Horticulture meets the periodic table: a century of elemental research

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Abstract

Not only is 2019 the 100th anniversary of the Journal of Horticultural Science and Biotechnology, but to celebrate 150 years since Dmitri Mendeleev formally proposed the system of organising the chemical elements it is also the International Year of the Periodic table of Chemical Elements. This Centenary Review highlights work that has been published in this journal across its full history, illustrating how horticultural research involving the chemical elements of the periodic table has evolved over the past 100 years. The development of understanding of mineral nutrition is particularly highlighted, along with research through the century on crop protection and post-harvest spoilage prevention. More recent areas of research such as how mineral composition of horticultural crops affects the nutritional qualities of our food as well as investigations into bio-fortification are reviewed. How research into the importance of other elements such as silicon can mediate against environmental stressors is also included.

Keywords

chemical elements, periodic table, mineral nutrition, bio-fortification, post-harvest spoilage prevention

Introduction

Not only is 2019 the 100th anniversary of the Journal of Horticultural Science and Biotechnology, but to celebrate 150 years since Dmitri Mendeleev formally proposed the system of organising the chemical elements it is also the International Year of the Periodic table of Chemical Elements. To date, 14[*] of the naturally occurring chemical elements have been shown to be essential for plant growth, whilst the exact role of others such as silicon are yet to be fully elucidated. This Centenary Review highlights work that has been published in this journal across its full history, illustrating how horticultural research involving the chemical elements of the periodic table has evolved over the past 100 years.

Mineral nutrition

Early Studies

From its inception as the Journal of Pomology and Horticultural Science 100 years ago, research into the importance of chemical elements as micro- and macronutrients required for healthy plant growth and crop production has featured prominently within the journal pages. In the very first issue, the final article was a detailed review of a newly published book "Fruit Culture and Science"[1] which summarised the work of the "Woburn Experiments", a series of trials on fruit trees. A substantial section was devoted to the subject of manuring, discussing the results of trials where apple trees were grown under different manuring regimes. Whilst the set-up of the trials was somewhat disparaged, there was no hiding the importance of nitrogen, phosphorus and potassium for growth and crop production.

In 1920 a paper discussing the importance of manuring to ensure a consistent fruit crop each year (rather than biennial bearing) was published.[2] With no data presented, this would not be recognisable as a scientific paper today, but it does serve to illustrate that 100 years ago, the requirement to manure fruit trees was a contentious one. In 1925, the first of a series of papers on the manuring of fruit trees was published by Thomas Wallace, working at the University of Bristol Agricultural and Horticultural Research Station at Long Ashton.[3] This paper included a summary of field trials investigating the manuring of fruit trees to that date, which highlighted the very real need for fundamental research into the nutrition of fruit trees in controlled environments. The outcomes of a series of experiments were then reported. A method was described whereby fruit plants could be grown in sand filled pots and "fed" by means of nutrient solutions, looking at the effects of particular mineral deficiencies, by systematically omitting nitrogen, potassium, phosphorus, calcium, magnesium, and sulfur from the nutrient solutions. This method would be applicable to apples, gooseberries, blackcurrants, raspberries and strawberries, although only results from the apple tree experiments were reported in this particular paper, with work on gooseberries following in the subsequent volume.[4] Further work on the nutrition of apple trees grown using the same method was also published within a short period of time.[5, 6] Apple trees grown without potassium in the nutrient solution were severely affected by leaf scorch and subsequent published work deepened the understanding of this issue.[7,8] Considerable further work on the importance of potassium nutrition in fruit trees was reported in the journal over subsequent years.[9,10,11,12,13]

Although work on the systematic investigation of mineral requirements for fruit trees was progressing both in the United Kingdom and worldwide,[14] there was still much to discover about

[*] N, P, K, Ca, Mg, S, Cl, Fe, B, Zn, Mn, Cu, Ni, and Mo

how minerals were taken up through the soil by plants. Application of minerals to soils did not always effect an improvement in plant health. Innovative methods for the application of “artificial manures”, such as the use of direct injection of mineral salts into fruit trees were investigated.[15] Injections directly into the trunks of apple trees were carried out using a bespoke apparatus. Growth and death of the plants (and parts thereof) were monitored and a method of injecting weak (0.25% solutions) mineral solutions was developed that did not cause damage to the trees, and actually led to increased plant growth. Researchers in New Zealand, looking at link between boron deficiency and internal cork of apples used a direct injection method for one of their studies.[16] The merits of top dressing and foliar application of borax were also investigated.[17, 18]

Mineral deficiencies and diagnostics

The results of research relating to the mineral deficiencies of horticultural crops more broadly were also published in the journal. Three papers from 1940 show the breadth of the research at the time. A paper on the effects of deficiencies of nitrogen, phosphorus, potassium, calcium, magnesium, iron, sulfur and sodium on the yield of carrots, onions and radishes was published.[19] The author concluded that the lack of potassium elevated the tendency of the crops to scorch and wilt, and that deficiencies of nitrogen and phosphorus gave rise to greatly diminished crop yields. The results of an investigation into the amounts of inorganic salts removed from the soil during the growth of the winter broccoli crop of Devon and Cornwall were published together with a detailed examination of the nutritive value of the crop.[20]

Work was not restricted to edible horticultural crops. The results of a study on the nutrition of tulips and narcissi appeared.[21] These were the first extended studies on the nutritional requirements of bulbs. The consequences of omitted potassium, nitrogen and phosphorus across subsequent years is reported. The inclusion of photographic images of the trial set-up and of experimental plants is noteworthy.

Throughout the 1940’s work continued on the mineral and nutritional requirements of fruit trees. Almost two decades of work on manurial trials on apple trees at East Malling was reviewed and summarised.[22] This work showed that each cultivar has different nutritional requirements, and that these requirements also depend on the rootstock used. The outcomes of work on magnesium requirements for apple trees[23] and overcoming a manganese deficiency in cherries[24] were reported in addition to the results of a detailed investigation into the distribution of minerals in the foliage of apple trees.[25]

It became clear that rapid, accurate methods for field analysis of elemental deficiencies were required. Until now, time-consuming ash analysis was the standard analytical method. To this end, a chemical tissue test method was developed, initially for the diagnosis of mineral deficiencies in field grown potato and cauliflower. The test was looking specifically at the soluble nutrients: potassium, magnesium, calcium, phosphorus, nitrate nitrogen and manganese.[26] The work was subsequently shown to be applicable to a wide range of horticultural crops including tomato, black and red currant, and apple.[27] The work was of particular value in resolving complex nutrient disorders such as acidity complex in potato where potassium, magnesium, calcium, phosphorus and nitrogen deficiencies and manganese toxicity occurred together. This new technology also enabled investigation of deficiency situations where one element may be impacting on the uptake of another. A 1946 review concerning the inter-relationships of iron and other mineral elements[28] highlighted the complexity of the situation and in particular noted that “the importance of the ratio Mn/Fe in producing iron deficiency in acid soils requires further study”. Just four years later, a publication describing how the new rapid and sensitive chemical tests were employed to further the understanding of the inter-relationship between iron and manganese appeared.[29]

In 1939 it was established that Molybdenum was an essential element for the nutrition of higher plants and this element subsequently became an important area of investigation. In order to facilitate the study of this essential nutrient, methods of culture whereby molybdenum could be effectively excluded from the growing environment needed to be developed. In 1947, a method of sand culture to produce molybdenum deficiency in a range of crops including tomato and various brassicas was reported.[30] This enabled a thorough investigation of the influence of molybdenum on a range of brassica crops[31] and a study into the control of whiptail (a disorder of cauliflower and broccoli known since 1945 to be due to molybdenum deficiency)[32.] The initial laboratory studies then led to a field experiment looking at the effects of molybdenum deficiency and manganese toxicity on acid soils for brassica and lettuce crops.[33]

The boron nutrition of hops was the focus on a report in 1956[34]. The research examined the boron content of hop plants throughout their life cycle, defined the symptoms of both boron deficiency and toxicity and applied the information to a field trial.

By the 1960s less work was being published on manurial trials for field grown vegetables. However, two papers relating to work on carrots were published in 1963. The first detailed the outcome of a long-term manurial experiment[35] and the second described sand culture experiments investigating more closely the effect of potassium on the growth rate of carrot seedlings.[36] An additional paper in the same period discussed systematically arranged fertiliser experiments.[37] It was determined that this kind of systematic experiment required much less land than a fully randomised design, but whilst still providing meaningful results.

Protected crops

A report on the outcomes of experiments aimed at correcting magnesium deficiency in another important horticultural crop, glasshouse tomatoes, appeared in 1948. [38] Foliar application of magnesium sulfate was shown to be more effective than soil application. Working in New Zealand, Elsa B Kidson was investigating hard core – a nutritional disorder that she established was due to a potassium deficiency in the growing media.[39] The effects of potassium concentration on tomato fruit quality and yield using a liquid feed delivered via trickle irrigation in a glasshouse environment was the subject of a study published in 1961.[40] This work highlighted the difficulties of soil analysis as a guide to the nutrition of the crop, grown with trickle irrigation, due to the steep nutrient gradients found in the soil. It also observed that the ripening disorders of tomatoes warranted further investigation. These were duly investigated and revealed the complexity of the interactions between pH, potassium, magnesium and phosphorus and of these on the incidence of ripening disorders.[41] Nowadays, with some commercial tomato production using nutrient film technique (NFT) together with a non-nutritive substrate such as rockwool, understanding the effect of the composition of applied nutrient solutions is critically important. A highly cited paper from 1991 discusses the effect of increasing salinity of the nutrient solution on the yield, quality and composition of tomatoes grown in this manner.[42]

Later studies

Although "Pomology" was removed from the journal title from the 1948 Volume onwards, there were still significant papers relating to top fruit growing beyond this date, and these continue to the present. In 1953 two papers were published highlighting the investigations of workers at Long Ashton on zinc and copper deficiencies of fruit trees at the National Fruit Trials at Wisley.[43, 44]

Work on magnesium deficiency was still being undertaken in the 1960's. A study looking at the response of Edward VII apple trees to variations in the timing and composition of foliar sprays was published.[45] Whilst pre-blossom sprays of Epsom salt prevented the development of early-season magnesium deficiency symptoms, only post-blossom sprays affected fruit set and hence crop yield.

A publication from 1983 details work undertaken at East Malling to follow trends in calcium uptake by developing fruit in particular apple cultivars.[46] This work was important in order to understand better how to minimise the incidence of various storage disorders including bitter pit. Whilst much is now understood about mineral deficiencies and the impacts thereof, research into the best methods to mitigate against these deficiencies continues. A more recent publication is a review on foliar iron-fertilisation of fruit trees.[47]

The stress caused to plants experiencing mineral deficiencies is covered within a 1990 review on the accumulation of nitrogen-containing compounds.[48] The paper looks at which nitrogen containing compounds are accumulated under which stress conditions in a wide range of horticultural crops.

Crop Protection

Various chemical elements, in the form of inorganic compounds, were formerly used as pesticides. By the time this journal was first published, lead arsenate was an established pesticide. However, although effective, it was observed to have "one great disadvantage", that of its high density, causing rapid settlement from an admixture with water. A paper was published in 1924, detailing the ability of a range of "protective agents" to promote suspensions and to wet the dry lead arsenate.[49] Gelatin was found to be the best at promoting and stabilising the suspensions. In 1938 a report was published investigating the effect of lead arsenate and copper carbonate on the quality of oranges harvested from sprayed trees.[50] In addition to establishing the effect of the sprays on quality markers such as acid levels, the amounts of residual lead, arsenic and copper in the harvested fruit were analysed. Levels of all these elements in the juice of the fruit were found to be within those deemed acceptable to human health. However, this was of course not the case for the fruit rind!

Elemental sulfur was also under investigation as a means of treating big bud mite on blackcurrants.[51] Whilst found to be extremely effective in laboratory conditions, its duration of action was limited, and there was at the time "no machine capable of giving the requisite cloud under open-air and commercial conditions".

Spoilage prevention

Sulfur dioxide has a long history of use as a preservative for fruit. A paper published in the first decade of this journal's history, describes the results of a thorough investigation on the use of sulfur dioxide to "inhibit the development of moulds, yeasts and bacteria".[52] It also covers how to subsequently store the treated fruit, and to what uses the treated fruit could be put.

The delay of post-harvest decay remains an important topic in the food supply chain. A 1997 paper from researchers in Israel describes the use of another inorganic compound, this time potassium carbonate, as a potential anti-microbial agent for treating bell pepper fruits.[53]

Uptake of elements: ornamental and nutritional qualities

In 2003, workers at the Institute of Plant Nutrition, University of Hannover reported details of a study they had undertaken with an aim to providing an improved understanding of the relationship between aluminium supply, uptake, translocation and blueing of sepals in *Hydrangea macrophylla* cultivars. [54] That aluminium is significant for blueing the sepals of this species has been known since 1897, but growers continue to struggle to develop approaches to consistent blueing of these plants in cultivation.

In 2005, a report on the historical variation in the mineral composition of edible horticultural products was published.[55] The work was based on the hypothesis that the nutritional value (with regard to mineral composition) of vegetables, fruit and nuts had altered since the 1930s. Historical food survey data from the UK and USA was used to look at the concentrations of calcium, chlorine, copper, iron, potassium, magnesium, phosphorus and sodium. A 2012 paper investigates the bio-fortification of potato tubers with zinc using a foliar fertiliser, highlighting the estimate that over one-third of the world's population are zinc deficient. [56]

Not all elemental uptake could be considered positive for consumers of horticultural crops. A 2013 paper shows the potential negative consequences of growing horticultural crops in soil contaminated by heavy metals. [57] The varieties studied showed that lettuce has a high capacity for cadmium accumulation. Perhaps this has potential as a bio-remediation tool.

New directions

Whilst much has been discovered over the past 100 years about the details of the importance of chemical elements to plant growth, the more recent papers show that our understanding is not yet complete. Researchers across the globe continue to investigate the effects of chemical elements on plant growth in a wide variety of ways. The potential of silicon to aid in overcoming negative consequences of salt stress was the subject of two recent publications.[58, 59]

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NB. The book was actually entitled "Science and Fruit Growing" and is available from various sources as a reproduction from original copies.

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