable troughs

Among the Northwest European countries, The Netherlands has the highest concentration of greenhouses, as surrounding countries like Germany, Belgium, Sweden, Denmark and UK, have only 500−3,500 ha of greenhouses scattered over much larger areas. Consequently, the polluting effects/risks have a different scale (Van der Salm et al., 2020).

In open soilless cultivation systems (Figure 6A) the discharged nutrient solution (30-40% of the volume supplied to the plants) is flowing to the surface water or into the sewage system. In the first situation smaller ditches might be polluted, in the latter case large canals might receive the discharged solution with, amongst others, nitrate, phosphates and PPPs. In The Netherlands an open system is not allowed anymore. In the closed soilless systems (figure 6B) most of the drainwater is reused and only 5-10% of the volume supplied to the plants is discharged. Discharge of nitrogen must be decreased to nearly zero by 2027, while the PPPs must be eliminated with purification by 95% already since 2018.

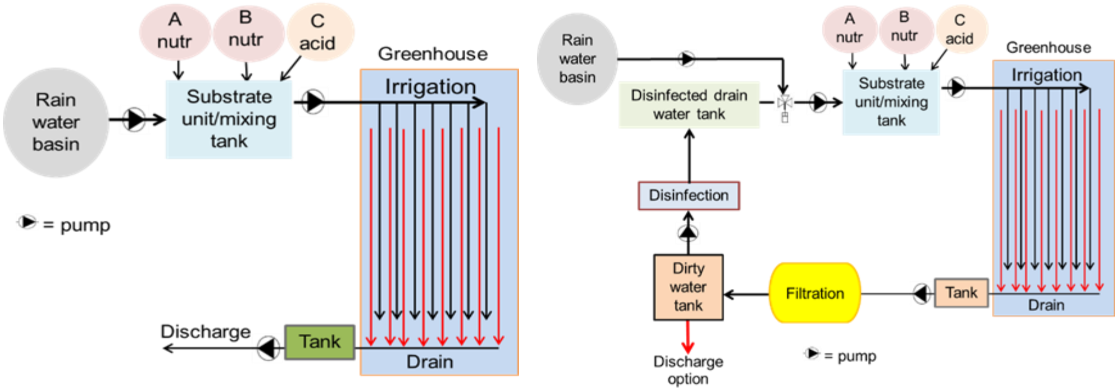

Figure 6. Schematic scheme of an open (A, left) and a closed (B, right) soilless culture system (Van der Salm et al., 2020).

In soil systems the irrigated water seeps into the soil and if there is too much it drains away via drain pipes into the ditches around the greenhouse. Drain pipes are common in the Dutch polders where the ground water table is artificially maintained at 80-90 cm below surface level. Here there is infiltration and seepage of water depending the water table of surrounding canals and ditches.

2. Quality of the surface water

In large parts of the Netherlands surface water quality does not meet the chemical and ecological standards as indicated by the EU Water Framework Directive (WFD). The largest exceedances were found amongst others in areas with greenhouse horticulture, mostly caused by intensive agriculture, shallow groundwater tables and intensive drainage systems. In 2014, concentrations for both nitrogen (N) and phosphorous (P) were exceeded in 45 % of the water bodies and exceedances of PPPs were found at 60 % of the locations (Van der Salm et al., 2020).

The current regulatory measure of the Dutch government to improve water quality in greenhouse areas is by achieving (nearly) zero emission of nutrients by 2027. It is assumed that a reduction in N emission will be mainly achieved by a reduction in the discharge of the water volume and will thus also reduce the emissions of P and PPPs. Enforcement of regulation is assigned to the Water Authorities (regional semi-governmental bodies responsible for water quantity and quality).

For soilless cultivation, crop (and company) specific norms for the emission of N are defined, which will be gradually decreased until 2027. The nitrogen emission standard (2015) varies with crop type (9 categories) from 25 – 300 kg N ha^{-1} yr^{-1}, with an estimated discharge volume of 100 – 3,600 $m^3ha^{-1}.yr^{-1}$.

Since emission standards are not feasible for soil grown greenhouse crops, a different approach was chosen to minimise losses. Solutions were directed towards optimising irrigation and a sustainable use of fertilisers, together with regulations on crop-specific maximal nutrient usage.

In addition to that, an obligation exists to remove PPPs from drain water by 2018 onwards (Figure 7). This regulation, the Purification Decree (Hoofdlijnenakkoord Glastuinbouw, 2015), based on an agreement between authorities and the growers' organisation, states that at least 95 % of the PPPs must be removed from discharge water by using purification equipment (Van Ruijven et al., 2020). This rule applies for both soilless and soil-bound greenhouse cultivation and for discharge to surface water and sewer systems. Van Ruijven et al., 2020 mention active ingredients as abamectin, boscalid, esfenvalerate, imidacloprid, kresoxim-methyl, pirimicarb, py,etrozine and spinosad as tested pilot substances for their environmental risks and representing various chemical groups.

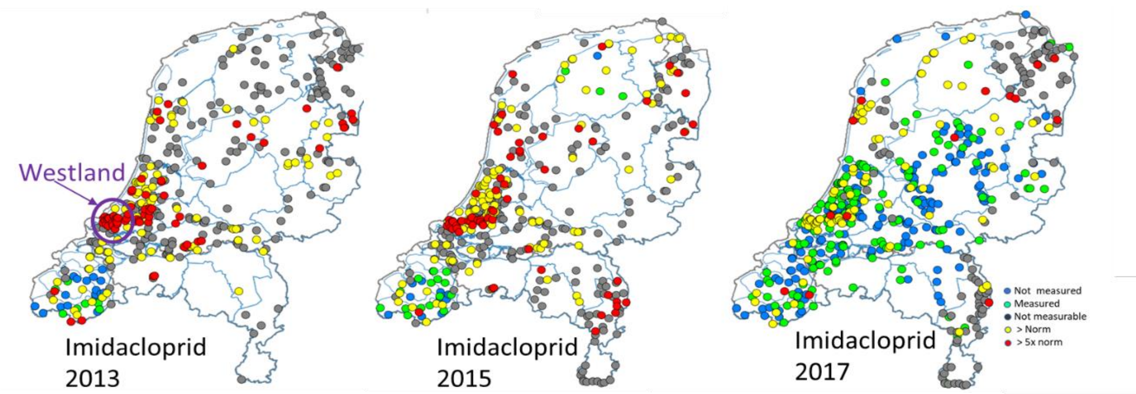

Figure 7. Number of exceeding of norms by imidacloprid, measurements in 2013, 2015 and 2017. Red dots >5x exceedance of the allowed norm, yellow dots 1-5x and green dots no exceedances of the norm (www.bestrijdingsmiddelenatlas.nl).

Research to find appropriate practises for farmers to comply with these regulations showed that for soilless cultivation a Zero Liquid Discharge (ZLD) system gives the best option (Van Os et al., 2020). For soil-bound cultivation the situation is more complicated and a combination of tools and measurements to help the farmer to tune irrigation to crop demand is most promising (Voogt et al., 2018). These approaches will hopefully lead to a substantial decrease in discharge of nutrients and PPP to surface water, and, consequently to a better surface water quality as meant in the EU Water Framework Directive. Some progress can be seen in the reports of Delfland Water Authority in the Westland Region (Waterkwaliteitsrapportage 2019). For some obstacles still solutions need to be found, as for problems with soil-bound cultivation, leakages in soilless cultivation and sodium limitations in certain crops.

3. Implementation at growers

Soil-grown crops

An obvious solution for soil-grown crops would be to switch to a soilless culture. However, for various technical and economic reasons this is not always feasible. Most soil-grown crops have a relative short growing period (weeks or a few months) and a high planting density with almost full surface coverage. To achieve a similar setting in a soilless system, a yield increase of at least 15% would be needed to make soilless cultivation economically feasible. Since this is not possible for all crops, following measures are proposed for soil-grown crops (Voogt et al., 2015, 2018; Van der Salm et al., 2020):

- Reuse of drainage water
- Tuning irrigation to crop demand
- Tuning fertilisation to crop demand

Reuse of drainage water will drastically reduce the quantity of discharged drainage water and a strong improvement of the nutrient use efficiency. As the individual nutrient concentrations of the discharge waters is unknown and rather variable, the use of an in-line NPK-sensor would be beneficial to control the fertigation.

The most effective way to reduce leaching is to reduce the inputs of water and fertilisers, although a certain over-irrigation is the common strategy for soil grown crops to avoid salt accumulation. For many growers this can be a tricky approach as exact water need of the crop is usually not well known. To support these practises, a combination of Evapotranspiration (ET) and hydrological models, soil water content sensors or lysimeters are advised and investigated at this moment.

The concept of tuning fertilisation aimed at optimum production and quality has been used since the seventies and eighties in The Netherlands. There are possibilities to reduce N and P concentrations. The use of an in-line NPK monitoring technology could be useful to support this practise. Besides the irrigation and fertilization are more commonly done at the same moment to realise the right amount of nutrients during the entire growing period. In the past stock fertilization with organic manure or compost was much more important, while during cropping hardly any fertilizer was given.

Soilless cultures

Emission reduction is relatively easy in soilless cultivation compared to soil grown crops, as drain water flows can be controlled. Dutch growers have fully climatized and computerised greenhouses, including measurement of global radiation and the irrigation is strictly related to the amount of (solar and artificial) radiation. However, as soilless systems have a small rooting volume, reducing irrigation can lead to severe problems. In practice the irrigation surplus can be reduced, but a drain fraction of at least 0.2 (vegetables: 0.3, flowers: 0.5) is recommended to prevent problems of heterogeneity in release of drippers, transpiration and uptake. The new legislation for emissions has forced growers to take up following practices (Van der Salm et al., 2020):

- Recirculation of drain water, to reduce emission of both nutrients and PPP.
- Purification of discharge water for the removal of PPP, to reduce emission of PPP.
- Zero Liquid Discharge (ZLD).

Recirculation of drain water has led to new infra-structures at the growers and is mandatory. Those systems are semi-closed as discharge is only allowed in rare occasions when the system fails to maintain a good quality water composition for production. Common practise is to control EC, pH and volume of irrigation continuously and to measure nutrient composition at least once per 2 weeks. Here is a possibility to use an on-line motoring system for the major nutrients (*e.g.* NPK). Still a tricky point is the leakage of nutrient solution. Within the greenhouse, water is lost by connections of troughs and pipes, drippers which are standing wrong or creating the first drain of the slabs. Each point has to be solved, growers has to be aware that between 0.5 and 1.5% of the volume applied is lost by leakages of the system.

Purification of discharge water. The water discharged from a semi-closed cultivation system still contains nutrients and PPPs (if applied in the cultivation) and needs to be treated to remove 95% of PPP. Prior to treatment, discharged water is stored separately and to reduce cost, the amount of discharge is kept as low as possible. According to Dutch regulations, the water needs to be treated with approved purification equipment (Van Ruijven et al., 2020). As the infrastructure for transport of water is expensive, water treatment is best done in-house. Several options are available: dedicated equipment, combined systems also for disinfection, or even a mobile carry-in service. In concentrated greenhouse areas, multiple neighbouring horticultural enterprises could decide to treat their discharge water at a central location. This however requires a strong commitment of the growers. Also, earlier studies showed that the implementation of collective treatment of wastewater flows (including nutrients) from (semi-) closed systems appeared to be rather expensive (Van der Salm et al., 2020). The use of on-line sensors that can measure the specific PPP used in the greenhouse can help to reduce treatment time. Hand-held and sample systems for monitoring PPP can be used to check the performance of the water treatment units, for occasional failures or to determine common treatment times.

Zero liquid discharge cultivation (ZLD). The ultimate step in simultaneously solving emission problems for nutrients and PPP is to achieve zero-emission by avoiding any periodical discharge. This requires good quality irrigation water and using optimal control of the quality of the recirculating nutrient solution. To prevent unbalances in nutrients, the fertigation must be based on plant needs. The whole system requires water treatment units, filters, and sufficient storage volumes and adequate piping. A ZLD cultivation system requires even more attention to the quality of inputs and the recirculating nutrient solution, compared to a semi-closed system. The use of NPK and PPP sensors might support the effective use of such systems.

4. Use of sensors

The above-described overview of horticulture in the Westland Region gives opportunities to use NPK sensors as well as sensors able to measure individual PPPs. Below a short description where to use them adequately.

NPK sensor

1) Grower

The grower can use the NPK sensor for the following goals:

- In-line measuring during cultivation in the drain and in the supply side to optimise the supply to the plants. Accurate sensors are required to be used for calculation and adaptation of the composition of the nutrient solution. Dosing equipment measures EC, but within the EC all essential elements may vary but need to be within limited margins. Now once in 1-3 weeks the composition is analysed at a laboratory.
- Hand-held measuring of NPK to control delivery by the automatic equipment. The grower may check the water in the drain tank or the supply or below the dripper to see if NPKs are at the right level.
- Hand-held measuring of NPK to check for leakages in the greenhouse. Reasons for leakage might be the failure of connections, an overflow of troughs, growing of algae, clogging of troughs, staff caught with equipment on drippers. Water pools develop and measuring on the NPK solves where it comes from. Leakages in soilless cultivation (Groen, 2015) is one of the causes of ongoing emissions to water bodies, even within a ZLD strategy.
- Hand-held measuring of NPK around his farm to check on leakages in ditches or pipes. If certain water flows appear, the question is: “Is it clean or fertilized water?” Accuracy of the equipment might be less than for instance for in-line monitoring practices; an indication of origin is sufficient here.

2) Water authority

The water authorities are responsible for the quality of the surface water. For this the upholders daily visit a part of their work area in the Westland Region (figure 8). For this a group of so-called maintainers visit canals and ditches and sample them. They also have fixed measuring locations (Figure 8). The approach of the last few years is to investigate the water quality within a hydrological unit (i.e. a polder) by visiting the growers and talk to them instead of direct fining them. They hope for a better behaviour by an increased commitment. Together they look to various discharge and leaking points within and around the greenhouse. For them a hand-held NPK meter can be used for:

- Frequent measuring to get an indication of the presence of the nutrients. Accuracy might be less (5-10 mg/l NO_3). Normal is below 2 mg/l, above 10 mg/l rapid action is required. It may lead to direct discharge of unwished nutrients in the surface water.

- Measuring pipe outlets: “Is it pure water flowing out or are there higher values of NPK measurable?” Illegal discharge might be detected earlier and juridically easier proven.
- Measuring at fixed places: to get a good impression of the water quality variation during the year; each 2-4 weeks the same place is measured resulting in a time series of data indicating the variability in quality of the surface water.

Recently, experience has been gained in a test polder with measuring nitrate using colour strips and a smartphone, but this method, although cheap, is not practical for growers and is not sufficiently reliable. A robust and portable measuring device that can measure nitrate in surface water and process water electronically, instantaneously could be very helpful for the water authorities.

Figure 8. Traditional pipes leaching to the ditch (left). Sampling by Delfland Water Authority (right top). Fixed measuring point in a ditch to measure NPK (right bottom).

Plant Protection Products biosensor

It is expected that the biosensor for measuring individual PPPs will be used by the water authorities. The concentrations in the drainwater of the growers are that low (0-2 mg/l active ingredient) that mostly no effect might be expected against plagues and diseases. Those concentrations are also not harmful to the plants, so a grower is not very interested in measuring.

However, those concentrations are high in surface water and may influence biodiversity in the aquatic environment. All PPPs for soilless cultivation are only approved if their concentration in the surface water is below a certain norm or threshold level. For soilless cultivation, the Greenhouse Emission Model (GEM) is in operation in The Netherlands, but not yet in Europe (Vermeulen et al., 2010; Van der Linden et al., 2015). For soil-bound crops it is still under development and comes in 2021. The model describes the water uptake by a crop and, because of the sodium concentration of the irrigation water, the required discharge in combination with filter cleaning. This output is used as input for a substance model in which a PPP is applied at a certain date and the emission concentration can be calculated. Next is that the concentration of the substance comes into a standardised ditch to determine the environmental effect.

As a biosensor can measure individual PPPs, per location or per work field (i.e. greenhouse horticulture, bulb growing, arable farming), specific representative sensors for certain PPPs should be developed. Now imidacloprid and pirimicarb were chosen (see report D3.1 of this project) after an inquiry among the partners, but it can already be seen that the use of imidacloprid is decreasing and that in a couple of years another representative PPP must be chosen and developed as biosensor. A next step would be that approval of a new PPP is only possible if a biosensor is available.

As a fixed measuring spot in the surface water, as shown in Figure 8, a biosensor can also be placed there as a continuous observation of the quality of the surface water. Probably more than one sensor is required. Wouldn't it be interesting to have all dots in Figure 7 measured by a biosensor?

5 Conclusions

In the Westland Region about 25% of the Dutch greenhouse area is located (2400 ha). It is a knowledge and capital-intensive area. 65% is soilless grown and the water is collected and reused. Discharge to surface water is decreasing and must be zero (N, P) in 2027. Present discharge must be purified to eliminate PPPs by 95%. Soil cultivation in the Westland is about 35%, they must purify discharge water too and as far as possible reuse the drainage water. NPK sensors can be used by the grower to have an immediate indication of the N, P and K levels in his circulating nutrient solution. A PPP biosensor is less attractive for the grower. Water authorities in the Westland and the other part of The Netherlands would be extremely happy to have a rapid indication of N, P and K as well as for a PPP biosensor. It gives them a much shorter reaction time compared to a long-lasting laboratory analysis, resulting in reduced costs and a higher quality of surface water.

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