ICL's Chloe Whiteside and Stephen Briggs discuss the properties of the peat-free growing media, including coir, wood fibre or bark.

Hort Science Live delegates were reminded that some of ICL's biological products are suitable for use in IPM programmes. These include the Seeka beneficial nematode range for controlling vine weevil, WFT and sciarid fly. While this useful product range is compatible with many crop protection productions, ICL's Steve Chapman warned growers to leave at least six weeks between applying the Pitcher and Seeka. Pitcher is ICL's biorational pesticide for the suppression of black vine weevil eggs and early-stage instar larvae. However, as it is garlic based, and nematodes are sensitive to garlic, this six-week period must be observed.

ICL's Mike Finney advised delegates to apply Seeka with ICL's penetrant, Transporter, which aids the nematodes' dispersion within the growing media. Growers were also informed that, to avoid getting blockages in the spray equipment, its best to remove fine filters before they apply the nematodes. Larger particles are more effective for soil applications, while medium particles are preferable for foil applications of the product.

Optimising spray applications was the subject of another talk by Syngenta UK's Sean Loakes, who highlighted that: "It's important that we get the best out of our crop protection products. So, we need to be better at applying them – how we use them." Sean therefore reminded growers to be mindful of their choice of nozzles, and the equipment's boom height, and speed, as each of these factors affect the products' application.

As growers' crop protection armoury dwindles, Syngenta's Sean Loakes emphasises the importance of optimising the spray applications of those few remaining products.

Undoubtedly, there are many considerations to be mindful of when sustainably producing plants – but those who attended this year's Hort Science Live no doubt refreshed their existing growing knowledge and picked up many new and useful tips. ■

FULLY AUTONOMOUS GREENHOUSE

PRODUCTION GETTING CLOSER

Events such as the annual Autonomous Greenhouse Challenge, which has just come to an end for another year, highlights the capabilities of modern algorithms and computer systems to manage and control greenhouse environments, often producing better results in terms of crops and yields than growers using a more traditional response based on a combination of sensor data and their own impressions of what the crop might need, *reports Richard Crowhurst.*

Rudolf de Vetten of Blue Radix.

In fact, many areas of greenhouse crop production are already automated as Rudolf de Vetten, chief product officer at Blue Radix points out. "Our team has been part of AgroEnergy, for which we have developed a solution that runs the energy installations of 150 greenhouses autonomously. We also have an implementable solution for climate and irrigation management and today we have more than 20 connected greenhouses divided over nine countries for which we autonomously control the climate."

One definition of autonomous growing is 'combining artificial intelligence (AI) and Internet of Things (IoT) technologies to establish an automated greenhouse management system able to monitor climatic conditions and carry out robotic crop treatments.' At the same time, climate control specialists Hoogendoorn refer to an 'Integrated Data Drive Growing' strategy, commenting, "The DDG strategy is a roadmap to autonomous climate and irrigation control and is based on the basic principles of Plant Empowerment. The use of AI combined with plant physiology is also of great importance for the grower because a proper working AI system has many benefits for growers worldwide. Growers achieve higher yields, enabling them to be more profitable and sustainable."

"Plant Empowerment principles are valuable in many cases and we definitely apply these," agrees Rudolf de Vetten. "It is a helpful overview of proven techniques that are also part of our solutions. However, many growers make the decision to deviate from these principles to adapt to local circumstances, like market conditions or energy costs. We allow growers to follow their own crop strategy and enable them also in these cases to run their greenhouse autonomously."

He says that while the current Blue Radix Crop Controller can generate set points, and automatic irrigation control is almost available, for fully autonomous crop production, more development is needed. "Based on the crop strategy of the grower, our Crop Controller generates setpoints specifically for the local situation. Crop variety, plant stage and actual climate conditions are all taken into account for optimal yield and lowest resource usage.

"However, the observation of the crop is still done by humans. Vision and sensor technology is developing rapidly but is still not at the level that we can fully trust the outcomes 24/7. The other component is labour support. Many robotic solutions are entering the market, and it is only a matter of time before robots will be able to perform some of the tasks in the greenhouse. Gradually we will move towards fully autonomous greenhouses, although the pace will differ per crop."

A Blue Radix team took part in the first WUR Autonomous Greenhouse Challenge, including the final round which involved operating an actual greenhouse for four months with algorithms autonomously. "An important lesson from this is that AI can perform at the level of experienced growers and the yield and quality do not have to differ from humanly operated greenhouses," adds Rudolf. "Many growers and other horticulture experts thought this situation would be at least ten years away from now. But we also see a lot of human intervention in case of unexpected events in these challenges. The other lesson to learn is that a well-designed interaction between growers and algorithms is needed to allow growers to build trust in the algorithms. Offering an easy-to-use interface is essential for a successful implementation."

The Autonomous Greenhouse Challenge was established to explore the potential of AI and technology in greenhouse production, and this year's challenge – the third – focused on hydroponic lettuce production, and had to be entirely autonomous, with competitors unable to change their algorithms during the challenge. It was won by a Dutch-American team called Koala. Silke Hemming of Wageningen University & Research (WUR) explains that while the success in the challenge is measured by gross margin based on yield and quality, factors such as the time taken for the crop to mature and the resources used are also key metrics, as the challenge also has a sustainability element.

Sike Hemming of WUR.

"It's been very impressive how we've been able to demonstrate some ideas around artificial intelligence in horticulture," adds David Wallerstein, chief exploration officer of event sponsors Tencent. "Food security is becoming a key issue. In my work I'm always thinking about global problems, and I'm wondering how indoor environments and horticulture can be scaled up in a way that can meet more of the earth's nutritional demand. It's a challenge as infrastructure is required and you have upfront Capex costs. Farming indoors at least you can control the environment with certainty."

Next year WUR will undertake its own project comparing autonomous and traditional growing techniques. The AGROS project, led by Anja Dieleman, aims to develop a commercially viable autonomous greenhouse. "The question is, if you want to control a complex system like this autonomously, where do you start?" she asks. "The answer is very simple: from the crop as that is what brings the profit." Therefore, you have understood and manage the processes in the plant, which in turn are managed by climate control factors.

"If you ask ten people what is autonomous control, you will get ten different answers," she warns. From an AGROS perspective, autonomous control is the control of crop growth and climate by intelligent algorithms based on a predefined goal function. "AGROS starts with crop physiology, measured with sensors which feed information into intelligent algorithms which support the grower, or even take over control," she explains. Manual crop inspection and trait measurement can have a number of issues, including unreliability, subjectivity and the need for trained and experienced staff carrying out the same tasks at a common time. Using accurate sensors to create this data

WUR and Tencent have now run three Autonomous Greenhouse Challenges.

A digital twin is a digital counterpart of a physical process or object [WUR].

overcomes these issues, so the starting point for autonomous control should already be better than for traditional growing techniques. "We have already been able to collect a set of data, which is very valuable," explains Anja. "This has changed our thinking about measuring commercial crops." For example, using PAR sensors at different heights in the crop overcomes the need to measure or calculate leaf area index in a crop of cucumbers. "It is faster, less labour intensive and gives more continuous measurements," she adds.

The next stage of development is to develop computer-based vision systems to measure factors such as newly formed leaves and fruit set or fruit size. This is particularly difficult in crops such as cucumbers and peppers which are 'green on green'. To overcome this, the team manually applied coloured labels to the plants which could be used to train the computer, until the system could be replaced by a fully automatic system to measure leaf formation, and from here a system to identify and measure cucumber fruit yield could also be developed.

"Plant observation technology will definitely contribute to a higher level of autonomy in many greenhouses," comments Rudolf de Vetten. "We believe a combination of plant sensors; micro climate sensors and vision technology will allow growers to see in real time their crop development and will allow companies like ours to react even quicker to changes in the plant development. The coming years will prove what technology will be the most robust and adds most value."

One term which is often encountered when discussing the Internet of Things and autonomous greenhouses is 'digital twins.' WUR's Pieter de Visser explains that a digital twin is a digital counterpart of a physical process or object. It differs from a model as it should be updated with real time information. "The goals of a digital twin can be optimisation, prediction or visualisation," Pieter explains "The goal of our digital twin tomato project is to monitor and understand the processes involved and have a viable product that growers might be able to use in the future."

3D software is used to grow model 'plants' – known as Functional Structural Plant Models (FSPMs) – in virtual reality by phytomere production which predicts how plants will grow (e.g., branching or flowering), and a number of plant species and types have already been modelled. These virtual models allow the effects of factors such as light distribution, wavelength, CO_2 or even pruning strategies which can affect plant growth. As part of the Digital Twin Tomato project, WUR created both physical and virtual copies of the same growth chamber, including 3D scanning of the actual tomato plants and measuring actual plant biomass. This allowed the team to create a full digital copy of eight weeks of tomato plant growth, which can be studied and reviewed, even after the physical crop has matured and been destroyed. "We use existing models, but we improve and calibrate them," comments Pieter. "If you have a new model, you might change your set points, and that leads to new outcomes."

Autonomous production requires systems to respond to lots of inputs [Blue Radix].

So, with so much attention on the future, what is the current level of autonomy in greenhouse crop production? "Large scale commercial production companies across the world now use our Crop Controller for fully autonomous control around the clock," says Rudolf. "Much of this activity started in the Netherlands, but soon after other countries followed suit, including Canada, USA, Mexico, the Czech Republic and Poland." He adds that work is also underway with a number of projects in the UK.

"Since we use large data sets of historic data, we are able to calculate setpoints in a wide range of climate conditions, offering growers the best possible setpoints for their specific location," he continues. "Growers are looking for a solution to be able to control more hectares with the same number of staff, while avoiding unnecessary mistakes in their climate control and having a solid crop strategy implemented in all their locations, based on a data driven approach."

Rather than the technology, perhaps the biggest barrier to the fully autonomous greenhouse is growers themselves. "Building trust is an important part of our way of working," stresses Rudolf. "An essential part of our offering are our Autonomous Greenhouse Managers who guide growers during the onboarding process, but also during the operational phase after the onboarding. This way growers can really let go of the 'steering wheel.'

"Since our Crop Controller directly affects the setpoints in the climate computer, it is vital for growers to understand how these setpoints are generated. We have regular calls with growers to discuss the crop strategy, adjust any settings if needed and check the crop results. In the background we continuously monitor all the greenhouses that are connected to our Crop Controller system and inform growers if there are any deviations from the expected conditions, which helps build trust in the system. For anyone considering the introduction of autonomous systems, we would recommend working with a partner like Blue Radix on a six-month trial basis." ■