Effect of perchlorate in fertilisers on lettuce and fruit vegetables

Uptake and distribution of perchlorate in greenhouse soil-grown butterhead lettuce and soilless-grown cucumber, sweet pepper, round and cherry tomato

Wim Voogt, Barbara Eveleens en Johan Steenhuizen[1]
Isabel Vandevelde, Raf de Vis en Joris van Lommel[2]
1 Wageningen UR Greenhouse Horticulture, 2 Research Station for Vegetable Production of Sint-Katelijne-Waver, Belgium

Report GTB-1321

WAGENINGEN UR
For quality of life

Proefstation voor de Groenteteelt vzw

Rapportgegevens
Report GTB-1321
Projectnummer: 3242176100

Disclaimer

Adresgegevens

Wageningen UR Glastuinbouw

Postbus 20, 2665 ZG Bleiswijk
Violierenweg 1, 2665 MV Bleiswijk
T +31 (0)317 48 56 06
F +31 (0)10 522 51 93

Research Station for Vegetable Production

Duffelsesteenweg 101, 2860 Sint-Katelijne-Waver, Belgium
T +32 15 30 00 60
F +32 15 30 00 61
E info@proefstation.be
I www.proefstation.be

Table of contents

Summary

In 2013 traces of perchlorate were detected in fruits and vegetable samples. Because perchlorate (ClO_4^-) is part of a group of substances (goitrogens) that may inhibit the uptake of iodine by the thyroid, these findings caused commotion in the markets. Fertilizers were named as one of the sources of perchlorate in food. Therefore, at the request of the fertilizer industry, research has been conducted on perchlorate uptake and distribution in the most relevant greenhouse vegetable crops in Belgium and the Netherlands. This paper summarizes the trials carried out and the main findings. A comprehensive study on the trial outcomes is being prepared for a peer-reviewed publication.

1 Introduction

During the spring of 2013, traces of perchlorate were detected in fruits and vegetable samples collected from the European market. Authorities, retailers and consumers organizations expressed their worries about these findings and the EU agreed on temporary limits for perchlorate in food in July 2013[1] . Under certain conditions, the uptake of iodine in the thyroid can be temporarily inhibited by so-called goitrogenic substances, such as bromide, chlorate, fluoride, nitrate, perchlorate and thiocyanate. Long term exposure to high concentrations of goitrogenic substances may result in reduced functioning of the thyroid, particularly in persons already suffering from iodine deficiency. This can negatively affect their growth and development. However, it has been observed that if a person suffers from iodine deficiency, rather than regulating perchlorate the more effective solution is to increase iodine intake, for example by taking iodine supplements [2].

1.1 Trials

In order to study the uptake and distribution of perchlorate among the various plant parts, one trial was conducted on a greenhouse soil-grown lettuce crop at the Research Station for Vegetable Production of Sint-Katelijne-Waver (SKW) in Belgium. At Wageningen University and Research Greenhouse Horticulture (WUR) in the Netherlands, another trial was carried out on cucumber, sweet pepper, round and cherry tomato, grown on rockwool in a system with recirculation of the drainage water.

---

1 http://ec.europa.eu/food/food/chemicalsafety/contaminants/statement-perchlorate_en.pdf

2 E.g., EPA, Office of the Inspector General, 2010, http://www.epa.gov/oig/reports/2010/20100419-10-P-0101.pdf; World Health Organization, 2014, http://www.who.int/water_sanitation_health/dwq/GDWQ_2013_Repor_microbial_aspects.pdf at p. 46

2 SKW trial

2.1 Trial set up and execution

From July until end of August 2013 a scientific trial was conducted at the research station of SKW to study the effect of increasing perchlorate concentrations applied to the soil on the uptake by greenhouse soil-grown lettuce. The experiment was carried out in 90 L plastic containers (78,5 cm L x 52 cm W x 31,5 cm H), which were closed at the bottom in order to avoid leaching. In each container 6 lettuce plants were grown at a distance of 26,5 cm x 27,5 cm, following commercial practice. Two soil types (light sandy loam and a sandy loam soil) were combined with three perchlorate concentrations in the fertilizers applied: 0 ppm, 25 ppm and 50 ppm perchlorate (mg perchlorate per kg fertilizer applied). The trial consisted of five replicates. Pre-trial soil and irrigation water analysis revealed that the perchlorate concentrations were below detection level.
Butterhead lettuce was sown on July 1 and transplanted on July 16 into the containers, which were placed in a greenhouse compartment at the research station of SKW. Harvesting took place on August 26. In total 734 kg fertilizers per ha were applied as basal and side dressings. Perchlorate was added separately. The fertilizers applied were free of perchlorate (below detection level). The amount of basal fertilizer application was based on soil analysis. However, in order to apply the perchlorate treatments, it was assumed that the basal dressing would consist of 500 kg fertilizers per hectare, as commonly applied in commercial practice, in order to be able to conduct a meaningful comparison between the various treatments. In addition, every side dressing with fertilizers consisted of perchlorate as well. Perchlorate solutions in water were prepared in order to be able to distribute perchlorate homogeneously per container.
Water was applied via a drip irrigation system with one dripper per plant. The amount of water applied was guided by the crop evaporation data. Crop protection means were applied when required and according to commercial practices.

Picture 1. *Overview of the lettuce trial on August 20th, six days before harvest.*

2.2 Harvest

Only the aboveground biomass was harvested. From each plant the outer 7 leaves and associated butt end were removed in order to obtain the marketable lettuce head. From both plant parts (i.e. marketable lettuce head and outer leaves plus butt end) the fresh and dry weight were analyzed. The removed parts were pooled per treatment, dried and analyzed for perchlorate. The perchlorate concentrations in the fresh weight were calculated as the perchlorate concentrations in the dry weight, multiplied by the dry matter content (grand average of 3,2%). During the harvest 14 out of 180 plants appeared to be infected by *Rhizoctonia,* of which 13 infected plants were grown on the light sandy loam soil. These infected plants were harvested separately and analyzed separately for perchlorate.

Picture 2. *Overview of the lettuce crop, grown in a sandy loam soil, at harvest on August 26th.*

2.3 Results

Fresh weight of harvested aboveground biomass
The average aboveground plant weight of healthy plants at harvest was 447 grams (100%), of which 403 grams (90%) marketable lettuce, 39 grams (9%) removed outer leaves and 5 grams (1%) removed associated butt end. Perchlorate treatments had no statistically significant effect on the weight of healthy plants at harvest.

Perchlorate uptake
A positive linear relationship was found between the amount of perchlorate applied (0 ppm, 25 ppm and 50 ppm) and the perchlorate concentration in the lettuce. This finding is in line with earlier scientific publications about the perchlorate uptake behavior in the plant. A statistically significant interaction effect ($P<0,05$) between soil type and perchlorate concentration in the fertilizers applied on the perchlorate concentration in the marketable lettuce head was found. In the treatment with 50 ppm perchlorate in all fertilizers applied, the marketable lettuce head contained on average 0,10 ppm perchlorate, when grown in the sandy loam soil, and 0,14 ppm perchlorate, when grown in the light sandy loam soil (Figure 1).

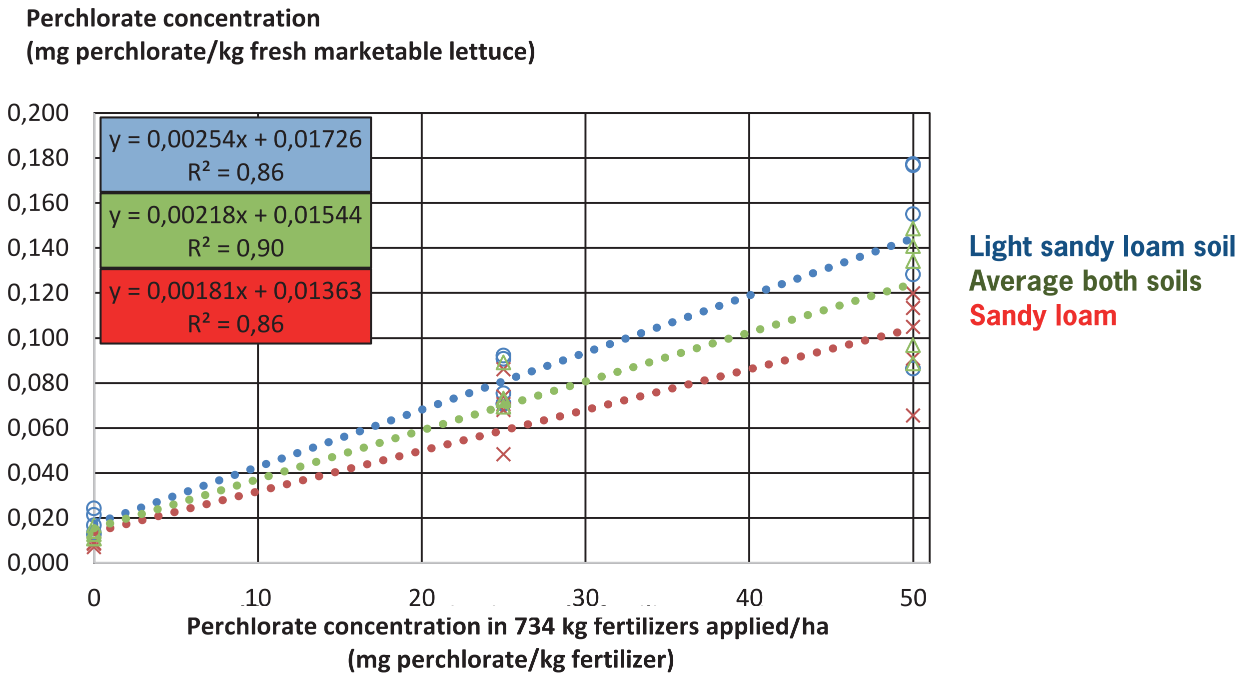

Figure 1. *The effect of an increasing perchlorate concentration in fertilizer (mg perchlorate/kg fertilizer), applied at the rate of 734 kg per ha, on the perchlorate concentration in the marketable part of greenhouse soil-grown butterhead lettuce (mg perchlorate/kg fresh weight), grown in a light sandy loam soil and in a sandy loam soil. Results are based on one cropping cycle.*

Perchlorate uptake efficiency and distribution

The perchlorate uptake efficiency was calculated as the amount of perchlorate analyzed in the aboveground biomass per container (including plants possibly infected by *Rhizoctonia*), divided by the amount of perchlorate applied per container. The average perchlorate uptake efficiency in the 25 ppm and 50 ppm treatments of both soil types was 23,6%, of which 17,8% in the marketable lettuce head and 5,8% in the removed leaves (Table 1). The perchlorate uptake efficiency was slightly greater in the light sandy loam soil than in the sandy loam soil. Furthermore, it can be derived that 76% of the perchlorate absorbed was present in the marketable lettuce head, and 24% in the removed outer leaves and associated butt end (Table 1).

Table 1. The average perchlorate uptake efficiency per container (including plants possibly infected by Rhizoctonia) of the 25 ppm and 50 ppm perchlorate in fertilizer treatments.

Soil type	Perchlorate uptake efficiency (%)		
	Aboveground biomass	Marketable part	Removed part
Light sandy loam	25,2	19,2	6,0
Sandy loam	21,9	16,4	5,6
Average of both soils	23,6	17,8	5,8
Relative average of both soils	100	76	24

2.4 Discussion

Extrapolation to 100 ppm perchlorate in fertilizers
Following the commotion about perchlorate, since the spring of 2013 the mineral fertilizer industry commercializes only fertilizers in the EU with less than 100 ppm perchlorate (as Fertilizers Europe informed the European Commission's Fertilizers Working Group during a meeting in Brussels on 2nd December 2013). Based on the outcome of this trial and the abovementioned positive linear relationship, an extrapolation of the perchlorate concentration in the fertilizers applied was therefore made to 100 ppm. After one cropping cycle, the treatment of 100 ppm will result in perchlorate concentrations in the marketable lettuce from 0,19 ppm, when grown in a sandy loam soil, and up to 0,27 ppm, when grown in a light sandy loam soil. These values are below the EU provisionally established threshold concentration for greenhouse grown lettuce of 1,0 ppm.

From one to more consecutive cropping cycles
This trial describes the perchlorate uptake in lettuce grown in a single cropping cycle. Based on modeling, assuming a constant amount of perchlorate input per surface area, a constant uptake efficiency in the lettuce plant (in %), and a constant distribution of perchlorate among the marketable head and the outer leaves and associated butt end, it can be predicted that the perchlorate uptake over time in a continuous cropping system will level off to finally reach an equilibrium concentration, both in the lettuce plant and in the soil (Figure 2). It can also be derived that the perchlorate uptake efficiency in the marketable lettuce is a decisive factor for the moment that the equilibrium concentration in the marketable lettuce will be reached; the greater the perchlorate uptake efficiency, the sooner the equilibrium concentration in the marketable lettuce will be reached. It is worth noticing that the level of the equilibrium concentration itself does not depend on the perchlorate uptake efficiency. In contrast, the equilibrium concentration in the soil is determined by the perchlorate uptake efficiency of the plant.

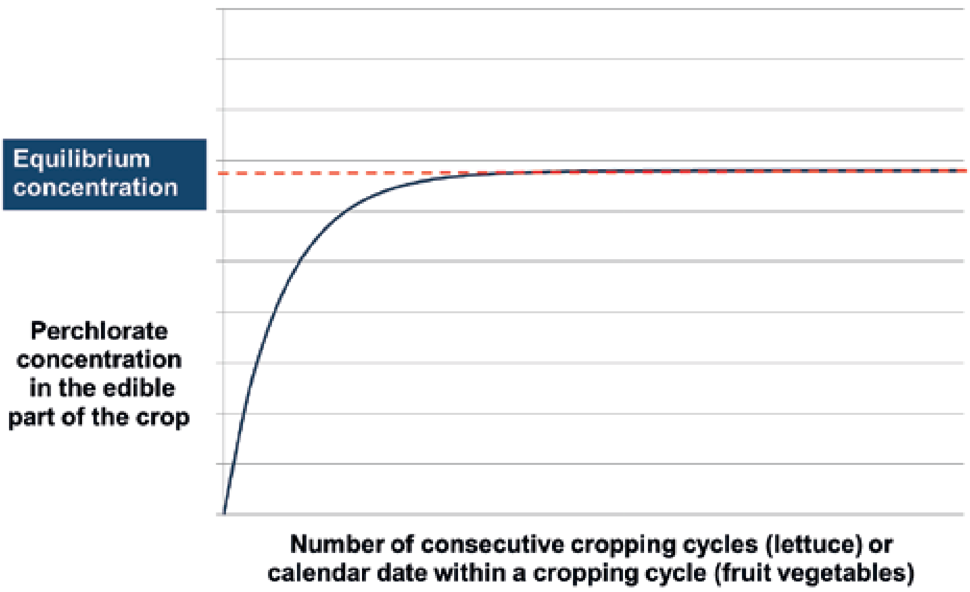

Figure 2. *Predicted evolution in time of the perchlorate accumulation in the edible part of the lettuce and fruit vegetable crops.*

The evolution of the line in Figure 2 and the final perchlorate concentration in the marketable lettuce is dependent on the amount of perchlorate added to the soil, the perchlorate uptake efficiency by the crop and the perchlorate distribution among the marketable lettuce head and the removed plant parts. In addition, possible perchlorate accumulation in the soil, potential contribution of perchlorate from other sources and potential losses from the rooting zone through leaching, fixation or chemical transformation may play a role. In order to gain more insight in these dynamic processes, both within a single cropping cycle as within multiple cropping cycles, a trial with multiple consecutive cropping cycles will be conducted in Belgium in the so-called "Perchlorem" project from September 2014 onwards.

3 Wageningen UR trial

3.1 Trial set-up and execution

Four fruit vegetable crops (cucumber, sweet pepper, round and cherry tomato), were grown in a greenhouse compartment at location Bleiswijk of Wageningen University and Research in the Netherlands. Plants were grown on rock wool slabs in a closed growing system with recirculation of the drainage water. The treatments consisted of 0 ppm, 12,5 ppm and 25 ppm perchlorate in the fertilizers applied. The nutrient solution was composed from a specific mixture of fertilizers aiming at zero perchlorate. The water source for the nutrient solutions was well-water, desalinated by reverse osmosis. The experiment started on July 11th (date of transplanting) and was ended on November 6th, 2013.

3.2 Harvest

For the determination of the perchlorate and minerals content in the dry matter, fruit samples were collected at three moments, i.e. at the beginning, mid-term and end of the cropping period. At crop termination leaves, shoots and stems were collected for perchlorate and minerals analysis. Residual plant parts (prunings) were gathered during the cropping period and analyzed separately. Roots were not analyzed.

Picture 3. *The four different crops on July 18th, one week after planting. In front sweet pepper, then round tomato, cherry tomato and at the end cucumber.*

Picture 4. *The four different crops on August 8th, one month after planting. In front sweet pepper, then round tomato, cherry tomato and at the end cucumber.*

3.3 Results

Perchlorate uptake and distribution among the various plant parts
Perchlorate is absorbed quite easily by these crops; no perchlorate accumulation in the nutrient solution occurred over time. Dry matter analysis of the different plant parts shows that the majority of perchlorate was translocated to the vegetative parts of the plants, mainly to the transpiring leaves and shoots. The quantity of perchlorate translocated to the fruits was very small for both types of tomato and sweet pepper (3 – 5 % of the total absorbed perchlorate). In contrast, 23 % of the total plant-absorbed perchlorate was translocated to the cucumber fruits (Table 2). The difference between cucumber on the one hand and sweet pepper and tomato on the other hand is explained by the greater transpiration rate of cucumber fruit, compared to tomato and sweet pepper fruits. Cucumber fruits are tube-shaped and have a larger surface to volume ratio than the ball-shaped tomato and, to a lesser extent, the blocked sweet pepper. Moreover, the stomata density of the epidermis of the cucumber fruit is also greater, compared to the other fruit vegetables.

Table 2. Relative perchlorate distribution among the dry matter of various plant parts of four crops (rounded-off averages of 12,5 ppm and 25 ppm perchlorate in the fertilizers applied).

Crop	Average perchlorate concentration in the dry matter of various plant parts (%)				
	Fruit	Leaf	Shoot	Stem	Total
Cucumber	23	70	5	3	100
Sweet pepper	4	85	10	2	100
Round tomato	5	91	4	1	100
Cherry tomato	3	92	4	2	100

Perchlorate concentrations in the fruits
A positive linear relationship was found between the perchlorate concentration in the root environment, which is a combination of the nutrient solution supplied and the re-used drainage water, and the fruit. The perchlorate content in sweet pepper, round tomato and cherry tomato was on average 0,02 mg/kg fruit fresh weight at the highest perchlorate level of 25 ppm perchlorate in the fertilizers applied. In cucumber the perchlorate content reached on average 0,06 mg /kg fruit fresh weight at the highest perchlorate level of 25 ppm perchlorate in the fertilizers applied (Table 3).

Picture 5. *Left the first fruits of cucumber on July 29th and right the first trusses of cherry tomatoes on August 26th.*

Picture 6. *Left the first trusses of round tomato on September 4th and right the first fruits of sweet pepper on September 30th.*

3.4 Discussion

Perchlorate uptake and distribution among the various plant parts
The finding that the majority of perchlorate taken up was translocated to the vegetative plant parts is highly consistent with the assumption that perchlorate is translocated primarily through the xylem by the transpiration flow. Likewise, analysis of the calcium distribution, known to be transported exclusively by the xylem, was found to have a similar distribution pattern as perchlorate.

Extrapolation to 100 ppm perchlorate in fertilizers
Extrapolation to 100 ppm perchlorate in the fertilizers applied will result in perchlorate concentrations of 0.24 mg/kg fruit fresh weight in cucumber fruits, 0,07 mg/kg fruit fresh weight in sweet pepper fruits, and 0,06 - 0,07 mg/kg fruit fresh weight in round and cherry tomato fruits of (Table 3). It can be concluded that within the perchlorate treatment range from 0 to 25 ppm perchlorate in the fertilizers applied, and even after extrapolation to 100 ppm perchlorate in the fertilizers applied, fresh fruit perchlorate concentrations will be below the EU provisionally established threshold concentration of 0,5 ppm (mg perchlorate/kg fresh fruit).

Extrapolation to 340 days growing period with 100 ppm perchlorate in fertilizers

The experiment lasted for just about 1/3 of the usual growing period of greenhouse fruit vegetable crops (approx. 130 days instead of 340 days). Therefore, a simulation was carried out on the data of cucumber, sweet pepper and tomato crops, to extrapolate the evolution of perchlorate in the growing system and in the crop and fruits for almost one year, based on the "Waterstreams" model[3]. Typically, at the end of each growing season, the greenhouse will be cleaned and disinfected in order to establish a healthy growing environment for the newly planted crop in the next growing period. This procedure includes the discharge of the remaining drainage water, which may contain accumulated levels of plant nutrients and contaminants, such as perchlorate. The next crop will start with fresh water without any historic buildup of these substances. The outcome of the simulation (Table 3) shows that the EU provisionally established threshold concentration of 0,5 ppm perchlorate in cucumber, sweet pepper and tomato fresh fruit will not be reached with 100 ppm perchlorate in the fertilizers applied. This is due to the equilibrium level which will be reached in closed growing systems, where perchlorate concentrations in the root environment level off (similar pattern as in Figure 2). With 100 ppm perchlorate in the fertilizers applied, perchlorate concentrations in the fresh fruit level off at 0,28 ppm for cucumber, 0,18 ppm for sweet pepper, 0,14 ppm for round tomato and 0,07 ppm for cherry tomato (Table 3).

Table 3. Perchlorate concentrations in the fruit of four crops, as obtained in the present trial and after extrapolation to 100 ppm perchlorate in the fertilizers applied, and after extrapolation to 12 months growth period.

Crop	Duration				
	4 months			12 months*	
	Perchlorate concentration in the fertilizers applied (mg perchlorate/kg fertilizer)				
	12,5 ppm	25 ppm	100 ppm*	25 ppm	100 ppm
	Perchlorate concentration in the fruit (mg perchlorate per kg fresh fruit)				
Cucumber	0,03	0,06	0,24	0,07	0,28
Sweet pepper	<0,01	0,02	0,07	0,04	0,18
Cherry tomato	<0,01	0,02	0,06	0,02	0,07
Round tomato	<0,01	0,02	0,07	0,03	0,14

* extrapolated

[3] Voogt, W. G.L.A.M. Swinkels and E.A. van Os. 2012. "Waterstreams": A model for estimation of crop water demand, water supply, salt accumulation and discharge for soilless crops. Acta Hort. 957: 949-955.

4 Main conclusions of two studies conducted

Under the conditions tested and assumptions taken:

1. A positive linear relationship was found between the perchlorate level added via fertilizers and the perchlorate concentration the edible part of lettuce, cucumber, sweet pepper, round tomato and cherry tomato.
2. The perchlorate level in the marketable head of greenhouse soil-grown lettuce after one cropping cycle was below the EU provisionally established threshold concentration of 1,0 ppm if the fertilizers applied contained 50 ppm perchlorate.
3. Extrapolation of the data to 100 ppm perchlorate in the fertilizers applied for one cropping cycle, resulted in perchlorate concentrations in the marketable lettuce head from 0,19 ppm, when grown in a sandy loam soil, and up to 0,27 ppm, when grown in a light sandy loam soil. These values are below the EU provisionally established threshold concentration for greenhouse grown lettuce of 1,0 ppm.
4. The perchlorate levels in fruits for hydroponically-grown cucumber, sweet pepper, round and cherry tomato after four months, were below the EU provisionally established threshold concentration of 0,5 ppm, if the fertilizers applied contained 25 ppm perchlorate for cucumber, sweet pepper, round and cherry tomato.
5. Extrapolation of the data to 100 ppm perchlorate in the fertilizers applied and by extrapolation to a complete growing season of nearly one year resulted in maximum 0,28 ppm (mg perchlorate/kg fresh fruit) for cucumber, 0,18 ppm for sweet pepper, 0,14 ppm for round tomato, 0,07 ppm for cherry tomato, which are below the EU provisionally established threshold concentration of 0,5 ppm.
6. It can be predicted that over time the uptake of perchlorate in lettuce, round and cherry tomatoes, cucumber, and sweet peppers will level off to finally reach an equilibrium concentration in the edible part of these crops. The actual equilibrium level will differ from crop to crop, and depends on several parameters. However, it is noteworthy that the equilibrium level itself does not depend on the perchlorate uptake efficiency for each of the crops considered.

To explore the potential of nature to improve the quality of life

Wageningen UR Glastuinbouw
P.O. Box 20
2665 ZG Bleiswijk
Violierenweg 1
2665 MV Bleiswijk
The Netherlands
T +31 (0)317 48 56 06
F +31 (0)10 522 51 93
www.wageningenUR.nl/glastuinbouw

PRI Report GTB-1321

Wageningen UR Greenhouse Horticulture initiates and stimulates innovations for a sustainable protected horticulture and a better quality of life. This is achieved by partnering with primary producers, the supply sector, plant breeding companies, the scientific community and governments in applied research.

The mission of Wageningen UR (University & Research centre) is 'To explore the potential of nature to improve the quality of life'. Within Wageningen UR, nine specialised research institutes of the DLO Foundation have joined forces with Wageningen University to help answer the most important questions in the domain of healthy food and living environment. With approximately 30 locations, 6,000 members of staff and 9,000 students, Wageningen UR is one of the leading organisations in its domain worldwide. The integral approach to problems and the cooperation between the various disciplines are at the heart of the unique Wageningen Approach.