

# Non-Nutritional Fertigation Effects as a Challenge for Improved Production and Quality in Horticulture

<sup>1</sup>Volker Römheld, <sup>2</sup>S. Jiménez-Becker, <sup>1</sup>Günter Neumann, <sup>1</sup>Joseph Patrick Gweyi-Onyango, <sup>3</sup>L. Puelschen, <sup>4</sup>Wolfram Spreer, and <sup>5</sup>Fritz Bangerth

<sup>1</sup>Institute of Plant Nutrition (330), University of Hohenheim, 70593 Stuttgart, Germany

<sup>2</sup>Vegetable Production, University of Almería, Carretera Sacramento s/n., 04120 Almería, Spain

<sup>3</sup>Kemira –Espoo Research Centre, Luoteisrinne 2, FIN-02271 Espoo, Finland

<sup>4</sup>Process Engineering in Plant Production, University of Hohenheim, 70593 Stuttgart, Germany

<sup>5</sup>Institute for Special Crop Cultivation and Crop Physiology (370), University of Hohenheim, 70593 Stuttgart, Germany

**Corresponding author:** Volker Römheld, Institute of Plant Nutrition (330), University of Hohenheim, 70593 Stuttgart, Germany. E-mail: [roemheld@uni-hohenheim.de](mailto:roemheld@uni-hohenheim.de).

## Abstract

Fertigation is generally accepted as a technology to improve use efficiency of often limited irrigation water and fertilizers, mainly in horticultural production. However, the possibility to use fertigation as a strategy to exploit the physiological and genetic potential of horticultural crops, independently of purely nutritional effects, has not attracted much attention. Three case studies are presented and discussed to demonstrate that this strategy could present a promising challenge for the near future. The use of an acidifying N/P fertilizer (urea phosphate) in fertigation systems is presented as a means to achieve earlier productivity (plant earliness) in vegetable production systems on calcareous soils. In a second case study, prospects for application of different nitrogen forms to manipulate formation of lateral shoots in tomato and cereals are discussed. A third case study addressed the possible induction of off-season lychee flowering by partial root drying or by a micro-nutrient (B, Zn) deficiency treatment, applied via fertigation. In all three examples, changes in phytohormonal balances, induced by fertigation treatments played a decisive role in regulating plant development for earlier and better yield. Thus, improved knowledge of hormonal regulation of plant growth and development, and

integration of this knowledge into fertigation systems could be a promising strategy to improve fertigation technologies in horticultural production.

**Keywords:** cucumber, fertigation, lychee, morphogenesis, plant earliness, phytohormones, off-season flowering, tomato.

## **Introduction**

Fertigation is a technology, increasingly employed in horticulture, mainly to improve the use efficiency of water and fertilizers, particularly in countries with limited water resources. Fertigation technology offers more possibilities to exploit the physiological and genetic potential of a given plant than conventional irrigation and fertilization practices. The technique can reduce costs by combining water and fertilizer application, and can be combined also with directed application of plant protection agents (chemigation). Nutrient and water use efficiency may be improved by local application, close to the root system, according to plant needs. Moreover, this may help to reduce nitrogen losses through leaching and evaporation. However, apart from the obvious nutritional advantages, there are also clear indications that certain nutrients perform additional functions as signals that trigger plant growth and development. This may offer largely uninvestigated opportunities to improve application techniques in fertigation systems. To optimize the exploitation of crop potentials, the increasing background knowledge on these processes at the molecular and physiological level has to be better integrated into practical applications.

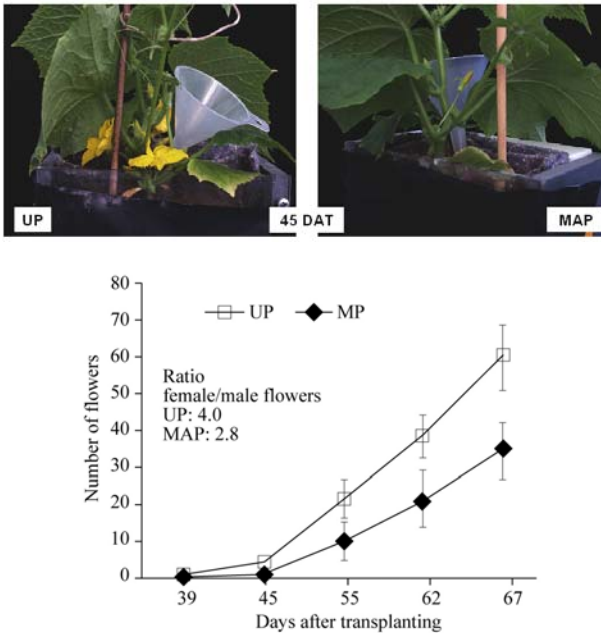
This report presents three case studies on non-nutritional fertigation effects as examples of approaches with prospects for directed manipulation of plant growth and development.

## **Urea phosphate for induction of plant earliness in vegetable production**

In horticultural practice, accelerated plant development and, particularly, earlier flowering has been reported with urea phosphate (UP) than with the mono-ammonium phosphate (MAP), used in fertigation systems for vegetable production on calcareous soils (Jokinen *et al.*, 2003). Therefore, the objective of this study was to compare UP and MAP fertilizers. Effects on plant development, nutritional status and changes of rhizosphere chemistry in the fertigation zone, induced by highly localized fertilizer application, were investigated in a greenhouse study with cucumber (*Cucumis sativus* L. cv. Vorgebirgstrauben), grown in rhizoboxes on a calcareous Loess sub-soil

(pH 7.5) during a 68-day culture period, with cumulative N, P and K applications per plant of 0.53, 1.05, and 2.22 g, respectively.

Plant dry matter production did not differ significantly between the MAP and UP treatments. However, UP application accelerated plant development as expressed in root growth, leaf development and earliness of flowering. Moreover, the ratio of female/male flowers was increased by UP fertigation (Fig. 1). These findings suggest the involvement of ethylene as a hormonal factor for female sex determination in cucumber (Yamasaki and Takahashi, 2003).



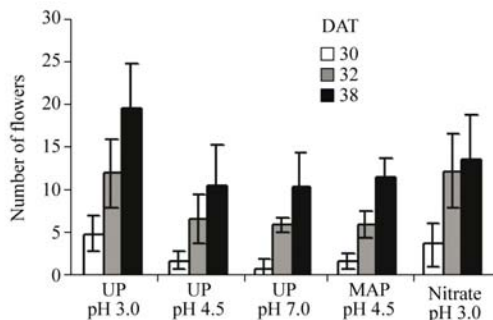
**Fig. 1.** Flower development and female/male ratios of cucumber flowers (cv. Vorgebirgstrauben), grown on a calcareous Loess sub-soil with UP or MAP fertigation.

The observed effects on “plant earliness” could not be attributed to any differences in the nutritional status of macro- (N, P, K, Ca, Mg) or micro-nutrients (Fe, Zn, Mn, Cu). However, in both treatments, shoot concentrations of Zn were in the critical range, probably related to low levels of available Zn in the calcareous Loess subsoil (Table 1).

**Table 1:** Concentrations of macro- and micro-nutrients in the shoot tissue of cucumber (cv. Vorgebirgsrauben), at 68 days after transplanting to soil culture on a calcareous Loess sub-soil, with UP or MAP fertiligation.

Nutrient	UP	MAP	Adequate range
----- % -----			
N	3.8 <sup>a</sup>	4.1 <sup>a</sup>	2.5-5.0
P	0.8 <sup>a</sup>	0.8 <sup>a</sup>	0.2-0.6
Mg	1.1 <sup>a</sup>	1.1 <sup>a</sup>	0.3-0.6
K	3.6 <sup>a</sup>	3.8 <sup>a</sup>	2.0-6.0
Ca	3.9 <sup>a</sup>	3.8 <sup>a</sup>	1.0-2.0
----- mg/kg dry matter -----			
Cu	12.7 <sup>a</sup>	11.4 <sup>a</sup>	5-10
Mn	43.3 <sup>a</sup>	42.8 <sup>a</sup>	100-200
Zn	29.6 <sup>a</sup>	24.6 <sup>a</sup>	50-150
Fe	73.6 <sup>a</sup>	71.7 <sup>a</sup>	30-150

Continuous application of the UP fertiligation solution (pH 2.9) persistently lowered the soil pH in the fertiligation zone, even in the strongly buffered calcareous soil. No comparable effects were observed in the MAP (pH 5.1) treatments, suggesting that continuous supply of the UP fertiligation solution exceeded the buffering capacity of the soil in the fertiligation zone after prolonged application cycles. At the same time, root-induced acidification was observed also, at the rhizoplane and in the rhizosphere soil of the UP treated plants; this may indicate preferential ammonium uptake and delayed nitrification in the UP treatments. Adjustment of the UP solution pH from 3.0 to 4.5 or 7.0 resulted in a lower rate of flower development, comparable with that in the MAP treatments (Fig. 2).



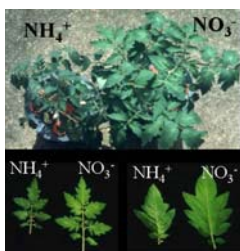
**Fig. 2.** Flower development of cucumber, grown on a calcareous Loess subsoil, as affected by the pH of the fertiligation solution.

These findings suggest a key role for the fertigation solution pH in triggering plant developmental changes. Repeated application of the acidic UP-fertigation solution, exceeding the soil buffering capacity, may impose a sort of localized stress treatment on the part of the root system in the fertigation zone, since the root system is physiologically adapted to high soil pH. Repeated exposure to this treatment may induce a root-to-shoot signal, which stimulates generative growth.

### Modulation of shoot growth by the form of the N supply

The availability and the form of the nutrient supply, especially of nitrogen, has a strong impact on plant growth and development. Nitrate in soils has not only nutritional functions, but also may act as a mobile signal molecule that helps plant roots to localize patches of less mobile nutrients, liberated, e.g., from “hot spots” of organic matter. Nitrate triggers increased formation of lateral roots in these nutrient-rich patches, via auxin signalling and activation of MADS-box transcription factors (Zhang *et al.*, 1999). Proliferation of lateral roots in zones with high levels of nutrients may also be an important factor for exploitation of the highly localized nutrient supply in fertigation systems.

Apart from its role in adaptive regulation of root growth, nitrate seems also to have significant functions as a signal that triggers shoot development (Walch-Liu *et al.*, 2000). In various plant species (tobacco, tomato, Arabidopsis, etc.) it has been demonstrated that removal of nitrate from the growth medium leads to inhibition of shoot growth (Fig. 3).

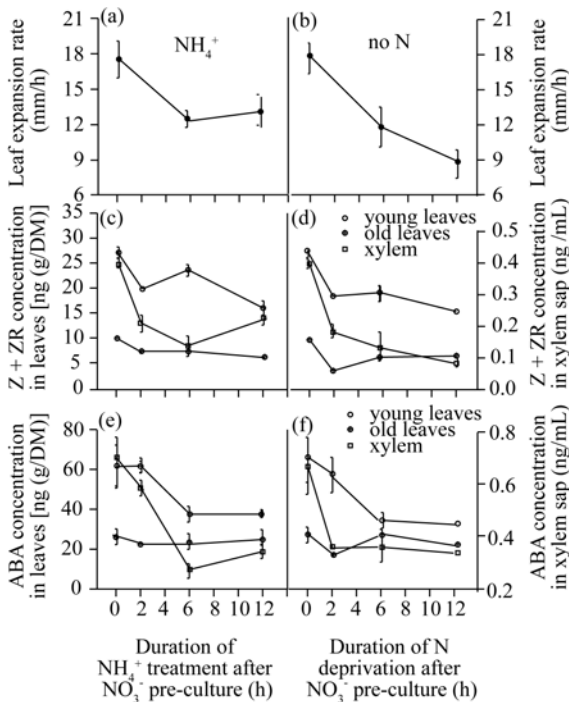


**Fig. 3.** Shoot and leaf morphology of tomato, as affected by the form of the N supply (2 mM  $\text{NH}_4^+$  versus 2 mM  $\text{NO}_3^-$ ).

This holds true not only for conditions of N deficiency; it occurs even when N limitation is avoided by application of  $\text{NH}_4^+$  or other alternative N sources (urea, amino acids), and when the toxic effects of ammonium nutrition are suppressed

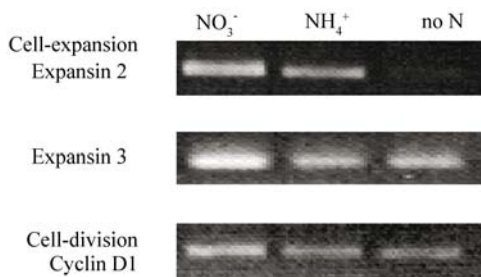
by moderate application rates (maximum 2 mM N) and pH buffering of the culture substrate (Fig. 3).

In tomato, inhibition of leaf expansion is a rapid response, detectable within 6-8 h after removal/replacement of  $\text{NO}_3^-$  in the growth medium (Fig. 4a, b); it probably results from decreased root-to-shoot translocation of cytokinins, which is already detectable after 2 h (Fig. 4c, d). Similarly to cytokinins, root-to-shoot transfer of abscisic acid (ABA) also serves as an important signal for down-regulation of shoot growth under various stress conditions (e.g., drought, salinity, soil compaction), and it rapidly declines in the absence of nitrate (Fig. 4 e, f), suggesting that limitation of the supply of cytokinins to the shoot tissue is the primary inhibitory signal (Rahaju *et al.*, 2005). However, in long-term studies, the absence of nitrate also induced a secondary increase of ABA translocation to the shoot. Preliminary studies on gene expression suggest that in



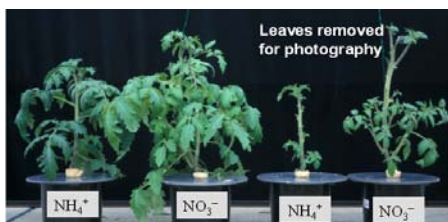
**Fig. 4.** Changes in leaf expansion and hormonal status (cytokinins = Z+ZR and abscisic acid = ABA) in tomato plants supplied with  $\text{NH}_4^+$  or no N after  $\text{NO}_3^-$  preculture.

the presence of nitrate there is a cytokinin-induced up-regulation of the cell-wall expansins involved in cell expansion and of D-cyclins involved in cell cycle control and cell division (Fig. 5).

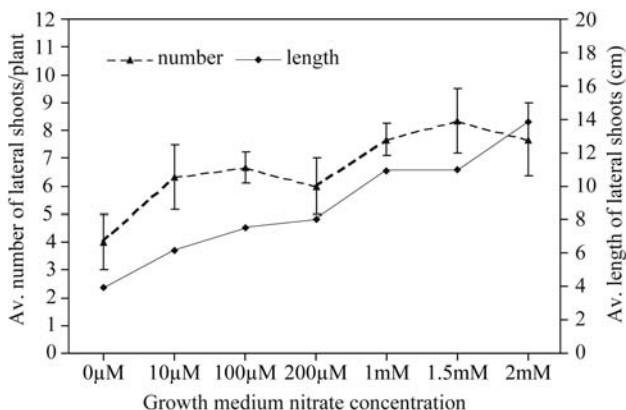


**Fig. 5.** Dependence on the form and level of N supply, of the expression of genes involved in cell expansion (expansins) and cell cycle control (cyclin D1) in tomato leaves (Northern analysis).

However, cytokinin-dependent regulation of shoot growth via nitrate supply is not restricted to leaf expansion; it also includes effects on shoot apical dominance. In tomato, outgrowth of lateral shoots can be reduced by increasing the  $\text{NH}_4^+/\text{NO}_3^-$  ratio (Fig. 6 and 7), and effect that probably is mediated by an increased auxin/cytokinin ratio in the shoot tissue that arises because the reduction in cytokinin translocation from the roots promotes apical dominance of the main shoot (Rahaju, 2003). This could offer an opportunity to manipulate fruit size in tomato culture by modifying the form and ratio of the N supply (Fig. 6).



**Fig. 6.** Fruit development and formation of lateral shoots in tomato grown in hydroponic culture with different forms of N supply.



**Fig. 7.** Outgrowth but not the number of lateral shoots is stimulated by increasing the  $\text{NO}_3^-/\text{NH}_4^+$  ratio in the hydroponic growth medium of tomato (total N supply = 2 mM, x-axis indicates the concentration of the  $\text{NO}_3^-$  supply, remaining N was supplied as  $\text{NH}_4^+$ ).

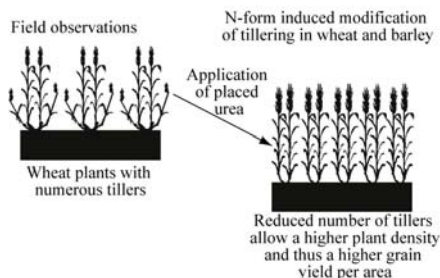
The biomass yield of tomato fruits was only marginally affected by the form of the applied N. However, a solely  $\text{NH}_4^+$  supply led to impaired fruit quality, expressed as higher incidence of Ca deficiency-induced blossom end rot, and lower concentrations of malate and citrate in the fruits (Table 2; Rahaju, 2003). Modifications of the  $\text{NH}_4^+/\text{NO}_3^-$  ratio and of the timing of the N supply could be employed to overcome these limitations and also to manipulate, e.g., malate/citrate ratios (Table 2).

**Table 2.** Incidence of Ca deficiency-induced blossom end rot, organic acid concentrations in fruits, fruit biomass and fruit number in tomato, grown in buffered nutrient solution as affected by the form of N supply (Rahaju, 2003).

N supply (2 mM)	Blossom end rot	Malate (fruit DM)	Citrate (fruit DM)	Fruit DM	Fruit number
	%	----- mg/g -----		g	No./plant
$\text{NO}_3^-$	0	20.5 $\pm$ 1.1	22.7 $\pm$ 1.2	58.2 $\pm$ 1.5	28.5 $\pm$ 1.5
$\text{NH}_4^+$	12.4 $\pm$ 0.9	5.3 $\pm$ 1.5	14.3 $\pm$ 1.8	50.0 $\pm$ 0.9	24.0 $\pm$ 1.5



In accordance with the same principle, deep placement of urea-based fertilizers close to the roots is used to regulate tillering in barley and wheat (Fig. 8), in order to optimize yield by avoidance of mutual shading and competition among individual tillers (Bauer, 2004).



**Fig. 8.** Reduction of tillering in wheat and barley by deep-placement of urea-based fertilizers.

### **Induction of off-season flowering in lychee by short-term water or micro-nutrient deficiency stress via controlled fertigation**

A widespread problem in lychee (*Litchi chinensis* Sonn.) production in northern Thailand (Fig. 9) is irregular annual fruit set (alternate bearing) as a consequence of inadequate low temperatures during December and January.



**Fig. 9.** Lychee production in northern Thailand.

In some tropical and subtropical fruits, off-season flowering can be induced by treatments with certain chemicals such as paclobutrazol (Mango) or  $KClO_3$  (longan) but these compounds are ineffective for lychee. Because of water

scarcity, micro-irrigation systems are of increasing interest for production of subtropical fruits, such as lychee.

A significant contribution to water saving under field conditions was achieved by using the partial root drying (PRD) technique, which restricts water application to parts of the soil surface around the trees. Under controlled conditions in split root culture vessels with divided root systems, PRD treatments to one half of the root system not only reduced water consumption but also induced flowering (Fig. 10).



**Fig. 10.** Induction of flowering by partial root drying treatments (PRD) to one half of the root system in young lychee trees grown in a split-root soil culture system.

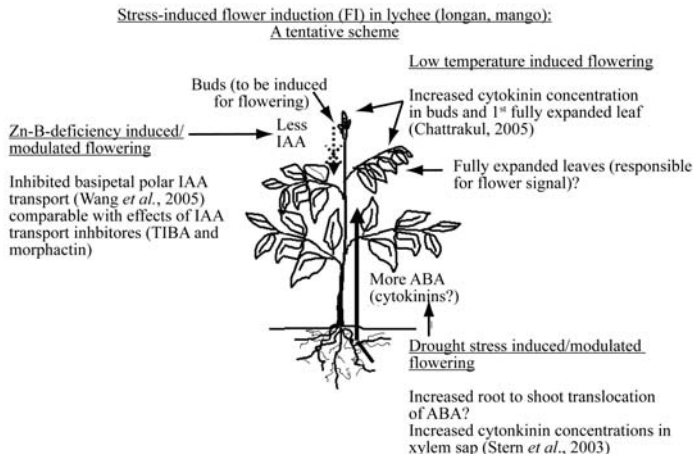
Against expectations, B and Zn deficiency also induced off-season flowering in lychee seedlings (Fig. 11). The drought stress signal to one part of the root system may result in a decreased cytokinin content in buds, because of the increased root-to-shoot translocation of the cytokinin antagonist, abscisic acid. Boron and zinc deficiency can lead to a reduction of polar auxin transport from shoot apices (Wang *et al.*, 2006), similar to the effects caused by application of synthetic auxin transport inhibitors such as TIBA (Fig. 12). A common result of all these treatments is a high auxin/cytokinin ratio in apical parts of the shoot, which may be involved in flower induction.

However, Stern *et al.* (2003) reported stimulation of flowering and increased cytokinin concentrations in the xylem sap of lychee under moderate drought stress, which may be attributed to reduction of the transpiration stream because of ABA-induced stomatal closure.



**Fig. 11.** Zinc deficiency-induced flowering in young lychee trees grown in hydroponic culture.

These alterations of hormonal balances may induce, or at least modulate signalling of flower development in subtropical fruit trees. Therefore, fertigation systems might offer an opportunity for directed application of localized stress treatments to induce off-season flowering in lychee orchards or, at least, to improve flower induction at marginal low temperatures. However, the practicability of such a practice under field conditions, in terms of irrigation intervals and strength and duration of stress treatments, remains to be evaluated.



**Fig. 12.** Hypothetic model for stress-induced alterations of hormonal balances, that induce off-season flowering in tropical fruit trees.

## Conclusions

The presented case studies clearly demonstrate that fertigation offers the potential to manipulate plant growth and development, independently of purely nutritional effects. In all the presented studies, changes in phytohormones played a decisive role in regulation of plant development to achieve an earlier and higher yield. Thus, better knowledge of phytohormonal regulation of plant growth and development could help to generate better, innovative fertigation strategies in crop production. The aim in presenting these case studies was not to give ready-to-use recipes, but rather to stimulate and encourage such a development for the benefit of growers.

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